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Design for Innovative Value Towards a Sustainable Society

Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing

EcoDesign
2011

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Preface

Since the first EcoDesign International Symposium held in 1999, this symposium has led the research and practices of environmentally conscious design of products, services, manufacturing systems, supply chain, consumption, as well as economics and society. EcoDesign 2011 — the 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing — is successfully held in the Japanese old capital city of Kyoto, on November 30th - December 2nd, 2011. The subtitle of EcoDesign 2011 is set to “design for value innovation towards sustainable society.” This subtitle indicates that, in EcoDesign 2011, we discuss the way to achieve both drastic environmental consciousness and value innovation in order to realize a sustainable society.

Over 300 abstracts were submitted to EcoDesign 2011 from 30 countries and regions all over the world. It indicates the further increase of the demands and interests in the topics of this symposium. In recent years, it is more and more demanded for academia, industries and governments to act globally and internationally. We expect that EcoDesign2011 provides a distinguished occasion to discuss the topics with people from various backgrounds.

In EcoDesign 2011, we have papers on the latest topics of EcoDesign such as of social perspectives in EcoDesign, business aspects of EcoDesign, user behaviour studies, and so on. As plenary keynote speakers, we have distinguished speakers from AIST, an organizer research institute, and three global leading companies — Panasonic, Siemens, and Kone. It is our great pleasure and honor to have such great plenary presenters and paper presenters from all over the world.

We would like to express our sincere appreciation to all contributors to the proceedings. We also would like to extend our thanks to the members of the executive committee for their efforts to arranging the conference and this proceedings book available to the public.

Yasushi Umeda, Executive Committee Chair of EcoDesign2011
Mitsutaka Matsumoto, Program Chair of EcoDesign2011

Panasonic's Environmental Vision and its Practices

Machiko Miyai
Panasonic Corporation

Abstract
There needs a shift of perspective on how businesses think about performance, which make us emphasize on environmental targets as much as conventional sales and profit. Panasonic has decided its corporate vision to be the 'No.1 Green Innovation Company in the Electronics Industry' in 2018. Where, aiming at 'integrating contributing to the environment and attaining business growth,' the group-wide initiatives with two major pillars of CO_2 reduction and resources recycling are promoted as a part of environmental management. Energy and material efficiencies are key strategies for a manufacturing industry, and we practice in pursuit of them throughout all our business activities.

Keywords:
Environmental vision, green innovation company, energy solution, resources recycling

1 INTRODUCTION

Going green is now a must for survival in general. In businesses, a serious consideration on the environment should take first-class priority at every activity including non-manufacturing processes. There needs a shift of perspective on how businesses think about performance, which make us emphasize on environmental targets as much as conventional sales and profit.

For Panasonic, it directly means reducing environmental impact like CO_2 emissions and improving productivity in all business activities such as designing products, production, sales, service, etc. At the same time, we must be encouraging resources recycling in the manufacturing system and a green culture amongst our employees.

This paper describes Panasonic's environmental vision for the 'No.1 Green Innovation Company in the Electronics Industry' in 2018 and its practices in particular two major initiatives of CO_2 reduction and resources recycling.

2 ENVIRONMENTAL VISION OF PANASONIC

2.1 To be the 'No.1 Green Innovation Company'

Panasonic was established in 1918 by the founder, Mr Kounosuke Matsushita, and reaches the 100th anniversary of its founding in 2018. Looking to this memorial year, we have decided our corporate vision to be the 'No.1 Green Innovation Company in the Electronics Industry.' The main concept is 'the more our business grows, the better the global environment becomes,' in other words, 'the integration of our contribution to the environment and business growth.' Therefore the vision toward the 100th anniversary of founding indivisibly incorporates a couple of environmental initiatives, and our environmental vision can be understood as the same as the corporate vision.

There are two criteria to manage the performances in pursuit of the vision. One is to 'Always meet Global Excellence Indexes,' which is related to financial aspects like sales and profit. And the other is the 'No.1 in Green Indexes,' which is on our environmental initiatives such as; contribution to CO_2 reduction and resources recycling, expansion of energy systems business, and increase in a percentage of sales for No.1 environmentally conscious products. As we simultaneously pursue such Indexes designated in both criteria, we aim to integrate our contribution to the environment and business growth throughout the entire company group.

With this ambitious concept Panasonic will make the 'environment' central to all of our business activities with a firm attitude which allows for no exceptions.

Table 1: Green Targets in GP2018

CO_2 Reduction	Make net CO_2 emissions peak and decline thereafter
Resources Recycling	Pursue recycling-oriented manufacturing to make the best use of resources
Water	Minimize the amount of net water consumption
Chemical Substances	Minimize environmental impact caused by chemical substances
Biodiversity	Identify impact on biodiversity and contribute to conservation
Increase the percentage of No.1 environmentally conscious product sales to 30% (Double fiscal 2010 level)	
Increase environmental contribution through collaboration with stakeholders	

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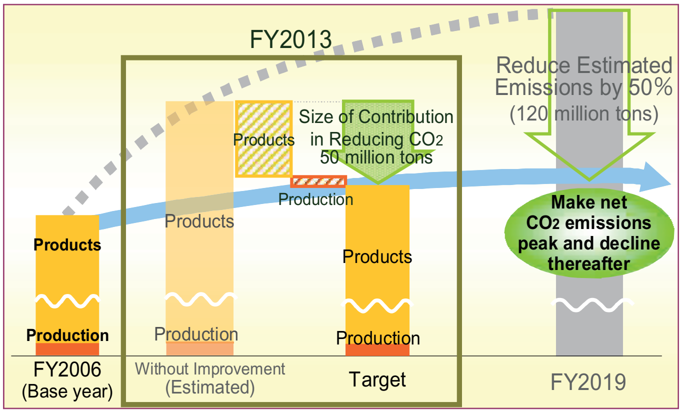

Fig. 1: Breakdown of CO2 Reduction

2.2 Action plan 'GP2018'

To promote the environmental initiatives throughout our business domains, the action plan named 'Green Plan 2018 (GP2018)' was developed as shown in Table 1. We also announced a midterm management plan including several green targets to be achieved by 2012 [1]. Where, aiming at 'integrating contributing to the environment and attaining business growth,' the group-wide initiatives with two major pillars of CO_2 reduction and resources recycling are promoted as a part of environmental management.

3 PRACTICES FOR CO_2 REDUCTION

3.1 Energy saving in production activities

Panasonic decided to make a contribution of reducing CO_2 emissions by 50 million tons in FY2013 in the midterm management plan. The contribution includes the reduction achieved through the use of our products, and the breakdown of it is shown in Figure 1. A rationalized index was also developed to quantify the efforts for reduction of CO_2 emissions according to the midterm management target [1].

Improving productivity makes CO_2 emissions reduce. In other words, every action for energy saving can contribute to both the CO_2 reduction and the productivity improvement as it directly leads to cost reduction and strengthened manufacturing structure. Therefore, we already incorporated CO_2 reduction as one of key management indicators for our manufacturing sites, and this then requires each site to make a positive investment to promote energy saving.

Some concrete activities promoted at our production sites include the implementation of instruments to visualize energy consumption of each production equipment and reduction effect of measures. We already introduced more than 40,000 measurement systems in all of our global manufacturing sites. This initiative enables us to drastically reduce energy wastage. We also conduct energy conservation diagnosis for factories, where internal experts review the manufacturing processes and propose concrete reduction measures at production frontlines. In addition, we share information on excellent reduction activities among our companies via the intranet. As a result of these, in three years from FY2008 to FY2010 we achieved 840,000 tons CO_2 reduction from the base.

3.2 Promoting energy efficient products

To complete the CO_2 reduction target, the improvement of each product's energy efficiency places a very significant position. Compared to our 1990 models, the amounts of annual power consumption of the latest models have been reduced by from 50% to 80% respectively. Also we have a group of representative products incorporating our unique sensor technology for further energy saving. Now, Panasonic is actively working to increase the number of industry-leading energy efficient products.

Penetrating such energy efficient products into the world-wide markets is also important for improving the energy efficiency of whole societies. In this context, global harmonization of rules and conditions to measure the performance of equipment accurately is valuable, and it is really effective for everyone to evaluate the worth of energy efficient products. Panasonic is, therefore, contributing to establish the international standards for products, too.

3.3 Expanding energy solution businesses

As well as energy saving by a wide range of energy efficient home appliances, frontier equipments for energy creation such as solar panels and fuel cells, and novel devices for energy storage such as lithium ion rechargeable batteries are key products to solve energy problems. Panasonic also offers energy management tools which connect them all in order to carry out optimal control. Demonstration of a lifestyle with net zero CO_2 emissions in a whole house including house structure by saving, creating and storing energy and linking its devices and appliances through networking technology is available at our 'eco ideas' House in Tokyo [2].

Furthermore, the system will be extended to community and city levels. Table 2 shows one example, 'Fujisawa Sustainable Smart Town (SST)' project [3]. Fujisawa is a city located at 45km south of Tokyo, and this is the first

Table 2: Project Overview of Fujisawa SST

Development Location	Tsujido-motomachi, Fujisawa City, Kanagawa Prefecture
Land Area	Approximately 19 ha
Planned Land Use	Approximately 1,000 residential homes / commercial facilities / public facilities
Planned Population	3,000 people (1,000 households)
Schedule	Open the town in the fiscal year ending March 2014
Total Project Cost	Approximately 60 billion yen

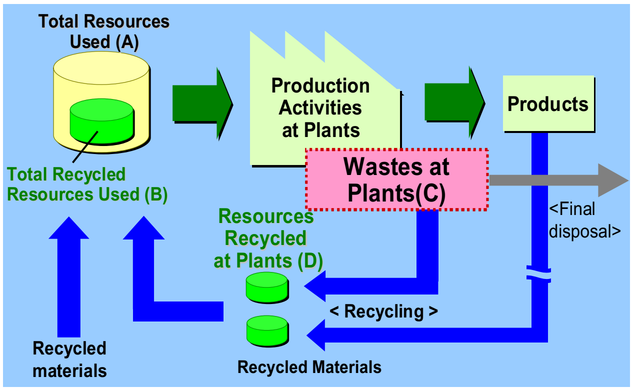

Fig. 3: Recycling-oriented Manufacturing System

smart city project for Panasonic to practically introduce comprehensive energy solutions for homes, buildings and communities. Specifically, we plan to preinstall its solar power generation systems and home-use storage battery systems across the town, including homes, various facilities and public zones. We will be looking at ways to overcome the challenges of adapting such energy solutions with the hope to develop it into a model smart city that can be replicated in other parts of Japan and overseas.

4 PRACTICES FOR RESOURCES RECYCLING

4.1 Promoting recycling-oriented manufacturing

Another major issue in Panasonic's environmental contribution is a concern for resources recycling through 'Recycling-oriented Manufacturing.' To reduce the total amount of resources used, the first task is to downsize our products and minimize the amount of resources needed for each. Then, we must make full use of all the resources that have been fed into our production activities.

In order to make the best use of resources, minimizing the total resources used and maximizing the recycled resources are required while pursuing zero wastes at plants as explained in Figure 3. In the illustration, we aim to increase the ratio of the total recycled resources used to the total resources used (B/A), to more than 16% in 2018. In pursuing zero emissions at plants, we also aim to increase the ratio of resources recycled at plants to wastes produced at plants (D/C), to as much as 99.5% or more at the same time.

4.2 Development of recycled materials using products

Furthermore, by working on 3R (reduce, reuse and recycle) design and by developing new recycling technology, we aim to contribute to improving the efficiency of resources recycling throughout all of society. In the midterm management plan, through company wide collaboration we will make our utmost efforts to improve on all these aspects starting from the design stage on through the entire manufacturing process.

'From product to product' is a key concept of our recycling system. These are some examples of recycled materials using product parts developed in Panasonic. Specifically with regard to air conditioners, copper and aluminum from old heat exchangers are recycled into new heat exchangers. As for TVs, CRT glass is recycled, too. On refrigerators and washing machines, we recycle the plastics from old products to new products, and now are challenging the development of technologies to further increase of their use. We are now considering a new trial about using recycled materials more actively and broadly in our new products. This movement will be bringing a great progress in our environmental vision with the perspective over resources recycling.

5 SUMMARY

This paper summarized Panasonic's environmental vision for the 'No.1 Green Innovation Company in the Electronics Industry' in 2018 and its practices in particular two major initiatives of CO_2 reduction and resources recycling. We believe that energy and material efficiencies are key strategies for the manufacturing industry, and Panasonic will pursue them to achieve our ambitious vision towards 2018.

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KONE's Corporate Environmental Activities and Solutions that Contribute to Creating a Positive Impact on the Environment

Hanna Uusitalo
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Abstract
The direction and shape of the global elevator and escalator industry are driven by four megatrends : urbanization, changing demographics, the increasing importance of safety, and concern for the environment. This paper explains how KONE contributes to sustainable urban development by developing energy efficient solutions that move people smoothly and safely in urban environments.

Keywords:
urbanization, eco-efficiency, sustainability, energy efficiency, elevator, escalator, LCA, EPD

1 SUSTAINABLE URBANIZATION

Buildings consume approximately 40 percent of the world's energy, and elevators and escalators can account between two and 10 percent of the energy consumption of an individual building. The elevator and escalator industry can play a vital role in helping to counter climate change and its negative effects by providing innovative solutions that help to reduce the energy consumption of buildings.

The growth of urban areas is most evident in Asia, where the long-term population growth and migration from rural communities is expected to continue. China, already the world's largest urban nation, is likely see the addition of 350 million people to its urban population by 2025 to reach a total of nearly one billion.

KONE is ready to meet the challenge this presents to the entire building industry. Through global processes combined with a strong local presence in over 1000 locations around the world, KONE is well-positioned to contribute to the different phases of urbanization with a local touch. Building urban areas where people can move around smoothly and safely supports the sustainable development of economies around the world.

2 ENERGY EFFICIENCY, GREEN AND NET ZERO ENERGY BUILDINGS

Since its launch in 1996, the KONE MonoSpace® elevator, powered by the EcoDisc® hoisting technology, has saved an amount of electricity equivalent to that produced by a 400 MW power plant, which is equivalent to:

- The consumption of three million barrels of oil, or
- The CO_2 emissions of 160,000 cars driving once around the world

The biggest environmental impacts created by elevators and escalators relate to the amount of electricity used by the equipment during its lifetime. This underlines the importance of continuing to develop and improve energy efficient innovations for elevators and escalators.

KONE's expertise in eco-efficiency enables us to perform in-depth analyses of traffic patterns, energy consumption, and the potential carbon footprint reduction over the entire operational lifespan of the solutions. The tools used to conduct these analyses are particularly valuable in helping to plan for net zero energy buildings and comply with green building requirements.

KONE actively follows the latest green building and energy efficiency trends related to elevators through its involvement in the working groups that are defining the new ISO 25745 (Energy Performance of Lifts and Escalators) standard, development of parts two and three of the VDI 4707 guidelines (German Elevator Energy Efficiency Performance Guideline), as well as through its involvement with green building associations. KONE also actively participates in the development of international energy measurement standards.

KONE's environmental product declarations (EPDs) provide comprehensive information about the environmental impacts of its products, such as the CO_2 emissions produced and the materials used during both the production and operation of KONE elevators and escalators.

In 2010 KONE became the first company in the elevator and escalator industry to achieve the VDI 4707 guideline A-class rating for its European and Asian volume elevators. Both KONE MonoSpace® and KONE MiniSpace™ have reached the A-class rating.

3 LIFE CYCLE VIEW

KONE is committed to its products throughout their lifecycle, from design and manufacturing to maintenance and modernization.

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KONE's life cycle assessment (LCA), carried out in accordance with the ISO 14040 standard, covers the essential environmental aspects at different stages of the product's lifetime from raw material production, component manufacturing, transportation, installation, use, and maintenance to end-of-life treatment. According to the assessment, our environmental impact excludes acidification (9.79E 05 per functional unit), eutrophication (0.011 per functional unit), ozone depletion (1.04E 08), water withdrawal, noise pollution, and impact on biodiversity.

A life cycle assessment has been conducted on all KONE volume elevators and escalators.

The life cycle assessment shows that our greatest environmental impact stems from the energy consumed by our products during their operational lifetime. Electricity production has a large environmental impact because it is carbon intensive and often relies on fossil fuels, particularly natural gas and crude oil. Energy production also results in atmospheric emissions, which include particulates, carbon dioxide (CO_2), nitrogen oxide (NO_X), and sulfur oxide (SO_X).

3.1 Life cycle assessment of an elevator

The assessment is based on the KONE MonoSpace® elevator, with a load range of 320–1000 kg, an estimated lifetime of 25 years, and a frequency of 150,000 starts per year traveling between five floors. The KONE MonoSpace represents more than two-thirds of all elevators ordered from KONE in 2010.

About 75 percent of carbon dioxide (CO_2) emissions, 51 percent of nitrogen oxide (NO_X) emissions, and 57 percent of sulfur oxide (SO_X) emissions are generated during the use stage. By comparison, material production accounts for 14 percent of the total carbon dioxide emissions, while component manufacturing accounts for six percent. About 90 percent of the total primary energy is consumed during the use stage.

3.2 Life cycle assessment of an escalator

The assessment is based on the KONE TravelMaster™ 110 escalator, with an equivalent step load of 25 kg and estimated lifetime of 15 years, operating 14 hours per day, 6 days per week, 52 weeks per year.

About 91 percent of CO_2 emissions, 91 percent of NO_X emissions, and 86 percent of SO_X emissions are generated during the use stage. By comparison, during material production CO_2 emissions are seven percent, while component manufacturing accounts for one percent. About 90 percent of total primary energy is consumed during the operational stage.

3.3 Monitoring and managing the environmental impact of products

As well as carefully measuring the environmental impact of products during their production and operational life span, it is also important to consider what happens to them when they reach the end of their use. The majority of the materials that make up an elevator or escalator's weight can be directly reused or recycled. KONE acts safely, responsibly, and in accordance with the relevant regulations in relation to the collection and processing of electro-mechanical waste from its products. Wherever possible, KONE aims to reduce or eliminate the need to use hazardous materials in the manufacture of its products.

3.4 Use of highly recyclable materials

At the end of its life cycle, approximately 55 percent of the material weight .of a dismantled elevator can be sorted and reused without pre-processing. The metals that make up approximately 93 percent of an elevator and 91percent of an escalator's material weight are fully recyclable, providing a clear reduction in environmental impact by reducing the demand for primary metals as raw materials. Plastics are used for energy recovery or landfilled. Packaging for our products includes wood (77 percent), cardboard and paper (11 percent), plywood (nine percent), and plastics (three percent).

These materials can be recycled or used for energy recovery. KONE focuses on using wood, cardboard, and paper materials from sustainable sources and provides customers with origin of wood certificates upon request depending on availability.

4 SUSTAINABLE SOLUTIONS

4.1 Eco-efficiency drives the solution creation process

Eco-efficiency is one of the key drivers of our solution creation process and is at the heart of the entire KONE offering, from low-rise and high-rise elevators to escalator and door solutions. When we develop new solutions, the focus is on minimizing environmental impact throughout the lifespan of the equipment, beginning with the extraction of raw materials and ending with recycling, waste treatment, and the reuse of recovered materials.

4.2 Aims of solution creation

In our solution creation, we aim to:

- Reduce energy consumption
- Reduce material use (including packaging and waste)
- Avoid the use of hazardous substances
- Maximize material durability and recycled content
- Maximize recyclability
- Ensure that our products meet voluntary green building certification requirements
- Minimize water consumption

Every solution creation project at KONE must follow detailed eco-efficiency criteria, verified using prototypes and pilots, with a special focus on minimizing energy consumption. In terms of product management, every new change to a product is evaluated against the existing solution to verify that the new solution delivers improved performance in terms of minimized impact on the environment.

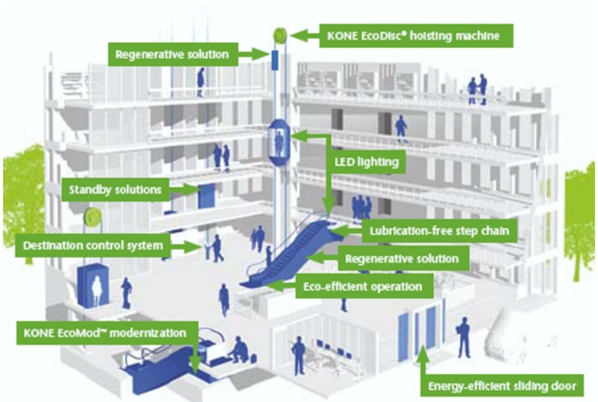

Fig 1: Eco-efficient solutions

4.3 Eco-efficient solutions for elevators

- Elevators equipped with the energy-efficient KONE EcoDisc® hoisting machine are 50–70% more efficient than elevators that use conventional traction 2-speed or hydraulic technology.
- Unlike hydraulic elevators, the KONE EcoDisc® requires no oil or hole drilling.
- KONE's regenerative solutions can provide 20–35% energy savings by recovering the energy created when the elevator is used.
- LED and eco-efficient fluorescent lighting can reduce energy consumption by up to 80% compared to halogen lights.
- Standby solutions power down the equipment when it is not in use, providing substantial energy savings, especially in buildings with periods of low elevator usage.
- The KONE Polaris™ destination control system optimizes elevator traffic, making it possible to reduce the size and number of elevators needed in the building.

4.4 Eco-efficient solutions for escalators

- The lubrication-free step chain saves oil, reduces chain wear, and decreases fire risk.
- Eco-efficient operation can save up to 50% energy by slowing down or stopping the escalator when it is not in use or increasing the efficiency of the motor when traffic is low.
- Regenerative solutions reduce energy consumption by up to 60% by recovering the energy created when the escalator is used.
- LED lighting consumes up to 80% less energy compared to conventional lighting technologies.
- The KONE EcoMod™ solution enables escalator modernization without removing the truss, saving construction time and materials.

4.5 Eco-efficient solutions for building doors

KONE's energy-efficient sliding door solution regulates the door's opening width and opening time based on the outside temperature, providing savings of up to 4000 kWh per year in building heating and cooling costs.

5 ENVIRONMENTAL RESPONSIBILITY IN KONE OPERATIONS

According to KONE's environmental statement, we provide safe, environmentally efficient, and responsible high-performance services, modernizations, and solutions. We strive for continuous improvement in all our business activities by following or exceeding applicable laws, rules, and regulations, and we work with our suppliers and customers to prevent or reduce emissions and waste generated by our business operations.

5.1 Environmental impact of KONE operations in 2010

According to the 2010 assessment, KONE's global greenhouse gas emissions amounted to 3.0 (2009: 2.9) M tCO_2e (million tonnes of carbon dioxide equivalent), of which 21 percent were generated by the production of materials used to manufacture our products, and another 71 percent by the production of electricity used to operate them over their lifetime.

The carbon footprint analysis reveals that less than one tenth of KONE's emissions are a direct result of its operations. In 2010, KONE's operational carbon footprint relative to overall operations (net sales) decreased by two percent compared to 2009. KONE's 2010 absolute operational carbon footprint amounted to 231K tCO_2e (tonnes of carbon dioxide equivalent), representing a three percent increase compared to the 2009 figure of 223K tCO_2e.

With 90K (2009: 92K) tCO_2e in 2010, the major source of carbon emissions continued to be our maintenance vehicle fleet, which is used by our service technicians.

The other major components are our logistics network with 76K (71K) tCO_2e, electricity consumption with 27K (27K) tCO2e, business travel with 22K (16K) tCO_2e, and fuels for heating and processes in buildings with 16K (17K) tCO_2e.

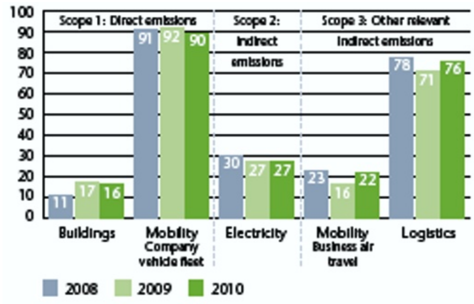

Fig 2: Absolute operational carbon footprint per category, $KtCO_2e$

5.2 Reduction of relative carbon footprint in 2010

In 2010, KONE achieved a two percent carbon footprint reduction relative to net sales compared to the base year of 2009. KONE's absolute operational carbon footprint for 2010 increased by three percent compared to 2009. The increase was partly due to the extension of the reporting scope to cover spare parts logistics and local logistics in countries, as well as increased production volumes. The best results were achieved by our maintenance car fleet, which achieved a 4.6 percent reduction of carbon emissions per unit of equipment under KONE's maintenance, compared to its target of five percent.

In 2010, all KONE's corporate functions and all production units were ISO 14001 and ISO 9001 certified. In 2009, 10 country organizations were certified, and in 2010 one more country organization was certified. The focus for the future is to maintain the achieved certificates and increase the number of certified country organizations. In 2011, two more country organizations are expected to receive certification.

In terms of supplier certification, 98 percent of KONE's strategic suppliers met ISO 14001 requirements by the end of 2010, and work to achieve certification for one remaining strategic supplier is due to be completed during 2011.

5.3 Vehicle fleet actions

Altogether, 39 percent of KONE's operationalgreenhouse gases are emitted by our global vehicle fleet, making it clearly the biggest contributor in terms of CO_2e. In 2010 our fleet consisted of 14,000 (2009: 13,300) vehicles emitting 90K (2009: 92K) tCO_2e. The absolute vehicle fleet carbon footprint decreased by two percent, whereas the relative carbon footprint (per unit in service) reduction was 4.6 percent.

Project O_2xygen was launched in 2008 with the aim of reducing the CO_2e generated by our global vehicle fleet. To help achieve this objective, we have implemented a renewed global fleet policy, improved our vehicle selection lists, and launched the new eco-safe driving program. Although Project O_2xygen concluded in 2009, we are continuing our efforts to further reduce CO_2e and make KONE's vehicle fleet as efficient and eco-friendly as possible through actions such as vehicle rightsizing, a call-out rate reduction program, using route optimization technology, and using alternative fuels that generate lower CO_2 emissions.

5.4 Logistics

Logistics account for 76K (2009: 71K) tCO_2e, or 33 percent of KONE's operational carbon footprint, making it the second biggest contributor after the vehicle fleet in terms of tCO_2e emissions.

The logistics carbon footprint relative to units delivered to customers rose by two percent, and the absolute CO_2 increase was seven percent. The increase was mainly a result of increased production volumes. The increasing focus on the Asian market also had an impact on the carbon footprint development. For 2010, the reporting scope has been extended to cover spare parts logistics, with the exception of shipment by air.

KONE's logistics operations are based on accurate, reliable, and timely information in all phases of the delivery chain, and using distribution models that take eco-efficiency into account. Special attention is paid to reducing the impact of transportation through route and shipment optimization, as well as careful analysis of alternative transportation models. The impact of packaging is managed by using environmentally conscious packaging design, for example, and this applies to both our own packaging and that used by our suppliers.

5.5 Electricity

Electricity consumption accounts for 27K (2009:27K) tCO_2e, or 12 percent of KONE's carbon footprint. The carbon footprint resulting from the use of electricity comprises both electricity consumption and the carbon intensity of electricity production. The electricity is used in KONE's offices, warehouses, and production facilities. Electricity consumption remained at the 2010 level despite the increase in production volumes. In fact, due to the six percent increase in the amount of green electricity used compared to 2009, KONE was able to reduce the greenhouse gas (GHG) emissions generated by the electricity it uses. In total, 11 (2009: 12) percent of the electricity used in our operations comes from renewable sources.

KONE's key country organizations have committed to specific energy consumption and electricity saving programs. For example, KONE's Finnish country organization is aiming to reduce electricity consumption at its facilities by nine percent by 2016, using 2008 as the base year. In turn, KONE's German country organization has signed a 100 percent renewable energy contract with its energy supplier. Our Italian production unit also uses renewable energy; together with other energy saving actions, this resulted in a 35 percent decrease in the factory's carbon footprint in 2010.

5.6 Business air travel

Business air travel accounts for nine percent of KONE's carbon footprint. In 2010 air travel related GHG emissions increased by 36 percent to total 22K (2009: 16K) tCO2e. The relative increase was 37 percent.

KONE actively encourages the use of virtual meeting tools in order to reduce the need for travel. In 2010 virtual meeting time again increased by 40 percent.

KONE also added video conferencing to its set of virtual tools in order to further facilitate global collaboration and decrease the need for travel.

5.7 Fuels for heating and processes in buildings

In 2010 fuels for heating and building processes generated 16K (2009: 17K) tCO2e of GHG emissions. This represents a decrease of seven percent compared to 2009. The reduction was achieved through an increased daily management focus on facility-related environmental issues.

5.8 Highlights of environmental achievements in KONE manufacturing units in 2010

Italy:

- Waste -20%
- Wood waste -37%
- Energy saved with photovoltaic system 4% (Cadrezzate)
- Water -5% (Pero)

Finland:

- Incoming waste -19%
- Scrap steel -24%

China:

- Oil -5% per unit
- Water -33% per unit
- Electricity -18% per unit
- Hazardous waste -44%
- Paper -21% per unit

Czech Republic:

- Water -14 %
- Thermal energy -14 %
- Metal scrap -17%

Mexico:

- Water -5%
- Wood pallet -12%

United States:

- Electricity -20% per unit
- Waste -45%

6 ENVIRONMENTAL TARGETS FOR 2013

KONE's long-term environmental objectives are to further improve the eco-efficiency of solutions, modernize existing elevators and escalators to make them more energy-efficient, and to further reduce the environmental impact of our operations, particularly our operational carbon footprint.

In 2011 KONE set new environmental targets for 2013. We will continue to improve the energy efficiency of our elevator and escalator solutions, and focus on reducing the carbon emissions generated by our operations. The target is to reduce our operational carbon footprint relative to net sales by three percent annually between 2011 and 2013.

By 2013 KONE aims to maintain and extend OneISO (ISO 14001 and ISO 9001) coverage, and continue to contribute to green building requirements. Wherever possible, LEED principles will be implemented at new KONE facilities. In addition, KONE will continue to focus on the sustainability of its delivery chain by ensuring that all strategic suppliers fulfill the requirements of an ISO 14001-certified environmental management system.

New Trends in Ecodesign

Dr. Wolfgang Bloch [1], Dr. Ferdinand Quella [1]
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Abstract
Over the last several years the focus on eocdesign moved away from the design of components or simple products only towards the design of systems. Especially the European product-related legislation, e.g. WEEE, RoHS, ErP and REACh, became a major driving force for integrating new design aspects like energy efficiency, materials and resource efficiency and design principles for recycling into the product design process. Standardization of design principles helps companies to meet internationally introduced regulatory requirements. In addition ecodesign principles are extended to the design of manufacturing sites and include the complete supply chain.

Keywords:
Ecodesign principles, European legislation, WEEE, RoHS, ErP, REACh

1 INTRODUCTION

Environmental European legislation has a high priority for the European, mainly in the area regulating product related topics. This is due to the fact that product related topics have to harmonized within the European economic framework and was not specifically regulated by individual countries until now. Having this in mind we can understand how and why topics like e.g. recycling, energy use and critical substances regulations were introduced to the European market.

In general the regulative environment is changing consequently the meet higher expectations of interested parties like NGO's:

- Number of regulations are worldwide increasing, setting minimum requirements
- More political reduction targets are visible
- Automatisms like increasing targets with time are foreseen in latest legislation, but also „toprunner" approach leads to continuous progress
- Numbers of environmentally compatible products are increasing worldwide and companies show the progress
- Basic tools are now available like ecodesign standards and materials record as basis for LCA, ISO 14006 (2011?) will publish missing „Guidelines for incorporating ecodesign into environmental management systems"
- Further standardization / provision of data is required

In parallel the design principles for developing more environmental conscious products changed from a more simple approach of designing components or products only to a more holistic approach of designing complex systems. The extension to plants as a possible next step to create higher reduction potentials is already in front of us.

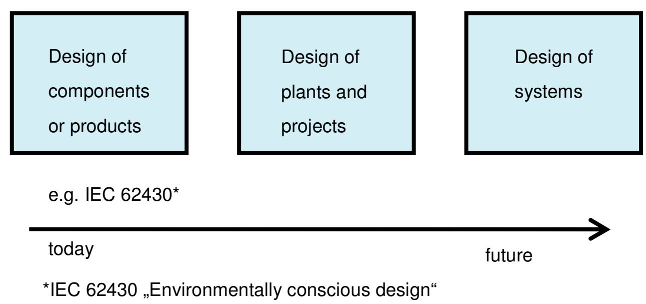

Fig. 1: Extension of Ecodesign scope in the last years

The extension of ecodesign principles for plants may include the following aspects [1]:

- LCA over the complete life cycle, Total cost of Ownership (TOC approach)
- Identify energy consumption drivers: ovens, fans, heating, cooling, energy intensive processes
- Apply already existing environmentally compatible components (purchasing dpt)
- Check software for energy consumption
- Identify local environmental regulations
- Energy reuse, avoid losses, stand-by
- Packaging and transport
- EHS concept for installation, take back and recycling
- Take back, re-use and recycling for manufacturing materials and equipment.

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2 EUROPEAN P RODUCT-RELATED LEGISLA-TION

2.1 Energy related Products Directive

By implementing climate mitigation measures to meet the politically given targets of the Kyoto Protocol the European Commission became aware that by setting emission reduction targets for the "energy intensive industries" only we will not meet the reduction targets. Consequently they introduced a legislation framework to reduce the energy consumption during the use phase of electrical energy using products. A set of "Implementing Measures" was defined together with the industries respectively. The already agreed "Implementing Measures" are listed below:

- Standby and off mode losses of EEE
- Simple set top boxes
- Domestic lighting
- Tertiary sector lighting (office and street)
- External power supplies
- Televisions
- Electric motors
- Circulators
- Domestic refrigeration and dishwashers
- Domestic washing machines
- Fans (motor driven with an electric input power between 125-500 W).

The lasted development regarding this legislation is the extension towards "Energy related Products", like

- Local room heating products
- Central heating products using hot air to distribute heat (other than Central Heating Products)
- Domestic and commercial ovens (electric, gas, microwave), including when incorporated in cookers
- Domestic and commercial hobs and grills
- Professional washing machines, dryers and dishwashers
- Non-tertiary coffee machines
- Networked standby losses of Energy using Products,

but the new view in terms of introducing ecodesign targets, the EU demands by means of **Corporate Social Responsibility** and **Sustainability** higher energy efficiency from manufacturers as well.

One demand in the EU IPP Communication (COM(2003) 302) is a decoupling of energy consumption from economic growth, first target -20 % energy consumption. Decoupling indicators could be: Resource productivity, energy efficiency, resource specific impact.

In general this can only be achieved if…

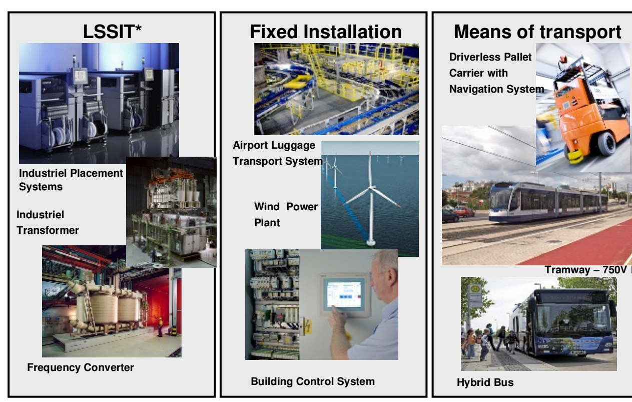
- the quantity of energy consumed by the total volume of products of one kind in the market is estimated and the reduction target is broken down to the next ecodesign process of these products and
- this can go beyond the „toprunner" approach and will be more eager.

2.2 Restriction of Hazardous Substance Directive

The RoHS-Directive (Restriction of Hazardous Substance Directive) was introduced to the market to ensure that all Electical and electronical equipment in scope do not contain certain hazardous substance:

- As of July 1st 2006, the RoHS-Directive restricts the use of Lead, Cadmium, hexavalent chromium compounds, Mercury and polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDE)
- A maximum concentration value (MCV) of 0.1% by weight in homogeneous material for PB, Cr(VI), Hg, PBB and PBDE resp.
- MCV of 0.01% weight in homogeneous materials for Cd is tolerated.

The actually controversy discussed topics are the changes of the scope of the directive, the review mechanism for all RoHS exemptions and the extension towards new substances. Latest in 2019, the EU Commission will introduce an open scope for all elevtical and electronical equipments. Important is the definition of "**electrical and electronic equipment**" which means equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1000 volts for alternating current and 1500 volts for direct current.



*Large Scale Stationary Industrial Tools

Fig. 2: Scope exclusions for RoHS are necessary for industry and were supported by Trade Associations

Common efforts by trade associations resulted in a RoHS Recast compromise considering several important topics for Industry. Positively we achieved:

- Important scope exclusions for e.g.
  - Means of transport for persons and goods
  - Large Scale Stationary Industrial Tools
  - Large Scale Fixed Installations

- No additional Bans of further substances
- No Annex III (REACh candidate list for future bans)
- 5yr validity date on exemptions cat. 1-7, 10,11
- 7yr validity date on exemptions cat. 8 & 9
- 24 Application exemptions for cat. 8 & 9
- Better review mechanism for exemptions
- Transition period when exemption removed of 12 to 18 months
- Case-by-case assessment
- CE Marking may result in better transparency,

but there are still some areas for discussion:

- „Open Scope“ (cat 11) implemented in legal text without impact assessment
- Review of Scope until 22.07.2014 not limited to „Open Scope“ impact assessment
- Weak methodology to amend restricted substances in RoHS and independent from REACH
- 1st review of additional substance bans until 22.07.2014
- CE Marking for RoHS results in a market entrance requirement
- Limited Reuse of spare parts (from EEE put on market before July 1st 2006) runs out July 1st 2016

Unfortunately the categories of the RoHS-Directive and the WEEE-Directive are not the same.

2.3 Waste of Electrical and Electronical Equipment Directive

By introducing the Waste of Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) the WEEE sets collection, recycling and recovery targets for all electrical goods. The main aspects are:

- Producers need to finance collection of all WEEE
- Producers need to register their products falling under the defined categories
- Products need to carry the WEEE label
- Collection rate of 4kg/person annually
- Art. 175 gives certain freedom to each Member State in transposing this Directive.

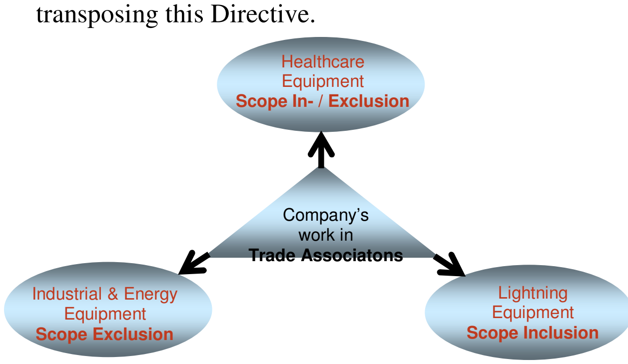


Fig. 3: Needs of an industrial enterprise

Again, industry positioning thru the network of Trade Associations is necessary to introduce feasible legislation. The industry position is:

Scope and Categories of equipment: In general all professional **industrial equipment should be removed** out of the scope. This means all professional industrial equipment.

WEEE collection: **No** producer responsibility should be introduced, to take **full ownership** on WEEE collection.

Rate of Collection, Recovering and Re-use/Recycling: It is **not useful** to introduce a general **collection rate of 65%**. Rather an **individual handling** in respect to the categories is necessary. To strengthen the Waste framework directive the re-use of products is recommended. The new waste hierarchy added re-use to the existing hierarchy:

Prevention before preparing for **Re-use** before **Recycling** before other **Recovery**, e.g. energy recovery and **Disposal**.

Because of higher new WEEE recycling rates re-use might become more important! But, re-use requires an internationally accepted concept of standardization like IEC 62309: Dependability of products containing reused parts - Requirements for functionality and tests.

For producers of high-end technologies the shortage of rare raw materials plays more and more a significant role. Future technologies will change the requirements for raw materials drastically. Many EEE technologies depend on conventional metals like copper and silver but additional growing demand of special metals is to register as lithium, gallium, indium and rare earth. [2]

Therefore long-term strategies to preserve valuable raw materials are essential. This means, that the possible conflicts are no longer inevitable conflicts, but much more useful mutual complements controlled by an intelligent WEEE management strategy.

3 CONCLUSIONS

Potential **Energy Reduction** with already existing electro products are still in the range up to 50 % (example: electro motors, lamps). In the next product generation there is more reduction potential, including Material Resource Efficiency. With the **Extension** of Ecodesign **to plants and systems** there is a new chance for reduction. For the future chances of manufacturing industries a substitution or intensified **Recycling of Specific Materials** is required (example: Indium, Silver, RE).

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Designing Supply-Demand Relationships of Food and Renewable Energy towards Ensuring Regional Sustainability: Case Study of Shinjo Village, Okayama, Japan

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Abstract

Regional sustainability with resilience is becoming an important concept. In particular, securing self-sufficiency of food and energy within local communities, together with local independence, is one of the essential conditions for realizing regional sustainability. In order to discuss such self-sufficiency of food and energy, re-valuing local natural resources and enhancing a proper balance between supply and demand of renewable resources within a region is of critical importance. However, studies which address this aspect are very scant. Shinjo village in Okayama prefecture, Japan is a unique municipality trying to enhance self-sufficiency in terms of energy, food and financial conditions, aiming to avoid a possible merger with other bigger cities. Unique visions and proper measures are needed for the village to keep the self-sufficiency viable and to pursue regional sustainability especially at a time when the labor force is shrinking due to the aging population and resultant declining local economy. In this study, we aim to discuss the outlooks of self-sufficiency level for Shinjo village especially from the viewpoint of supply and demand of food and renewable energy (biomasses). We first looked into geographical data and examined ecological conditions and local landscapes, which serve as the basis for evaluating local natural resources. We then developed inventory data of food and renewable energy available within the region by applying material flow analysis (MFA). Based upon the information we evaluated the regional sustainability from the viewpoint of demand and supply balance for food and energy as well as self-reliance of economic conditions. We found that Shinjo village has abundant natural resources more than the amount originally assumed from the existing official statistical data. We proposed institutional and technical options as well as policy measures, which utilize these rich resources, to further enhance regional sustainability of the village.

Keywords:

regional sustainability, natural resources, community environmental management, material flow analysis

1 INTRODUCTION

Sustainability has long been recognized as a crucial concept by the international society. The definition of sustainable development advocated by the World Commission on Environment and Development, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", articulates the significance of intergenerational responsibility as a sustainability principle [1]. On the other hand, Herman E. Daly, a prominent ecological economist, proposed three conditions for sustainability from resource use and pollution emissions viewpoints [2]. As these principles suggest, our present needs heavily rely on the non-renewable resources such as fossil fuels and minerals, and reducing the demand for those non-renewable resources while promoting the development and utilization of substitutable renewable resources in a sustainable manner is an imperative challenge. However, these sustainability principles alone provides no specific action plans or strategies for achieving sustainability.

Extensive sustainability assessment has been carried out as academic research. While various tools and indicators exist for sustainability assessment, their main focus is on making a balance between environmental conservation, economic development and societal equity. One of the main approaches collects related data and constructs an inventory of the data to demonstrate sustainability assessment by integrating multiple indicators in different domains. In this approach, the target scale can be different, stemming from the global, regional and country level to the small community level. Also the way to aggregate indicators in different domains varies across studies. These approaches are hence effective to

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understand the relative status of the target boundary to others with respect to sustainability components. However, such approach does not necessarily function to grasp the value of local natural resources which is also an important asset for ensuring local sustainability. Re-valuing such local resources and enhancing a proper balance between supply and demand of renewable resources within a region is of critical importance to address regional sustainability. However, studies on this aspect are very scant. In addition, in an attempt to achieving sustainability, it is essential to provide information useful and practical enough for making action plans or policy making. For this purpose, it is required to understand 1) the causal relations among sustainability indicators including socioeconomic ones, and 2) material and energy flow within a certain boundary, in addition to the construction of data base. In this paper, we demonstrate the assessment of regional sustainability through investigation of the relationship between the demand (i.e., the needs of the people) and supply of resources based on the material flow accounting and analysis method. We then briefly discuss institutional and technical options as well as policy measures with an aim to utilize rich resources and further enhance regional sustainability of the village.

2 WHY REGIONAL SUSTAINABILITY？

How to determine a scale or boundary in conducting sustainability assessment depends on the assessment purposes. This study exclusively deals with a small region in Japan that contains a few municipal villages, towns, and cities because of the following reasons. First, the selected region is proper to examine the significance of energy and food security in sustainability. Although everyone admits that energy and food security is important for sustainability, it is not obvious that self-sufficiency for energy and food within a small boundary is necessary. Nonetheless, it is important to understand the supply potentials of energy and food within a certain boundary. The monsoon Asia including Japan is endowed by the rich natural resources and soils, having been able to support large population within the region. Particularly, our target region consists of large farming areas with a few cities, meaning the large potentials of self-sufficiency of energy and food within the region. Once we understand to what extent the region can potentially produce energy and food within the region, it is then possible to reconsider the meaning of the current dependency of energy and food on other countries in terms of sustainability.

Second, we claim that adaptation and resilience, which is in general specific to local socioeconomic and ecological conditions, is another key component for regional sustainability. As for energy supply, large and centralized energy supply systems, which are commonly adopted in many regions in Japan, are vulnerable against natural disaster and other extreme events. While the demand for constructing small scale and decentralized energy supply systems are increasing, understanding regional energy supply potentials will be useful information for specific action plans. In this line, investigating the food supply capacity is also crucial, particularly when considering the fact that the world energy and food prices due to resource depletion show a sharp increasing trend.

The third reason lies in the significance of enhancing economical and political independency of individual regions. Japan is an aging society with decreasing population trends and coming challenges will be specific in individual regions. Hence, decentralization of authority is to be promoted in Japan because regional municipality in general better understands the regional conditions so that they can demonstrate more effective administration in challenging locally specific issues. Additionally, we claim that accumulating sustainability assessment at the regional level is necessary in order to foster the capacity of the region itself for moving it towards a sustainable society.

The fourth reason is related to the third one. We believe that this sort of bottom-up approach can also apply to other regions in Asia in achieving sustainability for a greater region and thus provide meaningful implications for them. Many countries and regions in Asia will become aging society facing region specific sustainability issues and hence capacity building of individual regions in terms of sustainability is important. Moreover, building a network among regions, in which each entity is supposed to be capable of enhancing sustainability by itself, is a critical condition for achieving sustainability at a greater scale. For example, EU has demonstrated that local governments are the main actor when taking initiatives for sustainability while they keep interventions of the central government at minimum.

To be summarized, energy and food security comprises of important components for regional sustainability. As well, regional independency along with capability and resilience possibly contributes to the regional and global sustainability. This is the rationale for why we should consider regional sustainability.

3 CASE STUDY

With this as a background, this paper carries out sustainability assessment for Shinjo village through a construction of natural resource inventory based on the material flow analysis approach. Though past studies attempted to analyze supply and demand balance of resources in a specific region, they lack the viewpoints of regional sustainability based on the analysis [3].

Shinjo village is located in the mountainous area in Okayama prefecture, Japan. According to Köppen climate classification, the climate is of type Cfa (humid subtropical climate). The yearly mean temperature is 11 °C and the mean rainfall exceeds 2,300 mm per annum. The snowfall period lasts 4 months (from December to

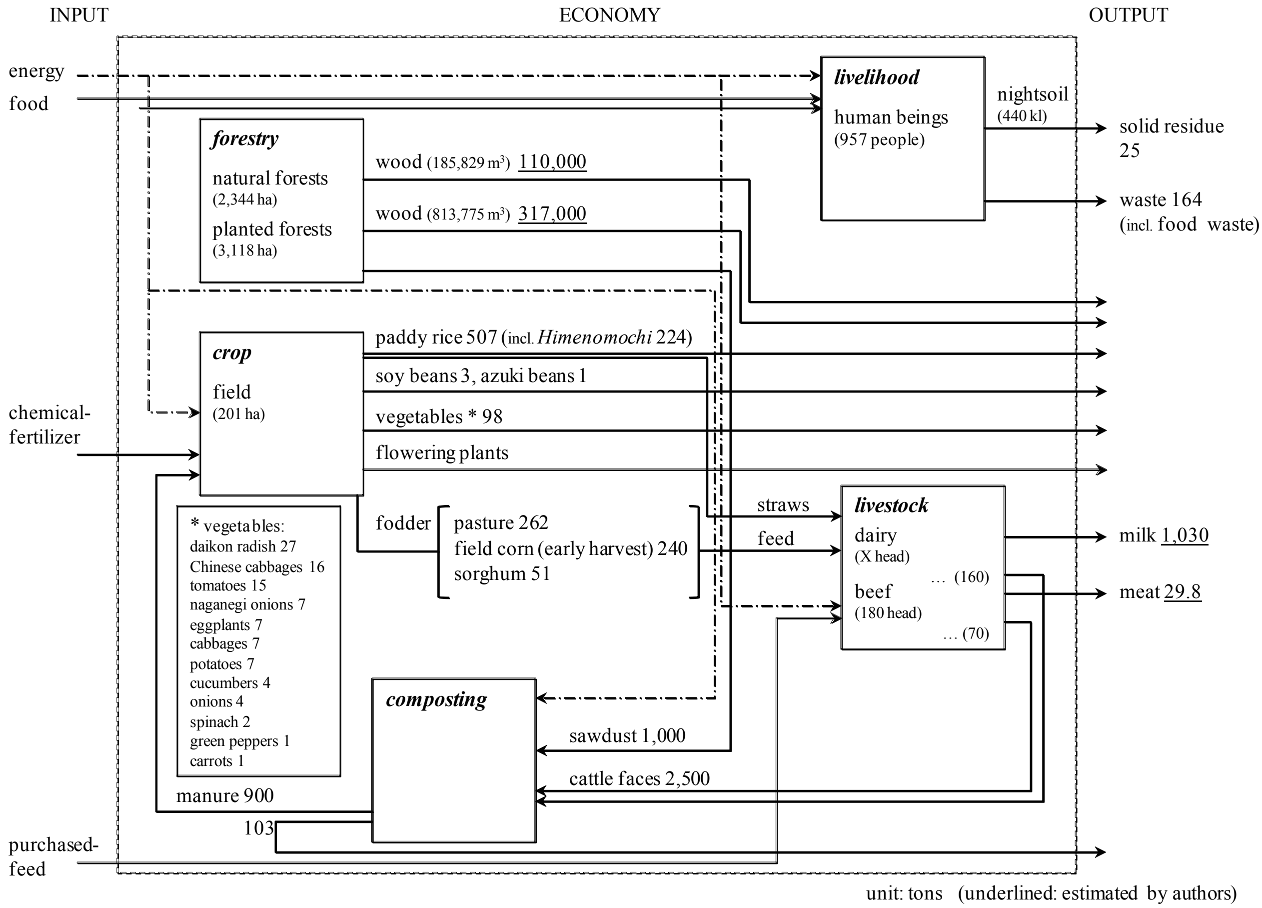

Fig. 1 Matrial Flow of Shinjo Village

March), and the amount of snowfall is also heavy. The total area is 67.1 km^2, of which the area covered by forestry account for about 90 %. The human settlements are scattered along the valleys ranging from 450 to 600 m of altitude [4]. As of 2010, the village has an estimated population of 957 [5]. In Japan, a large number of municipality consolidation cases evolved around 1995, but Shinjo village was one of few villages that refused merger with other municipalities.

3.1 Food

Fig. 1 illustrates the flow of material and natural resources in Shinjo village. The flow chart consists of forestry, agriculture, livelihood, and composting. The unit used in the flow is weight (metric tons) and those weights are directly obtained from official statistics or estimated by the authors [5-8]. Agriculture including rice and livestock is the main industry in Shinjo village. Rice, beef cow, and milk cow respectively account for 35%, 34%, and 22% in the agricultural sales. Small size farmers are dominant in Shinjo village and many of them are facing such issues as low agricultural commodity prices, aging, and absence of successors. As for paddy rice, this village promotes the production of *Himenomochi,* a high quality rice variety suitable to the village's climate. This variety consists of 40% of the total rice production. Shinjo village manufactures and sales *Himenomochi* rice products as local specialties.

They also have had crop rotation practices in the paddy fields, making flowering plants such as autumn bellflower and daily consumed vegetables. Most energy inputs for agricultural production including gasoline and chemical fertilizer come from outside the village. However, they have promoted the production of fertilizer using cattle manure and sawdust.

The estimated sufficiency rate of food supply of the village is 218% on a calorie base. However, the balance between demand and supply is not met. Except for self-consumed rice and vegetables, most of the agricultural production is shipped outside the village while many of the consumed food products including meat, fish and food oil are purchased at supermarket in the neighboring municipalities.

Hence, it requires delving into the contents of food demand and supply. Particularly because of aging and depopulation, household survey will be useful to understand consumption and dietary pattern of the residents.

3.2 Renewable energy

According to Chugoku Bureau of Economy, Trade, and Industry [9], the estimated total energy demand is 27.3 TJ and renewable energy production is 2.1 TJ as of 2009. So, the self sufficiency energy rate of Shinjo village is estimated to 7.76%. All the renewable energy was generated by small scale water-power generations. However, small amount of electric and energy generations by solar power is excluded from the statistics. We found through our field trip that 4 households are equipped with solar panel as of August, 2011. This solar panel introduction can possibly generate 18,300 kWh annually. Consumption data on gasoline, diesel oil and kerosene in the village were to be estimated.

As for biomass energy, charcoal production used to be vigorous decades ago but there are only 10 producers in the village. Chugoku Bureau of Economy, Trade, and Industry [9] estimated energy supply potentials as well. However, their estimates rely only on macro statistics. As large amount of firewood, wood/rice husk charcoal is probably used within the village, field research is necessary to figure out the supply potentials more precisely.

4 DISCUSSION

The previous studies highlighted the significance to regard urban and rural areas as one system and examined the connection forms among the individual areas [10]. Those studies maintained that at the regional level, establishment of resources circulation systems within the regional boundary is one of the effective approaches for the enhancement of sustainability. In general, rural areas are endowed with natural resources while urban areas have large population with dense energy and resource consumption. Identifying the functions of individual rural and urban areas could help promote of resource circulation within the region.

In this study, we showed Shinjo village has sufficient food production while it heavily relies on energy inflow for fossil fuels. On the other hand, the village has large supply potentials for renewable energy and materials. Maniwa city, a neighboring municipality of Shinjo village, is promoting wooden pellet production following the Japan's biomass town initiative. In particular, Maniwa Forest Cooperative attempts to collect wood waste from the mountains including Shinjo village. Although the amount of collected wood by the city is yet only a small scale, cooperative relations should be strengthened to increase bio-fuel production in the region. Furthermore, we emphasized that the residents' aging and depopulation is the biggest challenge for the village social sustainability. Given the biomass potentials for energy production and currently taken initiatives by the neighboring city as its advantages, it can be suggested that the village should find further ways to utilize the rich resources as provision of ecosystem services (including bio-fuels and recreation) to urban residents. Specific measures could include, but are not limited to, maintenance and optimum utilization of biomass resources by means of regional circulations, installation of low head hydro powers, and application of financial mechanisms such as carbon and biodiversity offsets. We conclude this paper by proposing the following as key research questions for this regional sustainability: 1) conducting assessment of ecosystem services in a rigorous and comprehensive way, which includes a completion of a material flow chart for the entire region, and 2) exploring the ways to utilize those ecosystem services along with the establishment of systems to mobilize human resources, money, and materials between the rural and urban areas.

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Introduction of Clean Energy System into Shopping Mall Business

-In Bandung Eco-town, Indonesia-

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Abstract

This research provided new perspective for Bandung Eco-town project with two scenarios about Municipal Solid Waste treatment system in Bandung, Indonesia. We estimated the effect of introduction of methane fermentation system and photovoltaic system into a shopping mall in Bandung, in which stable amount of food scraps would be generated, and photovoltaic system is suitable for Indonesia to reduce CO2 emission since Indonesia is in tropical area. We estimated the potential of methane fermentation system in center of Bandung city too.

Keywords:

Bandung Eco-town, CO2 emission abatement, shopping mall, methane fermentation, PV

1 INTRODUCTION

1.1 Background

Bandung city is one of the quickest developing cities in Indonesia. Bandung has been appointed as one of the cities in the Asia-Pacific region for the development of Eco-town project initiated by the United Nations of Environment Programme (UNEP). The ultimate goal of the Eco-town project is to improve city's environmental quality, that is, aimed to establish a sustainable city. This will be achieved through the implementation of a step-by-step environmentally-friendly city planning and environmental management. The project is also aimed to empower all relevant stakeholders, particularly civil society. Therefore, economic consideration is also an important point besides ecological thought. Although the concept of sustainable development has been sparked off since twenty years ago, yet its implementation both in local and national level is not fully realized. This is due to the practitioners conditions. They are facing a number of obstacles and challenges in creating a balance among the economic, social, and environmental dimension from many sectors of development. It is not surprising that there are still a lot of environmental issues rising, while the government is in the process of adapting the principles of sustainable development. In Bandung, the problems are mainly related to waste. There are not enough waste treatment system, and final disposal site TPA Sarimulti is expected to reach capacity by 2011. Furthermore, the citizen's interest about environment is low. In general, they don't distinguish their wastes with each type of garbage sort.

1.2 Research goal

The research objectives are to provide two scenarios for Bandung Eco-town project. First scenario is about clean energy system in a shopping mall to contribute Eco-town project. Second scenario is additional scenario of first one. In this research, mainly we focus on Municipal Solid Waste (MSW) treatment system and contribution CO_2 emission in a shopping mall in Indonesia, especially in Bandung city.

This paper discusses the renewable energy system such as photovoltaic and/or the methane fermentation which would be contributed to the global warming protection. In the developing country, the economic growth and the environmental contribution might be achieved simultaneously. Based on these requirements, the Eco-town project is raised which means the plan of town construction so as to reduce CO_2 emissions. The local government of Bandung has tried to reduce the waste materials from the residential and/or industrial sectors, because the disposal site would be insufficient. In that case, we have to consider the countermeasure of processing the waste materials generated in this area. In addition, due to photovoltaic system (PV), we analyzed the CO_2 abatement benefit which would be obtained in town area. Finally, this research proposes one Eco-town concept followed model for the sustainable development in Bandung.

2 LITERATURE REVIEW

2.1 Bandung city

Bandung is the capital of West Java province in Indonesia, and the country's third largest city, and 2nd largest metropolitan area in Indonesia, with a population of nearly 2.4 million in only city area in 2010. 31% of Bandung economy is secondary sector such as textile/apparel

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manufacturing, and 69% is other service such as hotel and restaurant. It is mainly built upon tourism. Therefore, Bandung city is nicknamed "Tourist Shopping City (Kota Wisata Belanja)."

Municipal Solid Waste problem

Municipal Solid Waste (MSW) problem is one of biggest problems in Indonesia, and its amount is getting bigger every year. To make countermeasures for this problem, it is helpful if there is future prediction about MSW production. There is correlation between GDP and amount of MSW production [1]. The history and prediction of annual MSW production per a person from 1980 to 2015 is indicated in Figure 1.

The amount of MSW in Bandung is also increasing because of rapid increasing of population whose rate is 1.55% on an average. Even through final disposal site TPA Sarimulti is expected to reach capacity by 2011, Citizens opposed building new final disposal site. It's because of two most catastrophic waste slides that occurred in the past. One is Payatas landfill in Quezon City of Philippines last July 2000, which involved recorded deaths of 278, and from 80 to 350 missing, presumed to be dead. Another is Leuwigajah landfill in Bandung, Indonesia, which involved 148 deaths last February 2005.

Therefore, open dumping system is no longer available, and the appropriate waste treatment system is needed.

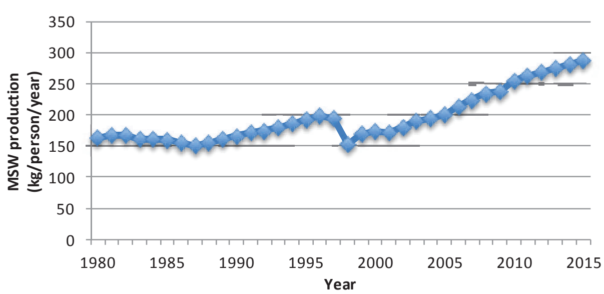

Fig. 1: Annual MSW production per person in Indonesia

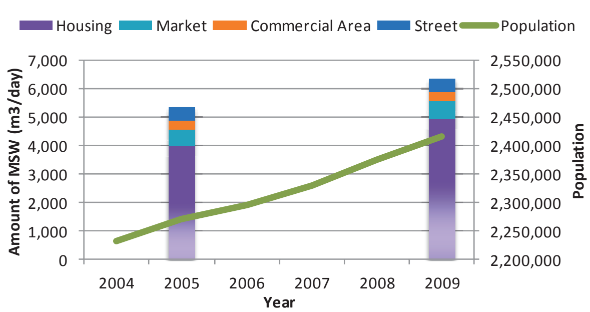

Fig. 2: The amount of MSW and population in Bandung

Shopping malls in Indonesia

Since Bandung city is famous as Tourist Shopping City, there are lots of shopping malls in Bandung city which are crowded almost every day, especially weekend, because so many people come to Bandung city for sightseeing and shopping from other cities.

The average of growth of energy consumption in commercial sector is 5.67% from 2003 to 2007. It's needed to reduce energy consumption or replace it by other clean energy for the abatement of CO_2 emission.

2.2 Methane fermentation system

Since much food waste is produced in Table 1, methane fermentation system is presumed as good and high efficiency treatment system in Indonesia.

In actual condition, one very common waste treatment facility is composting, which is managed by the local government, the private sector and/or the community. The value of methane is higher than compost, and methane has lots of usage, such as direct burning, generating electricity, or supply for fuel cell.

There is no methane fermentation system introduced into shopping malls in Indonesia. However, shopping malls have potential for methane fermentation systems, because they dispose a certain amount of food scraps from restaurants and cafes. In Japan, some demonstration experiments were implemented to gather some actual data for further research.

Table 1: Type of Municipal Waste Composition in Bandung

MSW Composition	%
Organic (bio-degradable)	52%
Inorganic, Non-Recyclable	22%
Other (inert items such as dirt, gravel, concrete, brick, tile)	17%
Inorganic, Recyclable	
Plastics	4.10%
Papers	3.60%
Glass	0.90%
Metals	0.30%
TOTAL =	100%

2.3 Photovoltaic system

As a tropical nation, Indonesia has a very large solar energy potential. Based on solar radiation data collected from 18 locations across Indonesia. Bandung city is in western part of Indonesia with a potential of 4,5kWh/m^2 per day and a monthly deviation of 10%.

Photovoltaic energy has been implemented to harness this large solar potential, and it is used to meet electricity demands for several purposes, including water pumps, televisions, telecommunication equipment, and freezers in health centers with a total capacity of ± 6 MW.

The electricity cost in Indonesia is getting more expensive because electricity supply cost is getting higher. PLN is Indonesian governmental electricity company. The history of the electricity cost and price is shown in Figure 3.

Furthermore, the Indonesian government is planning to increase the electricity tariffs by 10% in average annually starting in April 2012. This move is necessary as the government is trying to reduce the electricity subsidies in 2012 to USD 4.5 billion. This information was released by the Indonesian Minister of Finance Agus Martowardodjo at the Plenary Session of the House of Representatives in Jakarta on 7^{th} of September 2011.

The electricity is expected to be more expensive, and it will make payout time shorter, and make bigger profit from PV systems.

Fig. 3: Electricity price, supply cost, and PLN subsidy in Indonesia

3 SCENARIOS SETTING

3.1 First scenario

First scenario is to introduce waste treatment system clean energy system into a shopping mall.

This research focuses on one actual shopping mall having a hotel in same area in Bandung city. This shopping mall locates along the street having long been renowned as a tourist destination both locally and overseas. The site area of the target shopping mall is approximately 3.5ha, and the store opening hours are 11 hours from 9am to 10pm. The shopping mall doesn’t open their energy consumption data. Therefore, we assumed the energy consumption in this shopping mall by average of energy use intensity of Indonesian shopping malls. That average of energy use intensity is approximately 230kWh/m^2/year. Since there is no data about total floor area of the shopping mall, so we assumed it from similar scale of Japanese shopping mall. The energy consumption of conventional case is approximately 290 million MJ/year.

In Indonesia, a lot of data are not opened to public, especially, in shopping malls. Even the target shopping mall manager declined the offer from Eco-town project officer taking the letter from the head of province. Therefore, this research estimated lots of data from Japanese case and few available data in Indonesia.

According to the concept of Eco-town project, citizens are needed to be educated about importance of environment, and private sectors are required in order to reduce their wastes and energy consumption. Bandung city mainly focuses on industries as private sectors, and the activities in industries are not going well so far, and the concept of Eco-town is not diffused to the citizen. Even through Even through the 3R program is conducted in Segregation, the citizens don't separate their wastes into several kinds of beneficial content. It is necessary to diffuse the concept of Eco-town and increase citizens’ awareness of environment in new approach way.

Visiting facility could reduce opposition rate about new waste treatment system, and providing real image of facility seems to be the best form of public education about environment[2].

Shopping malls are not focused by Bandung city, but they are the places where so many people are gathered. Therefore, a shopping mall can spread around the concept of Eco-town, and improve citizens’ awareness of environment.

3.2 Second scenario

Second scenario is to introduce bigger scale of methane fermentation system in Bandung city, and gather MSW from some shopping malls, hotels, and citizens.

This scenario is only showing the potential of bigger scale of methane fermentation system in consideration of the density of population and MSW production in the center of Bandung city. In this scenario, larger scale of methane fermentation system is built in Bandung city, not inside of shopping mall to gather much amount of MSW from some shopping malls and citizens. Therefore, we don't consider the scale of methane fermentation plant, the place where the plant is built. The location would be affected by the transportation and the actual places where MSW would be able to be collected.

There are few kinds of methane fermentation from some venders. However, almost all methane fermentation systems can produce enough energy for themselves in the bigger treatment scale than 3t/day treatment scale. Furthermore, some methane fermentation system can be expected playability more than in 5t/day treatment scale.

4 ANALYSIS OF EACH SCENARIO

4.1 First scenario

Estimation of methane fermentation system

This study estimates the amount of food scrapes from shopping malls from Japanese data. There is the correlation between the annual amount of food scrap and the number of restaurant and café, to some extent. The coefficient of correlation between them is 0.923, and it’s very strong correlation. So this study estimates the amount of food scrape from the number of restaurant and café.

We estimate amount of food scrape from target shopping mall by regression analysis. The amount of food scrape can be estimated by Eq. 1.

$$y=5.814x+56.249 \quad \ldots(1)$$

From Eq. (1), the estimated amount of food scrap from our target shopping mall was 323.68kg/year.

There are no available data of components of food scraps from shopping malls in Bandung. This makes it impossible to calculate the expected methane yield from the waste. Thus, data from Japanese research conducted in Japan is referred to estimate methane production from methane fermentation system. We assumed that Indonesian components of food scraps are same as Japanese one. Furthermore, there are some methane fermentation systems in Japan, but they don't have big difference between them. Thus, we take data from one demonstration experiment[3]. This demonstration plant operates for gathering data from September in 2009 until December in 2010.

We assumed that almost same result could be produced in this scenario. From the outputs from the methane fermentation system, we replaced energy demands of the shopping mall. In that case, we could get the result shown as Table 3.

In this scale of methane fermentation system, it is needed to add electricity to operate plant. According to International Energy Agency (IEA), the specific CO_2 emission of electricity in Indonesia is 726.138CO_2-g/kWh. Thus, in the case of fermentation system to which 218.4t of food scraps are fed, the total CO_2 emission would be decreased to 18763.4CO_2-kg/year of fossil fuel origin.

Table 2: Operation result and capability of methane fermentation system from Japanese case

Total input of food scrape	218.4 t/year
Biogas production	33440 m^3/year
Electricity production	24720 kWh/year
Expence of electricity in the plant	50560 kWh/year
Input electricity from outside	25840 kWh/year
CO_2 emission	
CO_2 emission per unit of electricity	0.7 CO_2-kg/kWh
CO_2 emission from the plant	18.8 CO_3-kg/year
Efficiency	
Efficiency of electricity generation	14.1 %
Recovery rate of waste heat	31.5 %
Total efficiency	45.6 %

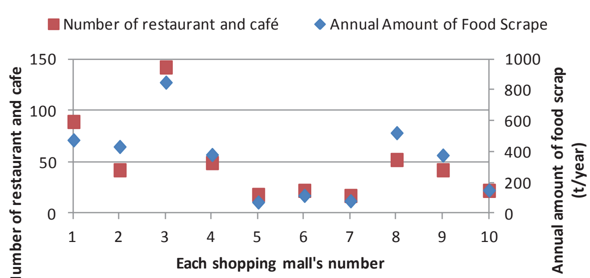

Fig. 4: Correlation between annual amount of food scrape and number of restaurant and café

Photovoltaic system

At first, the average of solar radiation In Jakarta/Bandung is approximately 4.2kWh/m^2 (depending on the location).

One photovoltaic system is provided from one company whose products are popular in Indonesia. The efficiency of the photovoltaic system is 14%-16%. Therefore, the electricity production is 0.588kWh/day, meaning approximately 211.68kWh/year. We need to be careful about the space where the photovoltaic systems are placed. This photovoltaic system uses 80% of space for electricity production, and there is limitation about the space in the shopping mall.

According to PLN statistics 2008, the average price per unit of electricity for commercial department is 842Rp/kWh. It is 1.380Rp/kWh without subsidy for generating electricity.

We assume that the area of roof of the target shopping mall building is 1.0ha, and half of that can be used for the photovoltaic system. In the case, the amount of electricity production is approximately 846.7kWh/year, and the abatement of CO_2 emission is 614,835.6CO_2-kg/year. The installation cost is 28,588,560,000Rp/unit, and the profit to replace to the conventional electricity would be 712,938,240Rp/year. The payout time of the PV system would be 40 years.

4.2 Analysis on basis of second scenario

Based on second scenario, we analyzed the effect of emission abatement.

There are some shopping malls, whose scale is similar to the target shopping mall of first scenario, built in 30km^2 in Bandung as shown in Figure 5. We estimated parameters shown in Table 3, in which the daily organic waste production from housing/settlement within the range of approximately 30km^2 would reach about 220.3t/day. From these conditions, we confirmed that would be enough potential on the big scale methane fermentation system so that the annual profit can be obtained. Also, there are some traditional markets producing lots of organic waste in Bandung city. There's no available data about the amount of organic waste from traditional markets. But it also can be used for methane fermentation system. From those potentials of food scraps, there is potential of methane fermentation system in more than 5t/day treatment scale.

In case of organic waste from housing/settlement, Bandung Eco-town project needs to educate people about 3R. First scenario can be contribution for this scenario.

Table 3: MSW in Bandung in 2009

Category	Source of Garbage	Generated	Collected	
		M^3/day	M^3/day	%
Municipal Solid Waste	Housing/Settlement	4,952	2,853	58%
	Market	619	384	62%
	Commercial Area	303	220	73%
	Street Sweeping	465	291	63&
	subtotal MSW	6,338	3,748	59%

Table 4: Parameters for estimation of amount of organic waste production

Population density	14275.9 persons/km^2
Waste production per person	361 kg/person/year
Ratio of organic in waste	52 %

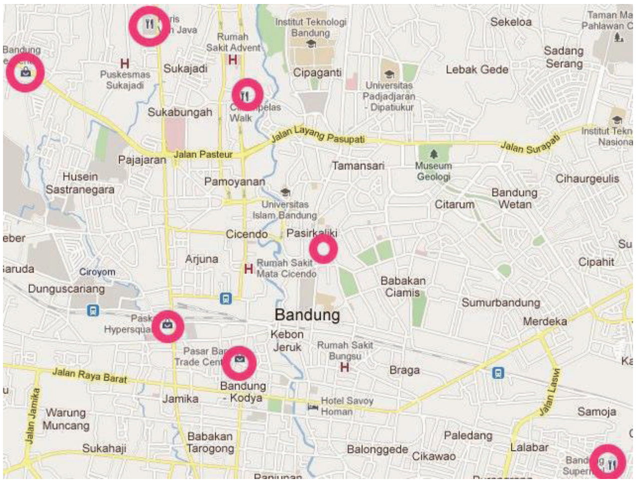

Fig. 5: Location of some shopping malls in Bandung

5 CONCLUSION

This research approached one actual shopping mall in Bandung, which was not mainly focused on by Eco-town project, from the perspective of concept of Eco-town. Results are as follows;

- The 1t/day scale methane fermentation plant in which 218.4t of food scraps is used as feedstock would emit 18763.4CO_2-kg/year.
- The PV system of 4.2kW whose space area is 0.5ha in the shopping mall would reduce approximately 614t-CO_2/year in comparison to the conventional case using electricity from fossil fuels.
- There is good potential on food scraps availability in consideration of the big scale of methane fermentation plant.

Indonesian government should provide subsidies for clean energy systems. In Japanese Eco-town, government provided some subsidies for several kinds of clean energy systems. They encouraged demonstration experiment with private sectors, and improved their concept. So far, Indonesia government still gives a lot of subsidy to fossil fuel. For instance, Indonesian government still focuses on fossil fuel. The subsidies for clean energy systems are still on debate/discussion. But so many experts now try to push the government to consider the renewable energy innovation which we discussed in this paper. The subsidies for several clean energy systems are necessary to make subsidies to make private sectors more corporative and to gather some actual data for further research to improve Eco-town project.

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Eco-Friendly Interface Metropolitan Campus Ecology Interface Design

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Abstract

Three hundred years ago, Taiwan Taipei City was still a wetland. So in essence it is supposed to be a promising candidate for becoming an eco-city. Yet, as a result of long-term development and expansion of man-made environment, inflexible urban space of frantic routines has made ecology a distant possibility. Constructing an eco-environment of water and greens in order to call back diverse species has become the earnest hope of citizens of Taipei. On the brinks of Zhongxiao East Road, NTUT campus is cornered by the road, buildings and walls. An unfriendly fence exists between the campus and the city, and numerous scooters are parked along the Zhongxiao East Road fence of the campus. The fences knocked off, the abandoned space is utilized to create an eco-river, to construct an eco-environment of water and greens in an attempt to callback diverse species, shape a very friendly campus-city interface, and ceremoniously declare that the open space of a city can be a friendly eco-interface,

from which we can build an eco-campus within and disperse eco-spots in other open spaces without.

Through the linkages in between, we can lay the foundation of an eco-city.

The 80-meter-plus fence along Zhongxiao East Road is taken down to transform the original "sidewalk-fence" image into one of "pedestrian strolling and eco-waterscape." On the strange land outside the original fence, an eco-street is built to demonstrate the image of water ecology and express goodwill to pedestrians via the eco-interface. A swirling waterway is constructed among the existing trees along the side walk to introduce the urban wind corridor into the sidewalk, to caress the surface of the river and bring cool air to the campus.

The interface between the campus and the city changes into a visually penetrable communication place, which not only beautifies urban landscape, but encourages ecological species to perch here, adding rich landscapes and diverse ecological features to the strolling pedestrians.

Keywords:

Ecological、Ecological Campus、Ecological Environmental Design, Interface

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1 INTRODUTION

Three hundred years ago, Taipei City was still a wetland. So in essence it is supposed to be a promising candidate for becoming an eco-city. Yet, as a result of long-term development and expansion of man-made environment, inflexible urban space of frantic routines has made ecology a distant possibility. Constructing an eco-environment of water and greens in order to call back diverse species has become the earnest hope of citizens of Taipei. On the brinks of Zhongxiao East Road, NTUT situated at the heart of downtown Taipei and the nucleus, of the transportation network, NTUT is surrounded, with major arteries, Near MRT Zhongxiao-Xinsheng Station, it is where MRT Banqiao Line, MRT Muzha Line and MRT Xinzhuang Line meet. Located near the northwest corner of the campus, Guanghua Mall is an important information technology outlet in Taipei City. With Hua-shan Special District for Arts and Jianguo Brewery around, NTUT has become a typical urban campus, a technological, educational and cultural center of the city hat demonstrates features of educational and academic endeavors. On otherwise, NTUT campus is cornered by the road, buildings and walls. An unfriendly fence exists between the campus and the city, and numerous scooters are parked along the Zhongxiao East Road fence of the campus. There for we used the abandoned space is utilized to create an eco-river, to construct an eco environment of water and greens in an attempt to callback diverse species, shape a very friendly, campus-city interface, and ceremoniously declare that , the open space of a city can be a friendly eco-interface, from which we can build an eco-campus within and, disperse eco-spots in other open spaces without. Through the linkages in between, we can lay the, foundation of an eco-city.

2 NTUT AND TAIPEI HISTORICAL CONTEXT HYDROLOGICAL

Back to 1736A.D., in the first year of Guo Xi-Liu moved his family north and settled near Zhonglun, beginning to cultivate around. (nowadays Shung Shen , Da An and Chung Sheng districs, Taipei City). To solve irrigation problems, he organized the farmers to create new waterways. He discovered that the untilled land near Zhongshan Districts today was of development potential. Following survey, he in the fifth year of 1740A.D. began to dig ditches to draw the water of Qingtan Stream. He also cut trenches, pits guided by the bridge north and south trend creek confluence of water, the water conservation engineering make abundant of water-network in Taipei City. 1970A.D.the urbanization environmental change make the water conservation facilities failed, and the historical waterways spaces that used to be visible everywhere have been appropriated and turned into public facilities or trenches, or covered or filled. Behind Liugongjun and development of Taipei City, there was a tangle of historical events. Recovered historical waterways are similar to rivers in ecological function and cultural landscape. In comparison with rivers beyond the embankment, planned recovery of the waterways gives urban residents better waterfront experience, ecological environment and landscape. Therefore, urban development must return to the issue of urban eco-environment order.

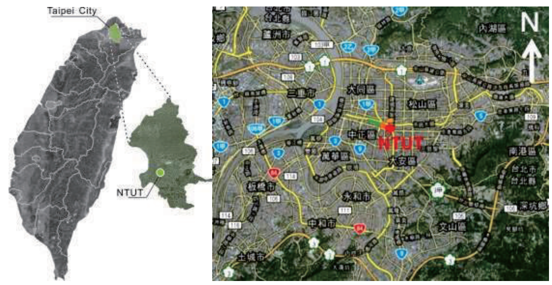

Fig.1:Situated at the heart of downtown Taipei and the Green line of nucleus

Fig.2: NTUT is surrounded, with major arteries, west near to Taipei station and east to MRT Zhongxiao-Xinsheng Station, it is where 5 transportation intersection place, Located near the northwest corner of the campus, Huashand gallery section and Guanghua Mall in Taipei City.

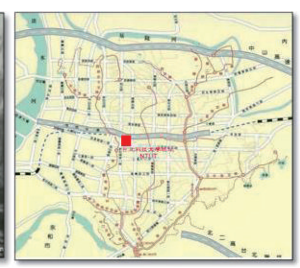

Fig.2: Xinsheng South Road Liugongjun(1963)

Fig.3:Three hundred years to the historical context showing Taipei hydrological context of industrial

Fig.4 Chung Xiao river friendly Eco-interface sketch image

2.1 Every school can build a city campus and the city's water and green

The beginning of NTUT's endeavor to construct the planning concept of eco-campus in response to the green fence of Xinsheng South Road. The following idea was proposed: "An open eco-campus space must be connected to the urban area through ecological interface. Creation of this eco-river is the beginning of a dream and a benchmark in NTUT campus development. Its taking shape marks the start of NTUT quest to become an eco-campus demonstration area and launches restoration of Liugongjun in NTUT Village campus (east campus).

Eco-city is a healthy city with ecological features. Its purpose is to build a living environment that is ecological, comfortable and healthy. Eco-street can mitigate the impact of urban development on environment and merge urban living environment with eco-landscape environment to give the public a place where they can draw near to nature. University campus is an open space in the city and an open educational facility. The interface between this open space and the city becomes an open, friendly waterscape interface that does its part in construction of an eco-city. The campus is part of the urban space. After removing the fences, the campus is merged with the city to form an ecology-friendly campus-city interface, an important link in eco-city construction.(Fig.4)

3 NTUT URBAN CAMPUS CONTENT

The city itself is an organic body that incorporates, various circulations and metabolisms, turning resources, into products and garbage to ensure human survival. It is, also a managerial machine that organizes all urban, activities. With social shifting, urbanization affects the, campus via variables resulting from relations between, he growth of the campus and the city . In the face of urbanization, urban campus gradually, opens up and transforms along the line of diversification, and internationalization. In the city, the campus is no longer merely a place for academic activities and, research undertakings. It has begun to fulfill the essence, of education, which is all-encompassing and expansive.

The cultural features of an urban campus can be used to promote district development, highlight urban characteristics and boost community development, offering a place for citizens to go for recreation and cultural exploration. Campus development is advantageous for urban growth. Yet problems generated by urbanization can limit the scale of the growth. In recent year, campus planning concept has evolved from focusing on the campus itself emphasizing integration and interaction of the campus with its surrounding environment. To the campus, its surrounding environment is beyond control. The peripherals of a campus can only passively, adjust to natural development. In response to the increasing degree of complexity of educational requirements and urban environment problems, how the campus should take the initiative to establish an interactive, mutually-beneficial and mutually-supplementing relationship with the city has become more important than ever.The area of the site totals approximately 1403.07m2. Included in the site are MRT exits, bus stops and Zhongxiao gate, which can bring in large flows of crowds for ecology education. The site is adjacent to this busy corner to enjoy ecological education and exhibit opportunities. Through eco-environment planning and design, an overall concept of "urban eco-street" can be shaped.(Fig.5,6)

4 DESIGN GOAL SITUATION

In this study, the Taipei historical hydrological context, located urban area of NTUT and the campus should have the task of education, the following four design concept and proposed the concept of the design strategy can be achieved. (Fig.7)

Fig.5,6 Chung Xiao river friendly Eco-interface sketch image

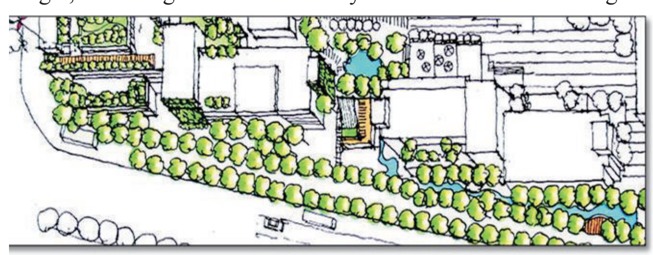

Fig.7 along the Chung Xiao river sketch image

4.1 Friendly Eco-Gateway

The water eco-environment on the border can become the interface between eco-city and eco-campus. Through this water eco-environment the wall, tangible or intangible, can be wiped out to give way to a friendly eco-gateway, which is known for the following characteristics:

a. Water can be shaped into any forms and can awake man's physical and mental desire to experience close encounter with water.

b. Water eco-environment can help cultivate most diverse creatures.

c. School education is a never-ending endeavor. Eco-environment requires persistent dynamic time and spatial process to take effect. Marriage of the two is the niche of the eco-city.

Friendly Eco-Gateway Situation Transforming Strategy(Fig.8)

Fig.8 Friendly Eco-Gateway Situation Transforming Strategy

4-1-1. Reverse back-side image

Turn the back side of the buildings within the fence into the frond side of urban space.

4-1-2. Attract crowd to show care

Multilayer eco-landscape encourages pedestrians to slow down. Overlay red bricks along the sidewalk for pedestrians and bus stop passengers to rest.

4-1-3. Use planting to create the street as a buffing zone

The elevation difference between the river and sidewalk furnishes buffing between pedestrians and ecology.

4.2 Multilayer Eco-Environment that Approximates Nature

The eco-environment in a city needs to take into account interaction of ecology with human activity and with local features. For the purpose of achieving a balance between urban street function and created landscape environment, alleviating interference of current built facilities, and mitigating visual intrusion of artificial facilities.(Fig.9)

a. A habitat that is biologically diversified must have soft, perforated, heterogenic irregular demarcations.

b. Attain maximum ecological benefit with minimum design.

c. Introduce available natural resource to sense its natural power and respect the tolerance of the ecosystem.(Fig10,11)

Fig.9 Artificial facility naturalized sketch image

4-2-1. Artificial facility naturalized

The facility is hidden in the midst of the planting or natural materials. The existing buildings are masked with bamboo fence with vines planted over.

4-2-2. Create diverse water shapes and multi-layer planting

Create a river range of varied depth and width to form different flowing speeds and flow patterns.

4-2-3. Continue existing eco-design

Incorporate the existing sidewalk trees and cause the waterway to swirl in their midst.

4-2-4. Create rich eco-vision

Utilize the smaller vertical visual angle formed via the elevation difference of the sidewalk and the waterway to shape up a greater depth that introduces wider scope of views into a small place.

4.3 Eco-Environment Education Facility

In view of the main artery Zhongxiao East Road, MRT station, bus stops, airport transit stop, Zhongxiao Elementary School nearby, crowd of diverse backgrounds, we can initiate environmental education on ecological issues and release maximized effect of eco-city education.

a. Through evolution of nature, we can display eco-showcase.

b. The best eco-marketing is to demonstrate maximum ecological benefit in the most hostile environment.

Eco-Environment Education Facility Situation Transforming

4-3-1. Eco-Tour-Guide

Organize an eco-tour-guide unit to offer guide services for teachers and students of NTUT and Zhongxiao Elementary School.

4-3-2. Eco-introduction plate

Utilize guide plates to help visitors understand the initiative, concept and influence of the project.

4-3-3. Participation-type eco-education

Organize eco-environment associations and attain the goal of environmental education via showing care and providing services for eco-environment.

Fig.10 Create diverse water shapes and multi-layer planting

Fig.11 Create rich eco-vision

4.4 Demonstration of Cultural Eco-Image

Humanities are the roots of culture. They are cornerstones of a quality city. Care for eco-environment is

demonstration of humanities. Cultural activity is incorporated with eco-environment to extend the image of cultural eco-campus.

a. A selfless concern for eco-environment can become the common language of mankind.

b. Cultural activity can turn this common language into an ambience

Demonstration of Cultural Eco-Imag Demonstration of Cultural Eco-Image Situation Transforming

5-4-1. Introduce water-related cultural activity

In addition to environmental environment shaping, organize water-inspiration activity and design contest in concert with the general education center.

5-4-2. Set up cultural steles

Erect a stone stele on the wooden platform and invite Professor Wu Hua-Yang to write a poem entitled

“Dream” on the stele.

5 CONCLUSION

5.1 Starting point of Urban Ecological Axis

NTUT has spared no effort in its attempt to break existing campus demarcations and integrate with the surrounding environment, making connection with Jianguo Brewery on the north of Civic Boulevard and restoring Liugongjun to the south of Civic Boulevard. Based on this project, it plans to establish linkage with Zhongxiao Elementary School, Huashan Special District for Arts and NTUT eastern campus in the future to create a demonstrative urban water-ecology axis. The purpose is to promote comprehensive development of the urban environment around NTUT and initiate an urban environmental planning that is founded on technology, rooted in humanities and targeted at ecological integrity.(Fig.12)

5.2 Accomplishments of Campus Waterscape

This project tears down the stereotypical stronghold that shuts the campus within walls and creates an eco-street that alleviates the physiological and psychological impacts of urban environment.

The back side of the campus and Zhong-xiao East Road, along which severe traffic impacts have engendered tension and confrontation along, are turned 180 degree around. Now, passengers waiting for the buses, pedestrians, creatures inside and alongside the water, shades of trees and breezes have formed a pleasant scene. This is one of the most natural educations.(Fig.13)

The ecological river in the city is still an ecological manner and growth, ecological environmental balance has been achieved over years and years, there are birds, insects, fish, shelter in the campus ecological corridor. As the ecological variety in recent seven years after the completion of construction of the outside campus Chung Xiao ecological water landscape. Our job is continue to make observations of ecological landscape, biodiversity, logging, planting record of water quality monitoring, and the current growth status of planting: planting the growth in good condition, some have flowers in spring and summer flowering of flowering.(Fig. 14)expect a complete record of the construction process in this eco- water landscape, these technology will be feedback to the construction of ecological communities in the future.(Fig.15) In this decated eco-campus have been operating properly, the legisters deeply experice the enviroment have been changing so well, they strongly promoted the idea to city development and communities, shared with all residients.

Fig. 12 The status of the river landscape with image

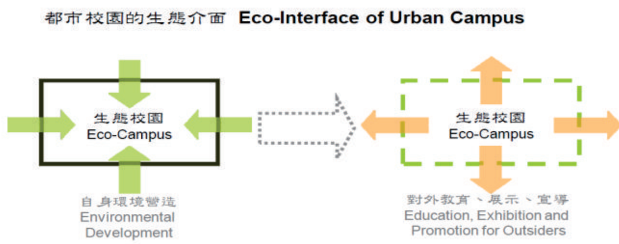

Fig.13 Eco-campus concept diagram

Fig.14 the current growth status of planting

Fig.15 The status of the river landscape

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Sustainable Consumption of Water by NEGA-Resources Approach

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Abstract
Negative resources (NEGA-Resources) are defined as the resources which could be saved by more efficient technology. NEGA-Resources approach is designed by less resource consumption by more value creation or by both. Water, being one of the most important resources for human living, can be considered in NEGA-Resources perspective, because of huge potentials in sustainable water consumption, energy consumption for water supply and resources for maintenance. In the industrialized societies people tend to enjoy the water consumption with low awareness about resource saving. Based on a generic model of NEGA-Resources approach, modern efficient technology is exploited for resource saving and extra-value creation. A so called water zero-emission house has been designed according to the concept of NEGA-Resources approach. Relevant newly designed components are grey water recycling, black water separation, energy harvesting and information processing for social awareness.

Keywords:
negative resources, sustainable consumption, water efficiency

1 INTRODUCTION

As a concept referring to cleaner production or design for the environment, eco-design describes a design process which takes into consideration the environmental implications of a designed product or process by using various approaches. The goal of such a process is to eliminate undesirable or potentially hazardous effects on the environment [1]. Nowadays, eco-design has extended as design for ecology and economy which takes not only the ecological impacts along whole product lifecycle but also economic even social impacts into count of product development. As the three dimensions of sustainability: ecology, economy and society, there are many similar points between eco-design and sustainability development in the view of product development.

NEGA-Resources approach is used to increase the resource efficiency in product lifecycle. So called negative resources are defined as resources which could be saved by efficient technology. Sustainable development always requires the helps from technology, which is traditionally considered as the motor of social development. This paper presents the NEGA-Resources approach with methods and guide for increasing the resource efficiency along product lifecycle.

A case study shows how to implement the NEGA-Resources approach in the practice, which focuses on water consumption. After describing As-Is situation of water consumption, the model and methodology of NEGA-Resources approach will be implemented to build the prototype of water zero-emission house aiming at low water consumption, high energy efficiency and people's awareness of efficient water comnsumption.

2 NEGA-RESOURCES APPROACH

Negative resources (NEGA-Resources) are defined as the resources which could be saved by more efficient technology. This definition presents the same philosophy as resource efficiency, which also aims at creating more value using less resource. The common resources required in industry are raw material, water, energy, human, knowledge and facility. In the whole lifecycle of product, i.e. design, production, use, recycling and disposal, resource is required to enable the realization of each phase.

2.1 Resources consumption matrix

The relationship between resource consumption and product lifecycle are presented on so called Resource Consumption Matrix which provides a method for qualitative analyzing of resource consumption. Quantitative analyzing is also expectable by experimental data. Fig. 1 shows the resource consumption matrix with example of washing machine along its lifecycle.

The positive value on the matrix means resource consumption to realize product and its function. Negative value means recycling or recovering resource. Typically, in the phase of recycling, raw materials can be recovered from used products by recycling, reuse and remanufacturing engineering. No value means resource consumption in this phase can be ignored. The numbers of plus or minus signs on resource consumption matrix present the quantity of resource consumed in corresponding lifecycle phase.

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	Design	Production	Use	Recycling	Disposal
Material		++	+	- - -	
Water			+++	+	
Energy	+	++	++	+	+
Human	++	+	+	+	+
Knowledge	++	+	+	+	
Facility		++		++	+

Fig. 1: Resource consumption matrix along product lifecycle on the example of washing machine

Therefore, products can be classified as different types due to different quantity of resource consumption during the product lifecycle. In the example of washing machine above, relative larger amount of energy and water is consumed in the phase of use comparing with other lifecycle phases. Based on that, washing machine can be considered as a water-intensive product in use phase. Another example is lathe machine which can be regarded as energy-intensive product in use phase.

There are many products reveal a single property in resource consumption, and also many products have a hybrid property in resource using. Some examples of the product category are shown as following:

- Knowledge-intensive in Design, e.g. electronics, etc.
- Material-intensive in Production, e.g. furniture, disposable products, etc.
- Water-intensive in Production, e.g. paper, chemicals, textile, etc.
- Human-intensive in Production, e.g. watch, etc.
- Water-intensive in Use, e.g. toilet, etc.
- Resources-intensive in Use, e.g. machine tools, etc.
- Resources-intensive in Recycling, e.g. beverage container, etc.
- Resources-intensive in Disposal, e.g. battery, etc.

Actually, the most percentage of resource consumption happens in production and use phases. For example, CO2 emission is usually considered as an indicator of energy consumption, the Product Environmental Reports of Apple Inc. shows that 45% and 46% of CO2 emissions of total product lifecycle are generated in production and use phases [2]. Production phase could be partly considered as the use phase of machines. Therefore, the NEGA-Resources are further confined as the consumptive resources, e.g. materials, water and energy, in product use phase.

2.2 Model of NEGA-Resources approach

A kind of NEGA-Resources approach is to be designed with efficient technology which could turn the positive value into negative. Resource will be not always consumed in product lifecycle, but also can be saved by technology that plays a key role in eco-design and sustainable development.

As mentioned before, consumptive resources are used to realize product lifecycle, in other words, product itself should be designed to create more value with less resource. Value-resource ratio could be taken into account to measure resource efficiency. By analyzing the existing product and its resource consumption the value of resource input could be generated, e.g. water volume or material weight, which used as input reference for the functional realization. Hereby, NEGA-Resources approach begins with the thoughts of resource consumption and value creation, and further provides a new viewpoint for product design with consideration of resource consumption. As Fig. 2 shows, three ways is built inside NEGA-Resources approach such as product design with low input resources, onsite closed-loop resource use and extra-value creation of output resource.

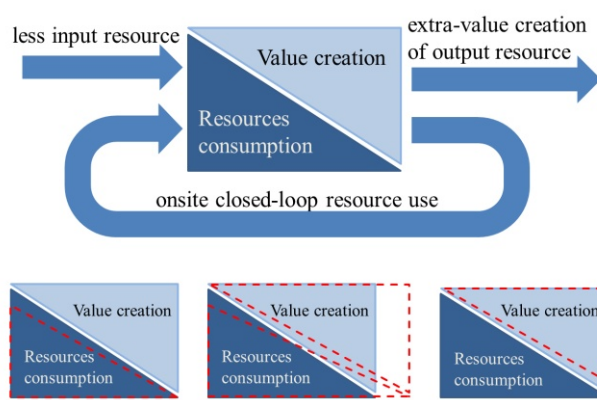

Fig. 2: NEGA-Resources approach for resource use

- Turning resource-intensive product into low resource consumption. The old style products which have been designed without consideration of efficient resource consumption in whole lifecycle could be replaced with new designed efficient one. End users are willing to choose the resource efficient product with innovative design due to increasing resource price and awareness of sustainability. Technology always plays the most important role in reducing resource consumption, not only in innovative product design, but also in improvement of production process.
- Turning mono-use into multi-use of resource. Additional functional module would be added on the product to fulfill the onsite closed-loop resource use. Recycling engineering inclusive reuse and remanufacturing provides huge possibility to recover

raw materials. But recycling works usually as off-site, the used products must be collected by a recycling service center and then recycled or reused again. The effectiveness and efficiency of material recycling depends largely on customers' awareness of sustainability development and benefits of recycling service providers. In the opposite, closed-loop resource use enables an on-site recycling for consumptive resource which could be reused and recycled immediately.

- Turning waste into new resource. Extra-value could be created from the used resource, secondary product and even waste. On the one hand, wastes need more resource to treat it and maybe harmful for environment. On the other hand, waste is resource at a wrong place which could create more value in the further. In global view the resource will create more value in longer lifecycle, and resource efficiency of whole system could be increased.

3 WATER CONSUMPTION

3.1 Water resource

As the origin of life, water is regarded as one of the most important resources of living and industry which has huge potentials in efficient use. The earth's hydrosphere contains the amount of water of about 1386 million km³, of which fresh water takes only 2.5%. However, 68.7% of fresh water is in the shape of ice, snow or polar cap and 29.9% is ground water which is difficult to use. Therefore, only 0.26% of global water quantity is accessible for economic needs and very important for water ecosystems. [3] According to GEO4 report [4], because of growing population, rural to urban migration, rising wealth and resource consumption and climate change, 1.8 billion people are expected to live in water scarce areas and two thirds of the world population could be subject to water stress by 2025.

About 69% of worldwide water is used for agriculture, 22% for industry and 8% for domestic use (household, drinking water, sanitation). In Europe, 50% of water is used for industry while 33% for agriculture and 13% for domestic use [5]. In industry, water is usually used as cooling water, process water, water products (e.g. food industry) and liquid medium material.

3.2 Sustainable consumption of water

The amount of water usage can be reduced with the help of several treatments, so that the resource efficiency can be improved, which results in a higher sustainable development of the countries. With regard to water efficient consumption in industry, a overall water management in plant is needed especially for water-intensive processes.

Water footprint (WF) is an alternative indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business [6]. During WF, water use is measured in water volume consumed and polluted per unit of time. As a necessary resource, water is used in all parts of manufacturing process. By reusing or recycling water, water footprint embedded in each product can be reduced and thus leads to less impact on the environment. At the present and in the visible future the most realistic and effective measures of eliminating fresh water in industry would be building an overall water management system with measurements to decrease water consumption in specific processes.

4 CASE STUDY

As mentioned before, water is a resource used everywhere every day in household, industry and agriculture, but water shortage is becoming an emerging problem for human-being. Therefore, water is a kind of NEGA-Resources which could and should be saved by efficient technology. Based on that, a case study named "NEGA-Resources-Approach in Household Water Consumption" has been conducted by our university. The objective of this case study is to design a water zero-emission house which realizes reduction of fresh water consumption, increasing water and energy efficiency and social awareness of efficient water use by using NEGA-Resources approach.

According to the water quality and source, referred water types in household are:

- Fresh water: water supplied by city water authority.
- Storm water: water from rain or melt snow.
- Grey water: wastewater generated from domestic activities such as laundry, dishwashing, and bathing.
- Black water: wastewater containing and urine, flushing water, feces and toilet paper.
- Yellow water: liquid part of black water, i.e. urine and flushing water.

4.1 As-Is situation and goals

In Germany, a single person use about 122 liters fresh water in year of 2007. In comparison, the average water consumption in European countries is around 200 liters/person/day [7]. The distribution of water consumption inside the house is shown in Fig. 3. Various water consumptions can be divided into different levels according to the required water quality, i.e. drinking, body care, washing/shower, toilet flushing. But the required water quality and quantity is contrary to each other, for example, 33% of water is used to flush toilet, in contrast, only 2% for drinking.

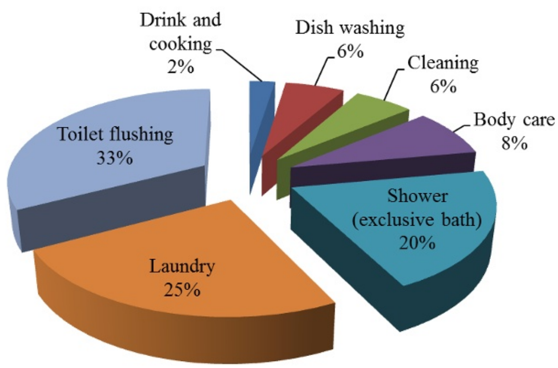

Fig. 3: Distribution of water consumption inside household [8]

Due to rising price of water supply and disposal, inhabitant should pay more money for water consumption. A data from shows form 1990 to 2005, the total price of fresh water per m^3 has increased by 350% [9], meanwhile, disposal of wastewater costs about 14% more than supplied fresh water. Therefore, the general goal of this water zero-emission house is to decrease the consumption of fresh water from 122 liters/person/day to 20 liters/person/day with no wastewater emission and using clean energy for heating water. In this case study, a 3-floor house with 4-people-family (2 adults and 2 children) is chosen to implement the water zero-emission concept.

4.2 Concept of water zero-emission house

Using resource consumption matrix, all the household water appliances are defined as a type of water-intensive products in use. Along the NEGA-Resource approach which offers three ways to improve resource consumption, three kinds of system have been built and integrated within the house. They are: a) grey water recycling system with b) black water separation system, c) energy harvesting system and d) information center.

4.2.1 Grey water recycling system

In order to reduce the fresh water consumption (20 liters/person/day), two measurements are developed: firstly, replace the water-intensive appliances with high efficient products, for example, toilet using 3.5 liters flushing water instead of original 6 liters[10]; secondly, recycling of grey water and storm water, see Fig. 4.

The filter technology offers the possibility of using storm water and reusing grey water. After analysis of each household water appliance, basin for kitchen needs fresh water, assuming that all the drinking water were got here. Grey water can be filtered by two filters that serially connected with each other. Thus, there are two quality levels of filtered grey water. The high level water can be used the water appliances with high hygienic requirement, such as washing machine, dishwasher, shower. The low level water can be used for cleaning, for example, garden, garage cleaning, toilet, etc. The two-level filter system is designed with consideration of costs and investment.

In addition, all the water appliances can use fresh water directly in case of insufficient capability on filtered grey water. Every design or product selection must be evaluated according to water efficiency, energy efficiency and investment.

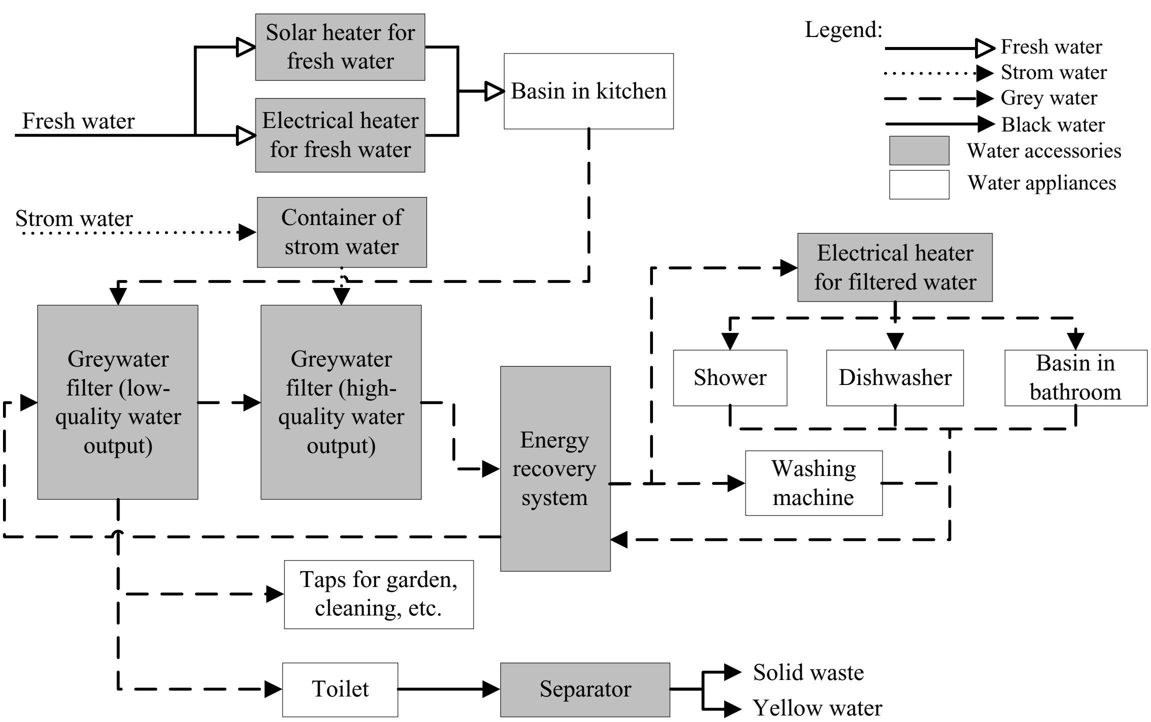

Fig. 4: Grey water recycling system in zero-emission house

Besides of grey water recycling, a black water separation system is also designed to create more value from waste of water consumption [11]. In many countries human waste is used in a traditional way to reclaim fertiliser by separating human waste, i.e. urine and feces. When installing in the house, the separation system should be full automotive without any manual operation. Thus, a kind of toilet waste separation system, which separates the yellow water and solid from black water, is designed based on the capability of 4-person-family. The 3D model of separator realizing 55% dry proportion of solid waste is presented in Fig. 5.

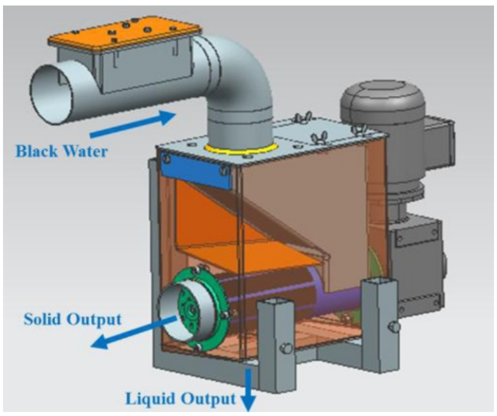

Fig. 5: 3D model of separator for black water separation

4.2.2 Energy harvesting system

Three methods for water heating, solar thermal, electrical heating and energy recovery from wastewater are used in the house to ensure the hot water requirements and meanwhile increase energy efficiency embedded in hot water. Hybrid solar panels with both photovoltaic and solar thermal technology are installed on the roof to use sunlight for heating the fresh water directly. Generated electricity by photovoltaic supplies part of energy consumption in the house. On the case of not enough sunlight or hot water for use, electrical heating system will be used to provide hot water.

Wastewater from shower is usually with temperature of 20-30°C which contains a number of energy normally ignored in water disposal phase. Technology of heat exchanger and heat pump is used to harvest the energy in wastewater. Heat exchanger system is installed before wastewater reaching the filters so that the energy is recovered from the remaining temperature of wastewater. This part of energy can be used to pre-heat the water used later for bath or washing. The energy harvesting system is designed under the concept of onsite closed-loop resource use which can be regarded as a typical implementation of NEGA-Resources approach.

4.2.3 Information center

The information center, which receives various information of water consumption in each water appliance, water temperature in water heating system, condition of whole system especially filters and storm water collector, leads to not only easier condition based maintenance of appliances, but also high awareness of water consumption for user. With the help of information and communication technology, decentralized monitoring system installed on each water appliance. Sensors measure the critical parameters and send the data through wireless communication technology to information center. In addition, grey water recycling system will be also monitored by information center, for example, the level of water in tank, to carry out more effective planning of grey water. People can read the information presented on decentralized monitors, there are information about the amount of water consumption of each appliance. With data of water consumption, the information center can also offer water saving advices by benchmarking or statistical analysis, in order to let user know about his water footprint and what he can do for efficient water consumption.

4.3 Sustainability assessment

Within this water zero-emission house, fresh water consumption per person per day has been reduced to 10 liters. All the black water, which is conducted to separation system, can be totally used to produce fetiliser for agriculture, also provides benefit potentials, see Fig. 6. With the rising price of fresh water and water disposal, such water zero-emission house has both ecological and economic meaning.

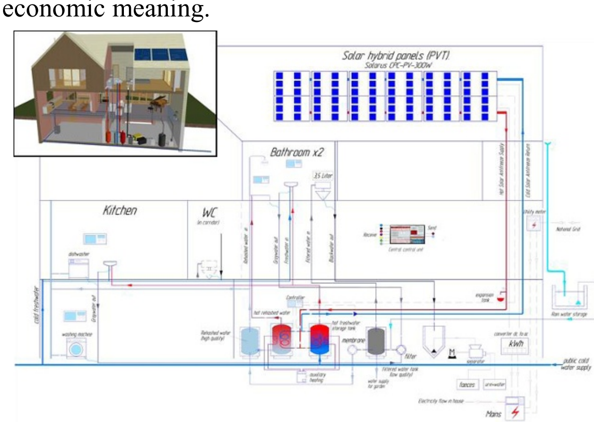

Fig. 6: Water zero-emission house

In order to prove the sustainable contribution, a sustainability assessment tool in terms of environmental, economic, and social aspects is be used based on the criteria system of Sustainability Reporting Guidelines of Global Reporting Initiative [12].

With indicators of decreasing CO_2 emission, energy consumption, fresh water consumption and water disposal for environmental effects; installation investment, operation costs and amortization period for economic value and possible multi-dimensional effect-chains for social impact, sustainability of the water zero-emission house is evaluated. Summarizing by Sustainable development index, all three pillars of sustainability is presented in a single score with a range of 0 to 1000, where 1000 represents the best possible score. Three scenarios are developed to present the comparable assessment: normal four-person-family house, water zero-emission house and future house. Scores for each scenario are calculated as 226, 624 and 815. The assessment result shows that the water zero-emission house has changed the sustainable status as three times as recent situation. Future house scenario presents higher sustainable grade concerning about decreasing costs by expending market, green policy, improvements in the infrastructure and demands of better living standards.

5 SUMMARY

With the concept of NEGA-Resources, an approach to realize high resource efficiency in product use phase is presented in this paper. The case study of water zero-emission house shows, how to implement the approach to achieve sustainable water consumption in household. Efficient technologies have been applied and integrated in the house and contributed to the sustainability of water consumption, e.g. improving the efficiency of water by grey water recycling system, creating more value from waste by black water separation system, recover energy by energy harvesting system, increasing the social awareness of resource saving by information center system. In the future, the NEGA-Resources approach will be expanded into whole product lifecycle, especially applied to increase resource efficiency in manufacturing industry.

6 ACKNOWLEDGEMENT

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Use of Natural Purification of Water Cycle and Water Management as a solution towards Ecodesign

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Abstract
One of the major problems now affecting the world is Water Pollution. Natural forms of pollution have been always presented in water systems, Except for exceptional cases, the natural purification processes is able to remove or convert the pollutants to harmless substances. With the development of civilization, human activities accelerate pollutants entering into the water, So that sometimes the amount of these pollutants exceed of the capacity of self purification of water. It means we need to increase the ability of water self purification with natural materials by physical, chemical and biological processes such as aeration, dilution, using of zeolite mineral, phytoremediation, bioremediation and so on. Sustainable use of aquatic resources is suggested as a solution to achieve a sustainable development based on the ability of aquatic ecosystems to maintain a certain level of water quality and preparing water management by eco-design.
Keywords:
Water purification, Phytoremediation, Bioremediation, Sustainable design, Ecodesign

1 INTRODUCTION

Globally we are facing complex Environmental problems which are not limited to one region or country. They are worldwide intricate issues affecting all human beings.The significance of sustainable development aims to attain and balance society needs with both economic development and environmental preservation. In line with this concept, environmental policy has shifted from the end-of-pipe approach to the pollution prevention approach. Water pollution is a major problem in the global context. It has been one of the leading worldwide cause of deaths and diseases [1][2] Water purification generally means freeing water from any kind of impurity it contains, such as contaminants or micro organisms. Water purification is not a very one-sided process; the purification process contains many steps. The steps that need to be progressed depend on the kind of impurities that are found in the water. Different types of water; in addition reviewing the similar cases in the past,it becomes clear that some of the most impressive and moving cultural and urban landscaping are nothing more than solutions to the irrigation system, domestic water supply, transportation, sanitary sewer and flood control problems of the time. But in current times "Living with Water" fundamentally is depend on the dependency of human needs on the centrally organized and mostly invisible infrastructure systems that transport drinking, rain and waste water. We are facing unintelligible urban outspread processes leading to completely new challenges concerning the management and design of urban infrastructure systems and landscapes. The capacity of these water infrastructure systems for shaping urban form, ecological and aesthetic objectives have much been lost. However the simultaneous worldwide processes of extreme and unpredictable urban growth and decline are leading to huge challenges concerning the affordability and functioning of present water infrastructure conceptions and thus demand new solutions such as increasing the ability of water self purification with natural materials either by physical, chemical or biological processes i.e. aeration, dilution, using of zeolite mineral, phytoremediation, and bioremediation. Taking these challenges as a departure point, this paper will introduce the significance of natural processes in the ecological systems and a landscape approach for the design of water management, circulation and purification systems which can be used as a basis or context for eco design of natural landscape.

2 NATURAL PURIFICATION PROCESS

Considering the reduction of permeable surface in the urban landscape, run-off level is increased. Discharge of large amount of sewage and fertilizer in water resources has resulted in pronounced eutrophication. This matter makes some hazards for city dweller's health. The growing population and increase of industrialization and agricultural production in

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numerous countries require more and more adequate quality of water with low effect on the environment. Therefore, improving self water purification is demanded through the sustainable design to protect water resources. Many physical, chemical, and biotic processes are important determinants for water quality and purification in aquatic ecosystems. [3], [4], [5], [6], [7], [8].

There are some processes and factors which are playing key roles in purification, remediation and enhancement of the quality of the water resources.

Types of Processes and factors of water purification are categorized by Physical, Chemical and Biological functions. Physical processes are including some factors such as Dilution, Adsorption, Sedimentation, Evaporation and Advection and mixing.

Chemical process are including factors such as Hydrolysis, Photochemical reactions, photolysis, Oxidation and reduction and Free radical-dependent destruction, Complication by and binding to other molecules.

Some factors of Biological processes could be mentioned such as Microorganism-dependent oxidations, reductions and other biotransformation, Transformations performed by excretion of chemical substances and enzymes, Accumulation by organisms, Filtering of water by suspension-feeding organisms, Excretion of molecules which are instrumental in increasing the rate of some chemical processes of degradation of pollutants, Producing oxygen that is involved in chemical oxidation of pollutants, Transpiration, Regulation of biological processes of water purification by other organisms [9].

3 THE MAIN PROCESSE OF NATURAL SELF PURIFICATION OF WATER

The dominant processes of the natural self-purification of aquatic ecosystems in the urban landscape can be as following:

(1) Filtration activity or “filters” [8]:

(2) Mechanisms of groundwater recharge, possibly combined with bank filtration, plant purification and/or the use of zeolite mineral, is especially efficient in areas where layers of gravel and sand exist below the earth’s surface

(3) Aeration and increases oxygen in the water

3.1 Filters

Filters comprise the following functional systems:

All invertebrate filter feeders and some vertebrates like fishes. At present, several species of organisms are used in water purification system which improves efficiency and/or ecosystem support. The use of these organisms improving richness of diversity of species which help Ecosystem stability and sustainable design of urban landscape without using dangerous chemical material with harmful effects to the environment that most of them usually have not an environmental life cycle.

Micro organisms, phytoplankton, higher plants, invertebrates, and fish are involved in the self-purification of aquatic ecosystems and the formation of water quality [9]. These groups are necessary for normal self-purification equally. Even the organisms that are not involved directly in the process of improving water quality are often helpful in the key processes of water purification. For instance, many phytophagous organisms cut the large structures of plants into smaller pieces or homogenous mass that is more appropriate substrate for protozoa, bacteria, and fungi that biodegrade that material. The organisms of higher trophic levels are instrumental in regulating the numbers of organisms of lower levels that are the direct participants of water purification [9]. There is a diversity of organisms that are involved in the bio machinery for water purification.

Moreover fishes can limit pests such as mosquitoes. One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide [10]. Finally, the use of native species is considered as an important element in the process of sustainable resource usage and eco-design approach, because it is the reason of stable design and using of indigenous materials in eco-design is important. Macrophytes, which uptake and sorbs part of the nutrients (including N, and P) and Pollutants entering the ecosystem from adjacent areas; Aquatic plants possess an outstanding ability for assimilating nutrients and favorable condition for microbial decomposition of organic matter.

Aquatic Plants Prefer to absorb Ammonium more than Nitrates, for example in the water depths of surface flow systems which typically vary between 0.1 m and 0.5 m, these systems are densely vegetated. May be the basis of wetland is permeable, so it allows exfiltration of water. In this system which is used in North America, amount of Nitrate in the water is high because of plants and undeveloped open water [11], [12], so it needs to utilize gabion of natural zeolite to increase capture of Ammonium.

3.1.1 Some of Macrophytes can be used in water purification

Phytoremediation has many advantages: it can clean-up a wide range of contaminants while also being cost-effective, natural, passive, and aesthetic. Because views of trees and green spaces can also provide important psychological and social benefits, phytoremediation has the potential to treat more than on-site contamination; it may also help to create stronger neighborhoods and industrial/business districts. For phytoremediation to be effective, the appropriate plant needs to be matched to the site. Not only must the species and varieties used be able to remediate the contamination, but it must also be able to survive well in the growing conditions and also not threaten nearby natural areas.

Phytoremediation Plant Selection

The goal of the plant selection process is to choose a plant species with appropriate characteristics for growth under site conditions that meet the objectives of phytoremediation. There are several starting points for choosing a plant:

(1) Plants that have been shown to be effective or that show promise for phytoremediation. These plants can be found in research publications on phytoremediation, or they can be enumerated by phytoremediation specialists.

(2) Native, crop, forage, and other types of plants thatt can grow under regional conditions. A list of these plants can be obtained from the local agricultural extension agent.

(3) Plants can also be proposed based on those plants growing at the site, extrapolations from phytoremediation research, inferences drawn from unrelated research, or other site-specific knowledge. The efficacy of these plants for phytoremediation would need to be confirmed through laboratory.

Ideally, there would be a plant common to lists (1) and (2), or there would be evidence that a plant common to lists (2) and (3) would be effective. These lists of plants can be narrowed down according to the criteria discussed in the outline of the steps for selecting a suitable plant [13].

3.2 Ground water recharge:

In many regions there is lack of surface water and severe water contamination is to be found. Shallow groundwater resources are often of insufficient quality and over-exploited.

The infiltration surface shall be constructed to preserve and enhance the capability of the soil to pass flows from the basin into the groundwater. Also using the planted surface, rather than crushed stone or sand surface can help to improve the groundwater rechargement quality because it prevent of runoff flowing. Groundwater recharge is the infiltration of surface water into shallow aquifers to increase the quantity of water stored in the subsurface and to improve its quality by processes of natural attenuation [14].

It can be practiced especially in river valleys and sedimentary plains by infiltrating river or lake water into shallow sand and gravel layers. The infiltration technique is chosen according to the hydrogeological conditions, the available ground space, the water need, the composition of the infiltrated water, and the degree of purification to be achieved [15].

The water being infiltrated at first passes filter sand or a layer of zeolite filter. This filter layer retains coarser particles by filtration.

Chemical reactions between infiltrated water, solid inorganic and organic substances in the subsurface, and the groundwater flowing towards the extraction well may cause precipitation of sparingly soluble carbonates, hydroxides and sulphides—governed by pH-value and redox-potential—within the ground layer and the aquifer. Dissolved compounds, among them also contaminants, can be adsorbed especially by clay minerals, iron-hydroxides, amorphous silicic acid, and organic substances [16]. Within the layer of filter sand and the aquifer, a great variety of natural micro organisms exist, which are highly involved in rehabilitation processes [17].

The rate of filtration drops in the course of time, and after a certain period the filter layer must be cleaned or replaced. For example if we use zeolite mineral as a filtration material after a certain period we need clean it with NACL solution.

Besides the purification effects, groundwater recharge also enables a better water management [18].

3.3 Aeration and increases oxygen in the water

Biochemical oxygen demand is a measure of the quantity of oxygen used by microorganisms (e.g., aerobic bacteria) in the oxidation of organic matter. Reduce oxygen in water decreases water quality and finally eutrophycation occurs. There are some methods which help to keep level of oxygen demand of water and maintenance of diversity in the aquatic systems.

3.1 Oxygenating plants

They can be one thing to add to the water to help keep the oxygen level up. There are many different oxygenating plants which are useful, including anacharis, cabomba, hornwort, and more. Adding plants like anacharis, the oxygen will be added to the water and help to keep the fish and other plants healthier.

These plants are known as oxygenators and because they grow completely under water, they add oxygen to the water during their photosynthesis, which is a benefit to the living organisms. They also work to improve the chemistry of the water, including softening the water, maintaining the pH, and more to help keep aquatic organisms as healthy as possible. They work as a natural filter for the water as well and are a natural cover and protection for adult and baby fish. Goldfish use the leaves of the oxygenators to attach their eggs as well.

Oxygenating plants are also very easy to maintain and being take care.

3.2 Enrich the water garden with a fountain or waterfall

Aquatic eco systems need oxygen and by aerating the water with a water fountain or pumps, oxygen can be added. Waterfalls can add oxygen and can add more interest to the water feature in the urban landscape.

4 SUMMARY

In the current times with the rapid growth of population water pollution as one of environmental problems is a global defect. The availability and presence of water in cities is a vital element for sustaining life of inhabitants. In this era of famine, infrastructure failure, climate change, unavailability and lack of resources societies are increasingly becoming aware of hazards of poor management. Although widespread investigations had been done regarding to the water purification, but there is not enough supervision on using Biological water purification methods. The natural purification processes are useful to treat the pollutants to make water with harmless substances for residents.

To achieve ecological and social justice in urban water issues, as well informed understanding of barriers for setting up sustainable urban water management must be proven. Frequently, the main barrier cited is “institutional inertia”, or the negligence of the government, industry, and research sectors to shift gears up.

This paper has demonstrated approaches to explain what drainage and water purification system are, as the way to improve water quality by ecological infrastructures such as Bioremediation and Phytoremediation. Ecological functions and green space percapita can improve dwellers life quality by providing oxygen, Microclima and also by purifying region so these functions can be served as the fundamental components for changing urban and regional landscapes. Accounting for these factors would enhance the thriving of the Environmental potential context in sustainable urban landscape. Making use of dynamic and self-correcting natural processes and the designed urban landscapes are working like “artificial ecologies”. They are containing a higher degree of ecological solidity; require less interposition and monitoring than customary systems and, at the same time, providing attractive landscape experiences. Such manner of pondering can shift the paradigm to the different understanding of environmental designing.

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Performance Evaluation of Electric Vehicle and Fuel Cell Vehicle Using the Biomass Gasification System Considering the Change of the Traffic Flow

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Abstract

In this research, we propose the low emission fuel supply system for electric vehicle and/or fuel cell one. In our system, we consider the traffic situation on the express way in domestic area. There are plenty of waste biomass resources which are generated by trimming trees and/or grass at the both sides of road on the express way. Here, we assume the biomass gasification system of Blue Tower (BT) using trimming trees and/or grass. Through BT system, electricity due to gas engine or fuel cell and/or H_2 due to the purification system can be produced. Moreover, the traffic flow would be depending upon seasonal condition. Based on the uncertainties, we consider the production plan for the fuels.

Keywords:

EV, FCV, biomass gasification system, traffic flow, waste biomass resources, LCA

1 INTRODUCTION

Recently, the support of global warming protection would be extremely significant.

In Japan, especially, the CO_2 emission in the transportation sector was 0.23 billion t-CO_2 as of 2009. This value was approximately 20% against the total CO_2 emissions of Japan. This situation would be promoted to install the low emission vehicles such as electric vehicle (EV) and/or fuel cell one (FCV). For instance, some Japanese carmakers have already sold EV on the commercial basis, and another maker has a plan to do FCV in 2015. However, in order to spread EV and/or FCV, it is necessary to prepare the charge infrastructure of electricity or H_2.

On the other hand, from the viewpoint of fuel supply, we might have to find a good countermeasure so as to reduce CO2 emission. In the case of H_2 fuel supply which is fed into FCV, there is conventional H_2 of fossil fuel origins (ex. Natural gas and/or COG). Since the specific CO_2 emission is higher than that of renewable resources origin, recently, there is the demo-H_2 fuel station based on the electrolysis process through photovoltaic power generation system.

The energy supply due to biomass resources would be promising for the H_2 fuel or electricity supply. Thus, we propose the low emission fuel supply system for EV and/or FCV. Especially, in our system, we consider the traffic situation on the express way in domestic area.

Because there are plenty of waste biomass resources which are generated by trimming trees and/or grass at the both sides of road, these are available as a feedstock for the energy production system. Furthermore, since express way is built for the purpose of driving a long distance, so EV or FCV needs to supply H_2 fuel or electricity on the express way.

Here, we assume the biomass gasification system of Blue Tower (BT). Through BT system, electricity due to gas engine or fuel cell and/or H_2 due to the purification system of PSA (pressure swing adsorption) can be produced. For instance, the performances of BT-SOFC (Solid Oxide Fuel Cell) for power generation and BT-PSA for H_2 production are 18.9%-LHV and 27.2%-LHV, respectively.

Considering the annual traffic flow in the model area, the traffic flow would be depending upon seasonal condition. Based on the uncertainties, we found more profitable production plan for the fuels in cosideration of the maintenance period of BT plant (ca. 2 month). Note that the operating condition of BT plant would be kept at 100% loading efficiency.

At the beginning, we find the optimal solution on BT plant location so as to minimize LC-CO_2 emissions which are mainly emitted by transportation of biomass feedstock such as tree and/or grass or auxiliary power of the plant.

Next, we find the feedstock supply plan corresponding to

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the traffic flow change. That is, our model applies the vehicle routing problem (VRP) which determines the route used as the minimum cost when collecting wastes from one or more disposal sites.

2 PROBLEM DEFINITION

The purpose of our model is to provide a basis for comparing actual performance of electric vehicle and fuel cell vehicle using the biomass gasification system. The comparison should provide information for planning or establishing incentive plans. Therefor, it should be simple, easy to understand.

Our model consists of two phase. One is a BT plant location problem, and another is feedstock supply planning problem.

2.1 Low emission fuel supply system

Figure 1 shows a schematic system flow design in this research. The cut-off trees and/or grass used as biomass feedstock are transported to BT plant due to the 4t-packer truck. The electricity and H_2 which were produced through BT plant are supplied to EV or FCV at a charge station. If the energy produced trough BT plant becomes excess supply, the surplus energy would be able to sell to the conventional market. On the other hand, if energy runs short, it is necessary to purchase energy from an external supplier, that is, a conventional supplier.

2.2 BT plant location problem

In this research, it is assumed that trimming tree and/or grass at both sides of road on the express way are collected to the nearest disposal site. On the express way, it is considered that disposal site is established in IC, JCT, SA, and PA. The tree and/or grass are carried to BT plant, and are used as biomass feedstock.

In this research, the target feedstock is cut-off trees and grass of the West Nippon Expressway Company.

Also, using the basic experimental results, we estimated the following material balance:

$$C_{32.394}H_{49.606}O_{21.431}N_{0.194}+32.394H_2O \rightarrow 26.125H_2+11.605CO+2.769CH_4+8.805CO_2+ 23.638H_2O+0.058N_2+7.01\times10^{-5}NH_3 +C_{3.522}H_{1.449}O_{0.371}N_{0.030} \quad (1)$$

For instance, at 950 ºC in the reformer, and at S/C=1.0, the following reaction formula would be obtained for 1 kg of raw material at 20% moisture content. Based on the material balance, we designed the specification of BT plant and the performance data was estimated for our proposed systems.

Tables 1 and 2 show the specification of BT-SOFC (electricity production case) and BT-PSA (H_2 production case), respectively. Note that the plant scale of BT was assumed to be the same of 5t-dry/d, and that the annual operation days are 300 day/yr in both cases.

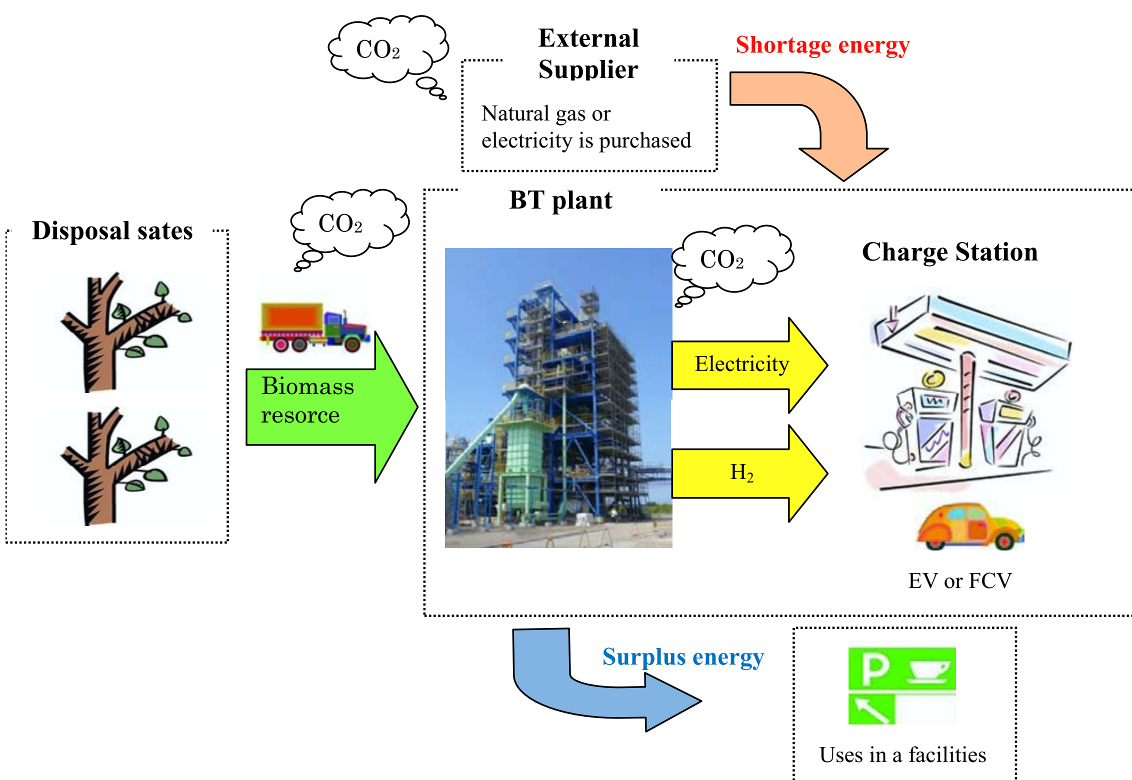

Figure 1: Conceptual diagram of biomass gasification system and energy charge station

In order to compare to the conventional case, it is assumed that the CO_2 emission of H_2 production from Natural gas is 120.8 g-CO_2/MJ [1]. Also, the emission of the conventional electricity in the Chugoku Electric Power Co., INC. is 674 g-CO_2/kWh [2]. Thus, we understand that there is good potential to promote BT systems so as to reduce CO_2 emission.

Table 1: Data of the specification of BT-SOFC

Item	Date	Unit
Total power scale	249.8	kW
Net power scale	197.6	kW
Total power efficiency vs. Feedstock	23.9	LHV-%
Net power efficiency vs. Feedstock	18.9	LHV-%
CO_2 emission for product	0.0	g-CO_2/kWh

Table 2: Data of the specification of BT-PSA

Item	Date	Unit
Volume of H_2	95.2	Nm^3/h
Concentration	99.99	Vol.%
Generation efficiency vs. Feedstock	27.2	LHV-%
CO_2 emission for product	68.0	g-CO_2/MJ-H_2

In this research, the power generation efficiency of BT plant is assumed to operate at 100% loading. That is, it is necessary to transport feedstock required for operation of BT plant from each disposal site. We found location of the BT from which CO_2 emission of a vehicle serves as the minimum. We consider SA and PA as a candidate site of BT. Because EV requires charge time, so it is possible to charge during the break in the SA or PA. And, if electricity remains, using by SA or PA is also possible.

Next, the mixed integer programming for solving the BT location problem is explained. Notation and assumption used by this research is shown in the following.

Notation

N : the number of disposal sites（IC, JCT, SA, PA）

M : the number of candidate sites of BT plant（SA, PA）

Numplant : the number of BT plants

Scalemax : quantity of the feedstock required for operation of BT plant

SP_i : the i-th disposal site（i=1,2,⋯,N）

BT_j : the j-th candidate site of BT plant（j=1,2,⋯,M）

R_i : total quantity of the waste in the disposal site i (t/yr)

F_j : total quantity of the waste in the candidate sites j (t/yr)

X_{ij} : quantity of the waste which transport depot i to disposal site j (t/yr)

D_{ij} : the distance between disposal site i to candidate site of BT plant j (km)

$TotalTransCO_2$: total CO_2 emission of transportation (kg-CO_2/yr)

*Fueluse*_0.8 : quantity of the fuel used when the load factor of a 4t-truck is 80% (L/t・km) (= 0.080)

*Fueluse*_0.1 : quantity of the fuel used when the load factor of a 4t-truck is 80% (L/t・km) (=0.430)

Emicoeff : CO_2 emission coefficient of light oil (=2.62 t-CO_2/kL)

Z_j : Binary variable（If BT plant is build on candidate site j, Z_j =1. Otherwise, Z_j =0.)

Assumption

・Trimming tree and/or grass at both sides of road on the express way are collected to the nearest disposal site (IC, JCT, SA, and PA).

・BT can be built at all the SA and PA.

・Moisture content of raw material transported to the BT plant is 28% [3].

・The plant scale of BT is assumed to 5t-dry/d (dry-base) and the annual operation days are 300 day/yr. The power generation efficiency of BT plant is assumed over 100%. That is, in order to operate a BT plant over 100%, *Scalemax*=2083 (=5t/d÷(1－0.28)wt.%×300day) [t/yr] biomass is necessary. Therefore, the optimal number of BT plants can be solved in the following equation.

$$NumPlant = \left\{ \sum_E R_E \right\} \div Scale\max \qquad (2)$$

・The waste collected to disposal site is transported to one or more BT plants.

・The distance of a packer vehicle is symmetric (D_{ij}=D_{ji}).

・The 4t-packer truck is used for transportation of feedstock. And, the maximum load factor of a vehicle is set to 80%.

・The 4t-packer truck transports the waste from disporsal site to BT plant, and returns to the disporsal site in the empty state.

・Since it is simply, a packer vehicle shall perform transportation to one BT from one disporsal site at once.

・In spite of the load factor of an actual truck, when there is a load, load factor of truck is 80%. And when there is no load, the load factor of a truck is 10%.

Objective function

$$TotalTrans\,CO_2 = \sum_i \sum_j D_{ij} \times \{X_{ij} \times Fueluse\_0.8 + X_{ji} \times Fueluse\_0.1\} \times Emicoeff \quad (3)$$

$$X_{ji} = 0.1 \times X_{ij} / 0.8$$

Subject to:

$$\sum_j Z_j = NumPlant \quad (4)$$

$$\text{Scalemax} \times Z_j = F_j \quad (5)$$

$$\sum_j F_j \times Z_j \le \sum_i R_i \quad (6)$$

$$\sum_j X_{ij} \times Z_j \le R_i \quad (7)$$

$$\sum_i X_{ij} = F_j \quad (8)$$

That is, BT plant location problem is formulized as mixed integer programming. In this research, mixed integer programming is solved using GAMS 23.7.

2.3 Feedstock supply planning problem

Next, we solve feedstock supply planning problem. In the model area, the traffic flow would be depending upon seasonal condition. And, the amount of supply of feedstock also changes with seasons. If electricity or H_2 remains in the BT plant, it can be used on the SA and PA. On the other hand, if electricity or H_2 runs short, we have to supply electricity or H_2 from an external supplier (*ex.* Natural gas and/or electricity of electric power company.).

Furthermore, we have to take the maintenance period of BT plant (ca. 2 month) into consideration and we keep the power generation efficiency over 100%.

In consideration of the above conditions, we try to solve simultaneously vehicle routing problem and feedstock supply planning problem which minimizes CO_2 emission concerning transportation and production.

Notation

$TotalProCO_2$: CO_2 emissions at the time of energy production and fue use (kg-CO_2/yr)

Y_{kt} : Binary variable（If BT plant k maintain in t month, Y_{kt} =1. Otherwise, Y_{kt} =0).

K_{kt_r} : Demand in *t* month of the diffusion rate *r* at BT plant *k* (car/month)

$SumK_{t\_r}$: Demand in *t* month of the diffusion rate *r* at all BT plants (car/month)

K_{max} : The number of vehicles which can be used to per month (car)

A : Augend of CO_2 at the time of supplying from an external supplier (kg-CO_2/car)

Assumption

・Fundamentally, it applies to assumption of above section.

・All the BT plants have to stop during two month continuously for a maintenance.

・When the BT plant stops by maintenance, the demand of the month is assigned to the other plants.

・When demand cannot be satisfied, electricity or H_2 is supplied from an external supplier.

Objective function(1)

$$TotalPrCO_2 = \sum_t Max\left\{SumK_{t\_r} - \sum_k Y_{kt} \times K_{\max}, 0\right\} \times A \quad (9)$$

Subject to:

$$\sum_k K_{kt\_r} = SumK_{t\_r} \quad (10)$$

$$\sum_k Y_{kt} = 2 \quad (11)$$

$$Y_{kt} = \begin{cases} 0, & \sum_{i=1}^{t-1} Y_{ki} = 2 \\ 1, & \sum_{i=1}^{t-1} Y_{ki} = 1 \\ 0,1 & otherwise \end{cases} \quad (12)$$

This research also estimates that of various diffusion rates, assuming that the diffusion rate of EV and FCV will increase in the future. If the diffusion rate of EV or FCV increases, the number of gasoline-powered cars will decrease. Then, we added the CO_2 reduction effect that it shifted to EV or FCV from the gasoline-powered car (GV) [1]. In this research, the reduction effect of CO_2 will be calculated as a difference from 1% of a diffusion rate.

Objective function(2)

$$TotalCO_2 = TotalPrCO_2 - ShiftCO_2 \sum_t (SumK_{t\_r} - SumK_{t\_0.01}) \quad (13)$$

3 CASE STUDY OF BT PLANT LOCATION PROBLEM

The west Nippon epressway company area's trimming trees and grass is used as biomass feedstock, and it considers producing H_2 and electricity in BT plant. The total amount of the biomass feedstock collected from 143 disporsal sites is 5,157 t/yr in 2009. Furthermore, in this research, it takes into consideration not only a express way but building of BT plant which utilized the intact biomass collected from Maniwa city. The total amount of the biomass feedstock collected from Maniwa biomass accumulation base (Maniwa-base) is 9,459 t/yr in 2009.

There are 38 SA and PA which can build BT plant in the model area.

Distance between each sites (SA, PA, IC, JCT and Maniwa-base) is plotted from the map.

As a result of calculating optimal BT location using the above data, the optimum location of BT plant became six places, Syouou-SA, Maniwa-PA, Yuda-PA, Takahashi-SA, Ueno-PA, and Hiruzenkougen-SA (see Figure 2).

Figure 2 : optimal BT location in model area

4 CASE STUDY OF FEEDSTOCK SUPPLY PLANNING PROBLEM

4.1 Energy demand of EV or FCV

When making the energy demand of EV and FCV, we pay attention to the long-distance driver and the tourist. For example, since the cruising range of an EV is about 180 km, when drive more than 180km, it is necessary to charge electricity at an electric station (see Table 3). On the other hand, since the car whose trip length is less than 30 km occupies 93%, shortage of charge station does not occur in now. However, the tourist needs to use a charge station of an outside.

We investigated the traffic flow in the West Nippon Expressway area. In this area, the traffic volume for every month is exhibited by the Japanese government. Therefore, we decided to make energy demand by multiplying traffic volume of a monthly, rate of long-distance driver and the diffusion ratio of EV or FCV [7].

The diffusion ratio of EV has a report that it becomes 20% in 2025 [8], and increasing from now on is expected. Thus, we find the optimal solution on some scenarios. Furthermore, the traffic volume of the tourist of the short-distance drivers was added to the above mentioned demand [9].

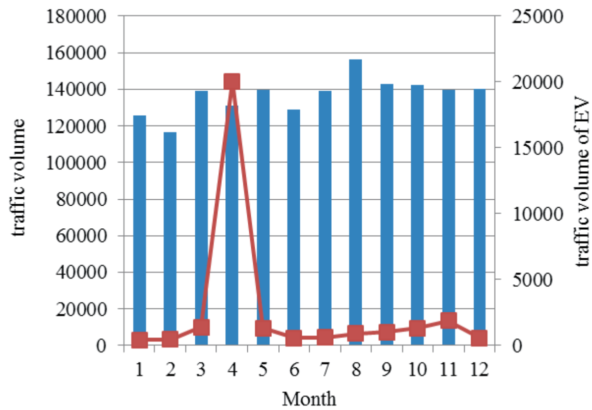

Figure 3: the monthly traffic volume in Syouou-SA

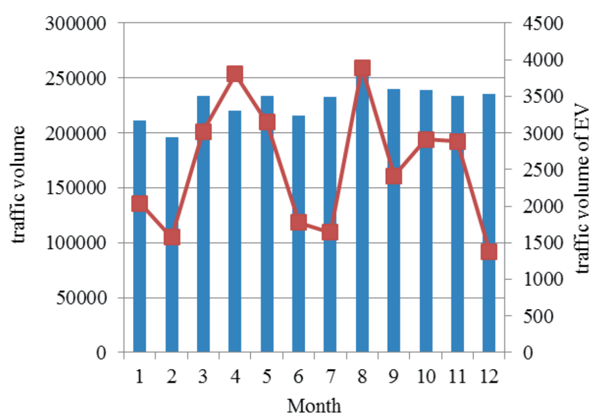

Figure 4: the monthly traffic volume in Maniwa-PA

Table 3: Data of the specification of target vehicles

	Gasolin [4]	EV [5]	FCV [6]
Vehicle type	Toyota NOAH	Nissan LEAF	Honda FC-X
Energy demand (per car)	60 L	24 kWh	59 Nm^3
Cruising range	864 km	180 km	620km

Figure 3 and 4 shows the traffic volume of a car in Syouou-SA and Maniwa-PA. The bar chart shows the monthly traffic volume. In the polygonal line, energy demand of EV of 1% of a diffusion ratio is shown. In the Syouou-SA, the number of tourists is concentrating in April. On the other hand, at Maniwa-PA, the number of tourists fluctuates in a season.

4.2 Comparison of the CO_2 emissions in EV and FCV

Figure 5 shows the variation of the CO_2 emission of EV over a diffusion rate in model area. The horizontal axis of the figure shows the diffusion rate. The vertical axis of the figure shows CO_2 abatement when based on 1% of a diffusion rate.

The solid line of the figure shows the CO_2 abatement when energy is purchased from an external supplier. If energy demand becomes larger than the quantity of energy production of BT, charge station purchases the quantity which ran short from the external supplier. Since there is larger CO_2 emission for energy product of external supplier than BT plant, CO_2 emissions increase it with the increase in purchase quantity.

On the other hand, if a diffusion rate increases, the shift to EV from GV increases. The dotted line of the figure shows CO_2 abatement following the shift to EV from GV.

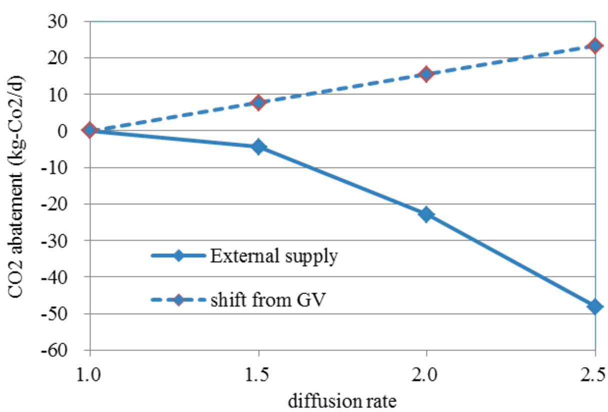

Figure 5: CO_2 abatement in EV

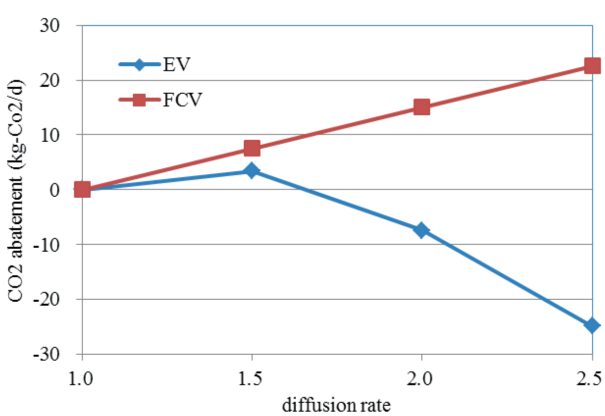

Figure 6: Total CO_2 abatement in EV and FCV

Figure 6 shows the variation of total CO_2 emission in EV and FCV. In the case of EV, CO_2 emissions become the minimum when a diffusion rate is 1.5%. It is because CO_2 emission reduced by shifting to EV from a gasoline-powered car. However, if a diffusion rate becomes larger, variation of CO_2 will increase. This is because the energy which ran short is supplied from an external supplier with large CO_2 emissions.

On the other hand, in FCV, CO_2 variation decreases with the increase in a diffusion rate. It is because the reduction effect by this shifting to FCV from a GV is very large.

5 SUMMARY

In this research, we designed the energy supply model of EV and FCV which used biomass gasification system. In this model, trimming trees and grass at the both side of road are used as biomass resources, and it is possible for reduction of waste treatment expense. The proposed model was applied to the actual biomass resources and traffic flow with a seasonal variation.

Moreover, we determined for the location of BT plant and the production planning of BT plant which achieve the CO_2 emissions minimum. As a result of comparing CO_2 abatement of EV and FCV, it turned out that the way which promoted the diffusion of FCV has an effect in reduction of CO_2. However, the comparison of the cost by the model was not performed. Thus, it might be necessary to reduce the cost due to the installation of eco-friendly system.

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Designing the renewable energy parks in order to reduce the environmental crisis in the framework of ecological design, case of renewable energy park of Manjil – Iran

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Abstract
Most of human activities consist of extensive fossil fuels consumption which has led to undesirable phenomena such as global warming and environmental pollution, which in recent decades have been the most important challenge of the governments and societies. On the other hand one of the most concerning threat and the most vitally important issue which the whole world is facing is how to provide affordable energy supply, which is sustainable and universally available. Renewable energy sources and energy efficiency improvements have the potential to provide the energy needed for human development while delivering substantial poverty alleviation, sustainable development and environmental benefits. Renewable energy parks are some kinds of ecological thematic park which have been proposed in order to educate people, raising the awareness of public in the subject of renewable energies and also producing clean energy.

Keywords:
environmental crisis, clean and renewable energy, renewable energy park, ecological design, Manjil

1 INTRODUCTION AND PROBLEM STATEMANT

The environmental crisis in the all world has already concerned environmentalists and scientists with its major effect on every country. They are affected by various factors such as rising number of the population, exploitation of natural resources, deforestation, overconsumption of the fossil fuels, and waste produced by humans. Extensive fossil fuel consumption in almost all human activities led to some undesirable phenomena such as atmospheric and environmental pollutions, which have not been experienced before in known human history consequently, global warming, greenhouse effect, climate change, ozone layer depletion and acid rain terminologies started to appear in the literature frequently. These phenomena are closely related to fossil fuel uses because they emit green house gases such as carbon dioxide (CO2) and methane (CH4) which hinder the long wave terrestrial radiation to escape into space, and consequently, the earth troposphere becomes warmer [1]. The energy sector is responsible for about three quarter of the carbon dioxide emissions, one fifth of the methane emissions and a large quantity of nitrous oxide. Emissions from fossil fuels are the main contributors to environmental and health problems at the local, regional, and global levels . On the other hand energy is a key element of the interactions between nature and society and is essential to economic and social development and improved quality of life all around the world. Energy production is intricately linked with human life, affecting industry, agriculture and our everyday domestic lives. Hence, the sustainable production of clean energy can mitigate many sustainability issues presently facing mankind, such as greenhouse gas (GHG) emissions, climate change, fossil fuel depletion and energy security [2]. The environmental crisis is perhaps the most long-term crisis, if we do not act now to mitigate it. Climate change threatens to completely change our planet, our societies and our economies. An important environmental challenge during the next decades will be to reduce the impacts of global warming [3]. We need decisive action in the short-term, in order to avoid severe consequences and the real crisis of climate change. In order to avoid further impacts of these phenomena and Under these circumstances the two concentrative alternatives are either to improve the fossil fuel quality with reductions in their harmful emissions into the atmosphere or more significantly to replace fossil fuel usage as much as possible with environmentally friendly, clean and renewable energy sources [1].

Renewable energy is energy which comes from natural resources such as sunlight (solar energy), wind, rain, tides, hydropower and geothermal heat, which are renewable (naturally replenished). Renewable energy is natural energy which does not have a limited supply. Renewable

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energy can be used again and again, and will never run out.

Renewable energy is an indispensable substitute for oil and fossil fuels. The production of renewable clean energy is a prime necessity for the sustainable future existence of our planet [4].

Energy park is one of the cultural, educational, research and practical land use which is recently used in many countries. Renewable energy parks are modern scientific/biological/industrial/thematic parks which would be designed and established upon these mentioned concepts. A/an biological/industrial park is a complex of productive and service industries which are located in a unique site. The different factories and trades are gathered together for economical, managerial and biological reasons and for the use of common resources in a specific place. New/renewable energy parks utilizes clean, renewable energy resources to encourage economic development, provide environmental protection, and offer educational opportunities that together will help lead towards a more sustainable future. We should discuss the strategies of mitigation of greenhouse gases through designing the renewable energy parks and using renewable energies.

Energy parks are some kinds of thematic parks which the main theme of them is energy. Thematic park is an amusement park in which landscaping, buildings, and attractions are based on one or more specific themes.

The current problem of today for supplying energy is not only serious environmental crisis around us but it is the increasing oil and energy price, which is definitely, will be inadequate for our next generation. Rising awareness and changing the point of view to the designing process is one of the ways out of this crisis. Ecological design which is based mainly on sustainability and being in line with the nature and environment is one the most innovative and smart way to deal with our today's environmental crisis. Being creative and constructive, ecological design also stimulates the economic development.

The designing process of Manjil renewable energy park in this paper is in the framework of ecological design. Manjil is located in the north of Iran in the mountains of Alborz and it is known as the windy city of Iran.

Ecological design was defined by Sim Van der Ryn and Stuart Cowan as "any form of design that minimizes environmentally destructive impacts by integrating itself with living processes." [5]. Interest in ecological design reemerged in mid-nineteenth century, when Thoreau, Olmsted, Marsh and others, worried about human intersections with nature. However not until the second half of twentieth century did ecological design and planning gain considerable momentum. Ecological planning and design is more than a tool or technique .it is a way to mediating between human action and natural processes based on the knowledge of reciprocal relationship between people and the land .

2 RENEWABLE ENERGY PARKS:

Renewable energy park is designed to meet the needs of tomorrow's world by addressing today's global challenges. The concept of renewable energy park usually based on "Sustainability", "Technology" and "Education". This concept represents a comprehensive vision of sustainable living that will create a collaboration platform which could have many components that will aim to integrate education, research, development and accelerated implementation of innovative renewable technologies into mainstream society. The function of the park concept intends to work with academic institutions, as well as governmental, industrial and public sectors. These parks can also be productive it means they can be a good source of producing electrical energy and for this reason they are located near energy consuming centers. Nowadays the production of electrical energy from renewable sources is not just a case of study but an irreplaceable ring in the chain of production many countries have already invested on green power and they will still invest more due to the diminishing fossil fuel resources, the Kyoto commitment and the obligations that result from it for every country with regard to the protection of the environment [6].

Some of these energy parks put more focus on research and commercialization of renewable and clean energy technologies along with environmental aspects and these parks usually give services to researches and industries which work on renewable energies and cooperate with the goal of marketing and commercializing the new methods of optimization of energy using.

Indeed, designing energy parks can be highly useful for two reasons first. It can be a good source for preventing environmental pollution resulting from using fossil fuels and emission of greenhouse gases and solve the problem of lack of energy for many countries and the second reason is that using renewable energies can preserve fossil fuels for future generations.

An integrated renewable energy park (IREP) approach can be envisioned for amalgamating different renewable energy industries in resource-specific regions for synergistic electricity and liquid biofuel production with zero net carbon emissions.

3 MANJIL RENEWABLE ENERGY PARK

Manjil is located between N36˚45'18" – N36˚41'42" and E49˚23'6" – E 49˚31'48" in the north of Iran.

It's known as the windy city of Iran; a reputation it owes to its geographical position in the Alborz mountains i.e., at a small cleft in Alborz that funnels the wind through Manjil to the Qazvin plateau.

Fig. 1 : The location of Manjil

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Furthermore, Manjil is known for its olive gardens and it is a big producer of olive and olive oil in Iran. Manjil is also known for the river Sefīd-Rūd (or "Sepid Rood", "Sefid Rood"). This river that passes by the town is formed in Manjil by two joining rivers and since 1960 has been the site of Manjil dam built on it that significantly contributes to Gilan's agriculture while generating electric power. The lake behind the Sepid Rood dam also ads to the beauty of the area. Manjil is the conjunctuion place of three differnent kinds of weather in Iran.

Because of being a windy area Manjil is capable of harnessing wind energy for electricity purpose. Manjil area has a great potential for capturing wind energy in order to convert it to electricity. It is also very important for development and economy of Manjil. It is one of the best locations in the world for installing wind turbines. Manjil is famous as the energy city of iran, therefore it is one of the most suitable places in Iran to design and establish a renewable energy park.

Fig. 2 : Manjil

The main goals of Manjil renewable enregy park is:

- To provide a suitable site for experts, researchers and students to compile and complete their research and studies in optimizing and using renewable energies.
- Public visits, specially families to instruct and raise the public awareness in regard to energies and renewable energies and their usage which can be very beneficial for people of different age ranges in each society.

Fig. 3 : A wide scenery of Manjil and the wind farm

The design of Manjil renewable energy park is based on some basic principles such as :

- Designing a green and sustainable infrastructure
- Preventing from pollution
- Cleaner production (The cleaner production approach is the continuous use of a general environmental strategy for products and services processes, in order to increase the total efficiency and decrease the harmful impacts for environment and human)
- Utilizing new energy with utmost efficiency
- Cooperating of different industries and companies
- Being an educational, recreational and touristic site.

Manjil renewable energy park tries to produce inexpensive energy in great amount and in this regard provide suitable situations and infrastructure for industries and researchers and by the use of renewable resources , it can be a good pattern for educating the use of these resources and promotion of energy production and conversion clean technologies.

The energy park of Manjil make use of a cycle of production conversion and consumption of energy ,in other words, this park can be used as an exhibition for raising people awareness of renewable energy and can also be used by experts and researchers for educational and research purposes.

In Manjil renewable energy park the attempt is to make use of the available and real elements to create an exciting and spectacular site to reach the goal of educating the public (people , tourists , students and etc.)

There are some points worth mentioning in the design of Manjil park:

- Using real generators to supply necessary energy for the urban spaces, public buildings and houses.
- Planning and applying an energy route in city to show different uses of renewable energies and optimizing of energy usage.
- Spreading the area of park in the manjil city in separate spaces and the same time consistent with park elements.
- Cooperating with schools and universities to expand schools and encouraging research related

to energy into the energy park.

The above mentioned factors made a connection between urban life and park and at the same time are like a permanent instruction of the energy related matters for people. The renewable energy park of Manjil, actually, is an urban community in which productive elements, optimization, education and research related to energy are used together like an alive and sustainable system.

The elements of park consist of three parts which are all located at an ecological matrix of the site: educational and research part, energy production sector and recreational zones. Equipped research sites includes labs and biomass plant buildings which will be used for research and educational aims.

Fig. 4 : A proposed sketch for the Manjil renewable energy park

For achieving the educational goals of the park all planning, design and technology of each building, energy generators and infrastructures are a model and pattern of using clean energies and the park can attract the human and industries and capitals. Producing energy in large amount is visible in the park. Electrical energy is produced by wind turbines and solar panels or photovoltaic cells which are spread all over the site. The placement of Sepidrood dam near the site and the hydropower energy as a renewable one, emphasize on the energy production role of the park. In addition the two mentioned sectors will increase touristic and recreational role and emphasize the strong genious loci of the park.

Thus a whole life and sustainable cycle of energy, industry, research, education, exhibition and recreation exist at park.

Fig. 5 : A proposed sketch for the Manjil renewable energy park

3.1 Designing the renewable energy park of manjil in the framework of ecological design

The designing process of Manjil renewable energy park is based on the framework of ecological design. As stated before Ecological design was defined by Sim Van der Ryn and Stuart Cowan as "any form of design that minimizes environmentally destructive impacts by integrating itself with living processes." [5] .

Ecological design is an integrative, ecologically responsible design discipline . Ecological design, also called green building, is defined as the reduction of pollution and resource use; and the protection or restoration of ecological processes with the intent of minimizing the impact of the built intervention on the local and global environment. [7].

The analogy between the natural environment and human environment has gained much interest. Due to the fact that natural ecosystems are effective at recycling their resources, they are identified as primary examples for the efficient recycling of materials and energy in industry. As a result the natural ecosystem has become a model for the activity of this park.

Ecological Design sees all systems as complex, adaptive systems, whether they contain human actors or not. Ecological Design therefore takes a systems approach. This perspective is essential if one hopes to reintegrate humans with the rest of nature and begin to heal the ecosystems we co-habit. Ecological Design employs transdisciplinary integration, cooperative energy, creative synthesis, and true participatory problem-solving to understand and resolve increasingly complex issues.

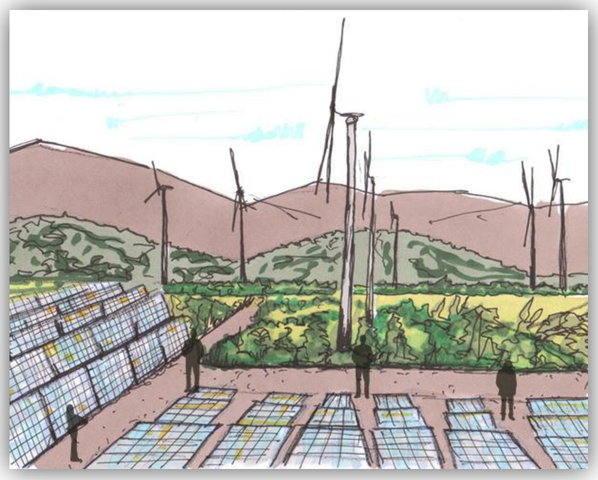

Fig. 6 : A proposed sketch for the Manjil renewable energy park

Ecological design can be applied at a variety of spatial scales. It can be applied in a variety of landscape, including urban, suburban and rural.

In the process of ecological design in the Manjil renewable energy parks the designer will be engaged in the following activities:

- understanding the nature of interaction between human actions and natural processes.

- Understanding and describing the landscape in terms of patterns, process and interactions at many spatial scales to illuminate independent or homogenous area in one or more ways.

- Analyzing the identified homogenous areas

- synthesizing the outcomes of assessment in terms of potential options.

- developing measures for implementing the preferred option.

And so some important points are to be considered.

- Increase the using of natural, clean and renewable energies and optimizing the process of natural cycles as well as water cycle.
- Improvement of seeds, energy, water, nutrients and animals all around the park.
- Improvement of connection of the site boundaries with the outskirts environment.
- Special attention to the ecological niches of animals in the region.

3.2 design strategies

Results of our studies and investigations could be stated as the following strategies:

- It is a tool for research and education in renewable energy and is open to the public.
- The other goal is to provide information to the public by demonstrating different aspects of renewable energy and technology.
- The park is designed for studying integrated energy systems.
- Demonstrate solar energy , wind , biomass , hydrogen and other available renewable energies for the public and offer both students and adults chances to learn about renewable energy, energy conservation, and sustainable environment & building design in a real-world, hands-on environment.
- The park will open up new opportunities for existing businesses.
- It would also be a recreational place for public.
- Designing thematic gardens in the park to show differnet energies in different places , such as solar garden , biomass garden, wind garden and etc.
- Demonstrating various usage of each kind of energy

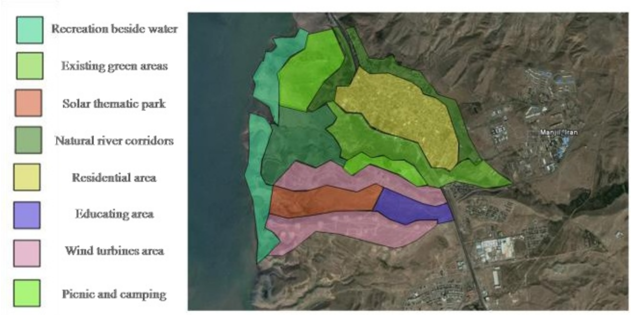

Fig. 7 : the proposed zoning

- The establishment of this park should be based on strong community support and local involvement.
- The park should have an effective and professional management; deliver policy and action for sustainable regional socio-economic, cultural and educational development across the territory.
- This Park must provide and organize support, tools and activities to communicate energy knowledge and environmental and ecological concepts to the public.
- Renewable energy parks should stimulate research and contribute to books and publications.

4 SUMMARY

Today, approximately 80 percent of all energy used in the world comes from burning of fossil fuels. At the same time, an ever-expanding catalogue of energy-saving technologies, as well as reliable and cost-effective sources of renewable energy, is available to policy makers, energy producers and energy consumers. In every part of the world, these technologies make sense from both economic and environmental perspectives . The first step in reducing our environmental and also carbon footprint is becoming more aware of the impact our actions have on the environment. Take some time to brainstorm and create an action plan to change some of our habits that have a negative effect on the environment. Burning fossil fuels such as natural gas, coal, oil and gasoline raises the level of carbon dioxide in the atmosphere, and carbon dioxide is a major contributor to the greenhouse effect and global warming and global warming results in other environmental crisis. Energy resources are essentially used to satisfy human needs and improve quality of life, but may generally lead to environmental impacts (fossil fuels).

So we should change our habits and return to renewable energies . Due to achieving this goal we should introduce and demonstrate green energies to people and describe the advantages and benefits of them . Renewable energy parks would help us to do this duty. Nowadays in order to educate and train people and to accustom public to renewable energies the concept of energy parks and renewable energy parks has been a new, innovative and important solution.

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A Methodology for Designing Future Zero-Carbon Electricity Systems with Smart Grid and Its Application to Kansai Area, Japan

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Abstract— **Zero-carbon power sources including renewable and nuclear energy are expected to be increasingly rapidly integrated into future electricity systems in Japan. On the other hand, one of the most crucial elements of future electricity systems will be the capability for "smart" controls on both supply and demand sides to perform under real-time dynamics. Therefore, the purpose of the study is to propose a methodology for designing zero-carbon electricity systems with smart grids. The methodology is organized into an input-output framework, and is realized using an hour-by-hour computer simulation to achieve a supply-demand balance in real time subject to various constraints. The methodology is developed as an operable software platform, and it is applied to Kansai area, Japan as a case study to test its practical feasibility. Scenarios with different energy mix in supply side and electric devices in demand side are proposed using the methodology. The analysis result shows that in future electricity systems, controllable loads are helpful for integrating zero-carbon power sources; effective and low cost smart control technologies, batteries, hydrogen storage and fuel cell technologies are crucial for realizing the desired zero-carbon electricity systems. Finally, the practical availability of the proposed methodology is proven through the case study.**

Keywords- scenario analysis; electricity system; demand-supply

I. Introduction

Although the Fukushima Nuclear Accident happened on March 11, 2011 in Japan led to many criticisms on nuclear power again, from a long-term viewpoint, there are very serious energy security problem and global warming pressure. Therefore, zero-carbon power sources including nuclear power and renewable energy are critical for Japan to reduce the high rate of dependence on overseas energy imports and CO_2 emission. However, renewable and nuclear energy pose a significant problem to traditional grid systems, which cannot cope with rapid, intermittent and uncontrollable peaks and falls in electricity demand depending on the time of day and season. Electricity production from renewable energy mainly photovoltaics (PV), wind and wave power depends highly on weather conditions which are unstable and cannot be adequately predicted. Nuclear power as a base load generation source with high capital cost and low operation cost cannot readily alter its power output for technological and economic reasons. Therefore, load levelling and fluctuation absorption remain a problem that power suppliers are unable to overcome by themselves[1][2]. On the other hand, new electric devices such as battery, electric vehicle (EV)[3][4] and heat pump (HP)[5], etc. will soon be added to the current electricity system, and their operation pattern can be controlled in real time. The new electric devices are expected to help electricity systems to integrate more nuclear and renewable energy by absorbing excess electricity and supplying deficient electricity. For this reason, smart control strategies of the electric devices are of vital importance to integrate zero carbon power sources into future electricity systems.

One of the most crucial elements of future electricity systems will be the capability for "smart" controls on both supply and demand sides to perform under real-time dynamics. However, there are many technology options on both sides and the designing of this kind of systems based on various conditions and constraints in a specific area needs an effective and flexible tool. Many models have been developed for analysis of the energy (electricity) mix with renewable energy penetration[6]. In particular, some of them are based on hour by hour simulation[7]. However, there is still not a methodology mainly focusing on zero carbon electricity systems with various new electric devices under various smart control strategies. Therefore, a methodology is proposed in the present study to fill this gap. The core of the methodology is an hour-by-hour computer simulation to realize a supply-demand balance with smart control of the fluctuations on both sides. In the study, continuous baseload and intermittent renewable energy supply, and various demand and supply-side future technology options are incorporated. The input of the methodology is historical electricity load, combined with anticipated new electricity loads and production and lifestyle factors. The objective of the simulation is to develop an electricity system with zero CO_2 emission, less surplus electricity and low cost. The result not only can give the appropriate mix but also the operation patterns of the devices in both supply and demand sides in the electricity system.

The methodology is developed as an operable software platform in the study, and it is applied to Kansai area, Japan as a case study to test its practical feasibility. Scenarios with different zero-carbon power source mix in supply side and different electric devices in demand side are designed subject

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to various constraints. Finally, the practical availability of the proposed methodology is proven through the case study.

II. METHODOLOGY

A. Framework of the Methdology

An analysis methodology is proposed for integrating more renewable and nuclear energy into future smart electricity systems defined previously with electric devices under their smart control strategies. The basic idea is to conduct analysis into three steps to (1) define a basic model; (2) specify electric device options and their control strategy options based on the basic model; (3) conduct scenario analysis under the specified devices and control strategies to integrate renewable and nuclear energy.

When we consider future electricity systems, we want to know the demand and supply balance; and to know a proposed system is feasible or not. Future electricity demand can be estimated by adding new load to historical load. In order to obtain a feasible electricity system integrated zero-carbon power sources and new electric devices, we need to check the basic demand-supply balance in real time based on input preconditions and predefined operation rules (control strategies). The obtained results are expected to give information on demand-supply balance, mix of system and economic and environmental performances. In general, all the data, rules and results can be organized into technology, economy and environment aspects.

Therefore, we proposed the basic model shown in Fig.1. It is organized in an "Input-Output" framework and realized by hour-by-hour demand-supply balance simulation. The arrows in real line and dotted line in the figure show the data flow and integration respectively. We divide the basic inputs into two classes, one is basic physical data the other is predefined operation rules. Main input data are historical traditional electricity load, solar irradiation, wind speed, fuel supply, installed capacity, CO_2 emissions factor and basic cost information, etc. A number of alternative regulation strategies are classed into technological, economic and environmental perspectives, with emphasis on control strategies of new devices, blackout permission (whether blackouts occur is allowed or not in the electricity system), generation priority of various technologies, upper limitation of excess electricity, range of capacity factor, cost and CO_2 emission constraints respectively.

New electricity devices (battery, EV, HP, etc,) and their combinations are optional, and their control strategies are also defined as optional rules. Outputs are mainly energy balances and the resulting annual electricity production, fuel consumption, total/average cost, total/average CO_2 emission, operation patterns of the new devices under their defined control strategies, etc. Through comparisons of the obtained performance data in different scenarios, appropriated systems can be selected. All the basic data is hourly, however, through statistics, daily, weekly, monthly and annul data can be obtained.

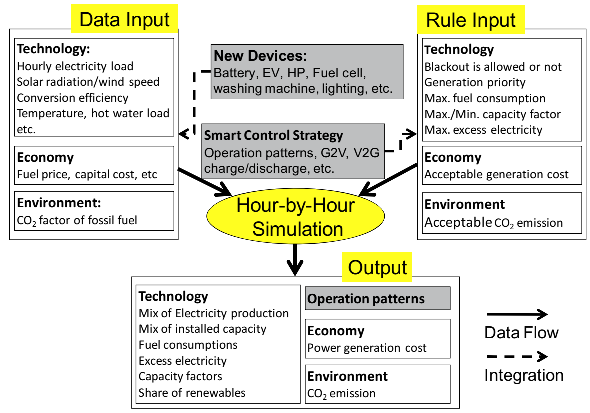

Figure 1. Methdology of sceanrio analysis on future smart electricity systems

B. Flow of the Scenario Analysis

Electricity generations from zero carbon power sources including renewable and nuclear energy are considered as basic supply, when it become more than traditional electricity load, surplus electricity will be consumed by driving HP and/or charging batteries. On the other hand, when basic electricity supply from renewable and nuclear energy is less than traditional load, battery and peak supply try to meet the deficient electricity. Finally, if no blackout happens, the system is considered as technology feasible, otherwise initial data will be changed and new iterative will start.

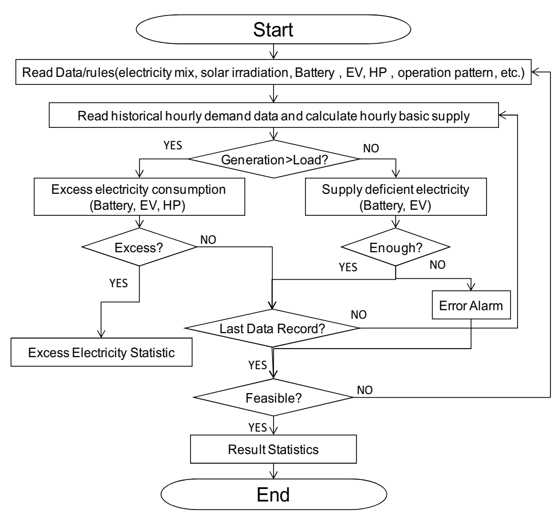

Figure 2. Concept flow chart of the methdology

C. Software Deveopment

The methodology has been developed as an operable computer software using VS.net 2008[8][9] and MS Excel, as shown in Fig.4.

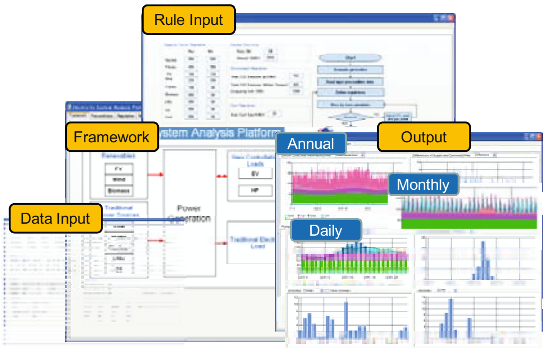

Figure 3. Infterface of the developed software

III. APPLICATION TO KANSAI AREA, JAPAN

A. *Electricity Demand*

The historical hourly data of electricity demand distribution in 2001 of Kansai Area, Japan is shown in Fig.4 [10][11]. In the present study, the final electricity load is the sum of historical load and new load from new electric devices.

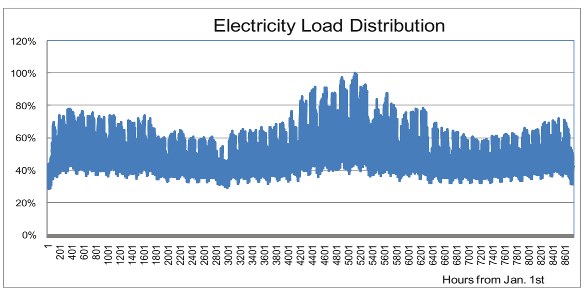

Figure 4. Hourly electricity load

The new loads include Electric Vehicle (EV). Batteries in EVs are not only used to storage surplus electricity and supply deficient electricity but also used to drive EVs, and the latter has priority obviously. The charge of the batteries stops when its SOC reaches 95% and when the SOC of the batteries reaches 30%, which is stipulated as the discharge depth, further discharge of batteries is not permitted in order to save electricity to drive EVs. The hourly data of passenger car on road is shown in Fig.5 through the real-time statistics [12]. The peaks in utilization can be seen to occur during 7:00-8:00 in the morning and 17:00-18:00 in the afternoon. All of the EVs which are not on the road are considered to be connected to grid and available for charge and discharge.

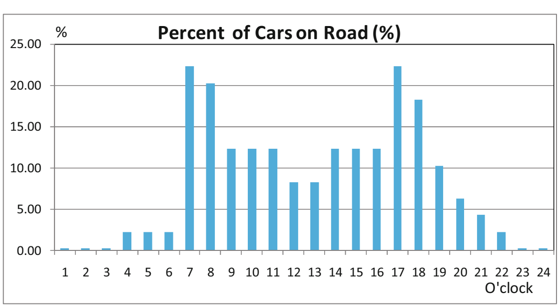

Figure 5. Hourly electricity load

Apart from EV, HP is also a promising future technology for hot water production in the residential sector. It operates on an electrically driven vapour-compression cycle and pumps energy from the air to water in a storage tank, thus raising the temperature of the water, which is especially effective during the periods of maximum solar intensity. In the present study, revised M1 mode is used as the hot water load. It means that 450L hot water at 40ºC is consumed per household on average per day, but the practical temperature of hot water is 65 ºC [13] And the hot water load distribution is shown in following Fig. 6 [14]

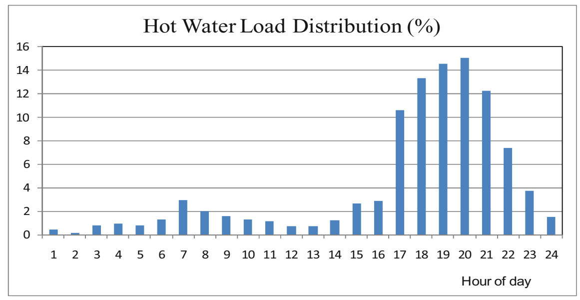

Figure 6. Hourly electricity load

There are 20 million people, 8 million households, and 7.76 million passenger cars in Kansai Area. We assume that a part of cars are assumed to be substituted by EV and a part of households would be using HP for hot water production. Although efficiency of EV in Japan is said to be about 8km/kWh using JC08 model in ideal situation, the practical EPA (Environmental Protection Agency) value-5km/kWh in average is used here [15], and daily travel distance is considered as 30km per EV. HP is used to supply 450 litres of hot water at 40°C according to revised M1 mode. However, the impact that these would have on the electricity load demand would be different according to the patterns of EV charge and HP operation patterns.

B. *Current Electricity Supply*

As shown in Table 1 [10], nuclear power supplies around 46% of Kansai's electricity, 43% is generated from fossil fuel power stations, relying on imported LNG, oil and coal. Hydroelectricity also provides a vital contribution – around 10% of its annual generation

TABLE I. ELECTRICITY SUPPLY IN KANSAI AREA

	Installed capacity		Electricity		CO_2 Emission	
	GWe	%	TWh	%	Million Tonees	%
Nuclear	10.1	28.9%	73.7	47.4%	0	0
Coal	4.4	12.6%	32.1	20.6%	65.6	75.6%
Gas	8.4	24%.1	27.3	17.6%	14.5	16.6%
Oil	8.4	24%.1	9.6	6.2%	6.7	7.8%
Hydro	3.6	10.3%	12.8	8.2%	0	0

C. *Renewable Energy and Excess Eeletricity*

Kansai area, Japan will have to increase substantially the amount of electricity provided by renewable sources, especially ‘‘new’’ sources such as solar and biomass. The wind power is not considered due to very low wind speed in the area. It is very difficult for traditional electricity mix models to integrate renewable energy sources because of the intermittency. Intermittent sources of electricity are expected to have technical and economic limitations in reaching a high level of penetration. Therefore, more intermittent power such as PV penetrated into the system, more excess power will appear when the based load power source level is stipulated as shown in Fig.7. Although, controllable electric devices such as battery and heat pump can absorbe excess electricity, finally the final excess electricity will happen when the absorption capacity is overed. The hour by hour simulation model is therefore vital here to find the feasible electricity mix.

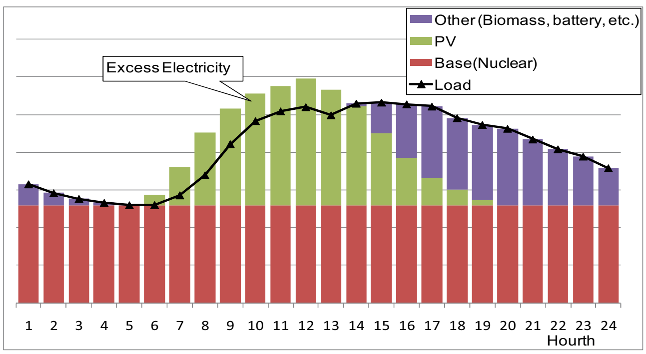

Figure 7. Concept diagram of excess electricity from PV power

IV. SCENARIO ANALYSIS

A. *Scenario Design*

Different penetration scenarios of nuclear, PV, biomass, battery, EV and HP are analyzed in the study as shown in Fig.8. Installed capacity of nuclear power is assumed as 15 and 18 GWe respectively as based supply, and PV power will be integrated as 30 and 15 GWp respectively in two supply scenarios. The deficiency electricity can be supplied from biomass power and hydrogen/methanol fuel cell, which can operate in load-following mode with capacity of altering 100% output in one hour. Pumped hydropower is currently used for load smoothing and energy storage, but will be replaced 100% by batteries including the ones in EVs in the current scenarios. Although the developed model can conduct analysis from technological, environmental and economic perspectives, economic issue is not considered in the present study.

In the demand side, there is no any electric device in D1, however, there are 80 GWh battery (10kWh per household) and 160 GWh battery (another 80GWh battery in factories, power stations, etc) in D2 and D3 respectively. Furthermore, based on the D3, 2 million heap pump for hot water production is assumed in D4. Finally, in D5, 3 million electricity vehicles with 50kWh battery are assumed.

Supply Side

Source	S1 (GWe)	S2 (GWe)
Nuclear	15	20
PV	30	15
Biomass/FC	?	?

×

Demand Side (D1-D5)

	Battery (GWh)	HP (Million)	EV (GWh)
D1	×	×	×
D2	80	×	×
D3	160	×	×
D4	160	2	×
D5	×	2	150

Figure 8. Sceanrio design

B. *Scenario Analysis Results*

The install capacity mix is shown in Fig. 9. Although, PV power has a big install capacity, less electricity can be generated comparing with unit nuclear power plant due to its low install capacity. Furthermore, battery can reduce the requirements of biomass/FC operating in load following mode, for example the comparison of D1 with D2 and D3. The hydrogen can be imported from overseas, also possible be generated from excess electricity from nuclear or PV power.

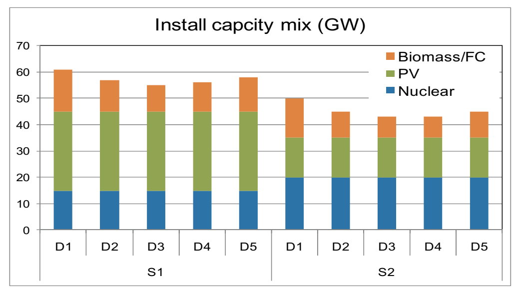

Figure 9. Scenario analysis result: install capacity mix

The results in Fig.10 show that battery, HP and EV can reduce excess electricity from PV power and nuclear power effectively when the D1 is compared with other scenarios. Furthermore, battery can reduce more excess electricity comparing with EV, because the batteries in EVs are used to drive the vehicle with priority and thus supply less available electricity.

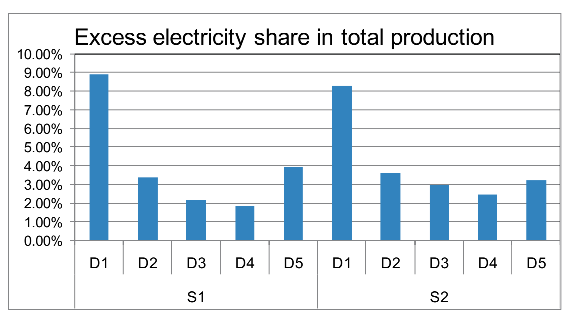

Figure 10. Excess electricity share in total produciton

There are many zero-carbon electricity system scenarios are proposed in the present study. In the future work, the selection of final scenario will be decided by the economy performance. For example, if battery becomes very cheaper than biomass/hydrogen fuel cell, much more battery will be used, on the other hand, more hydrogen/methanol fuel cell or biomass power will be used.

V. CONCLUSIONS

In the present study, a methodology has been proposed to integrate zero-carbon power sources including renewable and nuclear energy into future smart electricity based on input-output hour-by-hour simulation framework and comprehensive smart control strategy on new electric devices- battery, EV and HP. The methodology has been developed as an operable software platform, and it is used to conduct scenario analysis on Kansai Area, Japan. The analysis results show that, apart from nuclear and PV power, biomass, fuel cell based on hydrogen/methanol are crucial for the realization of zero-carbon systems; the excess electricity can be reduced greatly in various scenarios with the help of electric devices and their control strategies. It concludes that battery, EV and HP and their smart control strategies can integrate more zero-carbon power sources into the electricity system. Therefore, the feasibility of the proposed methodology has been demonstrated through its application to Kansai Area, Japan

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Future Power of Plastic Solar Cells for Zero–CO_2 Emission Society

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Abstract

Recent progress of plastic solar cells in terms of (1) materials design such as p– and n–type organic semiconductors and nanostructured metal oxide electrodes, (2) thin–film making through dry and/or wet process such as vacuum vaporization and spin–coating, and (3) device structure composed of multilayered thin–films is described. The descriptions refer the photovoltaic performance including I–V characteristics and stability test of the devices in addition to predictive estimation of energy payback time and CO_2 emission rate as life cycle analysis of photovoltaic power generation system.

Keywords:

organic photovoltaics, power conversion efficiency, stability test, energy payback time, CO_2 emission rate

1 INTRODUCTION

Plastic solar cells are lightweight, flexible, and low cost to make as compared to those of the conventional Si and other inorganic semiconductors-based cells. They are one of the promising tools for zero–CO_2 emission society. Efforts now focus on their efficiency and lifetime. Recent progress of the efficiency of polymer-based solar cells has been reached up to 10.1% reported by Mitsubishi Chemical [1]. While Michael McGehee at Stanford University stated that a polymer-based solar cell lasted 7 years [2]. Such progress is based on the multiple developments of various kinds of polymers, organic and inorganic semiconductors, transparent conducting metal oxide coated substrates, metal electrodes, sealing films, and the assembling of these new materials to construct the highly efficient plastic solar cells. In this context, this paper describes recent progress of organic photovoltaics (OPVs) in terms of materials design, thin-film making process, and device structure with regarding the power conversion efficiency (*PCE*), durability (*viz*. stability), energy payback time, and CO_2 emission rate.

2 MATERIALS DESIGN

2.1 Conducting polymers and fullerenes

Plastic solar cell is composed of multilayered thin-films. Typical device assembly is described as follows. Indium–doped tin oxide (ITO) as transparent conducting oxide (TCO), which is deposited on the glass is generally utilized as electrode. Onto the glass–TCO substrate, poly–(3,4–ethylenedioxythiophene)/polystyrenesulfonate (PEDOT:PSS) or other materials such as VO_x, MO_x, NiO is coated as hole-transporting (*viz*. electron-blocking) layer (HTL). Thereafter, mixture of conducting polymer (donor) and fullerene derivative (acceptor) is spin-coated onto the glass–TCO/HTL as active layer. After coating of electron-transporting layer (ETL) such as TiO_x or LiF, vacuum vaporization of Al or other metals as counter electrode forms bulk heterojunction (BHJ) solar cell as glass–TCO/HTL/active layer/ETL/metal.

In order to enhance open circuit voltage (V_{oc}) and short circuit current density (J_{sc}) of the device, one of the most widely used strategies is molecular design of narrow band gap donor polymers through the synthesis of an alternating copolymer from electron–rich (donor) and electron–deficient (acceptor) units in their backbone. In this regard, various kinds of narrow band gap donor polymers have been reported and achieved relatively high *PCE*s up to 7.73% [3–6].

Another strategy for higher V_{oc} is molecular design of novel fullerene derivative, which has optimized lowest unoccupied molecular orbital (LUMO) level as compared with the above polymers. Li *et. al*. had reported successful design of novel fullerene derivatives and attained higher V_{oc} of 0.80–0.87 V and *PCE*s of 5.44–6.48% [7, 8]. Solubility of various fullerenes in organic solvents has been investigated systematically for morphology/surface topology control of active layer of BHJ solar cell [9].

2.2 Metal oxide electrodes

The ideal structure of a BHJ solar cell consists of two phases of donor and acceptor being interspaced with an average length scale of around 10–20 nm equal to or less than the exciton diffusion length. The two phases have to be interdigitated in percolated highways to ensure high mobility charge carrier transport with reduced recombination [10]. Inorganic nanowire–polymer hybrid solar cell is promising to improve the electron conduction to the anode. In this context, polycrystalline TiO_2 nanotube arrays and single crystalline ZnO nanotube

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arrays for polymer hybrid solar cells have previously been developed [11, 12]. Li–doped ZnO and surface modified ZnO with dye showed remarkable efficiency improvement in terms of light harvesting, charge separation, and efficient charge carrier collection of the OPVs [13].

3 THIN–FILM MAKING PROCESS

3.1 Vacuum vaporization

Vacuum vaporization of low-molecular weight organic semiconductor is enable to form homogeneous thin-film with precise thickness by controlling the conditions of vaporization. By using multisublimed materials, highly purified organic semiconductor sometimes shows remarkable enhancement of J_{sc} with high *PCE* [14, 15]. However, significant loss of the starting materials during the vaporization is still problem for practical use.

3.2 Spin–coating

For polymer based OPVs, spin–coating is mostly adopted and remarkable progress has been reported recent years. In particular, additional pre– and/or post–treatments such as thermal annealing, microwave irradiation, addition of co–solvent, slow–drying, resulted effective enhancement of *PCE*, which is ascribed to the improvement of the morphology, crystallinity, and phase-separated state of BHJ [16, 17]. However, application of spin–coating for large area device is not so easy in addition to inevitable loss of the polymer solution during the spin–coating.

3.3 Other methods for printable electronics

Inkjet printing

Printing techniques are the necessary tool for significant cost reduction for OPVs. Although mechanical design of nozzle head and fine-tuning of the “semiconducting ink” are difficult, several groups have succeeded to prepare smooth, homogeneous, and highly efficient organic thin–films by inkjet printing [18, 19].

Spray coating

Spray coating can be done at high production speed and is compatible with various substrates since the sprayed droplets are transferred from the spray nozzle to the substrate without direct contact with the surface. In this process, characteristic performance of OPVs is limited by some drawbacks such as isolated droplets, non–uniform surface and pinholes. In this context, the film formation, surface topography and the morphology of spray coated active layers with additional solvent implemented by using an additional solvent spray deposition have been investigated [20]. Highly efficient OPVs with improved interconnection among droplets and reduced amount of pinholes were obtained by additionally spraying *o*–dichlorobenzene as a solvent after the conventional spray coating of the mixed solution of polymer and fullerene in chlorobenzene to form active layer. Moreover, the additional solvent spray causes changes in the matrix of the active layer resulting in the effective thermal annealing in terms of *PCE*.

4 DEVICE STRUCTURE

4.1 From single cell to tandem cell

Fine–tuning of donor and acceptor materials and careful assembly of the single OPV device will convert 11% of the non-concentrated sunlight. If preparation of an organic tandem device comprised of two sub–cells having different, complementary absorption spectra, is fully succeeded, a maximum *PCE* of almost 15% will be achievable according to Kirchhoff’s law and taking by precise screening of intermediate layer such as Ag or Au clusters as recombination sites [21]. Recent progress attained the *PCE* of 8.3% with 2-cell tandem [22].

4.2 Multicell and sub-module

Roll–to–roll is one of the promising processes to fabricate OPV modules with large area. Guo *et al* demonstrated the attachment of blended solution of polymer and fullerene onto TCO substrate with a gas-permeable silicon film before applying pressure and achieved *PCE* of 3.45% [23]. Krebs *et al* developed novel light–induced thermocleavage polymer and applied it for roll–to–roll process. Large module with the active area of 96 cm^2 was obtained [24]. Combination of screen-printing for making ITO pattern, slot-die-coating for application of ZnO nanoparticle layer coating, with depositions of polymer–fullerene and PEDOT:PSS was performed by using PET substrate for roll-to-roll process. After the device encapsulation with PET protective layer, laminated flexible modules were sent to the many different laboratories and examined their stability and proved their durability for feasible study [25].

4.3 Further extension

Stability test

PCE is the essential parameter for solar cells with respect to maximizing energy production and minimizing cost. A device efficiency of over 10% and a module efficiency of over 5% are regarded as critical market–entry values. On the other hand, lifetime is the second most important parameter for solar cells. For OPVs, a lifetime of 3–5 years (operational lifetime of 3,000–5,000 hours) is regarded as the market–entry point [26]. The organizing committee of the international summit on OPV stability (ISOS) summarized consensus stability testing protocols for OPVs [27]. They defined 3 levels of testing as basic, intermediate, and advanced. Test types are classified into 5 categories as dark, outdoor, laboratory weathering testing, thermal cycling, and solar–thermal–humidity cycling. Details of the conditions had also been settled and further examination will be discussed at the next summit.

Energy payback time and CO_2 emission rate

Net energy gain (*NEG*) becomes positive from negative after some period of time from the first settlement through the continuous accumulation of produced energy. Such duration is called as energy payback time (*EPT*). The balance of initial demand of energy and *PCE* is crucial to determine the *EPT*. On the other hand, CO_2 emission rate is defined as the amount of CO_2 exhaust per unit of produced energy such as 1 kWh, and so on. Komoto reported life cycle analysis of photovoltaic power generation system such as polycrystalline Si (module *PCE*: 13.9%), single crystalline Si (14.3%), amorphous Si/single crystalline Si heterojunction (16.6%), thin film Si (microcrystalline Si) hybrid (8.6%), and CIS (10.1%) for residential use and public/industrial one [28]. *EPT*s for residential use are ranged 1.4–3.0 year, while 1.9–3.4 year for public/industrial use. These values are apparently short as compared with the lifetime of the modules, which is generally over 20 years. CO_2 emission rates are estimated to be 46–78 g–CO_2/kWh for residential use and 62–87 g–CO_2/kWh for public/industrial one. These values are smaller than the average value of conventional utility grids. Regarding the OPV system, long–term examination is required to estimate such analysis. However, because of energy–saving process and recent progress in terms of *PCE* and stability of OPVs, relatively short *EPT* and low CO_2 emission rate are expecting to be realized in future.

5 SUMMARY

New materials of p– and n–type organic semiconductors and nanostructured metal oxide electrodes are expected to enhance open circuit voltage and improve the electron conduction to the anode. Thin–film making through vacuum vaporization, spin–coating, inkjet printing, and/or spray coating should be performed very carefully in order to form highly efficient carrier path. Construction of tandem cell is one of the promising strategies to achieve high power conversion efficiency. For the sake of practical use, roll-to-roll is appropriate technique to make modules with large area. As a consequence, organic photovoltaic system will become one of the future power generation systems showing relatively short energy payback time and low CO_2 emission rate.

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Solar induced ventilation for hot and humid regime; efficiency measure case for Tokyo and Jakarta

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Abstract

The global energy trend of fossil fuel depletion and potential for worsening natural disasters due to climate change has created worldwide concern not only on how to switch to non-fossil based fuel but also how to reduce energy consumption. One means of reducing global energy consumption is efficiency. The latest information from the IPCC through its AR4 report shows that the easiest and cheapest way to reduce energy utilization is efficiency. Efficiency measures start from power supply through power generation improvement or waste heat recovery; and carry through to end use, such as efficiency in industrial processes or efficiency in the building sectors.

One of the most challenging measures for improving efficiency in the building sector is replacing (partially or entirely) electricity driven appliances while maintaining human comfort. Therefore, this study applies passive methods to partially replace the work of mechanical and electrical devices in buildings by means of improving the air changes per hour (ACH) by utilizing solar induced ventilation or solar chimneys.

The design involves the optimization of solar induced ventilation by using small scale heliostat. The potential improvement is calculated for local climatic conditions in two case study cities - namely Tokyo and Jakarta. The ACH potential was assessed using multi-storey building models (5 storey, 20 unit) apartments.

The results show that solar induced ventilation creating more than 3.3 ACH means that heat, humidity and other pollutants could be removed. Annually for the modeled buildings this has the potential to reduce emissions by approximately 483 kg CO2 in case of Japan and more than 1800 kgCO2 in case of Indonesia. Also it has potential to save up to 250 US$ and 176 US$ for Japan and Indonesia respectively. Moreover with current statistics of apartments in both cities, the potential of CO2 reduction will reach 1.11 x 109 kgCO2 for Tokyo and 7.6 x 108 kgCO2 for Jakarta and monetary savings of approximately 578 million US$ and 73 million US$ for Tokyo and Jakarta respectively.

Keywords: methodology , economy, passive cooling, residential, energy efficient, solar ventilation

1 INTRODUCTION

Nomenclature	
A_{app}	Area of the apparatus (reflectors)
A_{rev}	Area of the receiver (absorber)
$CR_{theoritical}$	Ratio of apparatus to receiver areas
CR_{ideal}	The angle coefficient
η_{app}	Efficiency of the devices
Ts	Sun temperature
$\eta_{optical}$	Optical efficiency
ε_{abs}	Emissivity of the absorber

It has been reported by IPCC AR4 that human activities, mainly since the industrial era, have resulted in increases in the carbon dioxide (CO2) concentrations and therefore has lead to climate change [1]. In order to reduce the potential damage of climate change, global CO2 will need to be reduced by 50-85 per cent of year 2000 levels by 2050 [1]. Energy production is responsible for most GHG emission released into the atmosphere. AR4 demonstrated that improving energy efficiency would play a key role in the mitigation of GHG emission. Buildings have the highest potential for energy consumption reduction with low cost associated with these increases in efficiency.

The greatest share of electricity consumption in most of the tropical countries is cooling [3][4]. This cooling load share comprises the load from both the external heat and internal heat. The share of these two varies though two categories of buildings can be distinguished: In skin load dominated buildings most of the load influenced by external heat and in high-rise type buildings most of the load comes from internal heat. Many studies have been done considering the external dominated load, which consider optimization building envelopes. One of the oldest building codes used in most of the countries in South East Asia is the ASHRAE 1980, though this was based on codes of countries located in the northern

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hemisphere. External loads are responsible for 70-80 per cent in some houses and 30 per cent of cooling load in certain high-rise residential buildings. Improving the mechanical system in the air conditioning (AC) consumes more energy and is more expensive than improving passive measures in buildings [5].

The future electricity demand prediction should also be assessed in order to improve a country`s energy security, and in this sense the optimization of buildings materials also increases the potential of reducing the electricity demand in the future.

1.1 Passive cooling

The issue on reducing the electricity consumption through cooling is relevant enough, since the number of Households (HH) using AC as cooling system increases year by year. For instance in Indonesia more than 60% urban household uses an AC for its cooling system (mostly split system) and 90% from the middle economic family (minimum family income 400-500 US$ per month) are utilizing the active AC system [6], the number linearly increases due to the country's economic improvement [7] and the increases of the average daily temperature in cities 1.4-1.6 °C [8] in the last 100 years.

Therefore the potential on reducing the electricity consumption in the residential sector is high. However, the improvement of the cooling appliances is promising; however this approach proves to be more expensive [5]. The introduction of passive cooling through buildings materials proves to be less expensive [9], the approaches by means of more adaptable building's facade material and indoor materials or passive cooling to replace the electrical driven appliances.

The application for passive method to increase efficiency in the building sectors has been done in the last couple of decades. In arid region where hot and dry regime is dominant and the temperature different between day and night is relatively high, also relatively clear sky during day and night is beneficial for pond roof type passive cooling either by utilizing nocturnal radiation (without evaporation measures) [10][11] or pond roof passive cooling by utilizing convection, nocturnal radiation and evaporation [12]. Another method of pond roof with evaporative by utilizing gunny wetted clothes also shows promising result [13][14].

The utilization of water based as media to increase the cooling effect and maintain the comfort for indoor room temperature and humidity is working well in hot and dry temperate. However the utilization of water as media for passive cooling in hot and humid temperate are arguably, since high humidity and low nocturnal cooling becomes huge burden to apply those type of application.

The hot and humid climatic condition made the natural ventilation inefficient due to the low air temperature difference between the inside building and ambient; the air temperature difference is normally between 2-5°C. Moreover, in some areas (i.e Thailand and Malaysia) the indoor and outdoor air temperature different indicated in around 0.6- 3.5°C during the day [15][16].

Due to the potential of solar induced ventilation, studies on that strategy had been executed in the hot and humid climate [4-14]. Hirunlabh etal. [4] investigated the potential of a metallic solar wall in removing heat from a house in Thailand. The proposed solar wall was able to induce air flow rate of about 0.01-0.02 kgs1. Mean-while, a house ventilation rate of about 0.08-0.15m3 s1 m2 was able to be induced by roof solar collector in Thailand.[7] Due to this potential, various configurations of roof solar collector had been developed by Hirunlabhetal. [8] in achieving more ventilation rate.

Air movement created by the stack effect is usually not adequate to achieve physiological cooling. It is less than the recommended air speed range for cooling of 0. 15 to 1. 5 m/s in tropical condition (Satwiko, 1994). It can be seen that two means are available for improving air movement: firstly, by increasing the air volume (stack height) and secondly, by increasing the air temperature difference. The indoor air temperature has to be kept low. All the above designs involve stack effect. However, in terms of construction (complexity, technology, etc.) and material (cost, durability, availability, etc.) these designs are not suitable for wide application in low cost housing in tropical countries. [19]

2 METHODOLOGY

$$T_{abs} = T_s\left[(1-\eta)\frac{\eta_{optical}}{\varepsilon_{abs}}\frac{CR_{theoritical}}{CR_{ideal}}\right]^{1/4}$$

Where. T_{abs} is the temperature of the absorber; T_s is the temperature of the sun; ηoptical is the optical efficiency from the reflector (1 equal to the highest absorbent value, we use 0.1); εabs, is the emissivity factor (1 is representing the lowest reflectivity, we use 0.02)

$$CR = \frac{A_a}{A_r}$$

$$CR_{ideal} = \frac{1}{\sin(\theta_a)}$$

Where, Aa is the reflector area; and Ar is the absorber area; θa is the angle degree of the reflector

Buoyancy effect (artificial wind generated)

$$P_s = -\rho g 273 h\left[\frac{1}{T_{ext}}\frac{1}{T_{in}}\right]$$

Where, ρ is the air density (kg/m3); g is the gravity force (9.8 m/s2); h is the tower height (m); Text, is the temperature at stack (absorber), Tin is the inlet temperature (29°C) before entering the tower

$$Q = C_d A\left[\frac{2\Delta p}{\rho}\right]^{0.5}$$

Where Q is the flow rate created by artificial wind (m3/s); Cd is the discharge coefficient (0.65-0.70); A is the area of the opening (m2); ΔP is the pressure difference (Pa); ρ is the air density (kg/m3)

$$ACH = 60\frac{Q}{vol}$$

Where, ACH is the Air Change per Hour; vol is the indoor room volume

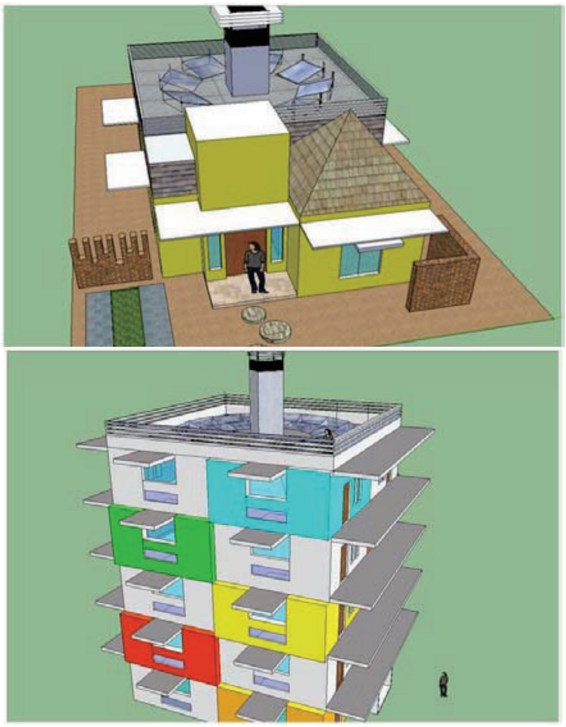

Figure 1 example of the application at dwelling and low rise buildings

Moreover, the flat roof designs for dwelling houses not only beneficial for assembling the solar tower but also reducing the heat gain through roof. The simple simulation by using simulation tools ECOTECT™ shows almost half of the heat gain is reduced for flat roof compare to the traditional pitch roof for Jakarta weather condition. The result by using the simulation tools has been validated by comparing the model and field measurement [20].

3. RESULT

Case in Tokyo, Japan

To calculate how much the proposed system worth in term of electricity reduction, this paper using an assumption with simplified number of buildings (single dwelling and multi-storey) which accounted 5,747,460 household [21] with approximate 91m^2 in average size in the city likes Tokyo [22]. Approximately 60 percent or more than 3.4 million is single dwelling houses and the remaining or more than 2.3 million is multi-storey houses [22].

Case in Jakarta, Indonesia

Based on the housing and household statistics (Susenas) [23] surveyed in 2004, the total number of Indonesian households reached 56.6 million, of which 2.3 million is in Jakarta with 80 per cent of them being single landed types, 2 per cent is apartment/condo type [24], and the remaining 18 per cent is multi-storey or multi-purpose buildings.

Conclusion

The results show that solar induced ventilation creating more than 3.3 ACH means that heat, humidity and other pollutants could be removed. Annually for the modeled buildings this has the potential to reduce emissions by approximately 483 kg CO_2 in case of Japan and more than 1800 kgCO_2 in case of Indonesia. Also it has potential to save up to 250 US$ and 176 US$ for Japan and Indonesia respectively. Moreover with current statistics of apartments in both cities, the potential of CO_2 reduction will reach 1.11 x 10^9 kgCO_2 for Tokyo and 7.6 x 10^8 kgCO_2 for Jakarta and monetary savings of approximately 578 million US$ and 73 million US$ for Tokyo and Jakarta respectively.

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Sustainable Manufacturing: Evolution and Future

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Abstract

Environmental consciousness is one of the most important aspects in the development of products and processes. Starting from the end-of-pipe processes, such as recycling, a lot of technological developments have been made for seeking the sustainability of manufacturing activities. For improving the resource efficiency, a comprehensive framework for resource circulation is advocated. Importance of life cycle strategy for integrating system technology and individual component/product technology is discussed. Current research topics and important future issues are shown.

Keywords:

sustainable manufacturing, inverse manufacturing, resource circulation, eco-efficiency

1 INTRODUCTION

Due to the rapid development of industrial activities in all over the world, the environmental influence of those activities becomes critical in recent years for the sustainability of the earth, such as gobal warming, resource depletion and environmental pollution. Consideration of environmental consciousness is one of the most important concern in manufacturing engineering research. This paper reviews the trends of environmental concern in the development of design and manufacturing engineering, and discusses the future perspective of sustainable manufacturing.

In late 80's, the increase of industrial waste and environmental pollution became evident in advanced industrial countries. Various technological developments were made for proper disposal and material recycling of disposed products. Comprehensive legislation have been introduced to enforce the activities of waste reduction and prevention of illegal dumping of waste materials. These activities are considered as the so-called end-of-pipe measure to properly process the generated mass waste. Instead it was srongly discussed the necessity of systematically reducing the mass of generated waste by renovating the products and their manufacturing processes.

In recent years, global environmental problems become more critical, and the more systematic approach is required to fundamentally reduce the environmental burden of human activities. A new paradigm was proposed to shift from mass production and mass recycling to proper production and resource circulation. For this purpose, a concept of resource circulating manufacturing is considered, where a whole product life cycle from product planning to product manufacturing, usage, and final dispoal/recycling is rationally designed, and unnecessary waste generation is systematically avoided. By resource circulation, the total anount of resource usage is expected to reduce, and the environmental efficiency of resource usage becomes higher. In addition to consider physical product production, it is also important to consider appropriate systems for providing product services and change of people's mindset for using industrial products.

By considering the whole product life cycle and clarifying its relations with the global resource circulation, it is expected to be able to evaluate the sustainability of manufcturing activities with respect to global warming, resource depletion and environmental pollution.

In Japan, due to the high rate economic growth in the past, the shortage of waste disposal fields and the increase of environmental pollution became a very critical issue. The government advocated the slogan of changing into the resource circulating society, and the Japanese industry made very strong effort to make their products and manufacturing processes more environmentally friendly and resource efficient. The industry consortium Inverse Manufacturing Forum was established in 1996 for the purpose of promting the concept of resource circulation and environmentally conscious manufacturing[1].

It is very interesting that at the start of the Inverse Manufacturing Forum, its symbol mark was the symbolization of the importance of recycling activity, as shown in Fig.1. Many research and development activities were done in this forum, such as reuse oriented life cycle design methds, a product environmental information management system and service oriented information devices. Throughout these activities, it is gradually evident that, in addition to the individual technology, it is

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necessary to consider the whole product life cycle and a scheme how to implement the proper product life cycle into the society. After 10 years of research, the Forum proposed the next picture showing the impotance of a top down and back casting approach for guiding the essence of sustainable manufacturing developments, as shown in Fig.2. This progress is considered to describe the evolution of a concept of sustainable manufacturing in past years.

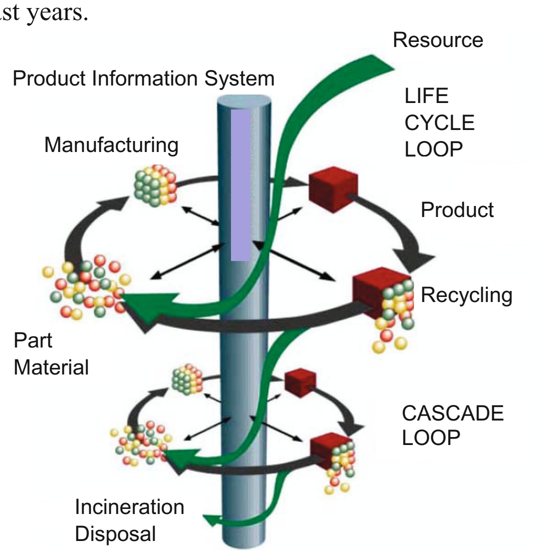

Fig.1 Closed loop product life cycle

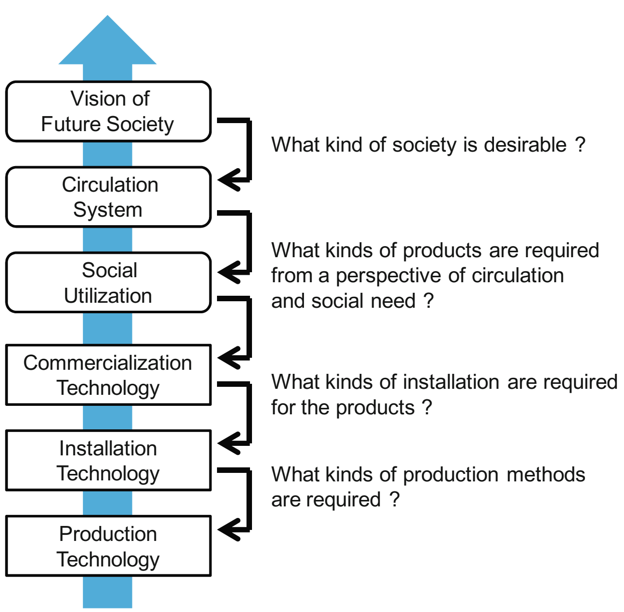

Fig.2 Toward sustainable society

2 MANUFACTURING AND SUSTAINABILITY

2.1 Importance of manufacturing

The discrete manufacturing is considered in this paper. Among the total resource consumption in the world, the amount of resources consumed directly by the discrete manufacturing sector is generally speaking very small. In this respect, sometime it is said that manufacturing is not important for reducing the global CO_2 emission. It may not be true. Manufacturing is tightly related with material production, transportation, social infrastructures and product usage, as shown in Fig.3. If some innovation is introduced in manufacturing, big change and reduction of material usage can be expected. In this sense, if the total life cycle is well designed, manufacturing is considered to be a effective mechanism to manage and to control the global resource flow.

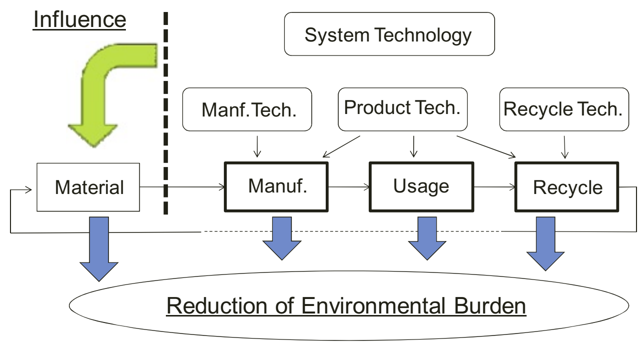

Fig.3 Influence of manufacturing for resource circulation

2.2 Resource and information circulation

In circulation oriented manufacturing, it is important to consider not only physical resource circulation, but also information circulation, as shown in Fig.4 [2]. Manufacturing is considered to transform design information into actual products. With appropriate scheme it is natural to keep the design information with the realized products, then to feedback the information with usage and user information. Such information is effectively utilized for proper reuse/recycling, but also for capturing usage status, adapting the current products to real situations, and creating new product/service concept.

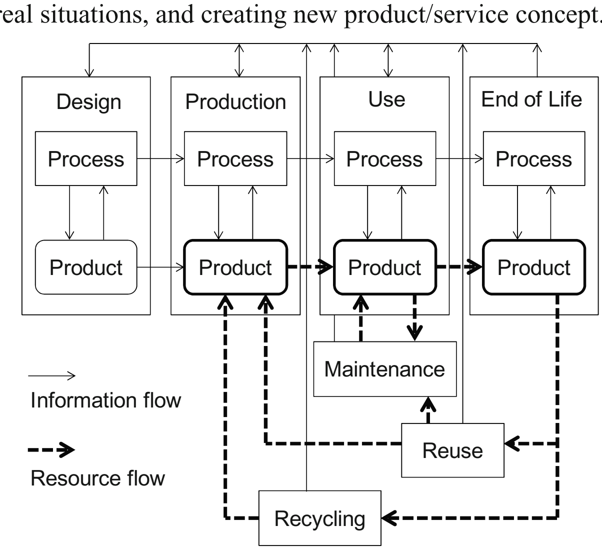

Fig.4 Information circulation in product life cycle

3 SUSTAINABLE MANUFACTURING

Sustainable manufacturing is considered in various aspects as shown in Fig.5. A total framework for sustainable manufacturing is not very much different from the conventional manufacturing, except for focusing on the holistic consideration of product life cycle and resource efficiency evaluation. It is interesting to see the possibility of selecting non-conventional life cycle options from the viewpoint of resource efficiency and environmental evaluation. Some of the examples are parts reuse, product modularization, remanufacturing, manufacturing system reconfiguration, component tracing in product usage, etc.

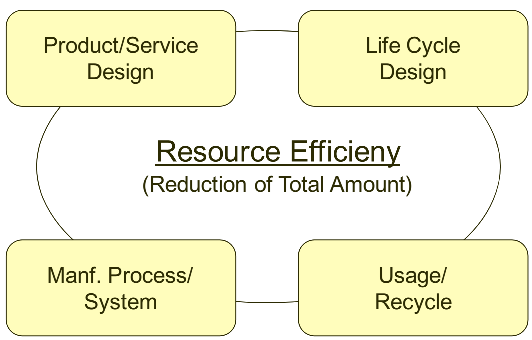

Fig.5 Sustainable manufacturing

For thinking about the total product life cycle, there are two approaches: a system technology approach and an individual technology approach, as shown in Fig.6. For achieving ultimate resource efficiency and reduction of environmental burden, one approach only is not enough, but appropriate combination of the two approaches is essential. The system technology approach includes life cycle design and management, product sharing, leveling of operations, etc. The individual technology approach includes light-weighted design, new materials, low friction design, energy saving, etc.

The followings are some of the important research and development items for sustainable manufacturing.

(1) System planning and product design technology
- Life cycle strategy and scenario planning
- Design guideline and method
- Design for environment

(2) Manufacturing technology
- Material flow analysis
- Clean manufacturing
- Recycling process design

(3) Management technology
- Inverse logistics
- Recycling information system
- Maintenance management

(4) Resource circulation technology
- Resource tracing in product life cycle
- Resource recovery

(5) Evaluation technology
- LCA database
- Life cycle cost and risk assessment
- Embedding LCA in product life cycle design

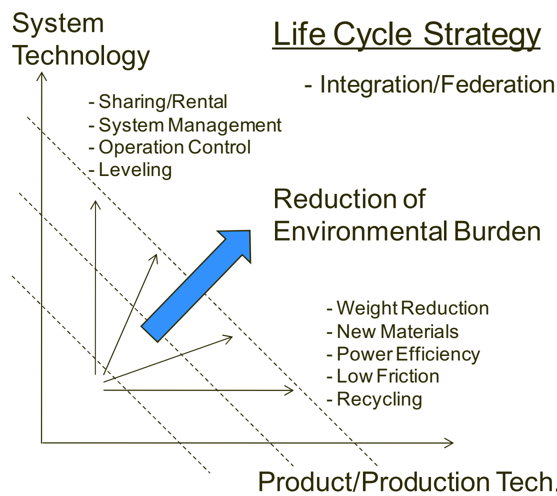

Fig.6 Life cycle strategy

4 FUTURE ISSUES

The basic concept and importance of sustainable manufacturing is well understood. The existing manufacturing technology can be adapted for the new requirements. However many issues still remain with respect to products, processes and systems.

4.1 Product quality management and innovation

Extreme resource efficiency is required, for example, for motor vehicles in developing countries. In such cases, in order to achieve environmentally consciousness with low cost, innovative product technology is demanded, such as low friction mechanism, high stress structures, etc. Not only to seek for long life and high quality, but also to realize appropriate life and quality adapted to market needs, precise life and quality control technology is required. In many cases today's products are in over quality and excess complexity, and then result in resource inefficiency.

4.2 Efficiency in manufacturing process

There are still many sources of inefficiency in manufacturing processes, due to the inherent incompatibility between product life cycle and manufacturing system life cycle. System installation is often too large and complicated for targeted products, and a lot of resources are wasted for indirect operations, such as air conditioning and peripheral device operations.

4.3 Improvement of resource circulation

Resource flow from law materials to production is relatively well managed and efficient, but reverse resource flow from used products to recycling and production is still very unclear and inefficient. Today's manufacturing is global, and resource flow across the country border is very difficult to trace.

4.4 New product/service for social innovation

Innovative new products, such as electric vehicles and electronic paper, can offer new services which consume less physical resources and create new value for users. However in order to implement such new products, new social infrastructure and change of people's mindset are necessary.

5 SUMMARY

Evolution of sustainable manufacturing is considered, ranging from closed loop manufacturing focusing on recycling to resource circulating manufacturing with the whole life cycle design. Important aspects of sustainable manufacturing and future issues are briefly discussed.

Many effective methods and tools for system technology development and individual component/product development are now available. Probably the most difficult issue is how to actually implement sustainable manufacturing scheme with active participation of product/service users and society. Normally users tend to act based on their intuitive consideration about environmental issues, and do not follow rational thinking. According to the economical development of the society, the users buy higher quality products by seeking higher product value. Therefore as shown in Fig.7, even if technology for improving eco-efficiency is introduced, the environmental load may not decrease as expected. It is essential to clarify a vision for sustainable future society, and to realize the change of people's mindset.

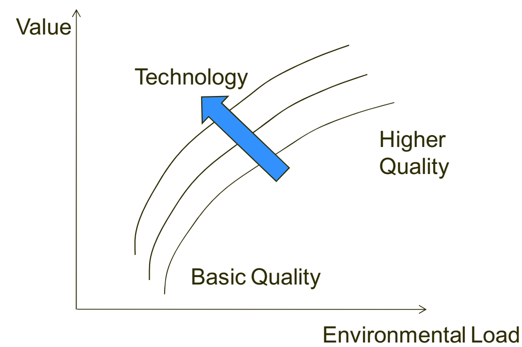

Fig.7 Eco-efficiency improvement

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Roadmapping of Sustainable Manufacturing Technologies in Japan

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Abstract

To enhance the competitiveness of Japanese industries, continuous R&D efforts of elemental technologies are important. It is also helpful to know the overview of the area to enhance efficiency of the developments. In industrial technologies, since the practical needs in future are the strong driving force, it is necessary to determine appropriate targets of development. Thus, making roadmaps of technological area is useful to know the appropriate and efficient targets of development. Since Inverse Manufacturing Forum is a research association covering R&D area of sustainable manufacturing technologies, the mission to make the roadmap was outsourced to a committee based on Inverse Manufacturing Forum which was organized under Manufacturing Science and Technology Center. This paper briefly introduces about the history and overview of the roadmapping effort of sustainable manufacturing technologies.

Keywords: sustainable manufacturing, inverse manufacturing forum,

1 WHY ROADMAPPING?

Few one disagrees that sustainable manufacturing technologies are the keys to satisfy high quality of life and low carbon society. However, it is very difficult to determine which technologies should be put emphasis on and what kind of approach should be taken, since so many sustainable manufacturing technologies have been proposed and it is impossible to implement all the technologies now. To take a strategic approach towards implementation of sustainable technologies, strategic thinking and categorization of technologies are necessary. The strategy of technological development extracted from these strategic thinking is so-called technological roadmap.

A committee organized under Manufacturing Science and Technology Center has been working on the technological roadmapping from 2007. Some members from Inverse Manufacturing Forum have been working for the committee. Many technologies which were discussed in the Forum were also listed up to the technological roadmap. In 2007, individual technologies were listed. In addition, possible candidates of national R&D project were discussed and three groups of technologies were proposed. Those three were "Highly efficient diverse-types-and-small-quantity production system," "Sustainable society simulator," and "manufacturing and inverse manufacturing integrated production system." In 2008, top-down thinking to show categorization which may help to achieve sustainable society was tried. As the result of the discussion, logic tree of sustainable manufacturing technologies was proposed. In 2009, a new integrated project proposal in integrating above-mentioned three groups was proposed. Again in 2010, modification of technological roadmap was discussed.

In the paper, the approach of roadmapping is explained with the layered categorization strategy of technologies. Then, the three project candidates and its visual images are shown. Through these efforts, the paper tries to draw a big picture of Japanese trends on R&D of sustainable manufacturing technologies.

2 SCENARIO ORIENTED APPROACH

2.1 Typical approach of roadmapping

Effort of making a technological roadmap is recently common in many industries in Japan. If there is a good technological roadmap, it is helpful to know what kind of development should be focused on for efficient R&D effort. For example, if the target of the development is 5 years later, it is necessary to focus on a technology which is predicted to be developed at least later than 5 years. This type of technological roadmaps is typically seen in device technology such as semi-conductor devices, MEMS, and so on. In these roadmaps, level of technologies should be exactly estimated and step-by-step progress of the technologies should be taken into account. Since these roadmaps are based on an extrapolation of practical technologies, these are very useful in predicting technological trends in near or mid-term future.

However, once there is a big change in social situations such as legislations, global economies, reduction target of global warming gas, and so on, this type of approach is not so appropriate. That was the motivation of technological roadmapping of sustainable manufacturing technologies.

2.2 Necessity of back-casting

As it is briefly mentioned in the former section, target of the reduction of green house gas is still under discussion. Therefore, there is a big possibility that a drastic change in the technological trend. It is so-called "paradigm shift" or

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"quantum jump." In such a situation, the step-by-step approach of roadmapping is no more effective. Instead, the roadmap should list necessary set of technologies to reach the designated goals. And it should clarify which technologies in current world will contribute to enhance sustainability and which technologies should be promoted. This approach is called back-casting. The roadmap of sustainable manufacturing also takes back-casting approach.

2.3 Scenario-based approach

To take the back-casting approach, a scenario which will be the goal of technological development should be decided. The following description is the essence of the scenario which the team decided at the beginning of roadmapping effort. The scenario is targeting 2025.

General situations:

Although there have been many efforts of the reduction of fossil energy consumption, according to the economical growth of newly industrialized country such as China and India, the world consumption of primary energy has reached 1.4 times of that in 2000. Development of renewable energy technologies that are being expected to replace some of the energy supply have been carried out. And the ratio of renewable energy has been increasing steadily. However, a drastic increase has not come yet.

The reduction target of greenhouse gas in 2050 has been agreed by major emitting countries. Corresponding to the agreement, the goal of greenhouse gas reduction in Japan has also been decided. (It is minus 60 to 70% of the amount of 2000.)

Production technologies which can enhance eco-efficiency (value of the products/lifecycle environmental burden) to 4 times of that of 2000 have been developed. However, since technologies have not spread to every industry, the reduction of greenhouse gas emissions in Japan is carried out by the combination of the lean production in industries, reduce designs and energy efficient designs of products, emission trades, the carbon tax and CO2 storage technologies.

However, in 2025, the problem of lack of natural resources is becoming more and more urgent. Thus, not only the linear development of current technologies but also a paradigm shift including the establishment of new lifestyles is being required, to establish the real low-carbon society in 2050.

In addition, more detailed scenarios was decided for all the lifecycle stages of products that are "design," "production," "usage" and "end-of life."

3 HISTORY OF DISCUSSION

3.1 First year; 2007

Through the first year's discussion in the committee, a categorization of element technologies has been carried out. As it is mentioned in the later section, the technologies were categorized to 4 roads and 9 approaches.

3.2 Second year; 2008

Based on the first year's discussion, the committee discussed the intermediate social situations to connect element technologies and the goal (societal scenario). The intermediate social situations have been named "meso-layer." Then, a logical procedure so-called logic tree to start from the meso-layer and reach to elemental technologies was drawn. In addition, 3 groups of elemental technologies that can be possible candidates of national R&D projects have been discussed and decided.

3.3 Third year; 2009

According to the change of the governmental policy, small modifications on the scenario were discussed. Plus, a general direction of R&D to integrate above-mentioned three subjects was considered and drawn on the introductory scenario.

3.4 Rolling of the roadmap; 2010

The roadmap was examined by some new committee members from private companies. Some claims, opinions and suggestions about whether the roadmap is helpful to show the direction of R&D to those private companies were extracted.

4 LISTING AND CATEGORIZATION OF TECHNOLOGIES

4.1 Four roads to sustainability

As it was mentioned in section 3.1, elemental technologies of sustainable manufacturing were categorized based on 4 directions to establish sustainability and 9 approaches to reach the goals.

These are the 4 roads.

1. Life cycle thinking
2. Minimization
3. Heightening of added value
4. Succession of skill

4.2 Nine approaches towards sustainabilitys

Elemental technologies are also categorized to 9 approaches to establish the sustainability. Not same as the usual technological roadmap, aforementioned 4 roads and 9 approaches are not large sections and intermediate sections, because the relations between 4 roads and 9 approaches are many-to-many correspondence. The next are the 9 approaches.

a. Servicizing
b. Visualization
c. Computerization
d. Ubiquitousizing
e. Reutilization
f. Substitution
g. Balancing
h. Standardization
i. Personal training

4.3 Element technologies towards sustainabilies

Each elemental technology for sustainable manufacturing was categorized using aforementioned 4 roads and 11 approaches as labels. Table 1 shown below is a part of the technological roadmap

Table 1 Technological roadmap of sustainable manufacturing technology (partial)

Life cycle thinking	Servicizing	Maintenance technologies	*Estimation technology of residual life * Risk-based preservation technology *Management technology of usage history * Maintenance business
		Design support technologies of environmental conscious business strategies	Software technology of supporting environmental conscious business strategies
	Systemi-zation	Lifecycle design technologies	* Design technology of LC strategies
			* Lifecycle simulation * Comparison technology of alternatives
			* Easy-to-recycle design technology
			* Easy-to reuse design technology
		Reduce design technologies	*Optimum design technology of structures *Utilization technology of high-functional materials *Utilization technology of recovered material and parts
		Lifecycle management technologies	*Management technology of lifecycle information *Management technology of usage history *Fusion technology of products and information
		Management and design technologies of global circulation of products	*Design technology for global product circulation *Technology assure traceability
			*Social system establishment for global product circulation
		Product life management technologies	*Product life prediction technology *Product life diagnosis technology *Product life design technology
		Quality management technologies	*Residual life diagnosis technology * Degradation diagnosis technology *Non-destructive testing technology *Remote testing technology
	Re-utilization	Management technologies of product circulation fro reuse	* Forecast of generation of reusable parts * Management of stock of reusable parts *Production planning utilizing reusable parts

5 SUBJECTS TO PUSH

5.1 13 groups of tecnologies

In the second year of discussion, since the first year's roadmap didn't show which technologies should be focused on strongly, the committee tried to extract group of key technologies that will be inevitable to develop to establish sustainable society. These are the 13 groups of technologies to be put emphasis on.

a. Lifecycle design technologies
b. Sustainability estimation technologies
c. Managment technologies for global product circulation
d. Modeling technologies of products
e. Fusion technologies with products
f. Technologies to ensure traceability
g. Technologies to design good balance of products and services
h. Fusion technologies of products and services
i. Technologies to minimize portotyping
j. High effeiciency various kind and vriant production technologies
k. Manufacturing system technologies to integrate mnufacturing and inverse manufacturing
l. Energy-efficient and resource-efficient technologies in manufacturing processes
m. Manufacturing process technologies with high yield of materials

5.2 Three candidates for national R&D project

In the second year of discussion, the committee also proposed three potential candidates of national R&D projects concerning sustainable manufacturing technologies. Fig.1 to 3 are the schematic images of the 3 subjects.

(1) Sustainability Scenario Simulater

Sustainability Scenario Simulater can express how development and spread of technologies, consciousness of citizens, societal lives and environmental impacts can change along the time, concretely and exactly, including the image of the society..

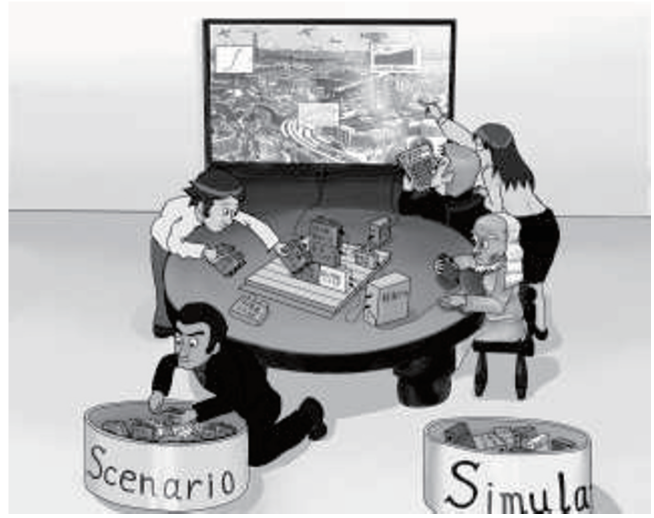

Fig. 1 Sustainability Scenario Simulater

(2) Efficient various-quantity-large-variety production

On-demand manufacturing can be a key to reduce waste, and enhance energy efficiency and resource efficiency of the production. Thus, the new manufacturing system should satisfy "on-demandness" of the production, from upstream to downstream. At the same time, functionalities of the products should be satisfied at a high level. Not only manufacturing process technologies but also diagnosis and prediction technologies of product performances are necessary. This kind of manufacturing system is also helpful to maintain knowhow of manufacturing and personal training.

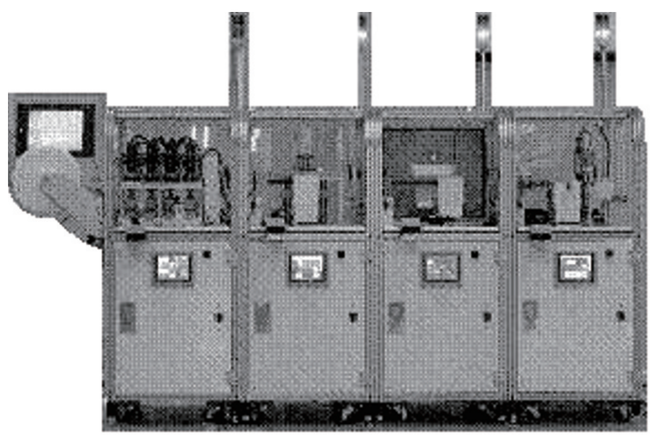

Fig.2 Prototype of the on-demand manufacturing system

(3) Manufacturing system combined with inverse manufacturing system

As it is recently seen in some of electronic products or automobile parts, reuse and remanufacturing of parts are becoming common. These remanufacturing especially combined with manufacturing will be a key technology nowadays to enhance competitiveness of manufacturing. Thus, to carry out R&D of the integrated system will be a good strategy to promote Japanese manufacturing industries.

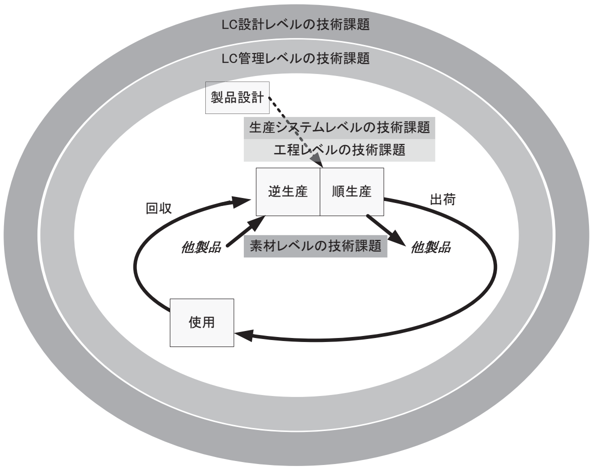

Fig.3 Concept of manufacturing system combined with inverse manufacturing system

6 ROADMAP FOR EFFICIENT R&D

Inverse manufacturing forum is a research consortium to discuss how the sustainable society can be achieved. Members have their own research topics. Concerning the research activities, R&D of actual manufacturing technologies, material technologies, design technologies, etc. have been carried out. Those efforts are the core of technological progress and very important. But, at the same time, for efficient developments and for enhancement of competitiveness of industries, having the overview of the area is helpful. In that aspect, roadmapping of the technologies is also necessary. And of course, for sustainable manufacturing technologies, Inverse Manufacturing Forum is the suitable organization to be in charge of the roadmapping.

Through 4 years effort of the committee, the technological roadmap of sustainable manufacturing technologies has been drawn. In addition, some promising groups of technologies which can be candidates of national R&D project have been extracted. The next step is to utilize the roadmap for efficient and strategic R&D, in private companies and public organizations.

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Corporate Environmental Targets Analysis:

Case Study from Japanese Manufacturing Industry

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Abstract
Nowadays it is increasingly important for companies to stay credible in connection with their commitment to address global warming and reduce their environmental impact. One way to do this is to consistently and transparently disclose environmental data. This research aims at investigating the environmental data disclosed by companies, with particular focus on corporate environmental targets. We analyze the historical timeline of corporate environmental targets on a sample of major Japanese manufacturing companies in order to understand patterns of target setting behavior. In a number of cases we identify a significant level of inconsistency. We examine the significance of this phenomenon by conducting a questionnaire among stakeholder group that deals with the issue of corporate environmental disclosure on daily basis – sustainability rating agencies.

Keywords:
environmental targets, environmental performance evaluation, target setting behavior

1 INTRODUCTION

1.1 Research background

The manufacturing industry is responsible for a substantial share of global CO_2 emissions and energy consumption. It is therefore important to closely monitor and manage the environmental impacts associated with the manufacturing industry, both at the industry level and at the company level. It is a globally established practice for major manufacturing companies to report on their environmental impact. CSR reporting and other environmental impact disclosure activities remain voluntary. However, many manufacturers are under increasing pressure from various stakeholders (governments, shareholders, NGOs, etc.) to consistently monitor, disclose and reduce their environmental impacts. In last decade, significantly more manufacturing companies have been issuing CSR reports and disclosing their environmental impact, from both manufacturing and non-manufacturing operations. Many studies have focused on analyzing the content of CSR reports and exploring factors that encourage environmental disclosure [1]. The practices of corporations have also been criticized. Kaenzig [2] concludes that in many sectors corporate disclosures only cover a very small share of the total environmental burden. To our knowledge, there are no studies analyzing the historical time lines and consistency of corporate environmental targets. A key question examined by this study is the development in corporate reporting represented by corresponding environmental targets setting behavior. In most of the more recent CSR reports we can find ambitious environmental visions, goals and targets claiming commitments to achieve zero emissions and zero waste in the distant future. We believe that future targets can only be assessed relative to the context of how companies have performed to their previously stated targets. That is the major motivation for our study.

1.2 CSR reporting in Japan

Japanese CSR reporting is often said to be based upon a Western-led discourse [3] but it also has roots in traditional Japanese business culture [4]. The current practice of Japanese manufacturing companies disclosing environmental data follows internationally recognized formats, such as that of the GRI (Global Reporting Initiative) [2]. The number of CSR reports has been growing rapidly [1]. However, industry standards or common practice guidelines for disclosing emissions associated with the 'supply chain' and 'product use' phases have not yet been established. Recently several studies have focused on the motivation of Japanese companies to adopt CSR reporting and the major driving forces behind this adoption. Socially responsible investment (SRI) in Japan has been one of the factors contributing to the spread adoption of CSR reporting [5]. Studies focusing on environmental reporting are supplemented by research discussing the establishment of environmental management strategies in Japanese companies [6] or research investigating future issues with

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environmental management [7]. The major players in the manufacturing industry in Japan have a long tradition of CSR reporting. Some have been formulating their environmental visions, corporate action plans and specific targets in order to demonstrate their commitment to address environmental and social issues for more than decade. The common feature of CSR reports are various targets relating to environmental impacts. We can find the analogy of ambitious goals at the national level as well. At the G8 Summit in June 2008, former Prime Minister Yasuo Fukuda announced a national goal to reduce CO_2 emissions by 60-80% from the existing levels by 2050 [8]. Our analysis of the corporate historical timelines for environmental targets can help us better understand the likelihood of future targets being achieved in corporate Japan, which is then partially indicative regarding targets at the national level.

2 CORPORATE ENVIRONMENTAL TARGETS ANALYSIS

2.1 Introduction

Our research is based on the analysis of sustainability targets. We focus on corporate targets related to environmental impact, particularly CO_2 emissions and energy consumption in the Japanese manufacturing industry. These targets are set voluntarily by the companies, but sometimes also represent the goals of industrial associations, such as Keidanren and its Voluntary Action Plan [9]. First, we screen the available environmental reports to identify the targets and their definitions. Second, we analyze the timelines for individual targets with respect to several factors. In this primary analysis we observe the target, baseline and time frame definition consistency and year-to-year achievement rate. At this stage of the research our aim is to understand the rationale behind target setting, and to identify particular patterns. The development of a sophisticated analytical tool that would allow comparison of the target setting behavior among companies or across industries is beyond the scope of this study.

2.2 Corporate environmental targets

Environmental targets can be classified into several groups of targets that are present in most of CSR reports, such as targets focused on prevention of climate change, conservation of resources, reduction of hazardous substances, recycling, protection of biodiversity, etc.). Rising CO_2 emissions represent a widely recognized symbol of global warming, and this measure is commonly used in Japanese corporate environmental impact studies [10]. Companies tend to use several metrics to monitor the direct impact of their operations – total emissions, emissions intensity, energy used and energy intensity being the basic metrics [11]. In terms of environmental target evaluation, the following aspects are considered to be important: clear definitions of target baselines, time frames, scopes and units; the relevance of the target to the overall environmental impact of the company; the consistency of the target over its duration; the ambitiousness of the target; and the achievement of the target. As a pioneering study in this area, one of our goals is to steer the discussion that would lead to a suitable target progress evaluation tool with capabilities to address all of these aspects.

In the following case study we demonstrate our findings based on an analysis of corporate environmental targets. The phenomenon identified is then addressed by a voice from important stakeholder group – sustainability rating agencies and SRI funds. Our study brings insights from the analysis of environmental target setting behavior and builds the overall knowledge also with practical suggestions based on the experience of rating agencies.

3 CASE STUDY

3.1 Introduction

In 2006, the manufacturing industry in Japan was responsible for 460 mil tons of CO2 emissions [12], where 4% of emissions were contributed by the electrical and electronic industry. CSR reporting has only been common practice among Japanese companies since about 2003 [4], and major companies in the electrical and automotive industries have been among the first to adopt CSR reporting. According to CRRA [13] Japan ranks as number three out of the top twenty reporting countries in the period from 1992 to 2010. CRRA notes that if Japanese language only reports were included, Japan would rank number one. Companies in the electronic and automotive industry have some of the longest records of CSR reporting in Japan. Our motivation for analyzing companies in the electrical and electronics industry is based on the fact that major players in the industry are conducting their operations globally and their reporting practice is therefore subject to intense scrutiny. We assume that the quality of environmental data disclosure is among the highest in corporate Japan. However it is still quite rare for CSR reports to address all of a company's environmental impacts, reflecting all impacts before procurement and after sales.

3.2 Studied companies and data

Our environmental target analysis was applied to a case study – a sample of major Japanese manufacturing companies from the electrical and electronics industry. We first screened data relating to environmental targets for seven companies. The data covered 68 environmental reports issued between 1997 and 2011. Corporate websites and publicly available corporate answers to the Carbon Disclosure Project (CDP) served as another source of data. For the target companies we analyze the available CSR reports and extract the selected information about the environmental targets. For more detailed analysis we selected two companies (A, B), which have the longest records of environmental reporting, with available CSR reports going back to 1997. In these two cases we analyze closely 27 issues of corresponding CSR reports. At this point, it is important to note that in most cases we work under the assumption that the disclosed data is accurate and follows best disclosing practices. We intend to study the data presented by companies themselves. We look at the environmental targets set by companies as one way to communicate with the stakeholder groups and create a public image. As one of the outcomes of this study we identify future opportunities for target setting and improved communication to stakeholders.

3.3 Targets in practice

Numbers or targets and changes implemented are an opportunity to observe dynamic processes in corporate target-setting. Detailed content analysis makes it possible to recognize and understand similar situational patterns leading to shift in a target setting behavior. In our analysis we first draw timelines for studied companies A and B, demonstrating the time of the implementation of an environmental plan, the declaration of an environmental policy or setting up of a new target or its revision. Such timelines make it easy to observe the duration of a target period. In the case of the company A, in 15 environmental reports we identified eight targets (TA1-TA8) under the category of "global warming prevention," relating to emissions from manufacturing sites. Targets were focused on reducing energy consumption per net sales; cutting unit CO_2; reducing GHG emissions other than CO_2; eco-efficiency and absolute CO_2 reduction targets. In the early years, targets focused primarily on covering selected manufacturing sites in Japan, gradually this coverage expanded to include global branches and manufacturing sites. The Table 1 shows a list of targets companies A and B with their basic description. In example, target TA1 was not achieved as planned. As a reason for failing the target company A uses the growth in device business. Similarly target TA2 addressing energy consumption per sales was not achieved (27% increase instead of 25% reduction). Company A in following CSR report states: "*We invested approximately 10 billion yen into the company-wide energy conservation activities in fiscal 2000, but was unable to achieve the target. This has been attributed to the impact of our business restructuring activities and rapid market fluctuations.*" Slower growth in sales due to the downtrend in product prices is another reason when the sales based relative targets fails. TA3 successfully reached its first milestone but then was substituted by another target. Some changes looks minor but have a significant impact on the calculation of the target. For instance TA6 is revised TA4 with "*per unit sales*" substituted by "*per basic unit*". In the case of the company B, a set of nine targets TB1-TB9 in same category was selected and their timelines were analyzed. A similar pattern was identified for both companies. In the early years we can see that often the defined targets are not achieved. The level of target discontinuity or failure of achievement is bigger than in case of the company A. Due to the change of methodology of scope, previously set targets are difficult to track further (TB1). Subtle moves in corporate target setting behavior is also expressed in case of targets TB4 and TB6. The definition of the relative targets was changed from reduction of CO_2 emissions to reduction of energy use converted into CO_2 emissions. According to our calculations neither of these targets was achieved. Targets were set to reduction of 15% in 2005, the actual results were TB4 -4.3% and TB6 -1.1%. Interestingly enough both companies A and B have set their targets in period 2006-2010 (TA7, TA8, TB8, TB9)

Table 1: Environmental targets of companies A and B

A	Target characteristics				
	CO2 Emissions and Energy consumption at manufacturing sites	Base Year (FY)	Target Year (FY)	Coverage	Note
TA1 (1997)	Lower the volume of CO2 emissions at factories to FY 1990 levels	1990	1998	Japan	0% not achieved (+7%)
TA2 (1997)	Reduce the amount of energy consumed per unit of sales by 25%	1990	2000	Japan	-25% not achieved (+27%)
TA3 (1998)	Reduce CO2 emission to 6.5% (0%) increase by 1999 (2005), to -7% by 2010	1990	1999, 2005, 2010	Japan	1999 achieved, discontinued
TA4 (2001)	Reduce CO2 emissions per unit sales by 5% (10%)	2000	2005(2010)	Global	re-definition
TA5 (2005)	Reduct CO2 emissions per unit of actual production 25%	1990	2010	Japan	revised TA3
TA6 (2005)	CO2 emissions 10% reduction per basic unit	2000	2010	Global	revised TA4
TA7 (2008)	Reduction 0.11 (0.3) mil tons of CO2 emissions	2006	2008(2009)	Global	move to absolut targets
TA8 (2008)	Reduction of CO2 emissions to FY 2000	2000	2010	Global	move to absolut targets

B	Target characteristics				
	CO2 Emissions and Energy consumption at manufacturing sites	Base Year (FY)	Target Year (FY)	Coverage	Note
TB1 (1996)	Energy Consumption/Net Sales 25% reduction	1990	2000	Japan	discontinued
TB2 (1998)	Achieve 95% of the energy unit per sales	1990	2002	Japan	revised TB1
TB3 (2001)	Revised to conform to an industry's target of cutting unit CO2 emissions by 25%	2000	2010	Japan	-25% not achieved
TB4 (2001)	Reduce CO2 emissions per unit sales by 15% or more	2000	2005	Global	discontinued
TB5 (2001)	Raise CO2 eco-efficiency by 1.5 times by FY2005 and 2times by FY2010	2000	2005, 2010	Global	1.5 not achieved (1.42)
TB6 (2003)	Reduce energy use converted to CO2 emissions by 15% or more per sales unit	2000	2005	Global	-15% not achieved (-1%)
TB7 (2003)	Reduce 30% emissions of GHG other than CO2 emission related to energy cons.	2000	2005	Global	non-CO2 related target
TB8 (2006)	Absolute reduction in GHG at sites (in terms of CO2) of 7%	2000	2010	Global	move to absolut targets
TB9 (2010)	Reduce GHG emissions by an absolute value of 30%	2000	2015	Global	move to absolut targets

to absolute emissions reduction. We can speculate that this is reaction to global recession and decreasing volume of production. By setting the year with record reaching production volumes as base year, targets then tend to be less ambitious and easier achievable. Both companies react to negative developments by redefining targets, discontinuing targets or setting up of new targets. These changes make it difficult for stakeholders to keep track of corporate progress in reducing environmental impact. The variety of target revisions, redefinitions, methodology and scope changes or annual recalculations (when more accurate coefficients become available) requires detailed content analysis of CSR reports, in depth analysis of individual targets and monitoring of the changes and the reasons behind them. In the number of cases, the explanation for revisions or discontinuations of targets is missing. We understand this is rather challenging task for companies to manage. However, we find the level of inconsistencies disturbing enough to further investigate this phenomenon. The question that kept on rising during our analysis was the following: Were there any negative consequences resulting from these frequent inconsistencies in target-setting behavior? What role would those inconstancies play these days? In the following section we present the results of a questionnaire that gives us a view from the perspective of one stakeholder group.

4 QUESTIONNAIRE

4.1 Outline of questionnaire

The timeline analysis of targets relating to carbon emission led to the identification of several inconsistencies. To address this issue, we conducted a questionnaire directed at globally recognized sustainability rating agencies and SRI funds. We will refer to this stakeholder group as “Raters”. Raters were selected for several reasons. First, they have a rich experience dealing with the corporate environmental reports and they are engaged in dialogue with corporations. Second, the role of rating agencies and SRI funds has been gaining in importance and is expected to become more significant in future. We contacted 34 established raters with an explanation of our research, a summary of our findings and a questionnaire containing following three questions:

1) How do you deal with any inconsistencies of corporate environmental targets in your rating/evaluation process?

2) What is, in your opinion, the best practice in setting environmental targets?

3) Do you believe that corporate environmental target setting behavior is/will be increasingly influenced by the positive pressure of rating agencies and SRI funds?

We have received answers from 8 Raters (namely: Trusco, CSRHub, Oekom research, Climate Counts, Roberts Environmental Center, Union of Concerned Scientists, CO2Benchmark and Corporate Knights) and another 6 Raters have stated reasons why they cannot take a part in the questionnaire. The following is a summary of individual questions and the approaches the Raters are taking when dealing with environmental targets in corporate reports.

4.2 Q1 - Dealing with target inconsistencies

Thee were a variety of answers to first question. Some Raters simply do not deal with target inconsistencies, they give credit if goals are set, but do not evaluate whether or not they are met other than to give credit if the performance has improved since the last report. Others use multiple sources of data for each company to remove systematic inconsistencies (not specifically rating either environmental targets or company performance against these targets). Another Rater considers targets on a project basis. Their experience with the problems and inconsistencies regarding future targets is addressed by focusing on the most accurate picture of a company’s environmental impact: “*and so prioritize ensuring we have accurate annual data that covers 100% of a company’s owned or controlled operations*”. The closest attention to environmental targets paid by one of the Raters is as follows: “*We not only evaluate targets but also performance of reductions, e.g. development of total CO2 emission during the last 5 years. To further deal with inconsistencies, the respective indicators of a company's rating are downgraded if:*”

1) set environmental targets (e.g. reduction of CO2 emissions) are not achieved
2) targets are not very ambitious compared to peer group
3) the time frame and the baseline for emissions reductions are unclear
4) no information is available on whether any company action plans are in place in order to achieve the targets
5) if coverage of data is unclear

The final Rater conducts a company scoring process on an annual basis which enables them to gauge a) whether or not the company is using the same environmental targets from the previous year and b) how the company is performing in comparison to their goals. In instances where the goal has been compromised (e.g. from 20%

reductions by 2015, to 15% reductions by 2015), the company will receive lower scores.

Overall we can see that not all Raters deal directly with corporate environmental targets. However, the practice of addressing target inconsistencies is seen in the responses from two out of five Raters. That itself could be a driving force supporting more consistent target-setting behavior and more relevant goals reflecting overall corporate environmental impact.

4.3 Q2 - Best practice in setting environmental targets

Addressing the question of best practice, we can see similarities across all responses. The Raters call for "*ambitious goals that the company has full intention of meeting and reasonably strong confidence that it can meet*". Furthermore Raters believe that any targets should be communicated publicly and that progress towards them should be reported transparently to the public for their own assessment: *"We believe that then outside observers will be able to correctly gage both the quality of the target and the extent to which the desired result has been achieved."* One of the Raters used specific example of a good target practice: *"In my opinion setting environmental targets that integrate both the intensity of environmental impact (relative to revenue or production) and industry averages are most appropriate."* Additional features of best practice are clear internal responsibilities, baselines and timelines for reduction targets, and action plans and measures for implementing them, as well as clear coverage of measured data and respective targets in terms of, e.g. production units, % of products produced or sales. The strength of target is described by one Rater as being dependent on:

1) the breadth of the target - is it company-wide and does it represent all owned/operated facilities
2) the target baseline year -- the further back the baseline year, the better usually (this isn't always the case, however, as some companies will choose a baseline year where they experienced atypical production levels
3) whether the reduction is "Absolute" or "Intensity" based -- Absolute targets are generally considered "true" reductions, versus intensity-based targets which are considered "relative" to other inputs and outputs.

One of the Raters called for a performance benchmarking as an incentive for companies to at least match the best industry performance and seek continuous improvement: *"The rationale is that target setting in isolation makes little sense for a company. Performance benchmarking should be the way how targets are set."* The same Rater than suggests establishment of a correlation between stock price and environmental performance as a way to encourage companies to meet or exceed their targets. The insights from all Raters help us create an image of what should the ideal target look like and what changes companies should further consider.

4.4 Q3 - Rater's influence

The majority of Raters consider themselves to be influential. They also believe that they will continue to be the influence in future as well. "*Any time corporate performance is scrutinized and the results made public, there is pressure to improve. Some companies, like some politicians, ignore the pressure, but the more likely response is to try to improve.*" One Rater considers the other stakeholder groups to be more important sources of long time pressure: "*Employees, managers (both senior and middle), suppliers, customers, competitors (peer pressure), NGOs, business organizations, the government, and communities - these group collectively (and in some cases individually) have much more power to effect positive change than shareholders and investors do.*" Skepticism was expressed by two of the Raters, firstly: "*The investors are keen to learn company level projections of the environmental impacts, which would take into account targets. However the issues with company's target reporting creates problems for projection estimates and consequently there is not much reliable data on this aspect available in the market.*" And secondly: "*The fundamental role (by law) of the CEO of a publicly held company is to increase shareholder wealth. Period. If a CEO can increase shareholder wealth and create greater gains for the company without investing in GHG emissions reductions, they will generally do so.... especially in the absence of regulation (carbon tax or cap and trade). So although SRI's and consumer awareness through ratings help motivate companies, I think the monumental change required to reduce the impact of industry on climate change needs to come from policy reform.*"

The examples of best practice as well as opinions about the future influence and driving forces of more responsible corporate environmental disclosure as viewed by professionals from rating agencies can be a useful guideline for companies seeking to improve their target-setting behavior.

5 SUMMARY

This research examines companies' environmental performance from the point of view of their environmental targets. In our study we observe common features in corporate target-setting behavior, not simply to point out their misconducts or bad corporate citizenship but rather to find a connection to identify opportunities for added value in this dynamic environment (with an increasing number of SRI funds, CSR raters, and NGOs). Disclosed environmental data and corporate goals are the subject of research scrutiny with the goal of drawing a clear picture of past progress towards reducing CO_2 emissions. We argue that improved environmental target-setting strategies have the potential to result in higher shareholder value by minimizing risk, building up brand value and creating a competitive advantage. Good corporate citizenship is now a common theme for global manufacturing corporations. We believe that eventually major manufacturing corporation will have to embrace the concept of zero or near-zero emissions for all of their global operations, supply chains and environmental impacts relating to product use. The corporate goals as presented to us are ambitious and far reaching. However, we should be wary of focusing on future targets without assessing performance in achieving previously stated targets. This way our study can be a modest guide for companies as they set new targets and reconsider business development and their further role in the society. For researchers, the opinions of rating agencies based on practical experience can serve as a guideline when designing sophisticated tools for evaluating environmental performance. Our future intention is to develop easy-to-understand evaluation metrics that addresses the path from current environmental impact to a more sustainable future, while helping companies communicate their commitment to reducing environmental impact. We believe that the timeline analysis of corporate emission reduction goals is an important indicator. By determining strategic patterns based on a target-achievement, we believe this method has the potential not only to contribute to reduction of corporate environmental impact, but also to increase companies' revenues and reputations. Various analysis and perspectives leave space for further research. We believe the main limitations of this study are the limited number of companies and targets analyzed, as well as lack of detailed target evaluation methodology. The concept of universal corporate CO_2 emissions reduction targets is a topic that we hope will be on the agenda in near future.

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A Methodology for Designing Sustainable Manufacturing Scenarios

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Abstract

Although the concept of sustainable manufacturing is very important both for the sustainable society and future directions of the manufacturing industry, its image is quite ambiguous. In order to clarify the image of the sustainable manufacturing and strategies for reaching it, Inverse Manufacturing Forum runs "Sustainable Society Scenario Simulation (3S Simulation)" project from 2006. This paper summarized achievements of this project focusing on scenario representation, scenario design methodology, dynamic scenario, scenario analysis, scenario achieves, and their practical use. The scenario design methodology is effective in guiding scenario design especially in the convergence phase, while it is very difficult to support the divergence phase. 3S Simulation project has contributed to construction of common understanding of the problems to be solved by the sustainable manufacturing. And, it will contribute to design of ideal and realistic sustainable manufacturing scenarios. 3S Simulator discussed in this paper is available through http://www-lce.mech.eng.osaka-u.ac.jp/3s/.

Keywords:

sustainability scenario, sustainable manufacturing, sustainable society scenario simulation, scenario design

1 INTRODUCTION

The traditional manufacturing industry, relying on the mass production, mass consumption, and mass disposal paradigm, has caused various environmental issues including global warming, air and water pollution, and resource depletion [1]. This implies that, if we can change manufacturing paradigm, the manufacturing industry will be a strong driver for realizing sustainable society. In this sense, we define "sustainable manufacturing" as the manufacturing industry that contributes to the realization of sustainable society, including business, manufacturing systems, and product development.

Then, the next questions are what the image of the sustainable manufacturing is and how to reach it. Inverse Manufacturing Forum, Japan [2] has been pursuing this image as one of its main activities. Here, we have taken scenario-based approach, because we needed descriptive representation of future visions of the sustainable manufacturing with thousands of unknown factors and scenario is suitable tool for this purpose. We call this scenario writing project for sustainable manufacturing "Sustainable Society Scenario Simulation (3S Simulation)," which consists of three research topics (see Fig. 1); that is, i) formalizing scenario design methodology, ii) developing computational support environment for scenario design, and iii) writing sustainable manufacturing scenarios. This paper summarizes achievements of the 3S Simulation project focusing on the topics i) and ii) and discusses directions of future works, while Fujimoto *et al.* [3] reports achievements on the topic iii). Based on the discussions until now, we understand that the issue of the sustainable manufacturing is to find out some stable points where both of the global warming problem and the resource depletion problem do not greatly affect human welfare even with assuming rapid economic growth of developing countries.

2 SUSTAINABILITY SOCIETY SCENARIO (3S) SIMULATION

In 3S Simulation project, we focus on "scenario design." Scenario design is not just describing scenarios, but consists of all tasks for composing a scenario and modifying it, including problem definition, data collection,

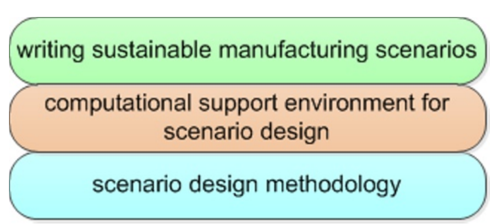

Fig. 1: Sustainable Society Scenario Simulation project

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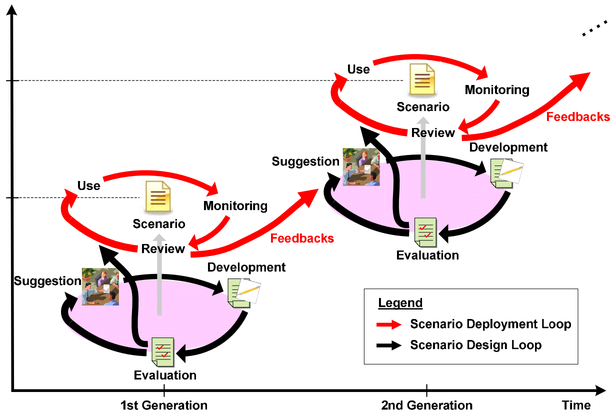

Fig. 2: Sustainable Scenario Design [4]

idea generation, discussions among different stakeholders, scenario development, simulation, analysis of scenarios, and deployment of a composed scenario (see Fig. 2) [4].

One of our main goals is to develop an intelligent CAD supporting the whole process of scenario design in an integrated manner as shown in Fig. 3. We call this computational environment "Sustainable Society Scenario Simulator (3S Simulator)" and set the following research issues with the system architecture shown in Fig. 4 [5]:

1. Representation methodology of a scenario: This topic formalizes scenario representation to clarify its causal structure and relations to associated simulations. This provides us with a formalized and computerized way of representing a sustainability scenario.
2. Scenario design methodology: This topic models the design process of a new scenario, including forecasting and backcasting, and develops a methodology for supporting design of a new scenario by reusing archived scenarios and their associated simulators.
3. Dynamic scenario: A "dynamic scenario" refers to a structured, computerized scenario representation that maintains dynamic links to its associated simulators. These links enable re-execution of simulations with different conditions and permits the modification of the scenario according to the simulation results.
4. Scenario Analysis: This topic supports the analysis of described scenarios, including logical structure analysis, what-if analysis, and sensitivity analysis.
5. Scenario Archives: This topic focuses on archiving scenarios and their simulators by using structured, computerized scenario representation to facilitate understanding and analysis of existing scenarios, as well as design of a new scenario using existing scenarios.

The system architecture of the 3S Simulator shown in Fig. 4 consists of the following five components:

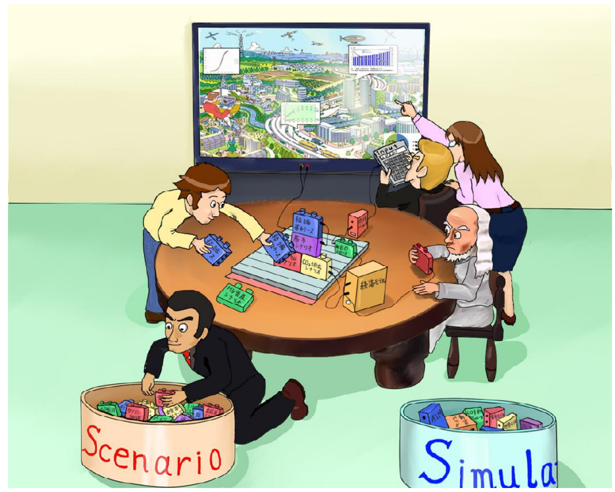

Fig. 3: Image of 3S Simulator [5]

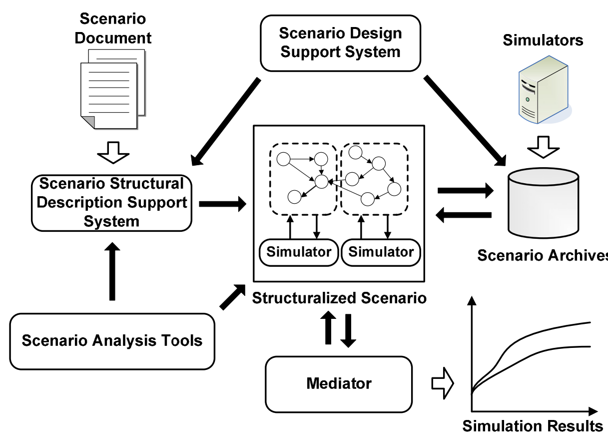

Fig. 4: System Architecture of 3S Simulator [5]

- Structural Scenario Description Support System: structurally supports describing new or existing scenarios.
- Scenario Archives: archives structuralized scenarios and associated simulators used in scenarios.
- Scenario Design Support System: supports designing a new scenario.
- Scenario Analysis Tool: analyzes the logical structure of a described scenario and conducts what-if and sensitivity analyses using its simulators.
- Mediator: exchanges data among simulators used in a scenario in order to run simulations.

3 ACHIEVEMENTS AND ISSUES

We have been developing 3S Simulation methodologies and implementing 3S Simulators, as well as describing various scenarios for about five years. The intermediate summary of achievements and issues is as follows:

3.1 Representation methodology of a scenario

The proposed method based on logical relations [6] was successful in providing formalized and computational representational scheme. We defined a set of types of concepts necessary for representing a scenario. This notation clarified rationale of a scenario such as references, data, and simulation results that the scenario is based on as well as hypotheses and assumptions of a scenario if they are clearly mentioned.

While the representational scheme is successful, we find out some difficulties:

(i) To illuminate storyline of a scenario was more difficult than we expected, because sentences written by scenario designers' are not so logical and the designers do not describe all intentionally or unintentionally. Explicit descriptions are not all but just a tip of an iceberg. Designers assume commonsense and common tacit knowledge with readers. This ratio of hidden iceberg is larger than expected. This makes logical representation of a scenario difficult, but ontological approach (*e.g.*, [7]) may be helpful.

(ii) It is tiresome to structurize scenario description since it is done manually. Here, structurizing means to translate sentences of a scenario into a graph of concepts and logical relations. However, there are undeterminable areas for judging kinds of nodes and links; *e.g.*, hypothesis or fact, and causal relation or logical jump. We consider they are unavoidable; rather, undeterminable sentences are cues for consensus making among stakeholders participating scenario design and we should develop a style of scenario description suitable for 3S Simulator. Ontological approach again might be helpful. And since this problem is similar to the problem of natural language processing, recent processing technologies based on huge amount of data might also be helpful, besides there are not so many scenarios. We are planning to semi automatize the structurization.

3.2 Scenario design methodology

We have succeeded in formalizing the process of scenario design in forecasting manner and backcasting manner. And now we are developing the design process that includes both of forecasting and backcasting in an integrated manner. We believe this is the most theoretically appropriate, since we can find both of forecasting aspect and backcasting aspect in designing a scenario.

However, supporting scenario designers well is another thing. Guidance based on these methodologies might be too rigid for human designers and does not always stimulate them in finding out good ideas in terms of contents of the scenario. We need some tools flexibly supporting designers with allowing trial and error. This is a common feature to the domain of design support methods in general; in other words, intelligent CADs, CADs, and other design support systems can help a designer in efficiency but cannot directly increase novelty or originality of the design results. In general, design process, including scenario design, can be divided into two phases; divergence phase and convergence phase. In the divergence phase, designers generate ideas as many as possible by employing, *e.g.*, brainstorming. In the convergence phase, designers categorize, combine, and detail the generated ideas so as to arrive at several alternatives of design solutions. Basically, design support systems are good at supporting the convergence phase but it is essentially difficult to support the divergence phase. These issues also apply to 3S Simulator. In this sense, the sequence of various intermediate representations of a scenario, which results in scenario description, in our design methodologies (*e.g.*, problem description table, logic tree, storyline, causal network, and so on in the backcasting method [8]) is effective to guide designers in the convergence phase in a stepwise manner.

3.3 Dynamic scenario

Dynamic scenario is a mechanism for enabling re-execution of simulations with different conditions and permits the modification of the scenario according to the simulation results by maintaining dynamic links from a scenario to its associated simulators. This mechanism is quite useful for sensitivity analysis and what-if analysis of a simulation in a scenario. In these analyses, it is very effective that the structured representation of a scenario explicitly expresses relationship among a set of simulation conditions, a simulator, and a set of simulation results. This is one of the main achievements of 3S Simulator. By mapping such relationships, we can do a sort of phase portrait analysis.

Combinational use of different simulators in a session of simulation and treatment of the case where a simulation result affects on conditions of another simulation are future works of this topic.

3.4 Scenario Analysis

Besides what-if analysis and sensitivity analysis, which are deeply dependent on the dynamic scenario, so far we can do just logical structure analysis that distinguishes "logically sound" part of a scenario from the rest. It is useful for, *e.g.*, finding out rationale of a sub-scenario.

We should find out plausible analyses since analysis is the key for supporting the scenario design in practical sense. Examples include:

- Evaluation: Although it might be impossible to evaluate originality, correctness, or completeness of a scenario, it is possible to evaluate a scenario from various aspects such as logical consistency, adequateness of rationale, and degree of logicality (or illogicality).

- It is helpful that the system points out a part of a scenario of which rationale, logicality, description is insufficient.
- Phase portrait analysis mentioned in Section 3.3 may help designers to find out conditions resulting in the future they want to achieve.
- Evaluation of similarity of two different scenarios is helpful for designing scenario by analogy based on the scenario archives.

3.5 Scenario Archives

Constructing archives of scenarios with their associated simulators was tougher work than expected. We structurized various scenarios (*e.g.*, IPCC SRES, IEA WEOs, IEA ETP, and Japan MOE LCS2050), but

- As discussed in Section 3.1, described scenario just a tip of an iceberg. Scenario writers may not have paid enough attention on logicality or reproducibility of scenarios. Basically, nobody describe everything.
- Simulation methods or extrapolation methods are not always mentioned. Even if mentioned, some simulators are not available. Even if they are available, almost no scenario describes simulation conditions completely. In reality, then, it was almost impossible to realize dynamic scenario with existing scenarios, except for scenarios made by our group or colleagues.

We aim at changing this culture and introducing scientific approach (*e.g.*, guarantee of reproducibility) into scenario design, but this is very tough work.

Anyway, we are constructing the scenario archives and more technical issues are:

- Increase of reusability: For increasing reusability of archived scenarios, it is effective to develop methods for decomposing a scenario into reusable building blocks, extracting scenario templates from existing scenarios, and applying case based reasoning techniques for reusing existing scenarios as cases.
- Search: In designing a scenario, it is helpful for designers if the system suggests a part of archived scenario that provides fundamental data, supporting conclusions, or conflicting conclusions.

3.6 Practical applicability

Development of 3S methodologies and its implementation (*i.e.*, 3S Simulator) progresses well with denoting achievements and issues discussed in Sections 3.1 - 3.5. This section discusses practical applicability of the methodologies and tools and its implications.

The scenario design methodology is effective in guiding scenario design with providing various intermediate representations, especially in the convergence phase. In other words, it is very difficult to support the divergence phase and this is the same for design support methods in general. The scenario representational scheme is also useful to represent a scenario with structurizing information.

As a software system, the scenario representation scheme is very powerful to analyze and understand a scenario once it is structurized. Dynamic scenario is also very powerful for sensitivity analysis and what-if analysis once a scenario is connected to a simulator. However, it is difficult to use the system during, for example, a workshop for scenario design; it takes time to structurize texts of a scenario and it needs some experiences to read the structured model of a scenario. It is, therefore, on the way for development of practical scenario design support system. On one hand, improving user interfaces and simplifying and semi-automatizing the structurization of a scenario are needed. On the other hand, expanding the power of systems, including dynamic scenarios, analysis tools, and scenario archives, is promising for increasing the practicality.

Until now on, it is verified that writing scenarios is very useful for scenario designers to think about the sustainable society and the sustainable manufacturing. Scenario writing is a very good tool for thinking about and simulating these topics. On the other hand, how we can use designed scenarios is another question. In other words, we could not deal with the scenario deployment loop in Fig. 2; especially, it is important to develop a mechanism for involving various stakeholders in the deployment loop, including reviewing scenarios, suggesting modifications, and making consensus among participants.

We have found new seeds and needs in this project. A new extension of the methodology we found, for instance, was business strategy planning [9], which provides a simplified scenario design method by supporting designers to design a detailed scenario (*e.g.*, long term business strategy of a company) by employing fundamental scenarios (*e.g.*, IEA ETP scenario). And, it might be a good test bed for verifying the effectiveness of the methodologies and the system to modify our existing scenarios by examining possibility of resource depletion led by developing countries and the effects of the Tohoku Earthquake.

4 CONCLUSIONS

In order to clarify the image of sustainable manufacturing and strategies for reaching it, Inverse Manufacturing Forum runs “Sustainable Society Scenario Simulation (3S Simulation)” project from 2006. This paper summarized achievements of this project focusing on scenario representation, scenario design methodology, dynamic scenario, scenario analysis, scenario achieves, and their practical use. The scenario design methodology is effective in guiding scenario design with providing various intermediate representations, especially in the convergence phase. In other words, it is very difficult to support the divergence phase and this is the same for design support methods in general. The scenario representational scheme is also useful to represent a scenario with structurizing information. As a software system, the scenario representation scheme and dynamic scenario are very powerful to analyze and understand a scenario. However, it is still on the way for development of practical scenario design support system.

Until now on, it is verified that writing scenarios is very useful for scenario designers to think about the sustainable society and the sustainable manufacturing. Scenario writing is a very good tool for thinking about and simulating these topics. Actually, we understand that the issue of sustainable manufacturing is to find out some stable points where both of the global warming problem and the resource depletion problem do not greatly affect human welfare even with assuming rapid economic growth of developing countries. 3S Simulation project has contributed to construction of common understanding of the problems to be solved by the sustainable manufacturing. And it will contribute to design of ideal and realistic sustainable manufacturing scenarios.

3S Simulator discussed in this paper is available through http://www-lce.mech.eng.osaka-u.ac.jp/3s/.

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Sustainable Car Society Scenarios: A "Game-changing" Approach

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Abstract

Discussed here are issues concerning standardized measures toward Low Carbon Society in Japan, through depicting a future "Electric-vehicle (EV) Society". In Japan, many activities regarding EV have pervasively spread into society. However, these activities are based on the simple idea that "EVs replace current gasoline vehicles", and have not considered future possible changes. A new design of a car society from a holistic perspective may be strongly required in order to achieve a "Sustainable society" in Japan. Scenario-planning and brainstorming methods were used in order to depict an "extreme" EV society (100% EV). A new kind of society can be created which will eradicate many of the social problems we face in our current style of car-society. These include issues related to an unprecedented aging population, such as decreasing work force, increase in social welfare, and economic stagnation.

Keywords:

electric-vehicle, aging society, game-changing, social-scenarios

1 INTRODUCTION

The number of private cars in Japan continued to increase from approximately 2.3 million in 1966 to 58.1 million (including 17.3 million mini-cars) in 2009. This huge increase in private car ownership has created a car-society, i.e. situations where cars have a dramatic impact on social/economic structures such as dwelling, industry, and health services.

The amount of CO2 emission from the transportation sector is 236 million tons, and accounts for about 20 percent of total CO2 emission in Japan, which was 1.2 billion tons of CO2 in 2008. Because about half of the amount of CO2 emission of the transportation sector comes from private cars, the amount of the CO2 emission from private cars was about 10% of total CO2 emission in Japan.

Against this backdrop, many activities related to EVs (Electric Vehicle) have pervasively spread into Japanese society. These activities include an improvement in battery performance, an increase in the number of battery chargers, grants for purchasing EVs, and so on. However, these activities are based on the conventional idea that EVs should simply replace current gasoline vehicles. This conventional approach seems to be inadequate when searching for effective solutions. Therefore, 'game changing' is essential when thinking about a sustainable car-society in Japan.

This paper presents a "sustainable car-society" in Japan. First, future possible social changes in Japan are addressed. After that, several kinds of future EV societies are depicted using scenario-planning and brainstorming methods. Finally, we consider not only how EV society is compatible with these changes but also how such an EV society can provide radical solutions.

2 WHAT IS "GAME CHANGING"？

Figure 1 shows our concept of "Game changing". The current approach to EV distribution is based on the continuation of current automotive society, i.e. EVs are required with similar performance and convenience of current gasoline cars. However, a different view can be taken. Current cars will not be favored and will fade out because of future social changes. In such a case, a different kind of vehicle will spread into society. It is believed that this new vehicle will be produced due to radical social changes such as aging society, oil depletion, and young people's change in purchasing behaviour. Many people can't accept this concept and the idea that the current car society will come to an end. However, there is evidence to support this concept from the perspective of two areas: radical social changes in Japan, and from the "side effect" of the current car- society.

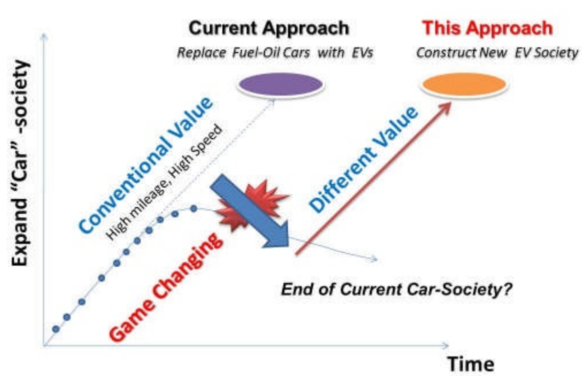

Fig.1 Game changing approach

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2.1 Social Changes in Japan

Japan has been facing radical social changes. The following are a number of typical changes related to a car-society

-World’s fastest aging society

There is no precedent for an aging society. Figure 2 shows an estimation of the percentage of the aged population toward total population of Japan. The value of people over 65 was estimated to reach 30% in 2025 and 40% in 2055 [1]. Furthermore, the percentage occupied by people over 75 rapidly increases.

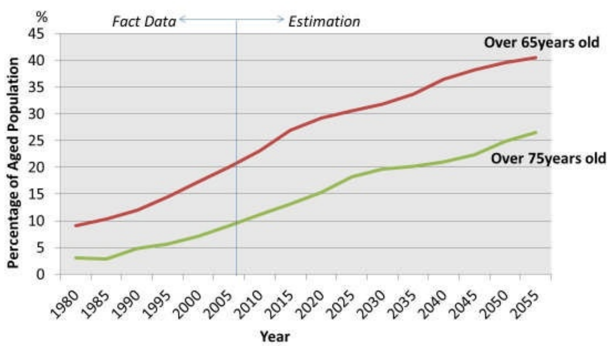
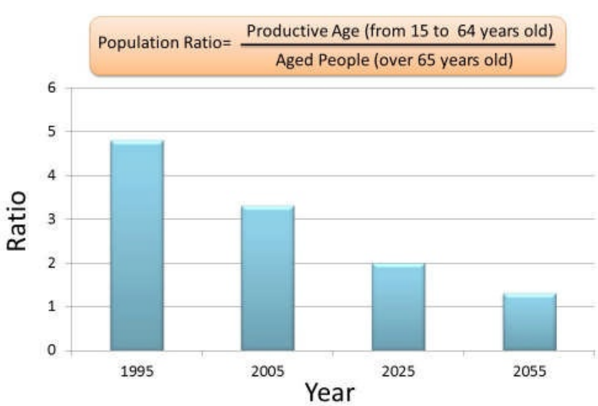


Fig.2 Percentage of aged population in Japan

-Over the peak of population

The population of Japan passed over its peak around 2006 due to a low-birth rate. The percentage of children under 15 years old has been decreasing from 1982 [2] Therefore, the population ratio of productive-age people(from 15 to 64 years old) to aged people (over 65) was 4.8 in 1995, 3.3 in 2005, and is estimated to be 2.0 in 2025 and 1.3 in 2055



(Fig. 3).

Fig.3 Who supports aged people in Japan

These statistics point to two essential issues related to people’s form of transportation. First, traffic accidents caused by senior citizens have increased remarkably [3]. Therefore, even if they have a driving license, they lose their desire to drive a car. Second, as the child population decreases, the total number of drivers would decrease rapidly in a future Japanese society. Third, depopulated areas in which senior citizens live alone have been expanding in the countryside. For developing a sustainable format of transportation, a new public system would be required. This would cause an increase of social cost regarding construction and operation of the new public transportation system.

-Decrease in Oil Demand

Furthermore, it is essential to achieve “Low carbon society” in Japan. However, there are some indications that Japan will naturally move towards a lower energy consumption society without the need for radical measures for achieving low carbon society. The demand of gasoline has decreased from 2005. METI estimation regarding gasoline demand was 49 million litres in 2013. As the demand of gasoline was 58 million litres in 2008, it shows that demand will continue to decrease in the future [4]

-Young People’s Consumption

Figure 4 shows the number of shipped cars in the Japanese market. The number of shipped cars peaked in 1996, increased again from 1998 to 2006, then decreased by 2006.

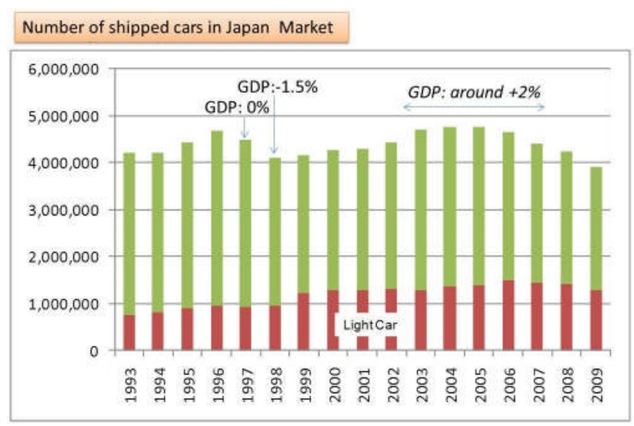


Fig.4 Number of shipped cars in Japanese market

For 17 years, the number of ‘light cars’ such as those under 1,000kg of car weight has gradually become a large part of total shipment. Furthermore, real GDP growth rate (changes from the previous year) in Japan was 0% in 1997 and -1.5% in 1997 [5], suggesting that the decrease in shipped cars during these years were closely related to economic conditions. However, the number of shipped cars from 2003 to 2007 fell from its peak even though GDP growth rate kept to around 2%. Therefore, it appears that the decrease in car purchases is not simply due to a decline in economic conditions. One of the important factors which caused this decline was thought to be young people’s change in purchasing behavior. According to the report “2008 Passenger Cars Market Trend Investigation” the benefit of having a car decreased due to an increase in distribution of games, cellular phones, and personal computers; devices which make it possible to pursue indoor activities and communicate with others at any time. Moreover, the relative "burden" of possessing a car, for example parking fee, maintenance cost, and running cost, increased as economic conditions worsened [6]. Basically, young people are not buying as many cars as previous generations, pointing to a change of attitude towards gasoline cars. This trend suggests young people may be open to the creation of an EV society.

2.2 Side-effects of current car-society

Japan has heavy debts. Because increases of cost related care and medical services for aged people, these debts will increase naturally with an ageing society. Currently we take air-pollution and sound-pollution caused by oil-fuel cars for granted. However, we "reap the benefit of freedom gained by transportation at great cost" [7]. For example, medical conditions such as respiratory disease can be caused by the exhaust gas of gasoline cars. The noise from gasoline car has been linked to mental stress. At great social cost the government spends a large amount of its budget on trying to treat such 'diseases'. How much money do we waste on such negative things? Furthermore, the nation also pays for preventing and measuring environmental problems caused by cars.

Due to the issues expressed above it becomes clear why our current car-society can't continue in the future. Therefore, how do we design a future car-society where EVs can naturally spread widely?

We considered "new society" from fresh perspective.

3 FUTURE ELECTRIC-VEHICLE (EV) SOCIETY

As stated in the introduction, in Japan, many activities regarding EV have pervasively spread into society. However, these activities are based on the simple idea that "EVs replace current gasoline vehicles", and have not considered future possible social changes stated above.

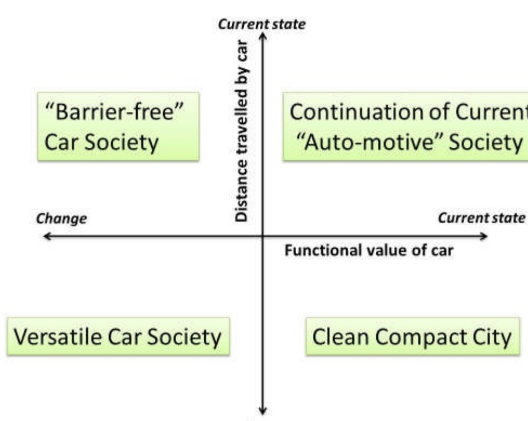


Fig. 5 Future EV society

3.1 Depicting Future EV Society

Scenario-planning and brainstorming methods were used in order to depict an "extreme" EV society (100% EV society). "Extreme" thinking was necessary for avoiding "conventional thinking", that existing technologies simply replace "low-carbon" ones in order to decrease CO2 emissions. The two chosen uncertain factors which have a large impact on future social shaping, were distance travelled by a car (no change or shortened) and functional value of a car (no change or having new value). The former factor is closely related to urban structure in an aging society, the latter is associated with young people's interest regarding a car. These two uncertain factors were expressed by two axes and four quadrants. The future society scenarios below were then placed in each quadrant (Fig.5).

3.2 Continuation of Current "Auto-motive" Society

There were 41.8 million ordinary cars and 15.7 million light-cars in 2007, Japan [8]. This scenario depicts all oil-fuel cars being replaced by EVs, and continuing in the direction of current society. Battery chargers would be set up in all public places due to the low capacity of electricity storage of battery. Furthermore, noncontact-type battery chargers would be used in a highway. People could use EVs in a similar way to gasoline cars. This scenario is the same as the usual scenarios considered in order to achieve "low-carbon" society. This means that there is a lack of consideration for social changes, such as how to transport the aged people (Fig.6)

Fig.6 Continuation of current "Auto-motive" society

3.3 Clean Compact City

In this society, it would not be necessary for an EV to have high mileage and high speed performance. Instead of these, "low speed", which wouldn't harm people in a collision and would make autopilot and auto-parking of a car possible, would be needed. If this society is realized, we could be free from negative cost of traffic accidents and disease caused by exhaust gas and noise-pollution.

The senior citizens could utilize a car and walk around safely in a “silent” town due to EV’s functional performance. Furthermore, an auto-parking system makes “Park &Ride” more convenient. If this society is realized, issues of the transportation for the aged people could be solved. However, a clear vision and leadership of the government would be essential to construct a new “Compact city”. In this society, cars will be mere a tool for people’s short travel. Cars would be utilized in a similar way to bicycles and scooters (Fig.7).

Fig.7 Clean compact city

3.4 Versatile Car Society

The car changes from “transportation device” to “my room with vehicle”. By using the unique characteristics of being “clean” and having a battery, EVs could be usefully integrated into the house.

Fig.8 Versatile car society

Some people who could even bring EVs into a house and use it as a room. Furthermore, there are some people who could live in EV’s docked with an “apartment station” which provides bath, kitchen, rest room, and laundromat. Because EVs have an automatic running mode with low speed, it could be used as a means of transportation for senior citizens who are physically-disabled. Moreover, it would be possible to come home in the automatic running mode after alcoholic consumption. Thus accidents related to drunken driving would become obsolete.

This society could be moderately achieved by using new and innovative ideas from the private sector. The government also has a role to assist its activity. The aged people could move freely, and young people could recover their interest towards new style of “cars” which combine ideas of growth industries, such as IT, Robotic. This could help stimulate Japan’s economy (Fig.8).

3.5 ‘Barrier-free” Car Society

The distance travelled by a car is similar to the scenario of “Continuation of Current Auto-motive Society”. However, there is the difference of how the cars are used. In this scenario, frequency of short trips increases because of the barrier-free concept. “Everyone” can use EV "Anytime" and "Anywhere". Therefore, a "Ubiquitous automotive society" would be achieved. A compact EV could be brought onto a bullet-train (Shinkansen) thus realizing the ‘automatic compact making’ function. An EV could be taken into a shopping center at any time without difficulty. This may reduce the need of stocking large amounts of food in the home. This society is similar to “Versatile Car Society”, but has the added concept of “barrier-free” car. The aged people could even travel long distance in Japan. Therefore, their daily life could be changed radically. This may help them to recover their motivation for extending work life. This would have a positive impact on social issues such as decreasing work force due to a low birth rate, and increase of financial support needed for rapidly aging society. However, there are technological obstacles for achieving “Barrier-free” cars. The government has to help solve such technological problems (Fig.9).

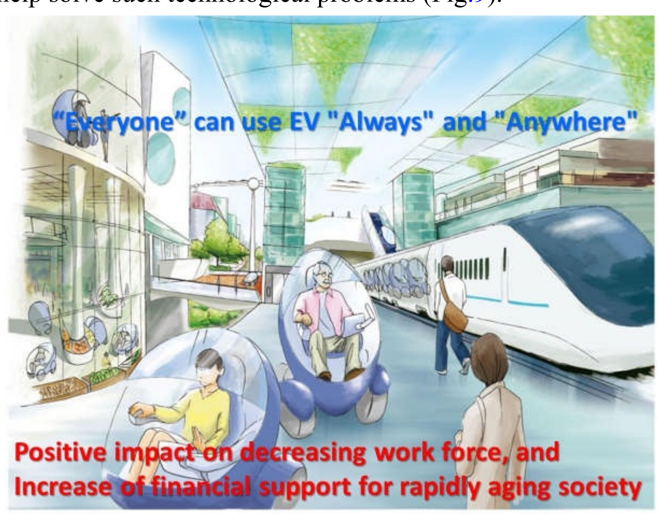


Fig.9 “Barrier-free” car society

4 RADICAL SOLUTION PROVIDED BY EVS

In modern industrialized nations the ‘car’ as a consumer product has symbolized many things: capitalism, status, innovation, environmental damage [9]. Fromm stated “The most striking example of today’s consumer-buying phenomenon is the private automobile. Our age deserves to be dubbed, ‘the age of the automobile’, for our whole economy has been built around automobile production, and our whole life is greatly determined by the rise and fall of the consumer market for cars”[10]. These sentiments are as true for 2011 as they were 30 years ago. Or so it is generally believed? There are already signs that consumer trends in Japan are already changing [11]. In addition to this, Japan has been facing radical social changes described in section 2. Cars and their transportation-systems may have reached a threshold.

Table 1 compares Current Approach, the previous first scenario, with “Game Changing”, the other three scenarios. It is clear that a quite different society is coming and a quite different procedure is needed whether social changes are considered or not.

Table 1 Current approach vs. “Game changing”

	Current Approach	Game Changing
Feature of EV	High mileage/speed	Auto pilot/parking, “Barrier-free”, Low-speed, Private room
Intended user	Productive People	Productive/Aging people
Policy	Advanced Technology development, Increase in number of battery chargers, Grants for purchasing	Social system change in various areas, Relocation of residence, Assist innovative ideas from private sector
Main player in Industries	Car, Electronics	Car, IT, Robot, Material, Electronics, Construction
Social cost reduction	Medical, Environment	Medical, Environment, Traffic accident, Public transportation, Financial support needed for aging society
Resource/ Energy Increase	Electric power consumption:50-100TWh (5-10%), Copper material:4.4million ton, Rare-earth (Nd): 17 thousand ton	
CO2 Reduction	Around 100 million ton (-10%)	

4.1 Car Industries

Regarding the main players in industry, EVs in “Continuation of Current Auto-motive Society” should be manufactured by the car industry in order to continue the basic performances of current cars. On the other hand, EVs in the other social scenarios, such as “Clean Compact City” could be manufactured by a new industry which blends IT, Robot, material, and interior design industries together. These new industries will supply cars which are only suitable for the Japanese market. This style has been called “Galapagos” approach, meaning the product is adapted to fit only one country. This approach has also been adapted by the mobile phone market in Japan. Because social conditions differ between countries, businesses must therefore take the “Galapagos” approach in order for a sustainable car-society in each individual country to be achieved. This is especially true for Japan due to its unique social situation. Meanwhile, the current major car industries have supplied similar types of gasoline cars, such as “high-speed”, “long-distance travelled, and “safe/ comfortable”, into several countries of the world. Therefore, when we consider Japan’s “car-society” in the future, we also cannot ignore the effect of globalization on the car industries. However, the coexistence of global and “Galapagos” businesses may occur in a future Japan market.

4.2 Negative social cost

Currently we take air-pollution and sound-pollution caused by gasoline cars for granted. We reap the benefit of freedom gained by transportation at great cost [7]. For example, medical conditions such as respiratory disease can be caused by the exhaust gas of gasoline cars. The noise from gasoline cars has been linked to mental stress. At great social cost the government spends a large amount of its budget on trying to treat such ‘diseases’. How much money do we waste on such negative things? In a 100% EV society, these social costs would become obsolete.

Three types of society without Continuation of Current “Auto-motive” Society would have less traffic accidents because of low speed car’s operation and automatic running mode, and wouldn’t need social cost in order to construct new public transportation system for aged people. The decrease in traffic accidents would also reduce negative social costs related to the treatment of these accidents. If the negative social cost that we have kept paying could be spent in new social system construction, we may achieve a happier society. It would be necessary to clarify the value of these negative costs in order to make a first step towards achieving a sustainable EV society.

4.3 Resouce and energy increase

Regarding resource/energy consumption and CO2 emission, we assumed there were no large differences between scenarios. The total mileage of private passenger cars in 2008 was 368,235 million km for ordinary cars, and 121,326 million km for light cars (MLTI 2008). If average fuel efficiency of EVs is 10km per 1kWh (best case estimated from current EV), around 50 TWh/ year (tera-watt-hour) of electricity would be required. This was around 6% of total electricity demand of Japan in 2008. If average fuel efficiency of EVs is 5km per 1kWh (practical case including usage of air-conditioners etc.), an increase in electricity demand becomes double. However, it is possible that their increase in energy demand could be supplied by renewable energy [12]. The impact of replacing gasoline cars with EV on resource consumption was also investigated. 4.2 million-tons of copper would be required if gasoline cars are replaced by EVs, which would be difficult to procure in current industry. Economic issues would occur with regard to a lack of copper resource [13]. Therefore, a copper recycling system would be fundamental to constructing an EV society [14].

4.4 Game changing approach

Figure 10 shows differences between current approaches of substituting gasoline cars for EVs and “game changing” approach toward sustainable car society. By considering a range of social factors, we can depict various social scenarios which contribute to a sustainable society.

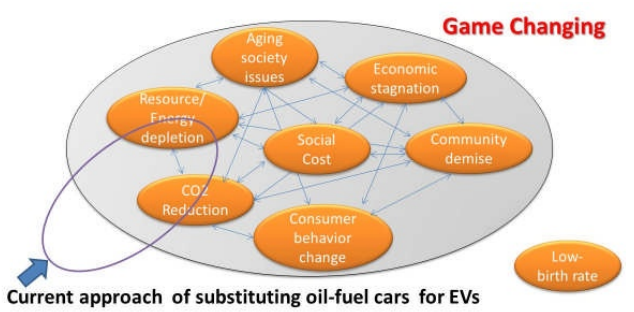


Fig.10 Differences between current approach and ‘game-changing’

5 SUMMARY

As stated in the introduction, in the same way that we had to undergo a radical change with regard to our method of study from pure engineering to a more ‘open’ approach, the scenarios show that our approach to society must also undergo a radical change by utilizing and integrating technology. The current method of substituting gasoline cars for EVs would be misguided if we consider future social changes in Japan. This is a conventional technological approach that is an approach guided only by technological innovation. If we take a more radical approach where technology is integrated with social issues, EVs technology provides us with the opportunity to radically transform social structure. A new kind of society can be created which will eradicate many of the social problems we face in our current style of “car-society”. These include issues related to an unprecedented aging population with low birth-rate, such as increased social cost regarding transportation, and medical care. It may be more effective to start investigating ‘Game changing’ approaches which broaden our horizons. We have to possess a holistic view of social issues (global warming, poverty, explosion of world population, and economic climate), and understand the causality between them. The integration of social science perspectives, such as human behavior and culture, with technology may be inevitable.

6 ACKNOWLEDGMENT

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Designing sustainable manufacturing scenarios using 3S Simulator

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Abstract

Designing scenarios is a hopeful approach for realizing sustainable society. Sustainable Society Scenario (3S) Simulator is an integrated scenario design support environment. The purpose of this article is to discuss the effectiveness of the scenario design support method in 3S Simulator. Here, we employ a backcasting scenario design support method. The key approach of this method is employing logic trees. A logic tree supports backward thinking and structuring ideas into scenarios. We designed "Manufacturing corruption scenario" as a case study. The purpose of developing this scenario is to discuss unsustainable future of manufacturing industry for designing "Sustainable manufacturing scenario." In the case study, we succeeded in designing the scenario based on the proposed process and two different corruption patterns are derived by constructing a logic tree. Through the case study, we identified the advantages of the design support method of 3S Simulator in structuring the designers' idea into a scenario.

Keywords:

Sustainable manufacturing, scenario, scenario design, backcasting

1 INTRODUCTION

Realization of sustainability is the most important issue of our society and drastic changes are needed for our society. For construction of sustainable society, manufacturing industry plays an important role, because manufacturing industry produces artifacts that are essential to the society from natural resources. In order to realize sustainable society and sustainable manufacturing part of it, drawing images and pathways toward them is a hopeful approach. For this purpose, developing scenarios is a useful means. Here, a scenario includes one or more stories, each of which connect descriptions of a specific future and the present situation in a series of causal links [1]. Especially, we call scenarios about sustainable society and its constituents as sustainable society scenarios. IPCC's Greenhouse Gas emission scenario [2] and IEA's Energy Technology Perspectives [3] are famous examples of sustainable society scenarios.

When developing a scenario, the scenario designers need to collect large amount of information, conduct times of discussions for drawing future visions and describe stories based on the collected information and the result of the discussion. Although scenario development requires long time and large amount of work in this way, there is no computational support for it. In order to tackle this problem, our research group has proposed Sustainable Society Scenario (3S) Simulator, which is an integrated design support environment for sustainable society scenarios [4]. The purpose of this article is to discuss the effectiveness of 3S Simulator and its scenario design methodology through a case study of scenario design.

This article is organized as follows. Section 2 introduces the concept of 3S Simulator. Section 3 describes the methodology used in this article, including scenario representation method and scenario design method. In section 4, a scenario is designed as a case study. Section 5 discusses the effectiveness of 3S Simulator based on the case study. Section 6 concludes this article.

2 SUSTAINABLE SOCIETY SCENARIO (3S) SIMULATOR

As mentioned in Section 1, 3S Simulator is an integrated scenario design support environment. 3S Simulator supports designing sustainable society scenarios by representing, composing, analyzing, and relating scenarios [3]. In order to develop 3S Simulator, the following five research topics have been set [3]; scenario representation method, scenario design method, dynamic scenario, scenario analysis, and scenario archives.

3S Simulator models the design process both in forecasting and backcasting [5] and develops a methodology for supporting these processes [5]. Here, forecasting and backcasting are two manners for developing scenarios; while forecasting explores the futures from the present situation, backcasting at first sets future visions and then going backwards to the present. This article discusses the effectiveness of backcasting scenario design method. It is because backcasting is effective to draw the future visions far different from the present, such as the visions of sustainable manufacturing.

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DOI 10.1007/978-94-007-3010-6_19,

3 METHODOLOGY

3.1 Appoach

There are three difficulties in designing a scenario. The first one is difficulties in backward thinking of backcasting scenario design process, finding out some causes from an effect. Second difficulties are that in generating future visions in a scenario. The last one is difficulties in composing a scenario from the result of discussion, thought, data collection, analysis, and simulation.

In order to tackle these difficulties, the key approach for the backcasting scenario design method is to employ logic trees [7]. Generally, a logic tree is used for analytical problem-solving. A logic tree breakdowns a key problem into specific sub problems. In the proposed method, a logic tree represents a set of causal pathways to meet the target, which is the condition that must be achieved in the future.

A logic tree supports backward thinking, finding some causes from an effect, by visualizing causal pathways. Determine the target at first, and ordering requirements generated by discussion and thought into a logic tree, the scenario designers can structure ideas in backward direction. In this way, the designers can gradually develop future visions that meet the target through structuring ideas in the logic tree. The designers can deploy main events and actions included in the sub scenarios from causal pathways represented in a logic tree. These main events and actions can be used as guidelines to composing the detail of sub scenarios from the result of discussion, thought, data collection, analysis, and simulation.

3.2 Scenario representation method

In this method, we employ Scenario Structural Description Method [8] for describing sub scenarios. It provides us with a computerized way of representing scenarios. The aim of Scenario Structural Description Method is to support understanding and analyzing scenarios rationally, by clarifying their logical structure and relations with associated simulations. Scenario Structural Description Method supports the designers in composing the detail of sub scenarios from the result of discussion, thought, data collection, analysis, and simulation by clarifying the relationships among them.

3.3 Logic tree

In the proposed method, a logic tree is represented as Fig. 1. A logic tree is composed of a target, requirements, which are events and actions necessary to meet the target, and causal relations among them. In addition, we set two types of causal relations in a logic tree, that is, exclusive and non-exclusive relations. When the causes of an effect are connected with exclusive relations, these causes do not occur at the same time. For example, node (a) and (b) in Fig. 1 are connected with exclusive relations to the target, so the conditions represented by node (a) and (b) are not realized at the same time.

In a logic tree, a sub tree represents a pattern to meet the target. We name it a causal sequence. Two causal sequences are picked up from the logic tree shown in Fig. 1. The designers can deploy the main feature of a sub scenario, the main events and actions connected with causalities, from a causal sequence. The way the designers deploy the main feature is described in section 3.5. Exclusive relations support the designers in picking up causal sequences. The causal sequences include exclusive events or actions do not occur at the same time, so those causal sequences are independent patterns to meet the target.

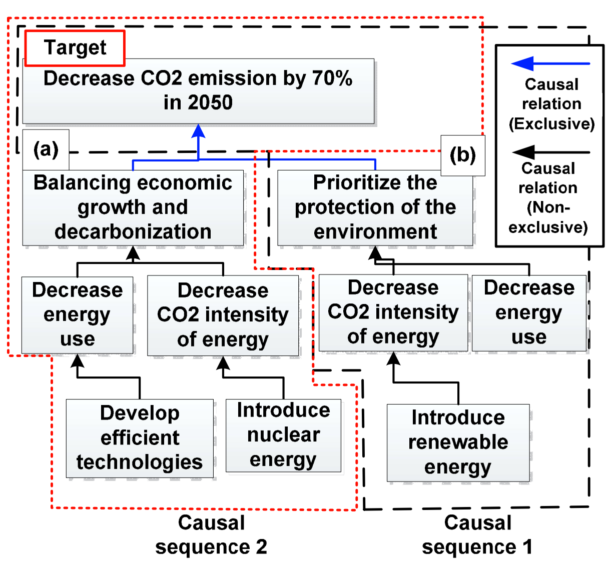

Fig. 1 An example of logic tree

3.4 The elements of a backcasting scenario

Fig. 2 summarizes the elements of a backcasting scenario. A backcasting scenario is composed of the five elements; (a) a problem, (b) a target, (c) a logic tree, (d) storylines, and (e) sub scenarios.

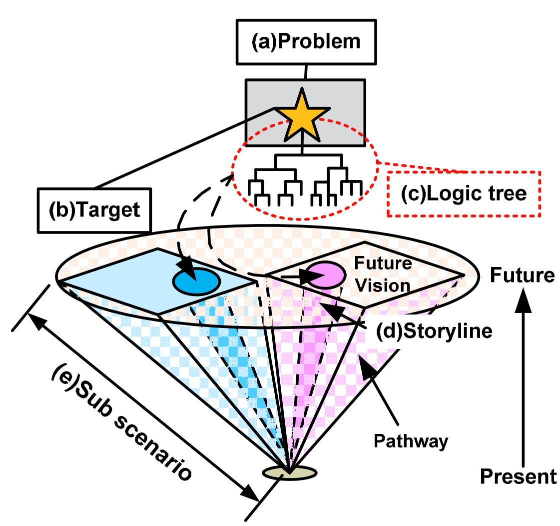

Fig. 2 The elements of a backcasting scenario

(a) Problem: the problem describes the objectives and backgrounds of the scenario to be designed.

(b) Target: target is a part of problem and represents the condition must be achieved in the future visions described in the scenario.

(c) Logic tree: a logic tree represents a set of causal pathways to meet the target.

(d) Storyline: a storyline is the main feature of a sub scenario, which are main events and actions connected with causalities in the sub scenario.

(e) Sub scenario: a sub scenario describes a future vision and pathways between the present and the future vision.

Here, a future vision represents a situation in the end year of the scenario, and a pathway is transitional events and actions between the future vision and the present that are connected with causalities. When describing sub scenarios, a storyline of each sub scenario is at first derived from the logic tree.

3.5 The design process

The design process proposed in this method is composed of four steps as shown in Fig. 3. The designers can design a scenario in backcasting manner through developing the five elements proposed in section 3.4 in the four steps. In step (1), the designers discuss and determine what to write in the scenario including target. In step (2), the designers spread a logic tree from the target. In step (3), the designers determine scenario structure, which means which sub scenario is included in the scenario and what is the main feature of each sub scenario. Lastly, in step (4), the designers describe the detail of each sub scenario.

Step (1) Setting a problem

In this step, the designers clarify the problem of the scenario to be designed. The designers discuss the objective, theme, time horizon, targeted region, and stakeholders included in the scenario. Then, they should discuss the ideal future that they want to achieve and set the condition must be achieved in the ideal future, namely, set the target of the scenario.

Step (2) Constructing a logic tree

In step (2), the designers brainstorm requirements to meet the target and ordering the result of the brainstorming into a logic tree like Fig. 1. The designers set the target as the root node, and order the result of brainstorming in the backward direction, from effects to their causes. When constructing a logic tree, the designers distinguish exclusive causal relation and non-exclusive causal relation.

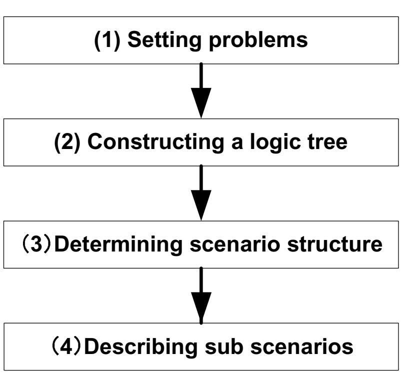

Fig. 3 The design process

Step (3) Determine scenario structure

In this step, the designers determine the scenario structure, (*i.e.*, the number and topics of sub scenarios) and their storylines.

At first, the designers pick up causal sequences by discussion, data collection, or analysis. In this step, exclusive relation helps selecting causal sequences. In Fig. 1, two causal sequences are picked up from the logic tree based on the exclusive relation among the target and nodes (a) and (b)

At last in this step, the designers describe storylines of sub scenarios by tracing causal relations forward from the terminal nodes in the causal sequence to the target. For example, a storyline is derived from the causal sequence 2 in Fig. 1:

"Introduction of nuclear energy decreases CO_2 intensity of energy. And development of energy efficient technologies decreases energy use. These factors enable both high economic growth and 70% of CO_2 emission reduction in 2050."

Step (4) Describing sub scenarios

In this step, the designers describe the detail of each sub scenario. In this method, sub scenarios are described using Scenario Structural Description method [8]. When describing sub scenarios, the causal sequences are used as a guideline for description of sub scenarios. The designers collect and analyze data and conduct simulation in order to add details of sub scenarios.

4 CASE STUDY

This article conducts a case study of scenario design methodology of 3S Simulator. This case study is a part of the project "Development of Sustainable Society Scenario Simulator for designing the vision of sustainable manufacturing." One of the objectives of this project is to design "Sustainable manufacturing scenario." In this project, the scenario is designed in two steps; drawing the unsustainable future of the current style of manufacturing and then describing the images of future manufacturing industry that overcome the catastrophic situation. As the first step, a scenario named "Manufacturing corruption scenario" was designed in this case study. We carried out workshops for designing this scenario based on the proposed method and we arranged the result of the workshops into the scenario.

4.1 Step (1) setting problems

Table 1 summarizes the problems in this case study. Referring to the objective of the project "Development of

Table 1 Problems of "Manufacturing Corruption Scenario"

Item		*Description*
Title		Manufacturing corruption scenario
Theme		Patterns and requirements of Japanese manufacturing industry's corruption.
Objective		Draw the catastrophic future of Japanese manufacturing industry and pathways to it.
Time horizon	Start year	2010
	End year	2050
Region		The world
Main Actor		Japanese manufacturing industry
Actors		consumers, material suppliers, energy suppliers, components suppliers, other countries, and so on…
Target		Japanese manufacturing industry breaks down

Sustainable Society Scenario Simulator for designing the vision of sustainable manufacturing," our research group at first set Japanese manufacturing industry as the main actor of this scenario. And we set the world as a targeted region because international trade is essential to Japanese manufacturing industry. We set "corruption of Japanese manufacturing industry" as the target of this scenario. And we detailed the definition of the target as follows;

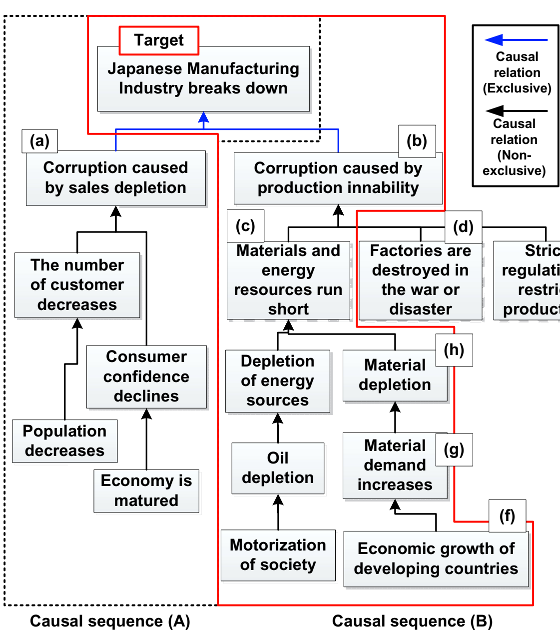

Fig. 4 The logic tree constructed in the case study

- The manufacturing industry cannot keep the employment in Japan
- The standard of living in Japan, such as standard of medical service or public health declines

This is because the important role of the manufacturing industry is to create employment and keep or improve living standards.

Other items in Table 1 are determined through the discussion among the participants of the workshop.

4.2 Step (2) constructing a logic tree

After setting the problems, we brainstormed the requirements to meet the target and simultaneously constructed the logic tree as shown in Fig. 4. Through constructing this logic tree, we developed two exclusive corruption patterns; (a) corruption caused by sales depletion and (b) corruption caused by production inability.

4.3 Step (3) determining scenario structure

In this step, by the discussion and data analysis, we picked up two causal sequences (A) and (B) from the logic tree. In Step (2), we set (c) "materials and energy resources run short" as a cause of (b) "corruption caused by production inability." Based on this causal relation, we conducted an analysis about resource depletion. We picked up copper as an example of depleting resource, and we collected data and analyzed future copper demand and supply [9]. When picking up causal sequence (B), we focused on the production inability caused by resource depletion by excluding node (d) and (e), referring the result of the analysis [9].

Based on causal sequences (A) and (B), we developed two sub scenarios, "Demand decline sub scenario" and "Resource depletion sub scenario." The storylines of these sub scenarios are respectively deployed from the causal

Table 2 Storylines of the scenario

Sub scenario	*Storyline*
Demand decline sub scenario	Population decreases and it causes the decline of customers. In matured economy, consumer confidence declines. Japanese manufacturing industries will breakdowns because sales depletion caused by these factors
Resource depletion sub scenario	Economic growth of developing countries and motorization of society increase the material and oil demand. Increased resource consumption causes the resource depletion. As a result, Japanese manufacturing industries will corrupt, because they cannot acquire enough material and energy for production

sequences as Table 2.

4.4 Step (4) Describing sub scenarios

In this step, we described the detail of each sub scenario. We added the detail of the sub scenario to the main feature of a sub scenario represented in the corresponding causal sequence. Fig. 5 represents a part of resource depletion sub scenario. Nodes (a), (b), and (c) in Fig. 5 correspond to causal sequence (B), these nodes respectively corresponds to (f), (g), and (h) in Fig. 4. We supplemented nodes about copper usage in developing countries, (d) and (e), between (a) and (b). Node (f) is the result of data analysis [9], which is referred by (c) to describe the detail of the situation of copper depletion.

4.5 Conclusions of the scenario

Through steps (1) to (4), we designed "Manufacturing corruption scenario." We concluded this scenario as follows:

"In 2050, developing countries are still in economic growth, so Japanese manufacturing industry can find new market somewhere in the world. On the other hand, copper will run out in the middle of 2030s. Therefore, from 2010 to 2050, resource depletion causes catastrophic situation of Japanese manufacturing industry."

5 DISCUSSIONS

In the case study, we designed Manufacturing corruption scenario using the proposed backcasting scenario design support method. Through the case study, 3S Simulator and its scenario design support method was effective in structuring the designers' ideas into a scenario. Specifically, we identified the following advantages in designing a scenario:

1. Logic tree employed in this method supports backward thinking in backcasting scenario design process by visualizing the relationships between the target and its causes. By ordering brainstormed ideas into the logic tree, we succeeded in extracting the two different future corruption patterns in the case study.
2. Through brainstorming and construction of the logic tree, the designers can identify the topic that they should consider in detail. In the case study, we identified resource depletion as the topic to collect data and conduct a data analysis. The result of this analysis supported us in picking up the causal sequence corresponds to resource depletion sub scenario.
3. By picking up causal sequences from a logic tree, the designers can easily clarify the main feature of a sub scenario. In the case study, when making resource depletion sub scenario, we picked up resource depletion as the main topic of this sub scenario and trimmed away other features, such as production inability caused by regulations and warfare. Distinction of exclusive link and non-exclusive link supports picking up causal sequences from the logic tree and By tracing the causal relations in a causal sequence, the designers can easily describe the storyline of sub scenario corresponding to the causal sequence.
4. Describing the sub scenarios in Scenario Structural Description Method, the designers can clarify the relationships among the materials of scenarios, *i.e.* the main feature of the sub scenario deployed from the logic tree, collected data, and result of discussions, data analysis, and simulation. It supports scenario designers in composing the scenario of these materials.

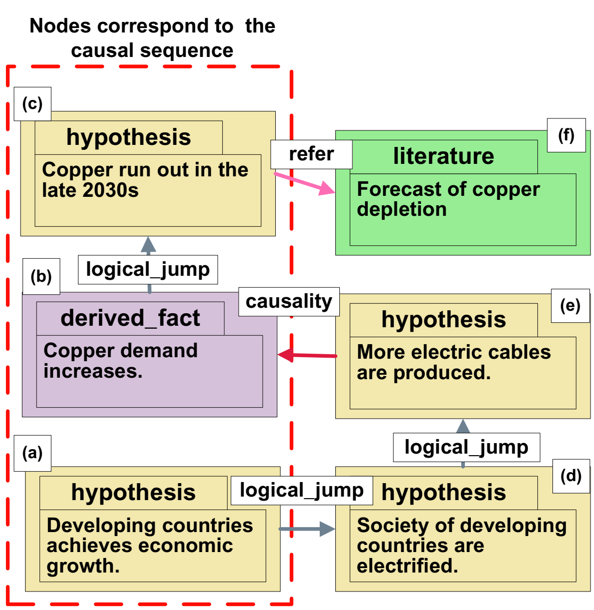

Fig. 5 The detail of resource depletion sub scenario described in step (4)

In contrast, backcasting scenario design support method of 3S Simulator does not support generating ideas from discussions, thoughts, data collection, analysis, or simulation. These procedures of scenario design are out of focus of proposed scenario design support method.

6 CONCLUSIONS

In this article, we discussed the effectiveness of scenario design support method of 3S Simulator. We designed "Manufacturing corruption scenario" by using backcasting scenario design support method as a case study. Through the case study, we identified the advantages of 3S Simulator and its scenario design support method in structuring ideas into a scenario.

Future works include updating this methodology, methodology for relating different scenarios on 3S Simulator, and designing "Sustainable manufacturing scenario."

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Dynamic Simulation of Renewable Electricity Supply in Japan

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Abstract
This paper reports on a dynamic simulation of electricity supply from renewable resources in Japan. After the surveys on potential energy of domestic renewable resources in Japan, a dynamic simulator is developed to evaluate the electricity generation from hydro power, solar photovoltaic, wind power, geothermal and biomass together with backup power and battery storage. The simulation is performed to calculate electricity supply for a target year around 2050. The hourly meteorological data of solar radiation and wind speed in 150 sites are used for dynamic calculation. From the simulation result we estimated the construction cost of renewable electricity generation plants, backup power plant and battery storage.

Keywords: renewable energy, solar photovoltaic, wind power, energy storage, backup power

1 INTRODUCTION

The domestic renewable energy sources are important from the view point of safety, security, energy independence and no carbon dioxide emission. It is not difficult to show the scale of national electricity supply mainly from renewable resources, such as solar photovoltaic(PV), wind, hydro, biomass and geothermal power.

In such studies, the annual electricity demand is compared with the available renewable energy sources, and the accounting balance table is used to show the necessary scale of renewable energy. Such accounting is basically static, but in case of electricity supply, there are dynamic problems of demand-supply matching and the necessary scale of electricity storage to absorb the fluctuations caused by PV and wind power generation.

To analyze these subjects, we developed a computer program to simulate renewable electricity supply with battery storage to supply the hourly electricity for demand patterns throughout a year.

2. DYNAMIC SIMULATOR OF ELECTRIC SUPPLY FROM RENEWABLE SOURCES.

The dynamic simulator is designed to estimate hourly renewable electricity supply using meteorological data to satisfy electric demand as follows.

2.1 Meteorological Data

The hourly data of solar radiation at 63 sites and the hourly wind speed data at 150 sites in Japan are used to calculate PV and wind power. The sites are distributed nation wide as dots shown in Fig.1. The data for 2001, 2002, 2003 and 2005 are prepared. [1]

2.2 Electricity Demand

There are ten electric power companies in Japan. They supply nearly 84% of national electricity demand. The rest of electricity is almost self-produced by energy-incentive industries. Ten supply grid areas from north to south are (1)Hokkaido, (2)Tohoku, (3)Kanto, (4)Chubu, (5)Hokuriku, (6)Kansai, (7)Chugoku, (8)Shikoku, (9)Kyushu and (10)Okinawa as numbers shown in Fig.1.

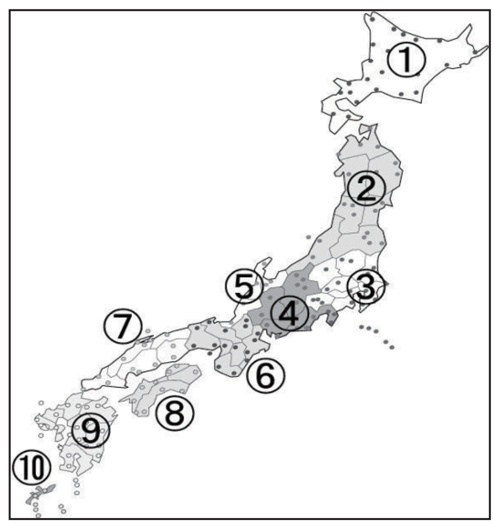

Fig.1 Map of ten areas of electricity supply in Japan

The electricity grid of Okinawa area is remote and not connected with the grid of other power companies, so we do not treat the electricity supply of Okinawa area in this study.

The mutual connection lines among the nine power grids are not so large. They are somewhat independent. Even more there is difference of grid frequency between 50 Hz in the east and 60 Hz in the west areas, which was caused

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by technology import from Europe and USA hundred years ago. But we did not treat the constraint of mutual electricity flow between grids in this study and we treat the nine areas as a single grid.

Tab.1 shows the monthly electricity supply data by generation category for nine grid areas in 2008, excluding Okinawa. The columns of pumped hydro present negative numbers that is the loss of lifting water amounts to 30% of stored electricity. The column of new energy is geothermal, solar and wind. The column of purchase means electricity purchase from other power supply companies. [2]

Tab.1 Monthly electricity supply of nine areas (GWh, 2008)

Month	Hydro	Thermal	Nuclear	New Energy	Purchase	Pumped Hydro	Total
1	3,190	42,860	23,760	10	14,828	−558	84,090
2	4,110	36,656	20,442	18	13,124	−390	73,959
3	5,383	39,236	19,633	17	13,094	−344	77,020
4	5,740	41,449	17,223	3	11,008	−586	74,837
5	6,112	40,260	18,693	3	10,800	−679	75,189
6	6,478	38,893	18,778	7	13,702	−737	77,121
7	6,003	49,864	22,443	11	16,036	−1,142	93,215
8	4,992	45,191	24,474	10	16,584	−1,201	90,050
9	4,732	43,316	20,037	17	14,921	−822	82,201
10	3,635	40,185	19,771	8	13,798	−538	76,859
11	2,804	41,373	19,765	16	12,982	−350	76,589
12	3,273	42,269	22,078	10	15,111	−379	82,362
Total	56,451	501,554	247,097	129	165,986	−7,725	963,492

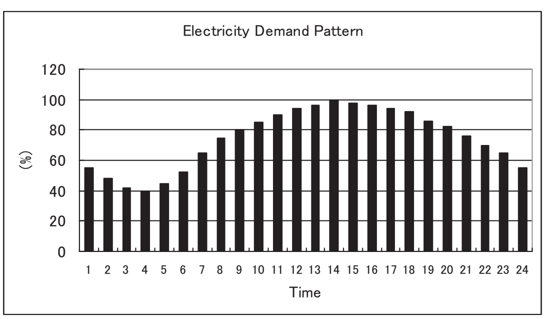

Fig.2. Hourly electricity demand pattern for a day

The hourly electricity demand pattern for a day is known as Fig.2, which depends on seasons. The demand is low in early morning and rises toward noon and reaches peak in the afternoon, and slowly decreases to midnight. The electricity peak is at 16:00 in winter and at 14:00 in other seasons in this study

3. Renewable resources

The situations of renewable resources in Japan and their simulation procedures are as follows.

3.1 Solar PV

"PV Road map: PV2030+" shows future possible scale of PV by NEDO in 2010. It reports PV will be used more than 550GW in 2050. [3] They will be built on roofs and walls of buildings and variety of land areas.

In this study, the hourly electricity generation from PV panel is calculated using horizontal solar radiation data at about 60 sites in Japan. The calculation method is to split horizontal radiation into direct beam and scattered irradiance and to combine both solar lights on the panel located at south oriented with tilt angle. [4] The optimum tilt angle is set at "latitude -5" degree at each construction site as is known experimentally. The inverter of 94% efficiency is included with partial load factor curve.

3.2 Wind Power

In this study, 2MW wind machine with three blades and horizontal axis is used to calculate the wind power in respective sites. The blades start to rotate at cut-in wind speed 3m/s, and stop at cut-out wind speed 25m/s. The conversion efficiency is assumed 40%. The diameter of rotor is 80m and hub height is 56m. Wind speed of meteorological data is extended by 1/6 th power factor law to calculate the wind speed at hub height. [5]

The wind data sites include remote islands. They are used for this study as wind machines are already built on semi-off shore in shallow coast lines of Pacific Ocean and they will be built off shore far from the coast lines in the future.

Japan wind power association estimated the future scale of wind power on land and off shore as 50GW or more for 2050. [6]

3.3 Hydro Power

The capacity of hydro power is 20.73GW now and will be 27.6GW in 2050 by official prediction. [7]

There are 25.64GW pumped hydro now. However it is not treated in this study in order to simplify the dynamic storage behavior.

3.4 Geothermal Power

The rated output of geothermal plant is 520MW today. The 2050 geothermal vision by Japan geothermal association shows the annual electricity generation amount by three scenarios, base scenario, best scenario and dream scenario.[6] In this study, we applied best scenario 4,819MW conservatively. The plant works constantly throughout a year.

3.5 Biomass

Japan is basically rich in biomass resources as the 69% of national land area is forest. Report by National Institute for Environmental studies shows that 1,779PJ thermal amount is available from biomass. [6] If half of the amount is converted to electricity at 20% efficiency, it is 49.42TWh, 5,642MW. This number is applied in this study.

3.6 Backup power

Natural gas power will be a candidate for backup power. The necessary fuel consumption for backup power shows the shortage of electricity supply and is one of the concerned subjects of this study.

3.7 Battery

The efficiency of battery is assumed as 95% of charge and 95% of discharge including inverter. The depth of charge is assumed as 100% for simplification. The inverter capacity is assumed 5 hours to fill the storage. Battery capacity (MWh) was presented by the time length (hours) during which it is possible to supply the average electricity demand (MW). It is also a concerned subject of this study as shown in latter part.

4. SIMULATION METHOD

The inputs to simulation program are as follows.

(1) Selection of the data year among 2001, 2002, 2003 and 2005.

(2) The ratio of future electricity demand against 2008 level.

(3) The supply share (%) of PV and wind against electricity demand

(4) The time length (hours) of battery capacity.

4.1 Electricity demand in the future

The energy demand of Japan in the future is discussed to decrease because of population decrease and efficiency improvement. The population of Japan began decreasing in 2008. The population forecast for 2050 is 74% (A scenario) and 78% (B Scenario) of year 2000 level in the study of "low carbon society scenario 2050" by National Institute for Environmental Studies.[8][9]

GDP growth rate is forecasted officially as low as 1% for period 2020-2030. The society will shift to more service oriented, with less material production and more recycling of industrial materials. Electricity demand around 2050 will be decreased by improving technologies such as light emitting diodes, high COP air conditioners, efficient home appliances, energy saving office machines and inverter controlled motors. So we assume the energy demand in this study will be relatively decoupled with GDP growth and the electricity demand around 2050 will be 60% of the year 2008 level.

4.2 Scale of PV and wind power

The 150 sites having meteorological data of solar and wind power are distributed nationwide. To calculate the electricity generation by PV and wind power in each area, the hourly generation amount by single unit of 100kW PV and 2MW wind machine for respective areas are calculated and stored in hard disk at first.

As annual shares of PV and wind power are input parameters, the amounts of electricity generation are supposed to be proportional to the annual electricity demand of nine areas respectively. As the wind power sites having capacity factor less than 18% are excluded, finally 42 sites are selected among 150 sites for data year 2005. Solar data are available for 63 sites for data year 2005.

Tab.2. Power plant (MW) and generation (GWh) by PV 50% and Wind 20% in respective areas (CF=capacity factor)

Area	PV	PV generation	CF of PV	Wind	Wind generation	CF of Wind	Electric Demand
	MW	GWh	%	MW	GWh	%	GWH
Hokkaido	9,685	10,737,000	12.66	1,385	4,294,799	35.4	21,473,998
Tohoku	24,242	26,739,900	12.59	3,591	10,695,960	34	53,479,802
Kanto	78,765	94,249,090	13.66	10,568	37,699,640	40.72	188,498,190
Chubu	33,453	42,366,720	14.46	3,392	16,946,690	57.03	84,733,429
Hokuriku	9,123	9,374,538	11.73	1,902	3,749,815	22.51	18,749,077
Kansai	38,721	47,726,940	14.07	7,300	19,090,780	29.85	95,453,878
Chugoku	15,849	20,044,760	14.44	4,606	8,017,905	19.87	40,089,525
Shikoku	8,179	9,633,423	13.45	669	3,853,369	65.73	19,266,846
Kyushu	21,544	28,175,280	14.93	4,979	11,270,110	25.84	56,350,568
9 Area Total	239,561	289,047,600	13.77	38,391	115,619,100	34.38	578,095,313

The necessary unit numbers of PV 100kW and wind machine 2MW are calculated as proportional to annual electricity demand of respective areas. These unit numbers of PV and wind machines are multiplied with hourly generation which is stored in hard disk to calculate electricity supply throughout dynamic simulation for the target year.

Tab.2 shows the PV and wind power calculated by the assumption of PV 50% and wind 20% of the annual electricity demand. The nationwide site selection of wind power resulted in the capacity factor 34.38% which is within experimentally known ranges.

4.3 Dynamic computational process

After settling the demand and scale of renewable resources, computer calculations are performed in the following order. The hourly electricity demand (D) is subtracted by renewable supply consequently as follows.

1) Electricity Demand (D) is supplied by geothermal which is constant throughout a year. Hydro power is supplied according to supply pattern that is predetermined depending on time.

D = D – geothermal– hydro power

The updated D is the demand for next stage as follows.

2) The next step depends on the amount of updated demand.

2-1) If PV and wind are less than demand, that is D > PV+wind power,

D=D - (PV+wind power)

Updated demand is supplied from biomass power.

D = D – biomass power

If it is not sufficient for demand, battery discharge can supply to demand.

D=D – battery discharge

If demand remains still, then demand is supplied by backup power. Backup power=D

2-2) If PV and wind are larger than demand,

that is PV + Wind> D then battery is charged.

Battery charge = (PV+wind) – D

If battery is fully charged, then the rest of electricity is accounted as excess.

Excess= (PV+wind) –Battery charge – D

Throughout dynamic simulation, the energy balance is confirmed at every hour by the following equation.

Excess = Power generation – Electricity demand

+ Battery discharge – Battery charge –Battery loss

Where,

Power generation = PV + Wind power

+ Hydro + Geothermal + Backup power

4.4 Details of simulation

The simulation starts on 1st April with battery half charged and ends in 31st March of next year for which the meteorological data of the same year is used.

Fig.3 shows the supply patterns of PV, wind, geothermal, hydro and battery discharge on 11th to13th in January.

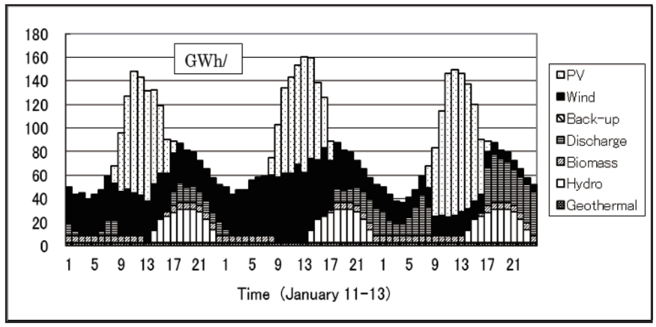

Fig.3. Supply of PV, wind, backup, discharge, biomass, hydro, and geothermal, (GWh/h)

The electricity demand grows in the morning and peaks around 14:00. Geothermal power is constant supply as base load. Wind power shows supply fluctuations. PV has bell-shape supply patterns in daytime. Hydro power supply is under the schedule peaking around 18:00.

4.5 Simulation summary

One of the simulation summaries of renewable electricity supply is shown in Tab.3. The supply shares are PV 50% and wind 20% of annual demand. The battery capacity is 8 hours (528GWh) in this case. It shows that renewable sources can supply electricity to the expected electricity demand within the scales of published materials by respective communities of energy experts.

Tab.3 shows the share of hydro 13.64%, geothermal 4.38%, biomass 7.25% and backup power 10.73% against the annual electricity demand. The sum of excess (4.5%) and battery loss (1.48%) is 5.98 %, which must be equal to the generation supply 106% minus 100%, that is 6 %. Small difference is caused by the initial charge to battery when simulation starts.

It is important that the peak of backup power is fairy large, 49,535MW in this case. The sum of PV, wind and other renewable energies are 95.27%, which is less than 100%. So the renewable power is lack of supply. The system has characteristics that even if renewable power is less than 100%, there is excess power. It is because of fluctuations of PV and wind power.

The battery capacity is 8 hours multiplied with average power 66GW, that is 528GWh. As the sum of PV and wind is 277.9GW, the battery capacity is 1.9kWh per 1kW of PV and wind. This ratio is not large compared with experimentally known small PV and wind system having battery.

Tab.3 The summary of simulation for data year 2005.

Electricity Supply	Unit	Total
Photovoltaics Capacity	MW	239,561
Wind Power Capacity	MW	38,391
Battery Capacity	GWh	528
Electricity Demand	GWh/year	578,095
Average Electricity Demand	MW	65,993
Peak Electricity Demand	MW	101,300
Total Electricity Generation	GWh/year	612,782
_Photovoltaics	GWh/year	289,048
_Wind Power	GWh/year	115,619
_Hydro Power	GWh/year	78,869
_Geothermal Power	GWh/year	25,333
_Biomass Power	GWh/year	41,902
_Back-up Power	GWh/year	62,013
Total Share of Generation	%	106
_Share of Photovoltaics	%	50
_Share of Wind Power	%	20
_Share of Hydro Power	%	13.64
_Share of Geothermal	%	4.38
_Share of Biomass Power	%	7.25
_Share of Back-up Power	%	10.73
_Peak Back-up Power	MW	49,535
Battery Charge	GWh/year	85,724
_Battery Discharge	GWh/year	81,543
_Battery Loss	GWh/year	8,569
_Battery Loss/Demand	%	1.48
_Max Charge Level	%	100
_Average Charge Level	%	34.94
Excess Electricity	GWh/year	25,996
_Excess Electricity/Demand	%	4.5

4.6 Battery storage level

Fig.4 shows daily average battery storage level and backup power in the above case. The daily battery storage level shows decrease in summer and autumn because of characteristics of wind power. When battery charge level is low, backup power is high.

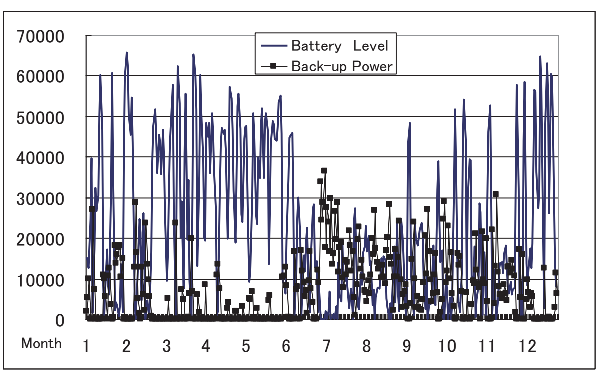

Fig.4 Daily average of battery storage level and backup power (MWh/h)

5. CONSTRUCTION COST OF RENEWABLE ENERGY SYSTEMS

How much is the construction cost of renewable energy systems? Photovoltaic cost has declined along with learning curve in the past 30 years.

The PV cost is analyzed by learning curve, and the past price records show that the cost decreased to 82 % at every time when the cumulative production doubled in 1979-1999 in Japan. [10]

Tab.4 Cost of PV by learning curve

Year	Annual Production	Cumulative production	Annual Domestic Market	Cumulative Domestic Install	Cost
unit	MW	MW	MW	MW	$/kW
2010	2,002	9,509	801	3,362	7,003
2020	12,397	71,880	4,959	28,310	3,894
2030	19,253	231,076	7,701	91,989	2,775
2040	29,899	478,303	11,960	190,880	2,247
2050	46,432	862,239	18,573	344,454	1,894

Production rate=+20% (−2020), =+4.5%(2021−2050) $1=80 yen
Domestic Use=40% of production, Progress Ratio=81.78%

We estimated the future PV cost by learning curve as shown in Tab.4. We assumed the PV production with 20% annual increase to 2020 and 4.5% increase from 2021 to 2050. PV Export will be 60% of annual production and the rest (40%) will be for domestic use annually. The progress ratio of leaning curve is estimated by regression analysis as 81.78% during 1979-2009. The progress ratio is cost reduction ratio when the cumulative production is doubled. The exchange rate is 1$ for 80 yen.

The column ‘Cumulative Domestic Install’ in Tab.4 shows the installed cumulative PV capacity. As the life time of PV is supposed 20 years, PV capacity 344-92=252GW will be installed between 2031 and 2050 and will be working in 2050. The average cost of PV is 2,193$/kW during this period.

Wind power is nearly commercialized. Battery cost also declined during competitive development for electric vehicles. There are several candidate technologies of battery. NaS, Nickel-hydrogen, and Lithium Ion are in competition. The battery will be used in the future at the cost of $200/kWh or less.

Tab. 5. The unit cost of energy plants around 2050

Technology	Cost	unit
Photovoltaic	2,193	$/Kw
Wind	1,500	$/kW
Battery	200	$/KWh
Backup Power		
Plant	900	$/kW
Fuel	8	$/KWh

The unit cost of PV, wind, backup power plant and battery around the year 2050 is supposed as shown in Tb.5. The plant scale of renewable energy systems of simulation result and the unit cost Tab.5 are used to estimate construction cost as shown in Tab.6. The fuel cost for backup power is shown for comparison.

Tab.6 The plant cost of renewable energy systems

Technology	Capacity	unit	Cost	unit
Photovoltaic	239,561	MW	525.36	Billion$
Wind	38,391	MW	57.59	Billion$
Battery	528	GWh	105.60	Billion$
Backup Power				
Plant	49,535	MW	44.58	Billion$
Fuel	62,013	GWh/y	0.496	Billion$
Total			733.13	Billion$
(Total dose not include Fuel cost)				

Tab.6 shows the construction cost of largely renewable energy systems is 733 billion$. If the investment is planned to be allocated into 20 years, the annual investment will be 36.66 billion$.

6. CONCLUSION

Using meteorological data in nine areas nationwide in Japan, dynamic simulation of annual renewable electricity supply and cost analysis of the future energy systems are presented. Main conclusions are as follows,

1) Renewable sources can supply electricity to the expected electricity demand around 2050 within the scales published by respective communities of energy systems.
2) Construction cost of renewable energy systems around 2050 is estimated. Annual investment for construction of renewable plant, backup plant and battery storage is 36.7 billion$.

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Resource Risks of Copper in Sustainability Scenario

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Abstract
Various sustainability scenarios have been developed to visualize images of a sustainable society, such as the IPCC's scenario. However, it is unclear whether or not such existing long-term scenarios are feasible in terms of resource depletion. The purpose of this paper is to propose a method for analyzing the balance of long-term copper demand and supply, aiming to assess feasibility of existing sustainability scenarios. This paper proposes two approaches, *i.e.*, macro and micro approaches, in order to estimate copper demand in a comprehensive manner. In the macro approach, metal demand is estimated using GDP/capita and population. The micro approach estimates metal demand based on dissemination of products. As a case study, this paper estimates copper demand in a long-term energy scenario. The results show that cumulative demand of copper will be beyond their reserve base after 2038. The results also indicate that, though copper consumptions will increase because of shifts from gasoline vehicles to electric vehicles, their impact to the whole consumptions is not dominant.

Keywords:
sustainability scenario, estimation, resource depletion, copper

1 INTRODUCTION

We are faced with various kinds of problems, such as global warming, pollution, and population pressure. Describing scenarios is considered one of the most hopeful solutions to deal with environmental-related problems by envisioning pathways to a sustainability society. An example is IPCC's scenario [1], which tackles with the climate change caused by the effect from greenhouse gas emissions.

Although there are many scenarios to deal with these problems, it is unclear whether such scenarios are feasible in terms of resource laminations. For instance, while existing sustainability scenarios that describe images of a low-carbon society often assume dissemination of electric vehicles (EVs), they do not pay attention to increases of metal demand by EVs. In fact, the amount of copper required for manufacturing an EV is 5 times as much as that for a gasoline vehicle [2]. Additionally, resource consumptions including copper will increase with economy and population growth in emerging countries, especially in China and India.

The purpose of this paper is to assess the feasibility of long-term scenarios by analyzing the risk of copper depletion. In this paper, copper depletion risks are identified by evaluating the balance of copper demand and supply.

We propose two approaches (*i.e.*, macro and micro approaches) to estimate copper demand in two ways to assess the feasibility of the scenario from the different viewpoints based on sustainability scenarios. Macro approach estimates whole copper demand using GDP and population. This approach takes economic and population growth into account. On the other hand, micro approach estimates copper demand based on the number of the products introduced in the long-term scenarios in order to evaluate the influence of introducing certain products to copper demand. To analyze the risk of copper depletion, we employ reserve base of copper as an indicator that shows the maximum of supply. Reserve base means the technical limitation of copper supply, not including economical limitation [3]. As case study, we analyzed ETP 2010 [4], which is an energy-related scenario, and identified depletion risk of copper until 2050 based on that scenario.

2 LITERATURE-REVIEW

There are various related works on estimating metal demand. Halada*et al*. developed correlation formula about 22 metals, including copper, between consumptions of each metal and GDP/capita based on the Japanese statistics over past 50 years [3]. Sawada analyzed cumulative demand of copper, showing the correlation between copper consumptions and electricity consumptions [6]. These works are useful in estimating the future whole demand of metals, however, they do not estimate copper demand properly based on sustainability scenarios. These approaches can't identify the copper demand carried by increasing low-carbon products, which are expected to increase in order to reduce greenhouse gas

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emission. That is the importance is to estimate copper demand based on the sustainability scenarios, and to identify the affection of introducing specific products to copper depletion.

3 METHODOLOGY

3.1 Approach

This paper evaluates the feasibility of long-term scenarios by assessing depletion risk of copper. For this purpose, we propose a method to evaluate the relationship between cumulative copper demand and supply based on sustainability scenarios. In estimating cumulative copper demand, we propose two approaches (*i.e.*, macro and micro approaches) in order to analyze the risk of copper depletion from two different viewpoints; the macro approach estimates copper demand carried by economic and population growth, while the micro approach estimates copper demand due to wide diffusion of specific products. It is because long-term scenarios usually describe numeric data of GDP, population and number of products expected to be introduced or sold. We then define the ratio of demand to reserve base [3] (RDRB) as an evaluation indicator of judging whether copper will be exhausted or not.

3.2 Macro approach

The macro approach uses a two-line model to estimate copper demand in order to reflect the economic and population growth. The two-line model means the correlation between GDP and copper consumptions, as Halada proposed [5]. According to his research, per capita consumptions of copper become stable after GDP/capita surpasses a certain level.

Fig. 1 shows the relationship between GDP/capita and annual copper consumption per capita from 1960 to 2010[7][8][9][10]. Based on the two-line model, we obtained formulas of copper consumption as follows:

$$y = 0.000482x \; (0 \le x \le 22{,}590) \qquad (1)$$

$$y = 11.0 \; (x > 22{,}590) \qquad (2)$$

Fig. 1: Historical data on annual copper consumption

where x is GDP/capita (2000 US$/capita) and y is annual copper consumption/capita (kg/capita). We derive these formulas by approximating plots on Fig. 1 to suite well the two-line model. We identified the transition point (certain level) at 22,590 (2000 US$/capita) judging from the shifts of slopes of the lines.

This paper calculates world annual copper consumption with these formulas, using GDP and population that are assumed in sustainability scenarios. Cumulative copper demand is defined as time integration of annual consumption in each year.

3.3 Micro approach

The purpose of the micro approach is to evaluate the influence of introducing certain products to copper demand. In this approach, we divide products into two categories in order to calculate copper demand; (i) one is specific products, influence of introducing that to copper demand we assess, (ii) the other is non-specific products that are other than specific products.

The micro approach defines annual copper demand as sum of copper demand relating (i) and (ii), and cumulative copper demand as time integration of annual copper demand. Annual copper demand relating (i) is calculated by multiplying the weight of the copper per product by its annual sales. On the other hand, annual copper demand relating (ii) is supposed as much as current consumption of them in order to know whether introducing specific products affects to the copper depletion or not.

3.4 Ratio of cumulative demand to reserve base

We evaluate the balance of copper demand versus supply by defining the ratio of cumulative demand to reserve base [3] (RDRB). Cumulative copper demand is estimated from each of the two approaches. Reserve base is, as this paper mentioned above, one of the best known indicators suggesting the technical limitation of copper supply, not including economical limitation [3]. In this paper, when RDRB surpasses 100%, we consider copper as an exhausting metal and the scenario as unfeasible.

4 CASE STUDY

This paper applies the proposed method to a long-term energy scenario called Energy Technology Perspectives (ETP2010) [4] to analyze the feasibility of the scenario. ETP2010 consists of two sub scenarios, *i.e.*, Baseline Scenario and BLUE Map Scenario. The former sub scenario assumes that the governments introduce no new energy and climate policies, while the latter assumes to deploy existing and new low-carbon technologies in order to halve energy–related CO_2 emissions by 2050 (compared to the 2005 level). In this case study, we estimate copper demand and then calculate RDRB of both sub scenarios.

Table 1: Assumptions on world GDP, population, wind & solar power according to ETP 2010 [4]

Category	2007	2050	
		Baseline	BLUE Map
GDP (billion 2000 USD)	39,493	133,299	
Population (million)	6,609	9,150	
Wind power generator (GW/year)	83	593	1,081
Solar panel (GW/year)	7	246	718
Truck & Bus (million sales/year)	26	60	47

4.1 Assumption of ETP 2010

In this case study, we calculate cumulative copper demand from 2009 to 2050 based on the ETP 2010 [4]. Given this timescale, we adopt the reserve base of 2009 (10 billion metric tons) [3] as the denominator of RDRB. We estimate copper demand based on assumptions for each of the macro and micro approaches as follows.

Assumption used for macro approach

ETP 2010 assumes growth of economic and population with same scales in both scenarios from 2007 to 2050 (see Table 1).

Assumption used for micro approach

This paper assesses the effect of introducing specific products to copper demand in the micro approach. In this case study we focus on automobiles and two kinds of power generator systems (*i.e.*, solar and wind power generator). These technologies are enthusiastically introduced in BLUE Map scenario in order to reduce more CO2 emissions than Baseline scenario. The dissemination of these products is obtained from ETP 2010. On the other hand, the amount of copper used for other products is fixed as much as that as of the 2009 level, as depicted in Table 2. BLUE Map scenario will introduce more clean generation technologies than Baseline scenario but less truck and bus (see Table 1). This is because the freight in BULE Map scenario is assumed to shift to train. Contrary to the truck and bus, BLUE Map scenario expects to deploy cars as much as Baseline scenario and the annual sales of cars at 2050 in both scenarios are estimated to be twice in 2010 (see Fig. 2). As depicted in Fig. 2, the types of cars are different in each scenario. Though ETP 2010 explicitly mentions the dissemination of these products, there is no description about how much these products contain copper. We assume the weight of copper used for each product from external resources, as shown in Table 3.

(GV: gasoline vehicle, DV: diesel vehicle, HEV: hybrid electric vehicle, PHEV: plug-in hybrid electric vehicle, EV: electric vehicle, HFV: hydrogen fuel-cell vehicle

Fig. 2: Annual sales of passenger automobile [4] (Left: Baseline, Right: BLUE Map)

Table 2: Copper usage by end-use sector in 2009[7][8]

Category	Sector	Copper consumption	
		Amount (thousand tons)	Percentage (%)
Electric & Electronic equipment	Power utility	2,098	11.5%
	Cooling	1,098	6.0%
	Electronic	634	3.5%
	Tele-communication	599	3.3%
	Diverse	1,948	10.7%
Building construction	Electric power	4,353	23.9%
	Plumbing	1,103	6.0%
	Architecture	270	1.5%
	Commu-nications	159	0.9%
	Building plant	110	0.6%
Transportation equipment	Automobile	1,313	7.2%
	Other transportation	798	4.4%
Consumer & General products	Consumer & General products	1,498	8.2%
Industrial machinery & equipment	Industrial machinery & equipment	2,264	12.4%
Total		18,244	100%

4.2 Results

Fig. 3 shows the results by both approaches (*i.e.*, macro and micro approaches). The result by the macro approach (green line) shows that the RDRB is 168% at 2050 and surpasses 100% around 2038. On the other hand, in the micro approach, RDRB at 2050 of Baseline scenario and BLUE Map scenario is 91% (red line) and 98% (blue line), respectively.

Table 3: Amount of copper included in products

Product		*Copper used*	*Remarks*
Automobile (kg/car)	Gasoline vehicle	15.0	Data is obtained from Reference [2]. Assume that a truck & bus uses 4 times copper that is contained in a gasoline vehicle.
	Diesel vehicle	15.0	
	Hybrid electric vehicle	28.9	
	Plug-in hybrid vehicle	41.6	
	Electric vehicle	91.6	
	Fuel cell vehicle	15.0	
	Truck & Bus	60.0	
Wind power generator (t/GW)		578	Data is obtained from Reference [11].
Solar panel (CIGS) (t/GW)		15.0	

Details of cumulative copper consumption divided into 5 sectors are shown in Fig. 4. In transportation equipment (including automotive sector), the cumulative copper consumption in BLUE Map scenario is 288 million tons and in Baseline scenario is 221 million tons. The difference of copper consumption in this sector results from the difference of the diffusion of EVs and PHEVs between Baseline and BLUE Map scenarios. The annual copper consumption in automotive sector is presented in Fig. 5. Fig. 5 illustrates that in BLUE Map scenario EVs and PHEVs require 390 thousand tons and 280 thousand tons, respectively. Consequently, in 2050, BLUE Map scenario consumes 1.6 times more copper than Baseline scenario. By comparing the annual consumptions in 2009, Baseline scenario will consume more than 2.6 times in 2050 due to dissemination of trucks, buses and gasoline vehicles.

The difference in electric & electric equipment comes from introducing more amount of clean power generator in BLUE Map scenario than Baseline scenario (see Table 2). The cumulative copper demand in this sector is 283 million tons in BLUE Map scenario and 276 million tons in Baseline scenario. This indicates that the amount of copper consumed by clean power generators (*i.e.*, solar and wind power generator) is minor relative to automobiles.

Fig. 3: Simulation results

Fig. 4: Cumulative copper consumption by end-use sector from 2009-2050

Fig. 5: Annual copper consumption in automotive sector

5 DISCUSSION

5.1 Risk of depletion

This paper proposed two approaches to estimate copper demand based on the long-term energy scenario. As shown in Fig. 3, the value of RDRB calculated by the macro approach will reach 168% at 2050 in both scenario because of economic and population growth, mainly in developing countries. This indicates that copper will be depleted by 2050 based on the assumption of ETP 2010.

According to the result from the micro approach, deployment of automobiles and clean energy generators made RDRB (2050) from 91 to 98%. That means diffusion of these products does not make the scenarios unfeasible, meaning the impact of introducing these products is minor. On the other hand, electric & electronic equipment, building construction and transportation equipment, which are called basic infrastructure, are expected to be dominant sectors to copper demand. These sectors in developing countries may require much more amount of copper to make facilities in accordance with economic and population growth. Estimating increasing consumption of copper from these infrastructure-related sectors is one of our future issues.

5.2 Uncertainties in estimation

There are some uncertainties in our estimation of copper demand as described below.

Substitution for copper

With the technical improvement in manufacturing, copper can be replaced with alternative materials. For instance, aluminum is expected to be substituted for copper in power cables, electrical equipment, and automobile radiators [3]. Additionally, many materials (*e.g.*, plastics in water pipe, drain pipe) also have possibility of substituting for copper [3]. Gathering information of possibility of substitutions for copper is necessary for further estimation of copper demand.

Recycling

Recycling is a key measure to conserve mineral resources. Copper is recycled around 16% in the world [7][8] and will be improved with, *e.g.*, technological improvement. In order to examine effect of recycling, it is necessary to construct a copper demand-supply model that enables to analyze life expectancy of copper-used products and amount of copper available from these products.

Technical innovation

Reserve base may change its amount by the invention of new mining technologies. In fact, the value of reserve base has been increasing. Reserve base is 10 billion tons in 2009 but was 650 million tons in 2000 [3]. Thus, we should continuously pay attention to technical matters and resource information for more accurate estimation of copper demand.

6 CONCLUDION

This paper analyzed the copper demand and supply to assess the risk of copper depletion based on existing sustainability scenarios. For the sake of estimation of copper demand, we proposed two approaches (*i.e.*, macro and micro approaches). The macro approach uses GDP/capita and population for estimation, while the micro approach employs the number of products that disseminate in the scenarios.

As a case study, we examined a long-term energy scenario called ETP 2010. The result by the macro approach revealed that ETP 2010 is unfeasible because of the depletion risk of copper due to the demand increase in developing countries. On the other hand, the result by the micro approach indicated that the diffusion of low carbon technologies, such as EV and PV, is not a crucial factor to copper depletion.

Future works include assessing the effect of copper recycling for improvement of estimation. In addition, we will continue to obtain mineral resource and technical information and build a copper demand-supply model for improving the accuracy of the copper demand estimation.

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Design for Resource Efficiency

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Abstract

There are already several approaches for Design for Environment or Design for Recycling and recently also the topic of resource efficiency received increasing interest. While procedurally existing ecodesign concepts might be also applicable for Design for Resource Efficiency, the main issue is to define relevant yet practicable indicators to measure resource efficiency. Depending on the definition, it can comprise raw material consumption only or the consumption and pollution of natural resources. Consequently, there is a variety of indicators available. However, resources are not only an environmental concern. Raw material availability is a critical issue for many industrial sectors which finally leads to a new area of protection, the economic material availability. Therefore, amongst others, new characterization factors are proposed by taking into account anthropogenic material stocks in addition to the lithospheric stocks.

1 INTRODUCTION

The integration of environmental aspects in product design and development has been recognized as an important strategy towards sustainable production and consumption. There are already several approaches for Design for Environment (DfE) or Design for Recycling (DfR), but recently the topic of resource efficiency received increasing attention. While procedurally existing ecodesign concepts might be also applicable for Design for Resource Efficiency (DfRE), the main issue is to define relevant yet practicable indicators to measure resource efficiency.

Even though the necessity of a sustainable use of natural resources is widely accepted, there is neither consensus on how "resource use" is clearly defined nor how it should be measured. Depending on the definition, it can comprise raw material consumption only or the consumption and pollution of natural resources. Consequently, there is a variety of indicators available.

This paper summarizes some relevant findings with regard to current resource efficiency indicators (see section 2), a new indicator to measure natural resource availability from an environmental point of view (section 3), additional criteria for an economic area of protection with regard to resources (section 4) and the potential to implement these into a DfRE-approach (section 5).

2 INDICATORS MEASURING RESOURCE USE

This section summarizes previous work of Berger & Finkbeiner with regard to indicators measuring resource use [1]. For deriving indicators the first challenge is to select an appropriate definition of resources. In a conventional sense, a resource is defined as "A concentration of naturally occurring solid, liquid, or gaseous material in or on the earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible" [2]. Based on this definition, physical indexes like mass and material input per service unit [3] or impact assessment indicators such as abiotic depletion potential [4] could be used to quantify resource use. Another resource definition has been introduced in the "Thematic Strategy on the sustainable use of natural resources" [5], which defines resources as "raw materials such as minerals, biomass and biological resources; environmental media such as air, water and soil; flow resources such as wind, geothermal, tidal and solar energy; and space (land area)." Accordingly, indicators measuring the pollution of natural resources like acidification, global warming, or ecotoxicity potentials [4] should be consulted in order to quantify resource efficiency.

For a number of different indicators results of 100 materials from the GaBi and ecoinvent databases were compiled using the GaBi 4.3 software [6]. The results obtained by different resource- and emission-oriented as well as single-score indicators were compared by means of linear regressions analysis to check for potential dependencies between indicators. The analyses revealed large differences regarding the correlations between indicators. While no significant correlations were found between emission oriented indexes (R^2=0.40–0.62), strong linear regressions were identified between indicators assessing raw material consumption (R^2=0.65–0.98). Therefore, the number of indexes can be reduced when defining resource use in a conventional sense. This phenomenon can be explained by the facts that all indicator results are dominated by the consumption of fossil fuels and that characterization models of these correlating indexes rely on net calorific values when computing characterization factors for fossil energy carriers.

When addressing resource consumption in life cycle assessment (LCA), current characterisation models for

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depletion of abiotic resources provide characterisation factors based on (surplus) energy, exergy, or extraction–reserve ratios. However, all indicators presently available share a shortcoming as they neglect the fact that large amounts of raw materials can be stored in material cycles within the technosphere. These "anthropogenic stocks" represent a significant source and can change the material availability significantly. Therefore, the anthropogenic stock extended abiotic depletion potential (AADP) [7] as a new parameterisation to model the depletion of abiotic resources was developed and is introduced in the next section.

3 THE ANTHROPOGENIC STOCK EXTENDED ABIOTIC DEPLETION POTENTIAL (AADP)

This section summarizes previous work of Schneider et al. which introduced the anthropogenic stock extended abiotic depletion potential (AADP) [7]. Gerst and Graedel [8] pointed out that the continued increase in the use of metals over the twentieth century has led to the phenomenon of a substantial shift in metal stocks from the lithosphere to the anthroposphere. As this stock will become available in the future for recycling and reuse, the accumulated stocks in society have to be acknowledged when assessing the future resource availability or the depletion potential of a material. As resources are depleted only when they leave the economy in a form that functionality can no longer be restored [9], these "anthropogenic stocks" represent a significant source and can change raw material availability significantly [10]. Thus the aim of the work of Schneider et al. was to introduce new characterisation factors, the anthropogenic stock extended abiotic depletion potentials (AADP), for the impact category depletion of abiotic resources. With these new characterisation factors, resource consumption is assessed by taking into account anthropogenic material stocks in addition to the lithospheric stocks to reflect the scarcity of resources more realistically. To include the anthropogenic stock into the assessment of resource depletion, data from material flow analyses (MFA) can be used [10].

The characterisation model is based on the ADP of Guinée et al. [4] but uses resources instead of ultimate reserves and adds the anthropogenic stock :

$$\text{AADP}_{\text{i,resources}} = \frac{\text{extraction rate i}}{(\text{resources i} + \text{anthropogenic stock i})^2} \times \frac{(\text{resources antimony} + \text{anthropogenic stock antimony})^2}{\text{extraction rate antimony}}$$

It was shown for a set of ten different metals that this new characterisation model leads to different characterisation factors. Even though this new characterisation model still mainly addresses an environmental area of protection, the choice of resources instead of ultimate reserves already addresses the interface to the economic dimension of resources. However, to reflect the economic scarcity of resources adequately requires the inclusion of even further aspects. An example for such an approach is introduced in the following section.

4 THE ECONOMIC MATERIAL AVAILABILITY AS A NEW AREA OF PROTECTION

This section summarizes previous work of Schneider et al. which introduced a method to address material availability as new area of protection [11]. Several geological and economic criteria are identified and selected according to their potential and relevance for quantifying economic material availability. These indicators are intended to put material requirements in perspective of availability, capacity constraints and demand. Different options for assessing these indicators are modelled and tested with regard to their usefulness and applicability.

The analysis is also based on recently published reports by the committee on critical mineral impacts on the US economy [12] and the Ad-hoc working group of the European Commission [13] that have identified several risks to supply. Similar indicators have also been assessed and used by Rosenau-Tornow et al. [14].

Several criteria were identified and selected according to their potential and relevance for quantifying economic resource availability:

- ❖ Recycling rate
  → recycled content of a material
- ❖ Reserve-to-production ratio
  → geological availability
  (based on current production technologies)
- ❖ Country concentration
  → reserve concentration to certain countries
- ❖ Company concentration
  → concentration of production/
  extraction activity to certain companies
- ❖ Political stability
  → stability and safety associated with a country
- ❖ Demand growth
  → assumed increase of demand in future

In order to illustrate the relevance of the new area of protection and the corresponding indicators, a comprehensive case study was accomplished. The life cycle inventory of a product of the automotive industry was assessed by means of the newly developed economic material availability indicators. The results were evaluated and compared to results obtained by means of the conventional abiotic depletion potential. However, no direct comparison is possible, as these results are based on different methodologies. For that reason, a significance analysis was used to show how individual materials contribute to the overall results and, beyond that, to illustrate the effect when taking into account other aspects beyond geological availability. In this comparison special focus is put on the contribution of fossil energy consumption which dominates the results of conventional impact categories by usually more than 95 % [1].

By introducing a new area of protection and in providing a set of new characterization factors denoting economic material availability, the proposed method expands life cycle assessment practice towards life cycle sustainability assessment and will promote a more comprehensive assessment of resource use and availability.

5 IMPLEMENTATION OF A DFRE-APPROACH

In this section, it will be highlighted how the resource efficiency indicators discussed above could be implemented into product design and development.

5.1 DfE-Approaches

A general outline of integrating environmental aspects into product design and development can be found in ISO TR 14062 [15]. According to Finkbeiner et al. [16] the environmental burden caused by a product is largely determined in the early development phase. Later corrections to product design can only be effected at high expense. The sooner design for environment is integrated into the development process; the greater the benefit will be in terms of minimizing environmental load and costs. This means 'building' environmental protection into the products from the very beginning. Ensuring this is the task of DfE. The goal is objective and measurable improvement of environmental compatibility and, simultaneously, compliance with the demands of more and more customers who consider environmental aspects like the reduction of fuel consumption and emissions or the use of environmentally acceptable materials.

As an example, the DfE concept at Mercedes-Benz implements a procedure based on simultaneous engineering comprising three main elements [16]:

1. A methodological procedure which allows integration of environmental targets and measures into the Mercedes-Benz Product Development System. This procedure defines interfaces with development phases and is used as a formalized PDCA cycle (Plan, Do, Check, Act).
2. Tools and databases to assist the DfE procedure in simulating and evaluating the environmental performance of future vehicles or parts.
3. An organizational structure that formalizes the integration of DfE into the development process

5.2 DfR-Approaches

Design for recycling (DfR) has a long tradition and was also driven by legal demands. It is – however – only one part of a more comprehensive DfE approach and often the DfR part does not address the most significant environmental interventions of a product. It can be defined according to the Danish environmental protection agency (EPA) Eco Design Guide [17] as a method that implies the following requirements of a product:

- easy to dismantle,
- easy to obtain 'clean' material-fractions, that can be recycled,
- easy to remove parts/ components, that must be treated separately,
- use as few different materials as possible,
- mark the materials/polymers in order to sort them correct and
- avoid surface treatment in order to keep the materials 'clean'."

From the perspective of life cycle based sustainability assessment [18] all these DfR-approaches are not necessarily sustainable, because they only look at the “output” side of a product and try to make it easy to deal with the waste at end of life. From a sustainability perspective, it is necessary to look at the “input” side, i.e. how much of these materials actually replace virgin materials. Sometimes recycling increases overall environmental burdens and resource demands. This is a reason, why DfRE is more efficient and effective than DfR.

5.3 DfRE-Approach

Rather than a traditional DfR-approach, it is proposed here to use the concept of Design-for-Resource Efficiency (DfRE). DfRE is built on the general features of ISO TR 14062 and the three DfE-elements described in section 5.1. Comprehensive resource efficiency indicators as outlined in the sections 3 and 4 should be used as performance characteristics of the alternatives in the product development process. While DfR can help to implement some recycling concepts that have been recognized as sustainable, DfR is not useful as an assessment approach. For the resource oriented assessment of products, DfRE-indicators are a more meaningful choice.

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Open Manufacturing for Value Creation Cycles

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Abstract

Regaining components and materials from used products can cope with the challenge of shrinking resource availability with growing global demands for useful physical artifacts. Value creation cycles constituting consecutive multiple phases of usage and remanufacturing enable for increased use productivity of resources. They can be stimulated in entrepreneurial initiatives with global reference by creative approaches of sustainable engineering. Setting up knowledge communities about successful experiences on sustainable open manufacturing creates innovative commons to exploit globally available knowledge in local application. A model of value creation commons instantiated in competitive product and material cycles is presented and illustrated by examples of implementation.

Keywords:

Recycling, material flow, commons, additive processes

1 INTRODUCTION

About 40 years ago, the Club of Rom introduced the issue of limited resources in growing markets. Still then, the situation did not improve and no generally accepted solution found.[1] However, to achieve a reasonably demanded sustainability on our globe, non-renewable resources must not be disposed anymore but regained in product and material cycles. Legislations for recycling of products are helpful but breakthroughs can be expected if dynamics of competition and cooperation in globalized markets are utilized by innovative technologies to cope with the challenge.[2]

Combining recycling and manufacturing in a consolidated planning approach enables demand driven material cycles rather than fulfillment of laws and regulations. The necessary knowledge base for such planning task about recycling, manufacturing, available waste and demanded materials is difficult to establish in dynamic markets. Different stakeholders like end-user, product designer, manufacturers and material broker may contribute with their individual insight.

In this paper, the concept of value creation cycles as integrated planning-model for manufacturing and recycling processes with focus on materials is presented. This model is translated into an open manufacturing architecture as collaboration platform for entrepreneurial initiatives. With knowledge about additive processes and upstream recycling, potentials of the model for local value creation cycle are shown and a possible use cases be presented.

2 AVAILABILITY OF NATURAL RESOURCES

As the earth can be understood as clothed system, non-renewable materials and renewable materials are limited. The geological limit reflects the total amount of so-called primary raw materials on earth like for iron with 29% of the earth mass. Not all 29% iron can be economically excavated with today's technology. Accessible natural reserves are predicted to last in case of chrome 15 years, copper 34 years and iron ore 69 years, taking current annual excavation rate and technologically accessible material into account [3]. The time of depletion is pushed into the future by technological innovation and investments in new mines. Most mines last decades and in order to gain venture capital, geological assessments are used to prove the existence of natural reserves. These reserves normally last about the payout time of a mine. Newly revealed natural reserves are added to the global amount of accessible material. For materials like iron ore or cupper, mining capacity can be increased by starting new excavation sites. Capacity for so-called couple materials are more difficult to increase. For example tellurium and indium are by-products of copper or lead excavation. Capacity increase mainly happens do to capacity increase of the primary materials. Beside technical or financial limits, geopolitical ambitions limit the global accessibility of materials. Most recent example is China, producing 97% of all rare earth elements world-wide. Metals such as neodymium or scandium, particularly important in high-tech industry, belong to this group. To support local economy, China continuously reduces its export – in 2010 by 40%. Besides countries, few companies like Vale and BHP Billiton from Brazil as well as Rio Tinto from Australia became monopolies and influence the structure of the global material market.

To increase availability, materials can be gained out of used goods as so-called secondary raw materials. This approach is limited too due to limited availability of used goods and the adequate return rate. In the European Union the recycling rates are e.g. for aluminum 32% and for copper 76% [4]. In case of aluminum, production of secondary raw material uses 20 times less energy than for primary raw material.

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3 VALUE CREATION IN CYCLES

Products and their manufacturing systems are traditionally reflected in their respective life cycles. In literature, the following basic concept of life cycles can be found [5]:

- **Flow oriented** life cycle phases reflect the flow of products and materials, oriented to their supply chain and chronological progress, like resource extraction, product development and manufacturing. The concepts vary between cradle-to-grave and cradle-to-cradle.
- **Condition oriented** life cycles demonstrating the dynamics of different systems by showing the development of certain characteristics like growth, maturity, saturation and decline of products.
- **Integrated** life cycles combine different life cycle phases with relevant characteristics, for example sales numbers, turnover, costs or ecological impact in different phases.

The different concepts are intended to describe different phenomena of product-market relations. As flow oriented life cycle concepts give an overview of theoretical end-of-life options like material recycling, remanufacturing or reuse and their related material flows. However, the number of particular products is rather low where material or components are used to create the same product once more or even a similar kind. In practice, secondary material follows a similar direction as primary material and goes into production, at location where needed and in required amount and quality. To reflect this behavior, the concept of value creation cycles was developed. Starting with recycling as the material source and ending with useful artifacts. Applying value creation cycles means to enable demand driven recycling. Not only are products produced on demand but used products should be recycled in order to substitute primary by secondary raw material for new products.

As depicted in Fig. 1, the concept of value creation cycles consists for a life cycle *n* of usage phase, production phase and recycling phase as well as value creation and product engineering. The use phase represents the final artifact, whether it is a product or belongs to a service/PSS. In the production phase, artifacts are created by manufacturing processes. In the recycling phase, products are transformed into materials or parts of new products. As the production phase proceeds, undefined material substantiates into specified artifacts. The phase of product engineering contains all the activities of product designing, satisfying customer demands or to create new markets with innovative products and services. Engineering of value creation contains all activities of strategic planning and operative scheduling of manufacturing and recycling processes. [6]

Number of parts in modern products with their countless parts, used materials, available recycling and manufacturing processes, and equipment capacities make the engineering process of value creation heavily depended on the knowledge base. Such knowledge base is difficult and inefficient to be established by a single person or company. Utilizing the combined power of many, contributing with their individual knowledge, offer a promising chance to establish such required knowledge base.

4 OPENNESS IN MANUFACTURING

Conditions and means of value creation changed in time regarding required qualification, used technology, locality and involved stakeholders. Around the 1970s-1980s, one-

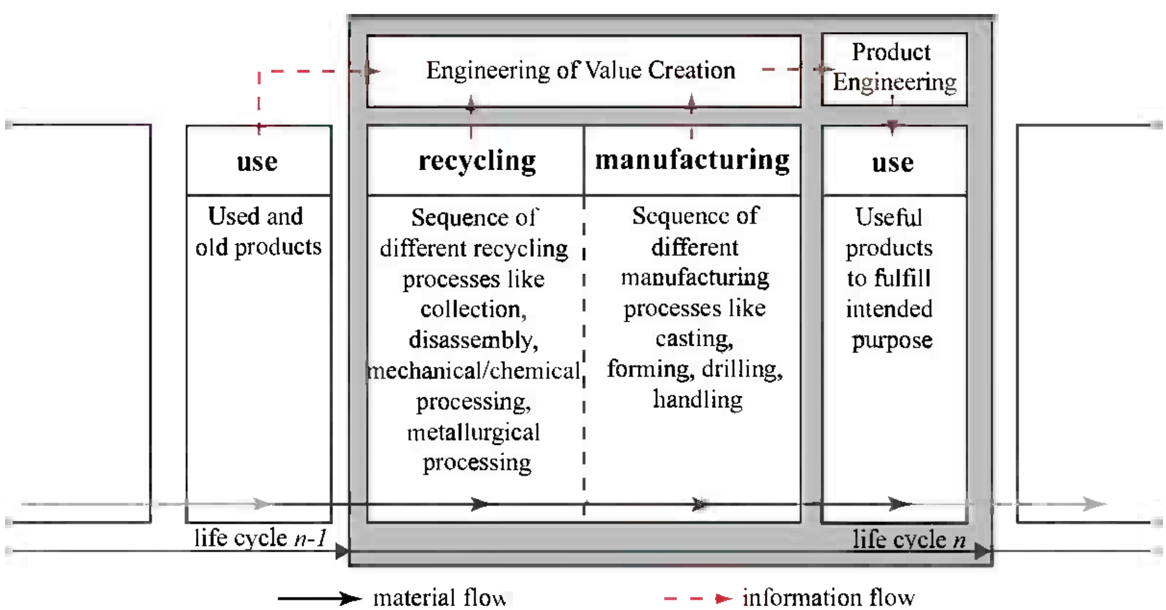

Fig. 1: Value creation cycles – model

way communication of producer aimed to gain access to target predetermined groups of buyers. It evolved to two-way communication, to increase market insight and establish a relationship of producers and customers. However, customers were seen as passive buyers with a predetermined role of consumption until the 1990s. Beyond 2000, customers were increasingly seen as co-creators in a joint value co-creation process [7], [8]. Customers as passive recipient of products change to prosumers, who actively consume and produce [9].

For intangible products like software, users were integrated in the design processes before since decades. In the 1980‘s, the Free Software Foundations was founded at the MIT [10]. Idea is to offer software that can be used, studied, and modified without restriction, copied and redistributed in modified or unmodified form. Software is handled as commons. Someone picks up and modified the software and later on shall return the improved version back to a common pool [11]. To indicate that free available software doesn’t mean free of cost, the open source initiative started in the 1990’s [12], adding licenses as legal frame for intellectual property rights to the existing commons approach.

4.1 Open design and open innovation

Initiatives including some degree of openness aim to increase of development capacity by outsourcing design tasks to an undefined generally large group of people in the form of an open call [13]. Variations like open design, open innovation and crowed-sourcing in general deal with intangible products, e.g. software, product designs or movie plots. These products do not require special equipment or a centralized creation as they can be shared via internet. For intangible products like the open source software Linux and its derivatives represented in 2008 a business volume of about $36 billion/a [11].

When design, manufacturing and use of tangible and intangible products, merge together, manufacturer are not able to control every detail anymore. Customer creativity, self-organization, individual and flexible adaptation as well as extensive knowledge transfer create a new concept of value creation, called open manufacturing [14]. At the Massachusetts Institute of Technology, so called Fab Lab (fabrication laboratory) were first introduced. In these Fab Labs, customers are enabled to produce self-designed products by operating small scale and simple machine tools [15]. In July 2010 were 45 labs in 16 countries operated by independent initiatives [16].

However, equipment is generally fixed to one place and shared by different customers, whereas the open source appropriate technology (OSAT) aims provide local communities with easily and economically equipment, made from readily available resources [17].

5 MODEL FOR VALUE CREATION COMMONS

Possibilities to use recycling output as feedstock for manufacturing depends heavily on available (recycling) and required (manufacturing) material. Information about the waste-to-product transformation process has to be adjusted for the individual instance and requires a broad knowledge base. By setting up knowledge communities with innovative commons, globally available knowledge may be used in local application. By utilizing the innovative force of such knowledge communities – globally distributed persons – requires the problem to be structured and until a certain point standardized. The already existing examples of open manufacturing were analyzed in order to develop an information model for value creation commons.

Idea, concepts, descriptions, etc. about a single process step or process chains do not compete for marked share but as similar processes occur, competition can and should be expected. This is comparable to horizontal and vertical integration in networks, where producing enterprises are confronted with an increasing complexity and a growing number of products and variants. In industry, companies focus more and more on their core competencies in order to survive in global competition, increasingly divide the value creation among numerous partners and organize themselves for global value creation in networks [2]. From top-down perspective, value creation can be considered as a network consisting of horizontal and vertical integrated modules and from a bottom-up perspective modules can contribute to respective networks. The dynamic shift between module and network perspective may allow revealing potentials for increasing material and energy efficiency and effectiveness. Value creation modules are characterized by a set of the value creation factors: Product (what? how many? which quality?), process (how?), equipment (whereby?), organization (when? where? What order?), and human (who?).

5.1 Character of communities contributions

Community driven initiatives do not follow traditional ways of industry collaboration where required input, expected output and intended benefit for each stakeholder have to be defined in the beginning. Why somebody is contributing in what kind of form have to consider when designing calue creation commons.

Why contributing?

Why people get involved in activities where their contribution does not directly pay off in a monetary way unlike most traditional business concepts? In open design, marketing and similar areas, the following forms of motivation can be observed:

- **Pragmatically**: To learn skills by doing that may be become relevant in their professional work or career and get-in-touch with persons that could be helpful to boost their careers.

- **Social**: To get recognition in peer groups and in improve personal feeling of self-worth, by helping others as an altruistic attitude; to establish community identification and being part or forming an lifestyle movement.
- **Hedonistic**: To establish an joint consumer empowerment or fight a mutual enemy (company); being some kind of brand zeal and may get access to certain privileges like product test; to live out creativity and uses self-expression

Networks like Facebook or twitter address primarily social forms of motivation, whereas open manufacturing and its element of tangibility offer the chance to address the other two forms as well.

Who contributes?

In community initiatives like open source software development, the 1-9-90 rule can be observed [11]. 1% of the community can be considered as very committed core individuals, driving large amounts of the activity, creating new content and provide infrastructure to a certain degree. 9% of the community sometimes modify content, but rarely create content from scratch. 90% of the community represent the “audience”, just reading or observing without active contribution.

What kind of contribution?

Knowledge contributions like experiences, ideas, concepts, etc. about physical artifacts and liked processes can be related to [19]:

- **Functionality**: adding, improving, narrowing or broaden the field of application
- **Use**: providing manuals or tutorials to increased ease of use and refined operation techniques; improved interoperability with other artifacts
- **Cost**: Lowering material and operation cost by increased efficiency and effectiveness
- **Components**: Substitution of components, which e.g. may be easier to acquire
- **Design**: Personalizing general appearance by varying design features
- **Build**: Improved description of assembly procedure and decrease production equipment requirements
- **IT**: Integration by creating new IT connections and interfaces and improved design architecture.

Beside the actual content, suggestions and ideas regarding improvements of the knowledge sharing infrastructure can be expected.

5.2 Contributions for value creation commons

The combination of value creation modules as steps in a value creation chain cannot be seen as permanent state rather than constantly adjust to meet more profitable configurations. Generic ways of reconfiguration when dealing with process chains from a perspective of companies are [20]:

- **Focusing:** Focusing on specific processes, improving these, traditionally couple with reducing the overall value added. (F)
- **Integrating:** Creation of horizontally substituting or vertically completing connections (P,S)
- **Coordinating:** Dissolving process steps into several other, e.g. to enable outsourcing of processes steps (M,P)
- **Condensing:** Integrating several process steps into one single process (M,P)
- **Expanding:** Adding processes into existing process chains (M,P)
- **Reconstructing:** Redesigning existing process chains (M,P)

As indicated in brackets above, value creation modules including their factors and the horizontal and vertical connections are modified or added in the different ways. In the sense of the above presented model, graph and its elements can be modified regarding:

- **Factors** (F): Specifying or correcting of different factors (Focusing)
- **Modules** (M): Copying/mirroring in order to instantiate modules including its factors for different application (Focusing)
- **Connections**(P,S): Adding, rearranging or removing connections of process chain and synergies between different modules (Integrating)
- **Modules and connections** (M,P): Adding connection and modules for example to create parallel processes chains of introduce new application fields (Coordinating, Condensing, Expanding, Reconstructing)

5.3 Usefulness of value creation commons

Including new ideas in value creation commons can expected to be done by ca. 10% of the community. The benefit for the other 90%, more or less consuming the knowledge should work in two directions.

From a bottom-up perspective, for single value creation modules, different process chains should be able to be identified where a promising and competitive integration could be possible. For a given stage n (input) all possible stages $n+1$ (output) or for a stage n (output) all required stages n-1 (input) should be obtainable.

From a top-down perspective, to manufacture a specific artifact, all possible process chains should be obtainable, including the respective input material and necessary equipment. Characteristics of alternative process chains allow narrowing down possibilities to identify solutions, appropriate for individual use cases.

5.4 Design of value creation commons

To model the relations between different value creation modules in networks, a multigraph with two layers of connections is used. Frist layer consists of directed connections, representing the consecutive process steps to transform input material into output material like a vertical integration in value chains. Second layer consists of undirected connections, representing similarities regarding process, product or material like a horizontal integration in value chains. The mathematic description of the network as value creation commons, consisting of modules is:

- $VCC = (M, P, S, f_1, f_2)$ .. Value creation commons as graph

With (knots)

- M .. Value creation Modules with
  $M = \{m_1, . . . , m_o\}$
  and connections (edges)
- P .. with f_{n-1}:$P \rightarrow M$ and f_n:$P \rightarrow M$
  Process flow (directed) where
  $P = \{p_1, \ldots , p_i\}$
  $f_{n-1}, f_n \in M$ .. start and end between two points
- S .. with f_{n-1}, f_n:$S \rightarrow M$
  Synergies between two points (undirected) where
  $S = \{s_1, \ldots , s_j\}$

with

- $M \cap P = \varnothing$ and $M \cap S = \varnothing$ and
  $o, o, j, n \in \mathbb{N}$

For two points, the connection is depicted in Fig. 2.

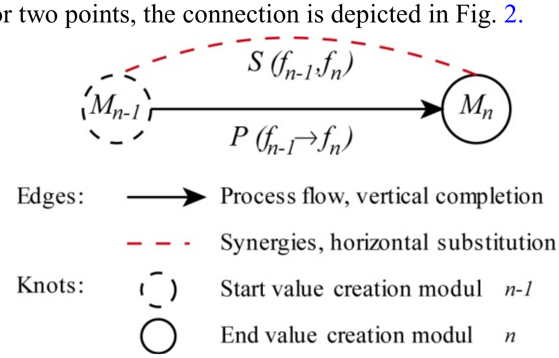

Fig. 2: Graph representation of value creation commons

6 CASE STUDY FOR LOCAL VALUE CREATION CYCLES

Process chains of daily- life and consumer goods are due to the number of parts and required manufacturing processes difficult to entirely grasp. Short process chains can be achieved by reducing the material diversity, applying additive processes to achieve near net shapes products and organize the processes local to avoid logistics. To demonstrate the idea and mechanics of the presented model, a use case for local manufacturing and recycling with few process steps are described in the following.

6.1 Case study outline

Destroyed roads or missing water and energy supply are not uncommon in emerging countries like Sierra Leone, postwar areas like Somalia or regions of natural catastrophes like Haiti. Water and food may be provided by non-governmental organizations (NGOs), utilizing available local logistics capacities. Supply of tools and equipment to improve conditions of living and working, is rather limited. Plastics waste like PET bottles, plastic bags or glass as leftover from food and water supply could be used as material source to locally realize simple tools, equipment and items of everyday living. Dependencies on external material supply could be reduced. It has to be expected that the qualification level regarding manufacturing is very low. Via Global System for Mobile (GSM) communications, product, process or equipment ideas may be shared, allowing locals to create a high variety of artifacts in the sense of self-sustaining help.

6.2 Process chain

Thermoplastics scrap is used as raw material to produce easy goods. In order to skip sorting, availability of pure material without contamination has been assumed. After shredding scrap, the plastic pellets are extruded to a thread as feedstock for 3D printers. Beside plastics, glass can expect to be available as well. For glass, the process chain consists of shredding glass to powder and laser sintering the powder to useful goods. Fig. 3 depicts the value creation modules for both process chains.

6.3 Physical realization and local integration

Following the process chain for plastics, shredding, extrusion and 3D printing was realized as small size facility. Due to local conditions regarding infrastructure – transport, energy supply –, qualification of local operators and social environment, equipment has to be inexpensive, modular, easy to use and easy to maintain. Solar panels or diesel engine serve as decentralized energy supply. GSM communication connects the decentralized facility to share schematics of manufactured products, operation descriptions of equipment and used materials from other users as well as gained experience. All information can be seen as commons pool. Producing items of everyday living for their own use and products for others, a positive impact in the sense of self-sustaining help can be expected.

7 SUMMARY AND OUTLOOK

Limited materials availability of non-/renewable materials affects modern manufacturing. Product and material recycling represent an alternative material source. However, recycling activities are rarely designed to meet required material demands. In the presented value creation simultaneously planned to realize situation specific recycling. Knowledge of numerous process-combinations

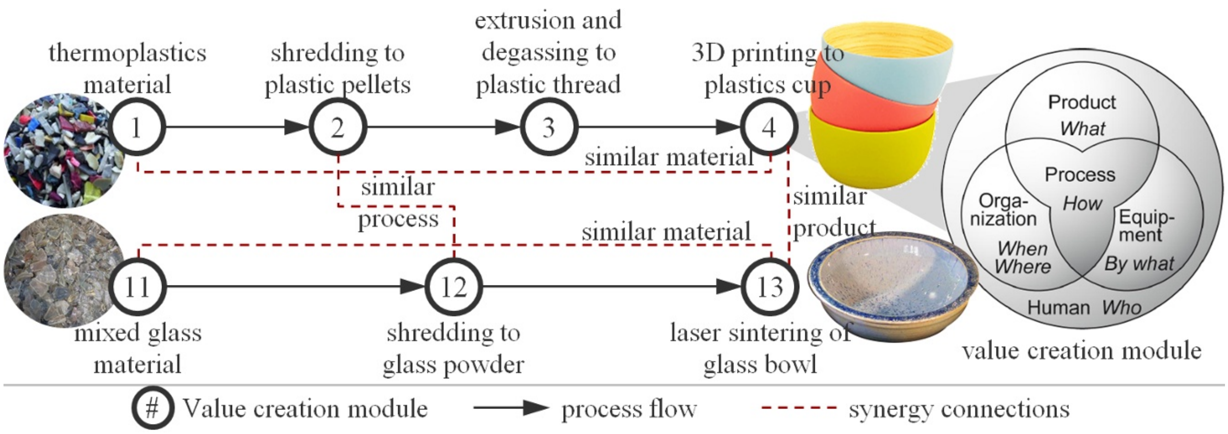

Fig. 3: Recycling and manufacturing with plastics and glass as simplified value creation commons

cycles, recycling and manufacturing processes are is hardly gained by individual planner. Transforming the concept of value creation cycles into a value creation commons allows a wide community to collaborate and utilize their joint knowledge. The shown model of value creation commons is described and instantiated using additive processes with upstream recycling. In future work, an easy to use design tool for value creation commons have to be developed, to ease contribution as much as possible.

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Electromagnetic Field Analysis on the Behavior of Selective Breakage at Phase Boundary in Electrical Disintegration

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Abstract

It is important in the comminution stage of waste treatment to liberate objective components from others for achieving the following compositional separation. However traditional (mechanical) comminution methods usually have problems of low selectivity of the breakage of phase boundary and low energy efficiency.

Electrical disintegration (ED) is one of the best communition technologies to break selectively at phase boundary and achieve good compositional liberation of the products. When high voltage pulse is applied in a flash to a composite particle, dielectric breakdown occurred preferentially at phase boundary, followed by sublimation of the boundary materials by Joule heat after electron avalanche, then, tensile stress becomes directly applied to phase boundary. In the process, good liberation could be obtained in relatively a large size range and energy required for the liberation becomes much lower than in the conventional comminution methods.

This paper aims to make clear the ED mechanism by combining electromagnetic simulation using finite element method and the experiments with synthetic particles which are composed of various mineral particles distributed in cement paste. In the simulation, charge density and Maxwell stress generated at phase boundary are calculated and compared with the liberation degree of ED products. It was found that high breakdown voltage is necessary for the samples of insulator minerals because only a small charge is accumulated at phase boundary but that high electrical charge is accumulated at phase boundary for insulator minerals at electrical breakdown. It was demonstrated that high electrical charge and Maxwell stress generated at phase boundary could be driving forces of preferential breakage at phase boundary, in other words, good compositional liberation in the ED

Keywords:

Electrical Disintegration, Comminution, Liberation, Electromagnetic Field Analysis

1 INTRODUCTION

Recovering useful components from waste is necessary with increasing various resources demands and the amount of waste generated. Therefore, the liberation of objective components from others in the waste is necessary as a pretreatment for achieving effective compositional separation, such as by energy saving physical separation, of the waste materials. Presently, most of solid wastes are communited with mechanical grinding and milling, but these methods have problems of over grinding to generate too fine particles and of much energy requirement, because few selective breakage at phase boundary is realized.

Electrical Disintegration (ED), in broader term, is a high voltage pulse communition which is classified in to two types. One is Electro-Hydraulic Disintegration (EHD) which is a shock wave comminution by applying high voltage in water. The other type is the Electrical disintegration (ED), in narrow term, which breaks materials in water from the inside by applying high voltage directy to them. ED is considered to be an energy saving method than EHD and can make better liberation, because tensile stress can be directly applied to the materials, especially at phase boundary. Hereafter, the ED described in the paper indicates the one in narrow term.

The mechansm of the ED was demonstrated by U.Andres [1] in which the ED process was classified into the following four stages.

1. Formative stage of current path: Electrically excited states are locally produced in the polarized dielectric when high voltage pulse is applied to a material.
2. Tree initiation of current path: Local field

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enhancement breaks intramolecular bonds, sublimates the solid by Joule heat and generates a pattern of thin (~1 μm) capillaries of current path.

3. Tree growth: The tree grows when capillaries develop in the direction from anode to cathode with supersonic velocity (10^6 m/s). In these capillary channels the energy of the pulse does not dissipate by heat condition, sound waves or fracturing solid during the propagation of channels. The small loss of energy takes place because of luminosity of channels.
4. Plasma expansion and electrical breakdown: In the return streamer the plasma channel expands rapidly. The temperature of plasma rises up to 45000 K, then, results in the complete electrical breakdown of solids.

Past researches in the ED made studies, for example, on the recovery of coal substance from impurity minerals [2] [3], and on the recovery of aggregates from wasted concrete [4], and so on [5] [6]. From the above results, ED is considered to achieve good liberation among compositional materials and contribute much as a pre-treatment of compositional separation in the field of waste treatment and mineral processing. However, the detailed mechanism of liberation has not been clarified yet [7] [8]. Therefore, this paper aimed to make clear the mechanism of selective breakage at phase boundary by using electromagnetic field analysis, in which relationship among the charge density accumulated at phase boudary, the Maxwell stress, and the liberation degree of ED products were analysed. Calculation was carried out by the finite element method (FEM) using free-software named "EMP3" developed by the Field Precision LLC.

2 EXPERIMENT

2.1 Samples

ED experiments were conducted using cement paste based synthetic samples in which mineral particles are dispersed. Mineral species were quartz, calcite, pyrite (from Yanahara and Spain), galena, cassiterite and rutile, as shown in Table 1.

Table 1: Electrical properties of the minerals and cement

Name of minerals	Composition	Relative permittivity	Conductivity
		-	S/m
Quartz	SiO_2	3.93	4.45×10^{-5}
Calcite	$CaCO_3$	7.66	4.28×10^{-5}
Pyrite (Yanahara)	Fe_2S	10.9	61.3
Pyrite(Spain)	Fe_2S	10.9	14.1
Galena	PbS	18	18.8
Cassiterite	SnO_2	23.7 [9]	1×10^{-4}～1000 [9]
Rutile	TiO_2	110 [9]	1×10^{-3}～1×10^{-2} [9]
Cement	-	26.8	1.54×10^{-2}

Minerals were communited and classified into the size range of 1.68 to 2.38 mm. The volume ratio of the mineral particles were set at 10 % in a sample lump, molded in 50 mm diameter and 100 mm height using a plastic tube. In the molding, the sample was rotated for one day for the mineral particles to be distributed uniformly in the lump, then, cured for 6 days. Finally, molded samples were cut in rectangular pieces of the size, 10×10×8 mm.

2.2 Equipment used

High-voltage generator, IVG-80G model, manufactured by the Pulse Electronic Engineering, Co., Ltd., was used in the ED experiments. Fig. 1 shows the conceptual diagram of the ED equipment.

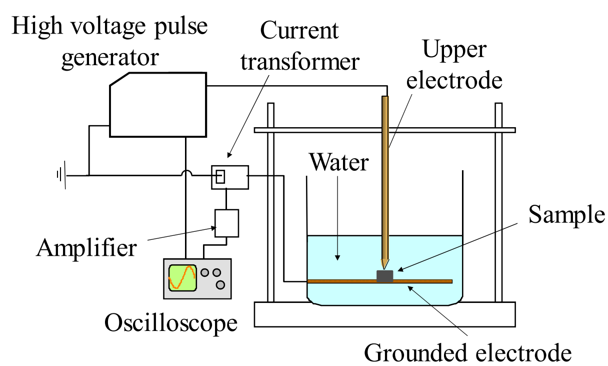

Fig. 1: Conceptual diagram of ED equipment

Table 2: High voltage pulse generator

Duration of wave front	μs	1.2
Duration of wave tale	μs	50
Nominal voltage	kV	80
Combined electrostatic capacity	μF	0.25
Maximum charge energy	J	800
Utilization ration	%	More than 80

2.3 Experimental Procedure

In the ED experiments, one piece of the sample was placed between the electrodes and high voltage was applied from 20, 24, 28 kV, ..., by the step of 4 kV, to the sample until the sample was broken from the top to bottom. The value of the maximum voltage divided by sample thickness, 10 mm, is difined as Dielectric Breakdown Strength ("DBS" in kV/m) of the sample.

After ED, particle size distribution of the broken sample was measured using the JIS standard sieves. Fig. 2 shows the size distribution of the ED products. Most of the samples tend to have similar size distribution.

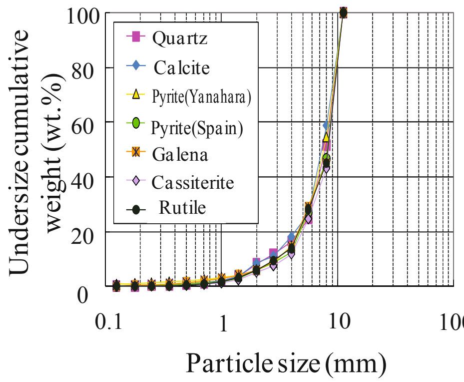

Fig. 2: Size distribution of the ED products with various mineral particles distributed in cement paste

2.4 Liberation

After the sieving, the liberation degree of mineral phase in each particle size range was measured. Liberation degree, L_B, is defined as the ratio of the amount of an objective component, B, which formed in free particles, X, to the total amount of the component, Y.

$$L_B = \frac{X}{Y} \qquad \ldots(1)$$

3 ELECTROMAGNETIC CALCULATION

3.1 Single Particle Model in Calculation

A simplified "Single Particle Model'' was created in three-dimensional meshes tool. Fig. 3 shows the diagram of this model in which one dielectric sphere mineral particle, 5 mm of diameter, is located in the center of cement paste. The size of cement paste was set at 10×10×10 mm, and of absorber was set at 10×10×1 mm.

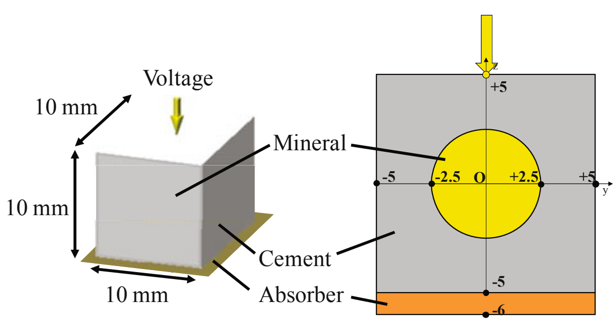

Fig. 3: Single particle model

3.2 Calculation

Unit fraction in the FEM was set at in a cubic of the size 0.1×0.1×0.1 mm. Electromagnetic field analysis begins with solving the following Maxwell equations.

$$\nabla \times E = -\frac{\partial(\mu H)}{\partial t} \qquad \ldots(2)$$

$$\nabla \times H = J + \frac{\partial(\varepsilon E)}{\partial t} \qquad \ldots(3)$$

$$\nabla \cdot (\varepsilon E) = \rho \qquad \ldots(4)$$

$$\nabla \cdot (\mu H) = 0 \qquad \ldots(5)$$

Here, E is electric field (V/m), H is magnetic field (A/m), J is current density (A/m), ε is dielectric constant (F/m), μ is magnetic permeability (H/m), ρ is space-charge density (C/m^3).

Driving terms in the Equ. (2) to (5) are ρ and J, and they are correlated through the equation of continuity in the following.

$$\frac{\partial \rho}{\partial t} + \nabla J = 0 \qquad \ldots(6)$$

In order to calculate the change in the E of each unit fraction as a function of time, the calculation involves the charge added to the system, in addition to the charge change in the system according to the Equ. (7).

$$J = J_0 + \sigma E \qquad \ldots(7)$$

Here, J_0 is the applied current density at t=0 and σ is electrical conductivity. The following two equations are introduced from the Equ. (2) to (7).

$$\oint E \cdot \mathrm{dl} = -\iint dA \frac{\partial}{\partial t}(\mu H \cdot \mathrm{n}) \qquad \ldots(8)$$

$$\oint H \cdot \mathrm{dl} = \iint dA\left[\frac{\partial}{\partial t}(\varepsilon E \cdot \mathrm{n}) + \mathrm{J_0} \cdot \mathrm{n} + \sigma \mathrm{E} \cdot \mathrm{n}\right] \qquad \ldots(9)$$

Step time was set at 10^{-14} s and the electrical properties of the materials adoppted the values shown in Table 1. Once J_0 is set at each unit fraction, H is obtained from Equ. (9), then, E is also obtained by substituting the H for Equ. (8). After these calculations are done in all the unit fractions at one step of time, the E value obtaiend is substituted for Equ. (9) at a next step in order to obtain the change in E as a funciton of time.

4 RESULTS AND DISCUSSION

4.1 "Dielectric Breakdown Strength" and electric charge at phase boundary

Fig. 4 shows the relationship between the maximum current density accumulated at phase boundary by applying high voltage and the "DBS". Applying voltage corresponds to the "DBS". The samples of highly insulating minerals, quartz and calcite, have a tendency to have high "DBSs", which indicates that a large amount of electric charge is accumulated at phase boundaries of these minerals until the breakdown.

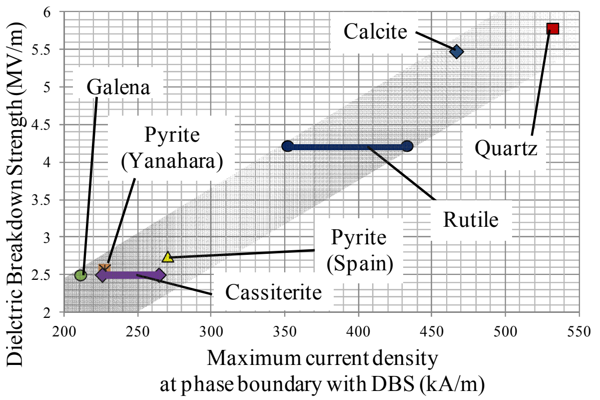

Fig. 4: Relationship between "DBS" and the maximum electric current density at phase boundary when applying the same voltage to the "DBS" of each sample

4.2 Liberation and electric charge at phase boundary

In the ED, liberation property of each sample must be changeable by the amount of electric charge accumulated at phase boundary. Fig. 5 shows the relationship between the maximum current density at phase boundary by the above calculation and the liberation degree measured for various ED products with different size ranges. This figure indicates that the higher electric charge accumulated at phase boundary, the higher liberation degree could be obtained in all size ranges and that the tendency is more obvious for the samples of higher "DBS". These facts would indicate that the sample materials in which insulating minerals, such as quartz and calcite, are dispersed need high voltage for the breakdown but that the ED products show a high liberation property.

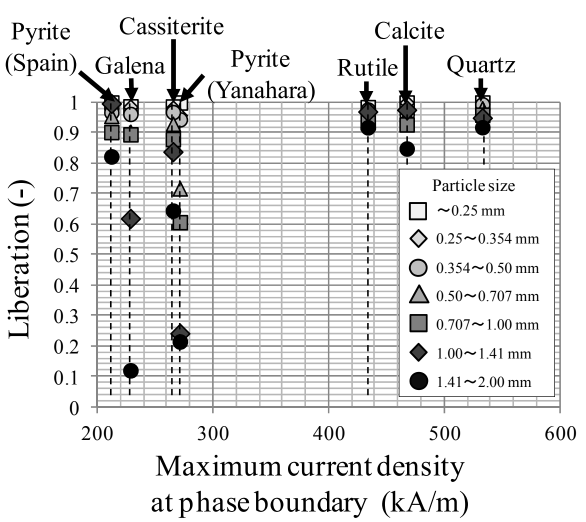

Fig. 5: Relationship between liberation degree and the maximum current density at phase boundary

4.3 Liberation and the Maxwell stress

The Maxwell stress, F_{Max}, is generated because of the difference of electric potential between the phases and is indicated as the following equation.

$$F_{\mathrm{Max}} = \frac{1}{2}\varepsilon_{\mathrm{in}} E_{\mathrm{in}\text{-}t}{}^{2} - \frac{1}{2}\varepsilon_{\mathrm{out}} E_{\mathrm{out}\text{-}t}{}^{2} + \frac{1}{2}\varepsilon_{\mathrm{out}} E_{\mathrm{out}\text{-}n}{}^{2} - \frac{1}{2}\varepsilon_{\mathrm{in}} E_{\mathrm{in}\text{-}n}{}^{2} \quad \ldots(10)$$

Here, E_{in} and E_{out} are electric fields in the inside and out materials, respectively in "Single Particle Model", and $\varepsilon_{\mathrm{in}}$ and $\varepsilon_{\mathrm{out}}$ are dielectric constants of inside and outside materials, suffix n indicates normal direction and t indicates tangential direction. Fig. 6 shows the relationship between the liberation degree of ED products and the maximum Maxwell stress at phase boundary.

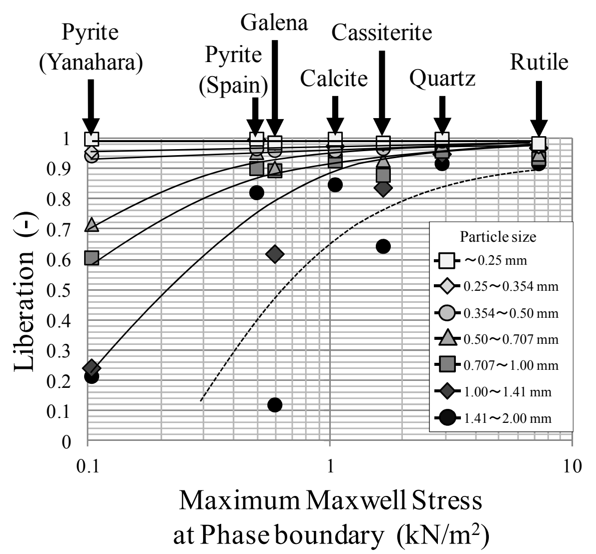

Fig. 6: Liberation degree and Maximum Maxwell stress at phase boundary

Higher liberation can be achieved by higher maximum Maxwell stress at phase boundary in each particle size. From the results, we can demonstrate that the Maxwell stress generated at phase boundary must become a driving force of the selective breakage at phase boundary and gives higher liberation products in the ED.

5 SUMMARY

This study aimed to clarify the mechanisms of selective breakage at phase boundary in the ED, by comparing the data of ED experiments with the current density and Maxwell stress accumulated at phase boundary that were calculated by FEM. Major contents are summarized in the followings.

1. The materials including highly insulating minerals have a tendency to have high "Dielectric Breakdown Strength", which indicates that a large amount of

electric charge can be accumulated at phase boundaries until breakdown, then, the ED products show a high liberation property.

2. In the ED, the electric charge and Maxwell stress induced at phase boundary could be driving forces of selective breakage at phase boundary and could produce the comminuted pieces of good liberation.

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Exergy Analysis of CO_2 Heat Pump Water Heating Systems

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Abstract

CO_2 heat pump water heating systems have been commercialized and widespread. It has become more and more important to enhance the system performance. In this paper, the performance of the systems is investigated from the exergy viewpoint. Exergy destructions results from the overall temperature drop due to heat loss from the tank surface and the temperature mixture due to heat conduction. A conventional system as well as a system revised by extracting water with middle temperatures from the middle of the storage tank are investigated. First, a numerical simulation is conducted to determine the hourly changes in the flow rates and states of the systems. Then, the exergy analysis is conducted based on the results obtained by the numerical simulation. The exergy destructions and efficiencies of the components are clarified quantitatively for both the systems.

Keywords:

heat pump, water heater, thermal storage, carbon dioxide, system performance, numerical simulation, exergy analysis

1 INTRODUCTION

Air-to-water heat pumps using CO_2 as a refrigerant have been developed. In addition, water heating systems each of which combines a CO_2 heat pump with a hot water storage tank have been commercialized and widespread. They are expected to contribute to energy saving in residential hot water supply [1, 2].

The performance of a CO_2 heat pump is affected only by instantaneous air, and inlet and outlet water temperatures. The technological development especially for compressors and heat exchangers has enhanced the coefficient of performance (COP) of CO_2 heat pumps. On the other hand, the performance of a water heating system is affected not only by instantaneous air and feed water temperatures but also by hourly changes in the heat pump operation, hot water demand, and their resultant temperature distribution in the storage tank. It has become more and more important to enhance the system performance.

It takes much time to conduct the performance analysis on water heating systems in consideration of the aforementioned items under various conditions by experiment, and it is expected that numerical simulation enables one to do it very efficiently. Some studies have been done for the performance analysis on water heating systems by numerical simulation [3, 4]. The author has conducted the performance analysis in consideration of hourly changes in the heat pump operation, hot water demand, and their resultant temperature distribution in the storage tank [5, 6].

In this paper, the performance of CO_2 heat pump water heating systems are investigated from the exergy viewpoint. The exergy analysis has been conducted on CO_2 heat pumps [7]. In this paper, the exergy analysis is focused especially on storage tanks by treating two systems. One is a conventional system with a standard storage tank, and the other is a revised one with a special storage tank. The hot water storage during a long time causes two types of exergy destructions, which result from the overall temperature drop due to heat loss from the tank surface and the temperature mixture due to heat conduction. In the conventional system, the latter type of exergy destruction reduces the COP and exergy efficiency of the CO_2 heat pump. On the other hand, in the revised system, the performance can be enhanced by extracting water with middle temperatures from the middle of the storage tank. This can reduce the temperature mixture due to heat conduction and its relevant exergy destruction. This can also increases the COP and exergy efficiency of the CO_2 heat pump.

First, a numerical simulation is conducted for both the conventional and revised systems to investigate the hourly changes in the flow rates and states of the systems. Then, the exergy analysis is conducted based on the results obtained by the numerical simulation. The exergy destructions and efficiencies of components are clarified quantitatively for both the systems.

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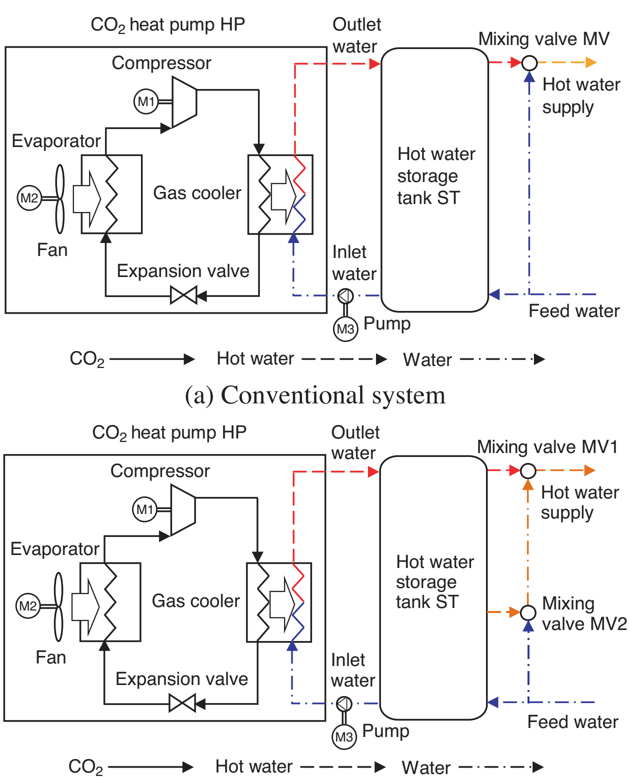
2 CO_2 HEAT PUMP WATER HEATING SYSTEMS

Figure 1 shows the configurations of the CO_2 heat pump water heating systems investigated in this paper. Each system is composed of a CO_2 heat pump and a hot water storage tank. The CO_2 heat pump is composed of a compressor, a gas cooler, an expansion valve, and an evaporator. The system is equipped with a fan, a pump, and motors M1 to M3 as auxiliary machinery. Here, inlet and outlet water is defined as water at the inlet and outlet of the gas cooler, respectively. The system heats water using the refrigeration cycle of the CO_2 heat pump, stores hot water in the storage tank, and supplies it to a tapping site.

Figure (a) corresponds to the conventional system with a standard storage tank. Hot water is extracted only from the top of the storage tank. Figure (b) corresponds to the revised system with a special storage tank. Hot water is extracted from both the top and middle of the storage tank depending on the temperature distribution in the storage tank. This system is used to enhance the performance by extracting hot water from the middle of the storage tank and reducing the part with middle temperatures which tends to expand due to heat conduction.

3 NUMERICAL SIMULATION

To conduct the exergy analysis, it is necessary to determine the hourly changes in the flow rates and states of the systems. Here, the flow rates and states at the periodically steady state with the period of a day are used for the exergy analysis. For this purpose, it is assumed that although the hot water demand changes hourly, its pattern does not change daily, and the periodically steady state is attained after several days, even if any initial state is given.



(a) Conventional system

(b) Revised system

Fig. 1: Configurations of CO_2 heat pump water heating systems

3.1 Simulation model

A simplified static model is adopted for the CO_2 heat pump [6, 8]: Although the CO_2 heat pump includes several components, they are not taken into account explicitly, and it is expressed by one model. The mass flow rates and temperatures of water at the inlet and outlet, COP, heat output, power consumption, and air temperature are adopted as basic variables whose values are to be determined. The mass and energy balance relationships as well as the energy input and output relationship are adopted as basic equations to be satisfied. The remaining equations to be considered are approximate functions of the power consumption and COP, and they are expressed in relation to the air, and inlet and outlet water temperatures.

A one-dimensional dynamic model is adopted for the storage tank [5, 6, 8]. To consider the one-dimensional vertical temperature distribution in the storage tank, it is vertically divided into many control volumes with the same volume, in each of which the water temperature is assumed to be constant. It is also assumed that the heat transfer occurs by water flow and heat conduction as well as heat loss from the tank surface. The mass flow rates and temperatures of water for the control volumes are adopted as basic variables whose values are to be determined. The mass and energy balance relationships for the control volumes are adopted as basic equations to be satisfied.

A static model is adopted for the mixing valves. The mass flow rates and temperatures of water at the inlets and outlet are considered as basic variables, and the mass and energy balance relationships are considered as basic equations to be satisfied.

At the connection points among the CO_2 heat pump, storage tank, and mixing valves, connection conditions are taken into account to equalize the values of the corresponding variables. The outlet water temperature is given as a control condition. The feed water temperature as well as the mass flow rate and temperature of hot water to the tapping site are given as boundary conditions. The air temperature is given as an ambient condition.

As for the concrete formulation of the simulation model, refer to reference [6]. The validity of the simulation model has been verified through an experiment and a three-dimensional thermo-fluid numerical simulation. As for this verification, also refer to reference [6].

3.2 Solution method

The aforementioned modeling for the numerical simulation is conducted by a building block approach.

The equations for the CO_2 heat pump and mixing valves are static, while those for the storage tank are dynamic. Therefore, the modeling results in the following set of nonlinear differential algebraic equations:

$$\left.\begin{array}{l} \boldsymbol{f}(\boldsymbol{x}(t), \dot{\boldsymbol{x}}(t), \boldsymbol{y}(t), t) = \boldsymbol{0} \\ \boldsymbol{x}(t_1) = \boldsymbol{x}_{\mathrm{I}} \end{array}\right\} \quad (1)$$

where $\boldsymbol{f}$ is the vector for all the equations, $\boldsymbol{x}$ is the vector for the variables with their derivatives, or the temperatures of water for all the control volumes of the storage tank, $\boldsymbol{y}$ is the vector for all the other variables without their derivatives, $\dot{\boldsymbol{x}}$ is the derivative of $\boldsymbol{x}$ with respect to time t, and $\boldsymbol{x}_{\mathrm{I}}$ is the initial value of $\boldsymbol{x}$ at the initial time t_1.

The set of equations is solved by a hierarchical combination of the Runge-Kutta and Newton-Raphson methods.

4 EXERGY ANALYSIS

4.1 General equations

Even if the periodically steady state with the period of a day is used for the exergy analysis, the flow rates and states change with time throughout the day. Therefore, the instantaneous exergy balance relationship at the unsteady state is used [9]. Figure 2 shows the definition of symbols necessary for the exergy analysis. With this definition, the instantaneous exergy balance relationship is expressed as follows:

$$\frac{dE^{\mathrm{cv}}(t)}{dt} = \dot{E}^{\mathrm{in}}(t) - \dot{E}^{\mathrm{out}}(t) + \left(1 - \frac{T_0}{T(t)}\right)\dot{Q}^{\mathrm{in}}(t) - \dot{W}^{\mathrm{out}}(t) + p_0\frac{dV^{\mathrm{cv}}(t)}{dt} - \dot{E}^{\mathrm{des}}(t) \quad (2)$$

where $\dot{E}^{\mathrm{in}}$ and $\dot{E}^{\mathrm{out}}$ are the exergy flow rates at the inlet and outlet of the control volume, respectively, $\dot{Q}^{\mathrm{in}}$ and $\dot{W}^{\mathrm{out}}$ are the heat flow and work rates, respectively, E^{cv}, V^{cv}, and T are the stored exergy, volume, and temperature of the control volume, respectively, $\dot{E}^{\mathrm{des}}$ is the exergy destruction rate in the control volume, p_0 and T_0 are the pressure and temperature at the reference state, respectively.

By integrating this instantaneous exergy balance relationship during a certain period from t_1 to t_2, the following total exergy balance relationship is derived:

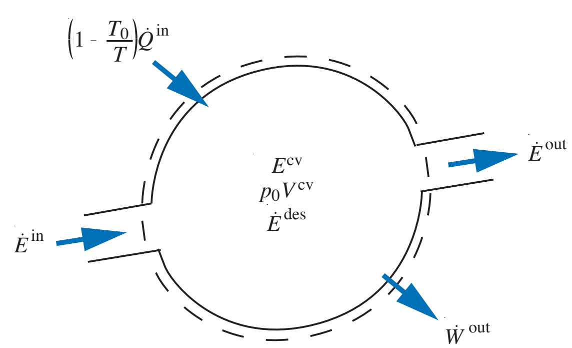


Fig. 2: Definition of symbols for exergy analysis

$$E^{\mathrm{cv}}(t_2) - E^{\mathrm{cv}}(t_1) = \int_{t_1}^{t_2}\dot{E}^{\mathrm{in}}(t)\,dt - \int_{t_1}^{t_2}\dot{E}^{\mathrm{out}}(t)\,dt + \int_{t_1}^{t_2}\left(1 - \frac{T_0}{T(t)}\right)\dot{Q}^{\mathrm{in}}(t)\,dt - \int_{t_1}^{t_2}\dot{W}^{\mathrm{out}}(t)\,dt + p_0\left(V^{\mathrm{cv}}(t_2) - V^{\mathrm{cv}}(t_1)\right) - \int_{t_1}^{t_2}\dot{E}^{\mathrm{des}}(t)\,dt \quad (3)$$

If the period is set at a day, the states in the control volume return to the initial ones after the day. In this case, therefore, the total exergy balance relationship is reduced to

$$\int_{t_1}^{t_2}\dot{E}^{\mathrm{in}}(t)\,dt - \int_{t_1}^{t_2}\dot{E}^{\mathrm{out}}(t)\,dt + \int_{t_1}^{t_2}\left(1 - \frac{T_0}{T(t)}\right)\dot{Q}^{\mathrm{in}}(t)\,dt - \int_{t_1}^{t_2}\dot{W}^{\mathrm{out}}(t)\,dt - \int_{t_1}^{t_2}\dot{E}^{\mathrm{des}}(t)\,dt = 0 \quad (4)$$

4.2 Application to CO_2 heat pump water heating systems

To conduct the exergy analysis on the CO_2 heat pump water heating systems, it is necessary to evaluate the exergy stored in the storage tank, the exergy flow rates of water from and into the storage tank, and the heat flow rate from the tank surface. Here, since the effect of the potential, kinetic, and chemical exergy is negligibly small, they are neglected, and the physical exergy is only taken into account.

First, the stored exergy is defined as

$$E^{\mathrm{cv}}(t) = m^{\mathrm{cv}}(t)\left\{(u(t) - u_0) + p_0(v(t) - v_0) - T_0(s(t) - s_0)\right\} \quad (5)$$

where m^{cv} is the mass, and u, v, and s are the specific internal energy, volume, and entropy, respectively. On the assumption that the specific volume and heat are constant, Eq. (5) is reduced to

$$E^{\mathrm{cv}}(t) = m^{\mathrm{cv}}(t)\left\{c(T(t) - T_0) - cT_0 \ln\frac{T(t)}{T_0}\right\} \quad (6)$$

where c is the specific heat.

Next, the exergy flow rate is defined as

$$\dot{E}(t) = \dot{m}(t)\left\{(h(t) - h_0) - T_0(s(t) - s_0)\right\} \quad (7)$$

where $\dot{m}$ is the mass flow rate, and h is the specific enthalpy. Since the effect of the pressure energy is negligibly small, Eq. (7) is reduced to

$$\dot{E}(t) = \dot{m}(t)\left\{c(T(t) - T_0) - cT_0 \ln\frac{T(t)}{T_0}\right\} \quad (8)$$

Finally, the heat flow rate per area is assessed based on the model for the heat loss from the tank surface as follows:

$$\dot{q}^{\mathrm{in}}(t) = -U\left(T(t) - T_0\right) \quad (9)$$

where U is the overall heat transfer coefficient.

The exergy destruction $\dot{E}^{\mathrm{des}}$ is assessed by substituting Eqs. (6), (8), and (9) into Eqs. (2) to (4).

5 NUMERICAL STUDY

The numerical simulation is conducted for eight days in mid-season on each of which an hourly change in a hot water demand is assumed. In addition, the exergy analysis is conducted based on the results obtained on the 8th day.

5.1 Conditions

The following are the conditions used for the numerical simulation and exergy analysis:

System specifications

Table 1 shows the specifications of the CO_2 heat pump water heating systems. The values of model parameters included in the equations are estimated based on measured data for existing devices. The rated heat output of the CO_2 heat pump is set at 4.5 kW. As an example, Fig. 3 shows measured values and approximate functions for the power consumption, COP, and their resultant heat output of the CO_2 heat pump in relation to the inlet water temperature for the air and outlet water temperatures of 16 and 85 ℃, respectively. Here, each value is relative to its rated one for the air, and inlet and outlet water temperatures of 16, 17, and 65 ℃, respectively. The volume of the hot water storage tank is set at 370 L.

The number of control volumes for the storage tank is set at 200, and the sampling time interval for the Runge-Kutta method is set at 10 and 180 s for the cases with and without water flow, respectively.

Ambient conditions

The feed water temperature in mid-season is set at 17 ℃, which is prescribed by the Japan Refrigeration and Air Conditioning Industry Association (JRA) [10]. The air temperature is also set at 17 ℃, so that the air and feed water temperatures are consistent with each other as the temperature at the reference state. These values are assumed to be constant throughout the the days.

Table 1: Specifications of the systems

Equipment	Specification	Value
CO_2 heat pump	Rated heat output	4.50 kW
Hot water storage tank	Volume	370 L
	Height	1.45 m
	Diameter	0.57 m
	Overall heat transfer coefficient	0.80 W/(m^2·°C)

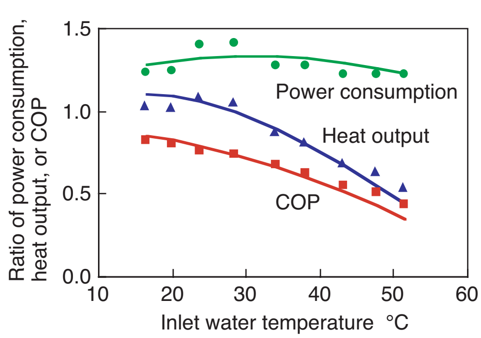


Fig. 3: Performance of CO_2 heat pump

Hot water demand

The hourly changes in the flow rate and temperature of the standardized hot water demand are given as shown in Fig. 4, which is also prescribed by JRA [10]. Here, the height of each vertical line means the flow rate, as indicated. The temperature is shown above each vertical line. In addition, the thickness of each vertical line means the duration.

Operation conditions

The system is assumed to be operated in the charging and tapping modes independently during the times 0:00 to 7:00 and 7:00 to 24:00, respectively. In the charging mode, the outlet water temperature of the CO_2 heat pump is set at 85 ℃. In addition, the CO_2 heat pump is started up at 2:00 and is shut down with a shutdown condition satisfied at an appropriate time before 7:00. The shutdown condition is that the inlet water temperature of the CO_2 heat pump attains 40 ℃.

As for the revised system, the combination of the top and middle of the storage tank from which hot water is extracted is determined depending on the temperature of water at the middle. When the temperature is higher than the supply temperature plus 5 ℃, hot water is extracted only from the middle. On the other hand, the temperature is lower than the supply temperature minus 5 ℃, hot water is extracted from both the top and middle. Otherwise, hot water is extracted only from the top, which is used for the conventional system. In the study, the extraction position at the middle is set at the 130th control volume from the top.

As the initial condition, the temperature of water in all the control volumes of the storage tank is set at the feed water temperature at 0:00 on the 1st day.

5.2 Results by numerical simulation

As an example of the results obtained by the numerical simulation, Fig. 5 shows the temperature distributions in the storage tank at 7:00 after charging and 24:00 after tapping at the periodically steady state on the 8th day for the conventional and revised systems. The temperature gradient at the part with middle temperatures for the revised system is larger than that for the conventional one. As a result, the volumes of hot water stored at 7:00 and unused at 24:00 for the former are larger than those for the latter.

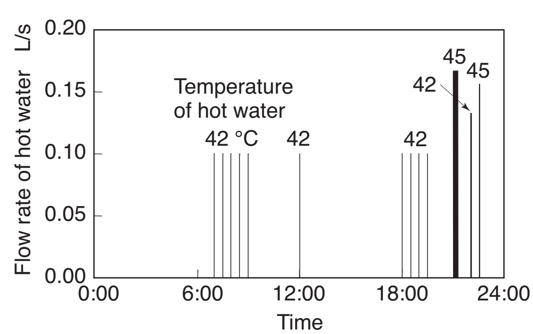


Fig. 4: Hourly change in hot water demand

In addition, the temperatures at the lower part with middle temperatures for the revised system are kept lower than those for the conventional one, which makes the COPs during charging for the former higher than those for the latter.

5.3 Results by exergy analysis

Heat pump

First, the exergy analysis is conducted on the CO_2 heat pump. Figure 6 shows the hourly change in the exergy efficiency for the conventional and revised systems. Here, the exergy efficiency is defined as the ratio of the difference between the exergy flow rates at the outlet and inlet to the power consumption. The exergy efficiency is constant after heat pump startup, because the temperature of water at the bottom of the storage tank is constant, and the COP is also constant. The exergy efficiency decreases drastically before heat pump shutdown, because the temperature of water at the bottom of the storage tank increases and the COP decreases. These changes in the exergy efficiency are similar to those in the COP. However, the exergy efficiency increases slightly on the way of heat pump operation, and this change is different from that in the COP. This is because the flow rate of water increases with the temperature of water at the bottom to keep the outlet water temperature, and the exergy flow rate at the outlet increases correspondingly, but that at the inlet does not so increase because of low temperatures of water.

Hot water storage tank

Next, the exergy analysis is conducted on the hot water storage tank. Figures 7 and 8 show the exergy balances for the conventional and revised systems, respectively. Figures (a) and (b) correspond to the charging mode during the period from 0:00 to 7:00 and the tapping one during the period from 7:00 to 24:00. The exergy at the inlet and outlet, the exergy destructions due to heat loss and conduction, and the change in the stored exergy are included in each figure. The exergy input for the revised system is slightly smaller than that for the conventional one. This is because the exergy efficiency of the CO_2 heat pump for the revised system is higher in some times and lower in the other times than that for the conventional one, as shown in Fig. 6. The exergy destruction due to heat loss is larger than that due to heat conduction for both the systems. Both the exergy destructions for the revised system are larger than those for the conventional one. The reason for this is as follows: As shown in Fig. 5, the part with high temperatures of water or the heat loss for the former is larger than that for the latter; In addition, the temperature gradient or the heat conduction for the former is larger than that for the latter. As a result, the exergy output for the revised system is smaller than that for the conventional one. This is because water with lower temperatures is utilized by its extraction from the middle of the storage tank. The lower exergy output for the former is balanced by the higher exergy efficiency of the mixing valves due to lower exergy destruction in mixing.

Summary

Table 2 summarizes the aforementioned results obtained by the energy analysis. Tables (a), (b), and (c) show the daily exergy input and output, exergy destructions, and

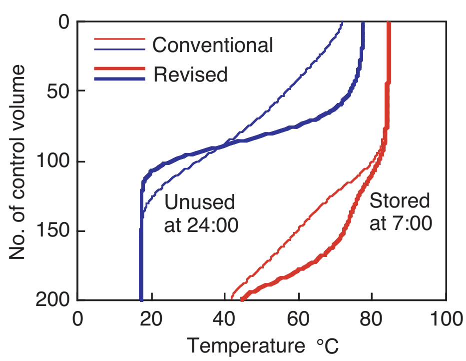


Fig. 5: Temperature distributions in storage tank

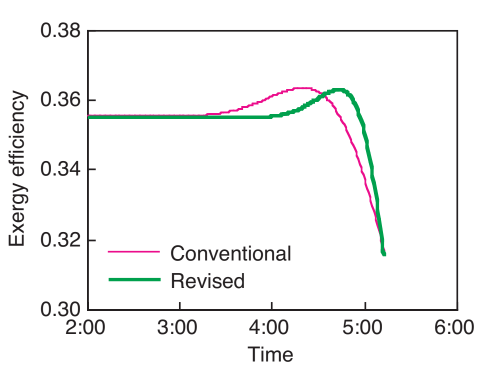
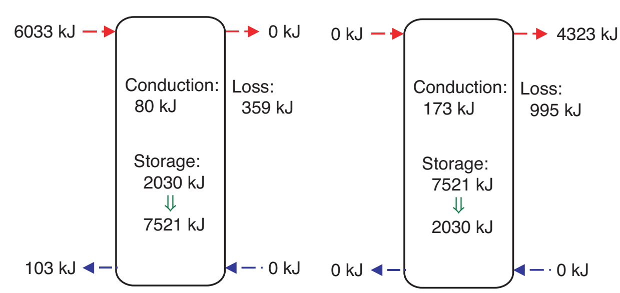
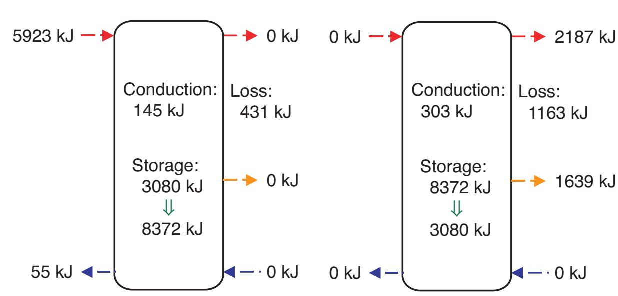


Fig. 6: Exergy efficiency of CO_2 heat pump



(a) Charging mode (b) Tapping mode

Fig. 7: Exergy balance for conventional system



(a) Charging mode (b) Tapping mode

Fig. 8: Exergy balance for revised system

Table 2: Summary of results by exergy analysis

(a) Exergy input and output

(Unit: kJ/d)

System	Conventional	Revised
Power consumption	16 699	16 502
Heat pump output	5 930	5 868
Storage output	4 323	3 826
Hot water supply	1 997	1 997

(b) Exergy destructions

(Unit: kJ/d)

System	Conventional	Revised
CO_2 heat pump	10 769	10 634
Hot water storage tank	1 607	2 042
Heat loss	1 354	1 594
Heat conduction	253	448
Mixing valve(s)	2 326	1 829
Total	14 702	14 505

(c) Exergy efficiencies

System	Conventional	Revised
CO_2 heat pump	0.3551	0.3556
Hot water storage tank	0.7290	0.6520
Mixing valve(s)	0.4619	0.5220
Total	0.1196	0.1210

exergy efficiencies for all the components. The exergy efficiencies of the CO_2 heat pump and storage tank are the smallest and largest among all the components for both the systems, respectively. Under the conditions in this study, the total exergy efficiency for the revised system is slightly higher than that for the conventional one. However, it is beneficial that the stored exergy for the former is much larger than that for the latter.

6 CONCLUSIONS

The exergy analysis has been conducted on CO_2 heat pump water heating systems based on the results obtained by a numerical simulation for performance analysis. A conventional system as well as a system revised by extracting water with middle temperatures from the middle of the storage tank have been investigated. These systems have been compared in terms of exergy destructions and efficiencies of components.

The following are the main results obtained though a numerical study:

- The exergy efficiencies of the CO_2 heat pump and storage tank are the smallest and largest among all the components for both the systems, respectively. The exergy destruction due to heat loss is larger than that due to heat conduction for both the systems.
- The exergy efficiencies of the CO_2 heat pump, storage tank, and mixing valves for the revised system is slightly higher, lower, and higher than those for the conventional one, respectively.
- The total exergy efficiency for the revised system is slightly higher than that for the conventional one. However, it is beneficial that the stored exergy for the former is much larger than that for the latter.

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R&D of the Gas Engine Heat Pump Water Heater

And Exergy Evaluation of the System

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Abstract

In "Ultra Long-term Energy Technology Visions 2005 " by the Japanese government , only "High Efficiency Heat Pump Water Heater " is shown as the vision for the future water heater . Actually, the electrically-driven type heat pump water heater using CO2 as refrigerant (Eco-Cute) have been developed and explosively spreading on the back of the economical late-night electricity rate system and all electrification strategy. In the meantime, with respect to the heat pump technology in the gas industry, although there are many track records of the technology used for air conditioning, there are rare cases of such technology used for water heating. Under such situation, in 2006, Hiroshima Gas started a study of "The Gas Engine Heat Pump Water Heater", which is a combination of "The Small-type Gas Engine" and "The Heat Pump". This time we will report on the element study we conducted, and analysis result of the exergy .

Keywords:

Gas Engine , Heat Pump , Exergy

1 INTRODUCTION

With the rising demand for energy saving as the gas water heater for household due to soaring energy prices and global environmental problems, the "Condensing Type Water Heater" and "Household Cogeneration" are promoted by the gas industry. In the meantime, "Ultra long-term energy technology vision" announced by the Japanese government in 2005, the Eco-Cute of "High Efficiency Heat Pump Water Heater" was shown as the development vision for the future water heater.

With respect to the heat pump technology in the gas industry, although there are many track records of the technology used for air-conditioning "GHP air-conditioning" , there are rare cases of such technology used for water heating. Under such situation, in 2006, Technical Research Institute of Hiroshima Gas started a study of "Gas Engine Heat Pump Water Heater" which is a combination of "Small-Type Gas Engine" and "Heat Pump." This time we will report on the contents of the element study.

2 GAS ENGINE HEAT PUMP WATER HEATER OUTLINE

This system is equipment in which heat pump used for air-conditioning is driven by gas engine, the equipment produces hot water through heat with collection heat from the atmosphere and heat with utilization exhaust heat of the gas engine. As the characteristics of the system, the equipment such as engine and compressor can be stored in the heat insulation box, the exhaust heat of the gas engine and the heat from such equipment can be recovered as heat source of the heat pump. It has become to improve the decrease in thermal efficiency in the winter-time low temperature season, which was a weak point of the heat pump water heater.

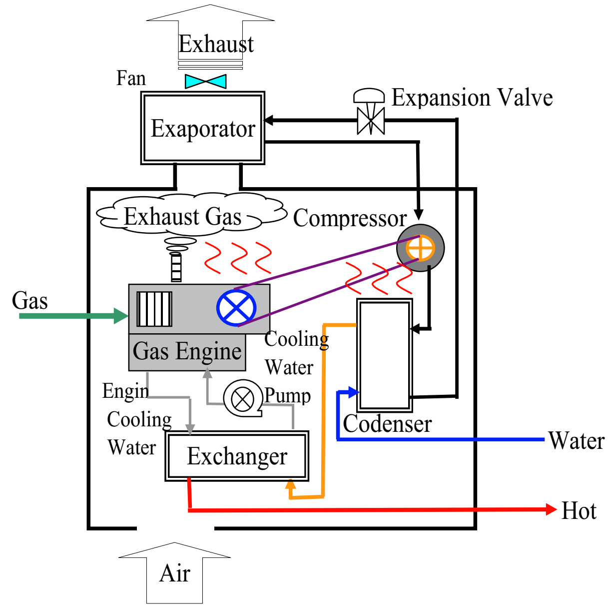

Fig. 1: System Outline

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Assuming that the heating value of consumed gas is 100%, and supposing that the shaft power of gas engine is 25%, Coefficients of Performance (COP) of the heat pump is 6.5 and the heat loss of the engine is around 10%, the expected best thermal efficiency of system will exceed 200% in primary energy equivalent. (Shaft Power 25%×6.5+Exhaust Heat Recovery 65%=228%)

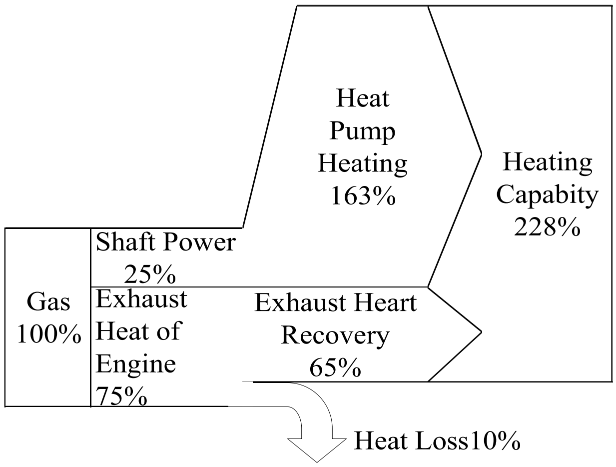

Fig. 2: Expected the Best Thermal Efficiency of System

3 PRODUCTION OF EXPERIMENTAL EQUIPMENT AND TARGETS PERFORMANCE

In producing the experimental equipment, we considered cost reduction and utilized the existing all-purpose products for the main equipment (the gas engine, compressor and heat exchanger) which are mass-produced, inexpensive and easily available.

We carried out preliminary tests before conducting full-scale performance confirmation tests , we changed some parts of the equipment to complete the experimental equipment.

Fig. 3: The Experimental Equipment

Since we utilized the existing all-purpose products for main components of the experimental equipment, this time we predicted that its target heat efficiency would be slightly lower in comparison with the exclusive use design. For this reason, in order to grasp theoretical performance of the experimental equipment and decide on target thermal efficiency, we reproduced its constitution in a process simulator (VMGSim) to predict the performance.

As a result of the analysis by the process simulator, because thermal efficiency in primary energy equivalent was assumed to be 151% at hot water outflow temperature of 60oC under winter environmental condition, we carried out the performance confirmation tests with this as a target.

Table 1: Experimental Equipment Specifications

Name of Components	Specifications
Gas Engine	163cc Single Cylinder, 4 Cycle
Compressor	Belt Drive Compressor , Oblique Plate Capacity-type
Condenser	1.4m^2, Plate-type Heat Exchanger
Evaporator	23m^2, Coil-type Heat Exchanger
Expansion Valve	Temperature Control System-type Electronic Expansion Valve
Refrigerant	HFC -134a
Ventilation Equipment	400～2100m^3/h , Ventilation Fan
Storage Box	1.2m×0.6m×1.1m
Engine Exhaust Recovery Equipment	0.7 m^2, Plate-type Heat Exchanger
Hot Water Tank	150 liters Capacities
Circulation Pump Hot Water	0.5～25 liter/min (Flow Control)
Circulation Pump Cooling Water	25 liter/min (For Engine Coolant)

4 PERFORMANCE CONFIRMATION TESTS

We confirmed the best thermal efficiency of the experimental equipment under seasonal environmental conditions (summer-time, intermediate-time and winter-time).

As for the specific test method, the room temperature and feed water temperature in the environmental test room were kept constant, then we controlled "Gas Engine Heat Pump Water Heater" at predetermined engine revolutions, we conducted performance confirmation tests after making the operation of the experimental equipment stable by adjusting feed water so that it can reach the targeted hot water outflow temperature. The test results of 60°C hot water are as shown in Table 2.

Table 2: Tests Result under the Seasonal Conditions (Hot Water Outflow Temperature 60°C)

Seasons (Temperature)	Thermal Efficiency (%) (*details)	Hot Water Outflow Volume (ℓ/min)	Hot water Capability (kW)
Summer (24 °C)	187 (122 , 64)	2.0	5.8
Inter-mediate (16 °C)	164 (99 , 65)	1.7	5.6
Winter (5 °C)	141 (89 , 52)	1.4	5.0

*details : Left , Heat Pump Efficiency
Right , Engine Exhaust Heat Recovery Efficiency

The thermal efficiency under winter-time condition was 141% which was 91% in performance of the target value (155%). The heat pump efficiency is the same, but the engine exhaust heat recovery efficiency declined remarkable than the result of analysis simulator. As mentioned above, we predict that it was caused by ventilation quantity from outside and heat loss of the storing box due to lower temperature inside the box.

In addition, the relation between test air temperature at each hot water outflow temperature and thermal efficiency (Performance Curves) is as shown in Fig. 3.

Because the relation between thermal efficiency and test air temperature at each hot water outflow temperature is linear, because the inclination and interval became constant, we can predict thermal efficiency of the experimental equipment at the ambient temperature.

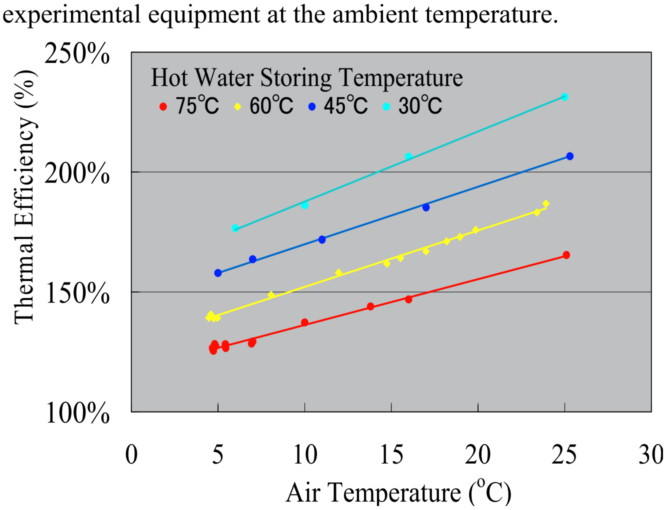

Fig. 3: Relation between Thermal Efficiency and Air Temperature (Performance Curves of Experimental Equipment)

5 EXERGY DESIGN OF THE EXPERIMENTAL EQUIPMENT

We conducted a study on improvement of thermal efficiency of the experimental equipment by exergy design. We grasped exergy flow and exergy efficiency of the energy system, and studied improvement of parts where hot water supplying energy and exergy loss at each process are substantial. The study results of the exergy evaluation are as shown in fig.4. Under winter-time operating condition, the heat pump efficiency is 89%, the engine exhaust heat recovery efficiency is 52%, however, based on the exergy analysis, the heat pump efficiency is 5%, the engine exhaust heat recovery efficiency is 10%, respectively.

6 CLOSING

We produced this experimental equipment using generally available all-purpose main components which we can get easily such as the gas engine. However, we succeeded in achieving thermal efficiency (primary energy equivalent) of 141% (91% in performance of the target value) under the severe winter-time environmental conditions (air temperature 5°C). This is about two times higher than the efficiency of the conventional type gas water heater which has been widespread in Japan. This will enable us to substantially reduce gas consumption and carbon dioxide emissions when operating the water heater. Furthermore, by the exergy analysis we have come to visualize or quantity the loss which could not be expressed by the conventional enthalpy analysis and find a clue to the performance improvement. We will continue to make efforts in the performance improvement of the equipment utilizing the exergy design which will minimize the exergy loss.

In closing, we hope that the results of this study will enable us to contribute even a little to promotion of lower carbon society in the future.

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Energy Saving Effect of Novel Desiccant Air Conditioner for Zero Emission House

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Abstract
The model of zero emission house [ZEH] made full use of leading-edge energy saving and new energy technology of Japan was exhibited at G8 Hokkaido Touyako Summit held on July 2008. Introduction in Japan is set as the goal of starting popularization of ZEH from 2015, change all newly-built houses to ZEH by 2030 and change all houses including existing house to ZEH by 2050. We have developed new style desiccant air conditioner which can supply dry cool air in summer and warm humidified air in winter by using heated water of solar heat or CGS. In this paper, we publish the energy saving efficiency of the incorporation of this desiccant air conditioner into ZEH and case example of exergy analysis compared with heat pump systems in summer extremely hot day.

Keywords:
ZEH, CGS, Heat Pump, Desiccant Central Air Conditioner, Exergy

1 INTRODUCTION

Due to the impact of the Great East Japan Earthquake on March 11 and the accompanying accident in the Fukushima Daiichi Nuclear Plant, there is an increasing demand for energy saving. At the same time, zero emission houses (ZEHs) for consumer use are attracting attention as a measure against global warming, and their demonstration is being promoted in various parts of Japan [1]. ZEH is a housing design aimed at avoiding CO_2 emissions by using photovoltaic power generation and other methods. Osaka Gas is conducting demonstration tests of a smart energy house (SEH) that utilizes photovoltaic power generation, fuel cells and storage batteries. The air conditioning in this SEH combines a commercial air conditioner with a desiccant unit. With focus on solar water heaters and gas engine cogeneration units of improving efficiency for domestic use, we are developing ventilation and central air conditioning for detached houses using the hot water generated by the units [2]. This air conditioning system ably combines dehumidification and regeneration capacity of desiccant and cooling capacity of water spray with air passage switching function to attain dehumidification cooling and humidification heating functions similar to those of air conditioners. The effect of this system, which is currently under development, on reduction of power consumption in households in summer was assessed with the process simulator VMGSim using assumed outdoor temperature and humidity values, preset indoor temperature and ventilation air flow as the parameters. In addition, the performance of the devices constituting this system was evaluated to identify the devices to be improved to reduce exergy loss, and its anticipated primary energy saving effect was compared with that of a conventional heat pump air conditioner and hot water energy supply system using grid power.

2 IMPROVEMENT OF HEAT & POWER SYSYTEM FOR DOMESTIC USE

As a commercial product to compete with the natural refrigerant heat pump hot water heater called “Eco Cute” released in 2001, “Eco Will,” a gas engine power generation system for domestic use, was put on sale in 2003. Table 1 shows the changes in its specifications. While the temperature of the stored hot water is 75 ^{o}C, the maximum temperature of the supply water is 80 ^{o}C due to an upper limit to the temperature of the hot water for cooling the main unit of the gas engine; also, the power generation efficiency on a lower heating value basis has been increased to 26.3% from 20% at the time of the release. In consideration of the trend for improvement in the power generation efficiency of the tens of kW class of gas engines, it is expected that power generation efficiency of gas engines for domestic use will exceed 30% in the future.

Table 1: Changes in the specifications of gas engine for domestic use.

Release date	Efficiency [%]			Gas input kW [LHV]	Gas consumption [Nm3/h]
	Power	Exhaust heat recovery	Total heat		
Mar. 2003	20	65	85	5	0.443
Oct. 2008	22.5	65	85.5	4.45	0.394
Jun. 2011	26.3	67.5	92	3.81	0.337
future	(30)	(60)	(90)	(3.34)	(0.295)

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The fuel cells for domestic use such as SOFC, which currently attract attention as high-efficiency power generation units, are being developed with a target of commercializing units with power output of 700W and hot water output of 620W (with power generation efficiency of 45% and waste heat utilization efficiency of 40%).

While we have proposed a system that can also use the high-temperature waste gas from solid-oxide fuel cells as air for regenerating desiccant, this paper assesses the energy saving effect of the system that can use waste heat from the gas engine already available in the market as part of the heat source for regeneration of the desiccant.

3 CENTRAL AIR CONDITIONING SYSTEM USING HOT WATER

Figure 1 illustrates the central air conditioning system using the hot water generated by a gas engine cogeneration unit for domestic use and a solar heater. The air conditioner is installed near a gas engine cogeneration unit with power output of 1kW, and the dehumidified cool air processed by the unit is supplied through air ducts in summer to various rooms including living room, dining room, bed room, study room and children's room. The cooling heat load for the central air conditioning with outdoor temperature of 35 ^{o}C and indoor temperature of 27 ^{o}C is assumed to be up to 4kW in a detached house with a floor area of 120 m^2 in the Kansai area, based on the coefficient of heat loss specified in the energy-saving standard for houses [3].

Figure 2 shows the equipment configuration of the whole system, and Figure 3 presents a psychrometric chart on the dehumidifying and cooling operation. The air conditioning system is outlined below. Hot water of approximately 80 ^{o}C heated with solar heat and waste heat from the gas engine is used as heat source for regeneration of the desiccant rotor. During mid-day hours, when the cooling heat load is large, with the aim of increasing the cooling heat load, indoor air in the amount equivalent to the air taken in from the outside is introduced to the desiccant rotor and dehumidified to lower the absolute humidity to around 8g/kgDA. The process air, heated to about 48 ^{o}C with the heat generated as a result of the dehumidification, is cooled with indoor air and supersaturated outdoor air. The cooling heat load is set to be 4kW. Then, in consideration of the moisture of 330g/h generated from human bodies, etc., water is sprayed to the process air to reduce the absolute humidity to below that of the indoor air. After spraying, the dehumidified cool air of around 22 ^{o}C is supplied through air ducts to the rooms. The psychrometric chart indicates that the temperature of the regeneration heat source can be lowered with the application of same amounts of outdoor and indoor air to the desiccant rotor. The ventilation air flow to generate cooling heat load of 4kW is 390 m^3/h, and the cooling air supply is about twice this amount.

The devices of the proposed system are configured such as to allow consideration of the cases where solar heat or waste heat from the gas engine cannot be used and where the regeneration air can be heated with city gas burner to increase the cooling heat load. Solar heat received during the daytime is stored in the hot water storage tank and can be used at night as a heat source for regeneration of the desiccant.

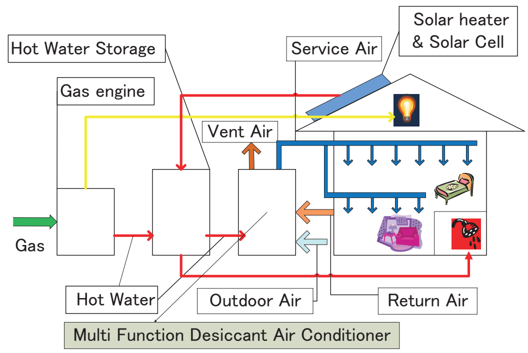

Figure 1: Image of the central air conditioning system.

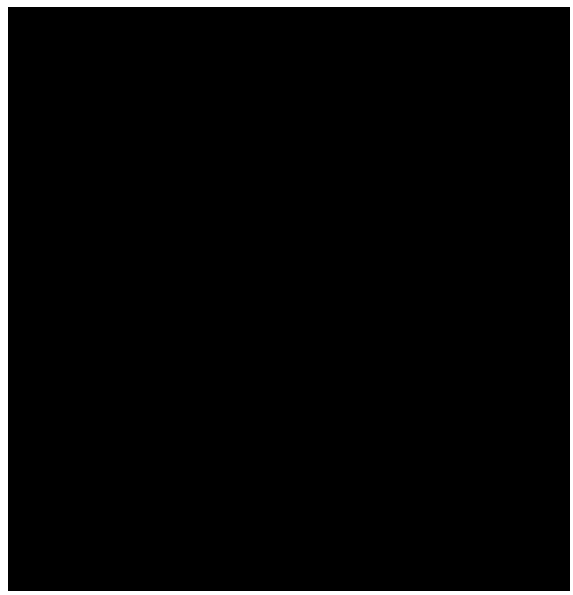

Figure 2: Equipment configuration of the whole system.

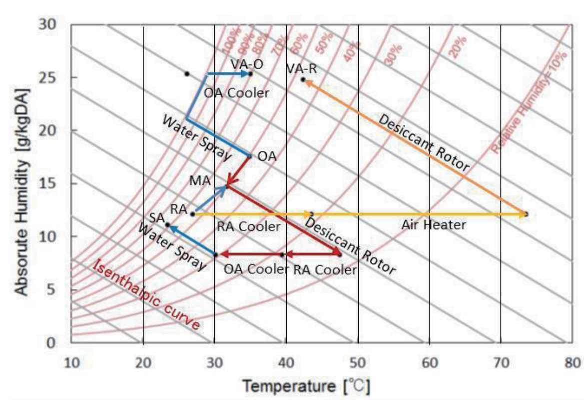

Figure 3: Psychrometric chart during dehumidifying and cooling operation.

Figures 4 and 5 respectively show temperature-heat load characteristics of the process air cooler (to cool the process air with indoor air and water-sprayed supersaturated air) and the regeneration air heater (to heat indoor air with hot water) that can address a cooling heat load of 4kW. The exchange heat quantity in Figure 4 less the heat input of the blower is the cooling heat load for the desiccant air conditioning system. Since the heat load of the hot water to heat the regeneration air in Figure 5 exceeds the waste heat collected from the gas engine with rated power output of 1kW, the shortfall will be met with the solar heat stored in the hot water storage tank. Relatively high thermal performance is assumed based on the premise that the minimum approach temperature of the heat exchangers is around 5 ^{o}C.

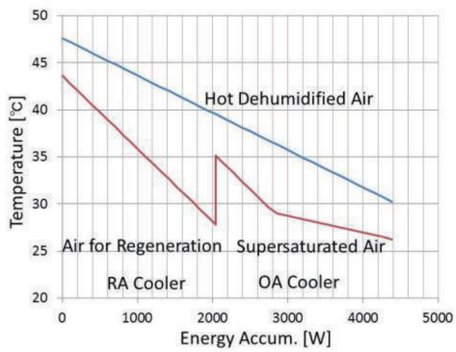

Figure 4: Temperature-heat load characteristics of process air cooler.

Figure 5: Temperature-heat load characteristics of regeneration air heater.

Figures 6 and 7 show the Sankey diagrams of an energy supply system with dehumidification cooling and hot water supply functions using waste heat from gas engine and city gas burner on enthalpy and exergy bases, respectively. Based on the exergy assessment of this system, the largest losses in the gas engine are generated in connection with combustion in the cylinder and cooling in the cylinder jacket, while the largest losses in the dehumidification cooling system stem from use of the city gas burner, efficiency of the blower, and heat exchange of desiccant rotor, hot water heater, etc. In the desiccant unit in Figure 6, the latent heat generated by spraying water to the dehumidified supply air is added to the cooling heat load mentioned above. Quantitative assessment is described in the examination of the factor analysis.

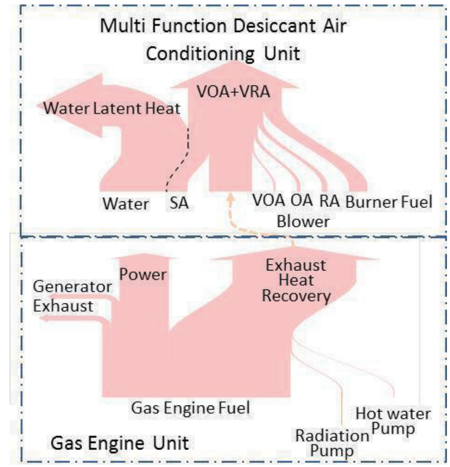

Figure 6: Sankey diagram based on an enthalpy basis.

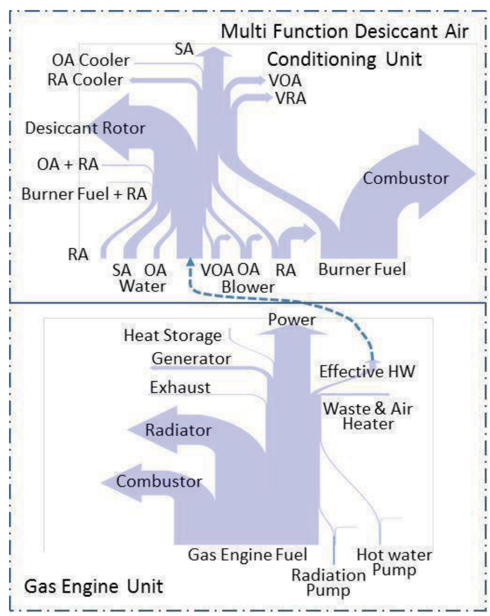

Figure 7: Sankey diagram based on an exergy basis.

4 AIR CONDITIONING AND HOT WATER SUPPLY SYSTEM USING HEAT PUMP

The "top runner system" enforced by the Energy Saving Act in 1999 mandates the display of energy consumption efficiency, etc. on products, and currently designates 23 kinds of equipment including air conditioners and hot water supply systems. The efficiency has direct impact on the sales of air conditioners in particular, and competition for improving their efficiency has intensified. Natural refrigerant heat pump water heater, which significantly saves energy in comparison with traditional electric water heaters, is included in the 10 items of the JSME Technology Roadmap. According to the literature, the energy consumption coefficient (coefficient of performance, COP), which is determined by dividing the quantity of heat production by energy input, is anticipated to increase from 3.5 at the time of the release in 2001 to 6.0 in 2030. These air conditioners and heat pump water heaters are currently obligated to display their efficiency in terms of APF (annual performance factor).

Based on the values shown in the catalogs of these products, we have developed a process simulation model to evaluate power consumption for dehumidification cooling and water heating, using outdoor temperature and humidity, preset indoor temperature, and ventilation air flow as well as the temperature of input water and heating temperature of water heaters as the parameters. Figure 8 illustrates the model. The air conditioner is a model with regenerative dehumidification capacity. R410A and CO_2 are assumed to be the refrigerants for the air conditioner and heat pump water heater, respectively. The power consumption can be calculated based on the outdoor moisture and heat taken in by ventilation and heat leakage from outside of the building in addition to the operation specifications of the desiccant mentioned above. The operation time and power consumption of the heat pump water heater to supply the same amount of hot water supplied by the gas engine cogeneration system mentioned earlier can be calculated in consideration of heat radiation during the storage of the hot water.

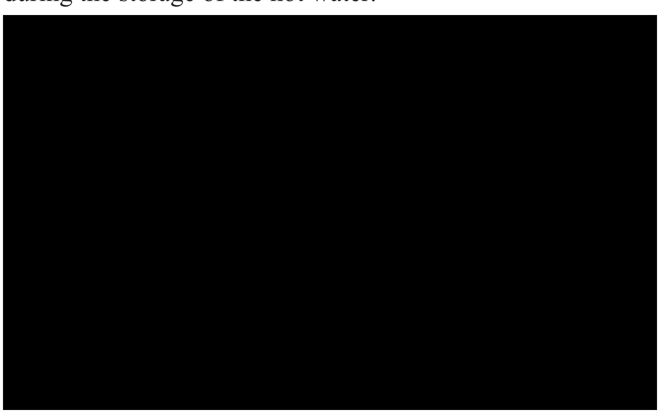

Figure 8: Equipment configuration.

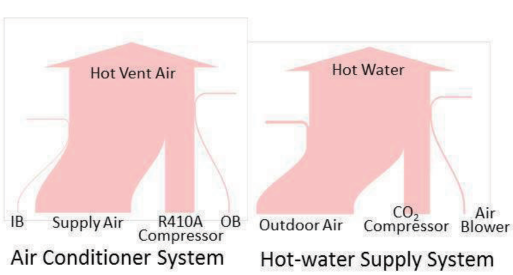

Figure 9: Sankey diagram based on an enthalpy basis.

Figures 9 and 10 show the Sankey Diagrams of this system based on enthalpy and exergy respectively. Exergy in the heat pump is mainly lost from the compressor, valve, evaporator, and condenser. As the temperature of the stored hot water in the hot water supply system is usually as high as 65 °C or more, the mixing process of hot water and tap water during use causes large losses.

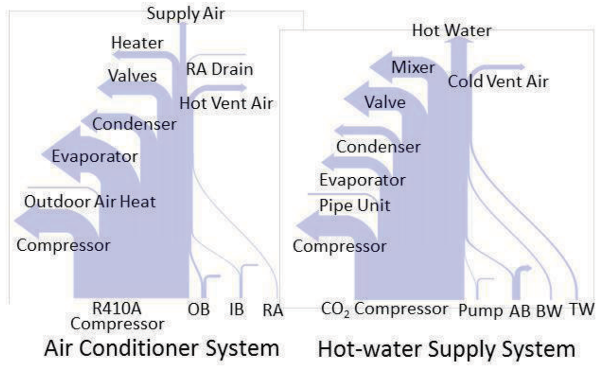

Figure 10: Sankey diagram based on an exergy basis.

5 QUANTIFICATION AND COMPARISON OF LOSS IN THE ENERGY SUPPLY SYSTEM FOR DOMESTIC USE

Based on data from Japan Meteorological Agency, typical changes in the temperature and humidity for an extremely hot day in Osaka and Kyoto this year are simulated and presented in Figure 11. As the sun goes up and the outdoor temperature rises, relative humidity declines. On the other hand, absolute humidity is constant at approximately 17g/kgDA throughout the day unless the weather changes, and discomfort index is over 77 even at night, at which half the people feel uncomfortable.

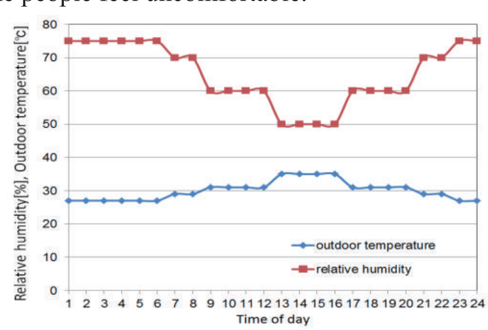

Figure 11: Outdoor conditions of an extremely hot day.

The power consumption and hot water requirement under the outdoor conditions simulated above were determined with indoor temperature of 27 °C, absolute humidity of 12g/kgDA and ventilation air flow of 390 m^3/h.

With the outdoor temperature of 30 °C or more, the process air flow was assumed to be twice as much as ventilation air flow to increase the cooling capacity. For the purpose of calculating the operation time of the cogeneration system and heat pump hot water heater, the daily hot water requirement was set to be 6kWh. To simplify the comparison of different systems, the energy saving effect of photovoltaic power generation was excluded. Although it was necessary to consider the axle efficiency of the rotary machine, inverter efficiency, and motor efficiency to calculate the power of the rotary machine, only the information on power consumption in the catalog was available, and adiabatic efficiency was therefore used to calculate the power consumption of the rotary machine in the process simulator.

5.1 GAS ENGINE SYSTEM FOR DOMESTIC USE

For the examination of this system, two cases on power generation efficiency of the stoichiometric gas engine for domestic use were selected, namely 26.3% (the current value) and 30% (a value expected in the future), and the temperature of the hot water supply was set to be constant at 80 ^{o}C. The waste heat utilization efficiency in the two cases was respectively set to be 63.7% and 58% in anticipation of some heat loss due to radiation, and the gas engine was assessed on an exergy basis temperature with the outdoor temperature of 35 ^{o}C. The assessment results with the input fuel to be 100 are shown in Table 2. The overall thermal efficiency is respectively 92% and 90% on an enthalpy basis and 30.1% and 32.9% on an exergy basis. It is obvious that improvement in power generation efficiency results in reduction in loss from the radiator. The energy requirement on a lower heating value basis in case of operating the gas engine from 7 a.m. to 11 p.m. is tabulated. Table 3 shows the exergy analysis of the desiccant air conditioner under different outdoor conditions as well as its power consumption according to the specifications and operation time. The types 35-A, 31-B, 29-C, 27-D, and 35-E involve different outdoor temperatures and supply air flows. The Arabic numerals represent the outdoor temperature, and the supply air flow is approximately 750 m^3/h in Types A, B and E, and 380 m^3/h, or about half of the former, in Types C and D. Types A and B are operation with high cooling capacity additionally using solar heat; Type C is operation with intermediate cooling capacity using waste heat from gas engine; and Type D is dehumidification operation using the heat of the stored hot water. In Type E, city gas is combusted to increase the cooling capacity. The results of the exergy analysis of the desiccant air conditioner shown in Figure 7 and the assessment of loss in this table demonstrate that the use of city gas for heating the regeneration air generates very large amount of combustion loss. In the calculation on the process, the dehumidification efficiency of the desiccant rotor was set to be 85% or less, and the head and efficiency of the blowers to be 350 Pa and 35%, respectively. For the heat transfer property of the heat exchangers, the minimum approach temperature with the maximum load was set to be 5 ^{o}C. In the exergy evaluation, the outdoor temperature was different between the cases. When the evaluation temperature dropped, the exergy loss in the blower efficiency increased correspondingly. The power consumption of the blower in case of operation for 24 hours a day is shown in the lower right of the table.

Table 2: Evaluation of the gas engine.

	Existing	Future
Input		
Gas Engine Fuel	100	100
Pump	1.2	1.2
Output		
Power	24.9	28.4
Hot Water	5.2	4.5
Exergy Loss		
Radiator	37.3	31.3
Combustor	25.2	27.4
Heat Exchanger	2.9	3.1
Generator	4.1	5.1
Pump	0.7	0.8
Exhaust	0.9	0.6
Spec		
Gas Consumption [W]	3,810	3,340
Operating Time [hrs]	16	16
Required Energy [Wh]	60,960	53,440

Table 3: Evaluation of the desiccant air conditioner.

OA Temp. [degC]-Type	35-A	31-B	29-C	27-D	35-E
Input [W]					
Effective HW	431	488	210	76	394
Blower	384	387	241	239	385
Burner Fuel	0	0	0	0	1,428
Water	78	73	18	5	129
RA	27	7	3	0	27
Output [W]					
SA	71	62	15	3	118
Vent OA & RA	10	21	32	7	21
Exergy Loss [W]					
Combustor	0	0	0	0	1,242
Desiccant Rotor	213	231	90	23	346
OA Cooler	80	98	37	35	98
RA Cooler	101	93	78	47	128
Air Heater	184	193	62	50	150
Blower	252	252	157	155	253
Mixing	8	3	1	1	8
Spec.					
SA Temp. [degC]	22.3	19.2	20.9	23.9	18.5
SA Volume Flow [m3/h]	754	752	376	383	745
Dehumidified Water [kg/h]	2.55	2.25	2.46	2.02	2.55
Heat Input [W]	3,780	3,897	2,300	900	3,409
Cooler Heat Duty [W]	4,239	4,329	2,926	2,047	5,105
Cooing Duty [W]	1,201	1,989	771	395	2,148
Regeneratied Temp. [degC]	72.2	72	60	43	85
Operating Time [hrs]	4	8	4	8	
Required Power [wh]	1,537	3,092	963	1,915	7,507

The amount of dehumidification by the desiccant air conditioner, which depends on the difference between indoor and outdoor absolute humidity, is 2.0 to 2.6 kg/h with ventilation air flow of 390 m^3/h. The room cooling capacity is influenced by regeneration temperature and outdoor absolute humidity, and increases as the temperature of the supply air falls. Even when the regeneration air temperature is 72 ^{o}C, the supply air can be cooled to 20 ^{o}C or less with water spray if the outdoor absolute humidity drops.

The cooling capacity, including the latent heat of the water, exceeds 5kW in Types A and B.

5.2 HEAT PUMP SYSTEM

Using the process simulator based on the values in catalogs prepared by manufacturers, the latest air conditioner was considered to have the minimum approach temperature of 3 ^{o}C, compressor with 75% efficiency and blower with 40% efficiency under its rated capacity. Table 4 shows the exergy evaluation results and power consumption of the air conditioner and heat pump hot water heater. As the outdoor temperature and dehumidification amount decrease, the power consumption of the compressor and blower falls. At the outdoor temperature of 35 ^{o}C, the COP of the air conditioner and heat pump hot water heater were 5.15 and 4.72 respectively, while their exergy values were 7.1% and 31.9% respectively. In the heat pump hot water heater, the effective exergy efficiency dropped to less than half due to mixing with supply water and heat radiation from the hot water storage tank.

Table 4: Evaluation of the heat pump system.

Reheat Type Air Conditioner					Heat Pump Hot Water heater	
OA Temp. [degC]	35	31	29	27	OA Temp. [degC]	27
Input [W]						
COMP	937	750	607	539	Comp.	786
Blower	95	87	76	59	Blower	29
RA	14	14	0	0	Water	6
					Pump	7
Output [W]						
SA	73	64	16	4	Hot water	262
Vent & Drain	64	60	30	15	Cold Vent	27
Exergy Loss [W]						
Comp	211	170	139	124	Comp.	134
Evap	368	291	226	184	Pipe	5
Condenser	163	143	115	109	Condenser	80
Heater	58	32	39	57	Valve	197
Blower	56	48	45	28	Evaporator	100
Valves	47	30	73	76	Blower	19
Mixing	7	12	0	0	Pump	4
Spec						
Cooling Capacity [W]	5,317	4,631	3,237	2,654	Heating Duty [W]	3,877
Power [W]	1,033	837	683	598	Power [W]	822
Dehumidified Water [kg/h]	2.55	2.25	2.46	2	Tap water Temp. [degC]	30
SA Temp [degC]	22	19	21	24	Hot Water Temp. [deg C	67
SA abs. Humidity [g/kgDA]	11.8	11.8	11.8	12.0	Heat Loss [%]	10
SA Volume Flow [m3/h]	754	752	376	383		
COP	5.15	5.53	4.74	4.44	COP	4.72
Operating Time [hrs]	4	8	4	8	Operating Time [hrs]	1.7
Required Power [wh]	4,131	6,699	2,731	4,781	Required Power [wh]	1,397

5.3 ASSESSMENT OF ENERGY SAVING EFFECT AND SURPLUS POWER

The replacement of the existing air conditioner with the proposed desiccant air conditioner is expected to produce energy saving effect of 1,574W (net output of gas engine: 925W, power consumption of desiccant: 384W, and power consumption of air conditioner: 1,033W).

Then, efficiency in the generation of surplus power was evaluated in the two cases of the grid power conversion efficiency of 40% (the current value) and 55% (the efficiency of the latest gas turbine combined cycle) on a lower heating value basis. The daily power consumption of the air conditioner and hot water supply was divided by the grid power conversion efficiency mentioned above to determine the primary energy requirement.

The primary energy corresponding to the surplus power of the gas engine is the daily energy consumption of the gas engine less the above energy requirement. Accordingly, the efficiency in the generation of surplus power can be calculated by subtracting power requirement of the desiccant air conditioner from net power consumption of the gas engine and dividing the difference by the primary energy corresponding to the surplus power. With blower efficiency of 35% and 55%, power surplus is respectively 6,693Wh and 9,470Wh. The values determined with the calculation mentioned above are shown in Table 5.

Table 5: Efficiency in the generation of surplus power.

System Power	blower efficiency 35%		blower efficiency 55%	
	Gas Engine Power efficiency			
	26.3%	30.0%	26.3%	30.0%
40%	61%	193%	86%	272%
55%	27%	39%	38%	55%

6. CONCLUSION

The exergy analysis has identified the components of the energy supply systems that need to be improved in the future. Especially, the energy supply system using the existing gas engine cogeneration unit for domestic use is more beneficial than the combination of existing power system efficiency and Eco Cute, but has no advantage when compared with the latest combined cycle because of the exergy loss due to combustion and heat transfer in the heat source device, and it is therefore necessary to improve the cogeneration efficiency. Meanwhile, in the central air conditioning system using desiccant, which is currently under development, it is essential to improve the blower efficiency. Nevertheless, in light of the current situation that peak power consumption has to be reduced, the air conditioner that makes use of waste heat at the peak power time in summer is attractive even if it is based on gas engine for domestic use. In the future, the power saving effect of the energy supply system in winter and throughout the year, as well as the effect of replacement of the heat source equipment with SOFC will be examined from the aspect of the exergy design of the devices.

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Describing Scenarios of Introducing Highly-efficient Gas Cogeneration Systems to Next-generation Apartment Buildings

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Abstract

Toward realizing a low-carbon society as well as ensuring energy security, there is an urgent need to describe scenarios for future energy systems. A cogeneration system (CGS) is one of key technologies and it is, in particular, promising for apartment buildings because of its high efficiency. This paper describes a scenario of introducing a CGS to apartment buildings in order to analyze the effect of this system using exergy as an evaluation indicator. Results show that dominant exergy losses of a CGS arise in combustor and radiator. Compared with the current energy system, a CGS has a potential of reducing energy consumption by introducing a desiccant air conditioner instead of a conventional air conditioner.

Keywords:

cogeneration system, scenario, apartment building, exergy, sustainable society

1 INTRODUCTION

The concept of smart grids draws more attention than ever as a promising enabler for achieving a low-carbon society as well as ensuring energy security. A smart grid refers to an electricity network that uses digital and other advanced technologies to manage the transport of electricity to meet the varying electricity demands of end-uses [1]. In a smart grid, introducing combined heat and power (CHP) systems, or cogeneration systems (CGS), is one of hopeful options. Advantages of CGS include providing consumers with not only electricity but also heat, which may lead to improving energy efficiency. In particular, CGS for apartment buildings is more energy efficient than that for detached houses [2].

However, it is still ambiguous about which conditions are suitable for introducing CGS, which future uncertainties might be driving forces or obstacles for CGS, and to what extent CGS is energy efficient compared with other energy systems. To answer these questions, this paper describes a scenario of introducing CGS to apartment buildings. In this paper, "scenario" means not a prediction, but a set of plural futures that might unfold [3]. Toward this end, this paper firstly presents a framework of designing scenarios for energy systems. We then describe two scenarios, *i.e.*, business as usual (BaU) scenario and CGS scenario, based on this framework. When analyzing these two scenarios, we conduct exergy analyses for examining energy efficiency. Exergy analyses are useful for designing more efficient energy systems by identifying inefficient parts in existing systems [4].

2 POSSIBILITIES OF COGENERATION SYSTEMS FOR APARTMENT BUILDINGS

2.1 Advantages and disadvantages of cogeneration systems for apartment buildings

While there are various types of cogeneration systems (CGS), their components may involve gas engine, fuel cell, boiler, and heat pump. Since CGS is capable of generating both power and heat using gas, it is robust over instability of centralized power grid. In this regard, CGS is a means of ensuring energy security for each individual consumer as the Japan's national long-term energy policy is now unpredictable and nuclear power plants might be closed in the future. CGS is more advantageous for apartment buildings than detached houses because efficiency of power generator becomes higher when the rated capacity is larger. In fact, centralized hot water distribution systems based on cogeneration systems have been adopted in parts of apartment buildings in Japan.

On the other hand, dissemination of CGS has been hindered due to some problems, such as considerable heat loss in hot water pipes, low utilization of the system in summer during which hot water demand is low, and low economic viability. Another possible obstacle is surge in energy prices, such as natural gas prices. In a long run, energy prices are projected to gradually increase in accordance with increase in global energy demand [5]. Given this situation, we have been developing a new CGS for multi-family apartment buildings. This CGS uses small diameter pipes with the use of heat storage units in each house for hot water supply and room heating for realizing

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high energy efficiency in terms of heat distribution. Also, we have started developing a new type of desiccant air conditioner that uses hot water for keeping the room dry and cool during summer and humidified and warm during winter. This development intends to reduce heat loss of CGS and improve entire efficiency of the energy system.

2.2 Related work

A number of studies have been carried out on analyses of energy systems [6][7]. Balta, *et al.* [8] analyzed energy and exergy efficiencies for several energy options, such as electric boiler and cogeneration. Yamaguchi, *et al.* [2] simulated effects of CGS for apartment buildings, showing that CGS which used a gas engine as a main generator reduces the annual use of primary energy. They also showed that, however, CGS brought heat loss or more heat than the consumers' demand in summer. Aiming to avoid abandoning the heat generated by CGS, Hirano, *et al.* [9] conducted energy and exergy analyses of CGS with desiccant air conditioner for detached houses. They revealed that energy efficiency of CGS would be improved when a desiccant air conditioner was used instead of conventional heat pump air-conditioning systems.

However, long-term perspectives of energy systems, including CGS, have not adequately explored. While existing studies rather focuses on energy efficiency of specific energy systems, economic and environmental assessments for CGS will easily change in the future because some external factors surrounding the energy systems are of high uncertainty. These factors include political situations, energy prices, consumers' behavior, and technological advancement. As related works, several future scenarios on energy systems (*e.g.*, [1][10]) have been published; nonetheless, they usually focuses solely on electricity systems, not mentioning heat systems.

3 FRAMEWORK OF DESIGNING SCENARIOS FOR FUTURE ENERGY SYSTEMS

3.1 Basic concept

To design scenarios for future energy systems, which are not limited to CGS, we propose a framework for scenario design as illustrated in Fig. 1. The basic idea is to describe scenarios not from a technological viewpoint only, but from a holistic viewpoint, which include technological, social, economic, and political aspects. As an approach to structuring these complex components in designing such scenarios, this paper defines three levels as illustrated in Fig. 1 as follows:

- Social level: defines future situations regarding social, political, and economic factors which are associated with the energy system.
- Regional level: defines targeted regions/areas and human behavior or lifestyles. This level involves information associated with regions/areas, such as geographical and climate data.
- Technological level: defines configurations of energy systems, such as CGS and renewable energy systems.

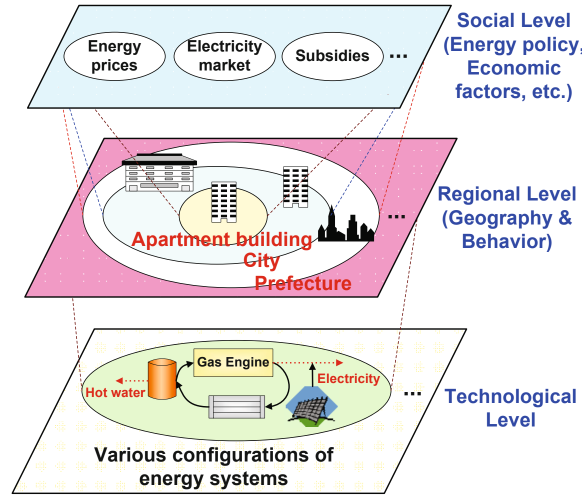

Fig. 1: Concept of describing energy systems scenarios

We describe a scenario by listing factors related to energy systems, classifying them based on the three levels above, and then connecting those factors with each other in order to make a story. In technological level, we construct a model of each individual configuration of energy systems. Taking CGS as an example, elements of CGS may include gas engines, high-efficiency fuel cells, highly-efficient heat pumps, and other advanced devices as its components. Based on the existing method of scenario design [11], the scenario design processes are composed of five steps as shown below:

1. Setting a problem of a scenario to be designed.
2. Listing factors which are related to energy systems, classifying them into the three levels in Fig. 1, and relating them with each other in each level in order to clarify the causal relationship among the factors.
3. Setting conditions of the factors listed in Step 2, followed by writing a story as text by detailing the relationships between the factors.
4. Executing simulations based on the conditions set in Step 3.
5. Describing several sub scenarios, usually 2-4 scenarios by repeating Steps 2-4, and comparing the sub scenarios.

3.2 Concept of scenario design system

Our research project plans to describe various scenarios for a variety of energy systems, including a scenario of introducing CGS to next-generation apartment buildings.

Table 1: Descriptions of each scenario

<table>
<tr><th rowspan="2">Level</th><th colspan="2">Scenario descriptions</th></tr>
<tr><th>(A) BaU Scenario</th><th>(B) CGS Scenario</th></tr>
<tr><td>Social</td><td>The current political, economic, and societal systems are maintained.</td><td>Power selling is applicable even to the power generated by CGS. CGS becomes more attractive to consumers by giving them subsidies from the government.</td></tr>
<tr><td>Regional</td><td colspan="2">The targeted area is a 400-unit apartment building, located in Osaka, Japan. This building has 180m-length pipe with a diameter of 4 inches and the area of the rooftop is 1,000m^2. The lifestyle of the residents is assumed to be unchanged from the present. The duty of cooling and heating in the apartment building is set as follows:
• Cooling duty of air conditioner: 432kW (cooling duty per household: 3.6kW/household, 120 households are keeping their air conditioners on)
• Hot water: 279kW (water flow per household: 10L/min (0.6m^3/h), hot water temperature: 40°C, outdoor temperature: 35°C, 40 households are using hot water)
In Scenario (B), the heat supply from the solar heating system is set at 163kW, by assuming that the heat flux from the sun is 0.32kW/m^2 (in Osaka [15]), solar heating systems are placed on 70% of the whole rooftop (700m^2), and the efficiency of solar heating is 72.4% (see Table 2).</td></tr>
<tr><td>Technological</td><td>The configuration of the energy system is described in Fig. 2. Electricity is distributed from the grid power, while heat is generated by a conventional gas boiler. The adiabatic efficient for air conditioner and the efficient of blower are assumed to be 75% and 40%, respectively.</td><td>The configuration of the energy system is described in Fig. 3. Electricity is supplied primarily from a gas engine and even from grid power unless the power meets the demand. Desiccant air conditioners are installed in each apartment. Solar heating systems are installed on the roof of the building. The hot water supply system (heat pump) is used for heating tap water up to 65°C as the heat pump is efficient when water temperature is low.</td></tr>
</table>

We are developing a system for helping to design these scenarios using Sustainable Society Scenario (3S) Simulator [12], which supports a scenario design team in describing and analyzing the scenarios. In describing the scenario, we execute simulations of various configurations of energy systems as well as conduct exergy analyses of these systems. In the simulations, we employ VMGSim [13] in order to model and analyze various energy systems.

The ultimate goal of developing this system is to connect 3S Simulator [12] with VMGSim [13]. 3S Simulator serves as a platform for describing a scenario where we articulate, in a text form, conditions of external factors of energy systems as well as the specifications of the energy systems. VMGSim plays a role of simulating various energy systems based on the conditions set in the scenario for assessing those energy systems quantitatively.

4 CASE STUDY

4.1 Two scenarios described in the case study

Based on the proposed framework, this section presents a case study of describing two scenarios, *i.e.*, (A) BaU Scenario and (B) CGS Scenario. Scenario (A) assumes a conventional energy system of Japan, while Scenario (B) assumes introducing CGS in an apartment building.

In this case study, we set the following assumptions for

Table 2: Specifications of energy devices in Scenario (B)

<table>
<tr><th>Device</th><th>Parameter</th><th>Value</th><th>Remarks</th></tr>
<tr><td rowspan="2">Gas engine</td><td>Rated output</td><td>394kW</td><td rowspan="2">Reference [16]</td></tr>
<tr><td>Power efficiency</td><td>41.5%</td></tr>
<tr><td rowspan="2">Hot water supply system (heat pump)</td><td>Output water temperature</td><td>65°C (in summer)</td><td rowspan="2">Reference [17]</td></tr>
<tr><td>Heating capacity</td><td>81.4kW</td></tr>
<tr><td rowspan="2">Solar water heater</td><td>Heating efficiency</td><td>30%</td><td rowspan="2">Reference [18] and assumption</td></tr>
<tr><td>Effective heating area</td><td>3.8m^2/unit</td></tr>
<tr><td>Desiccant air conditioner</td><td>Cooling capacity</td><td>3.6kW</td><td>Assumption</td></tr>
</table>

both scenarios:

- We analyze energy efficiency in daytime of an extremely hot day in summer in Osaka, in which heat demand is least of the year. Outdoor and indoor temperatures are set at 35°C [14] and 27°C, respectively. Water and gas temperatures are 30°C.
- We operate each device of energy systems in such a way that heat demand for the residents is satisfied. Note that the gas engine in Scenario (B) runs with its rated output for achieving high efficiency, whereas extra electricity from the gas engine is delivered over to the power grid, if any.
- We focus on heating and cooling systems as energy systems since only heating and cooling differ between Scenarios (A) and (B), while other energy devices, such as refrigerators and TVs, are installed in the same way in both scenarios.

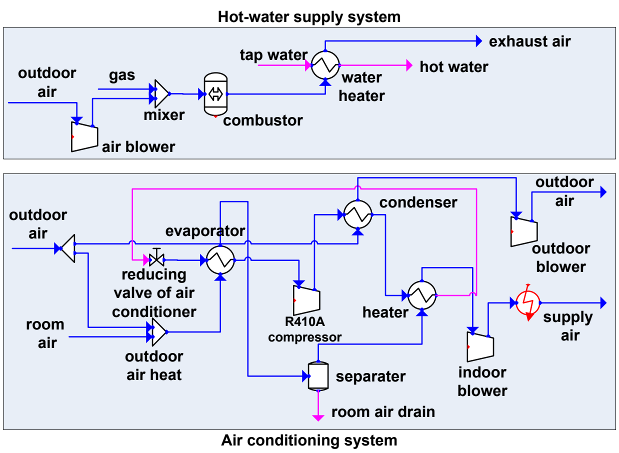

Fig. 2: Configuration of energy systems in Scenario (A)

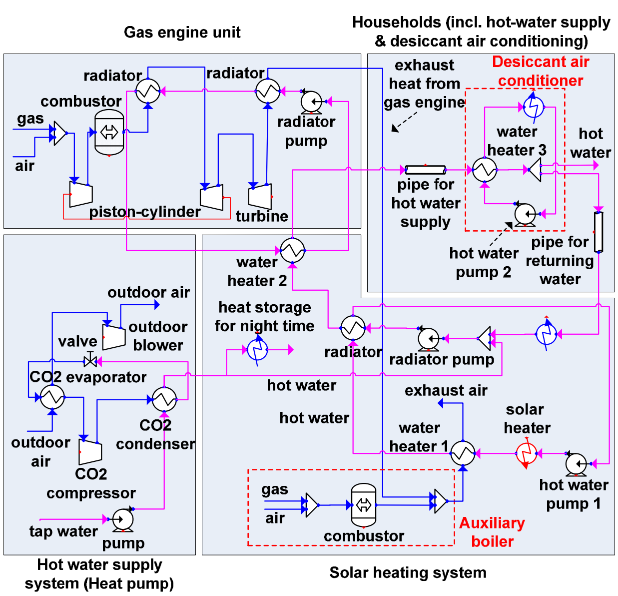

Fig. 3: Configuration of energy systems in Scenario (B)

Table 1 depicts an overview of each scenario in the three levels. Scenario (B) introduces gas engine, desiccant air conditioner, hot water supply system (heat pump), and solar heating system (see Fig. 3). The auxiliary boiler, a part of the solar heating system, is used when solar heat is not enough in, *e.g.*, cloudy days. Table 2 summarizes specifications of system components used in Scenario (B).

4.2 Simulation results of each scenario

Fig. 4 and Fig. 5 describe Sankey diagrams of Scenarios (A) and (B). As shown in Fig. 4, the exergy efficiency of the hot-water supply system (boiler) and air conditioning system (heat pump) in Scenario (A) is 0.9% and 12.5%. The sum of the exergy loss of evaporator, compressor, and condenser amounts to 72.9% in the air conditioning system.

In Scenario (B), electric power generated by gas engine is 393.9kW (rated output), while the power consumption by the cooling and heating systems shown in Fig. 3 is 74.6kW (see Table 3). In other words, the net power generation of CGS is 319.3kW (= 393.9 - 74.6), which is available for energy devices other than cooling and heating systems. The results of Fig. 5 indicate that the overall efficiency of the gas engine unit is 47.2% (power: 42.2%, hot water: 5.0%), while its exergy loss mainly arise in combustor and radiator (47.2%). The efficiency of hot-water supply system is 21.2%. In the solar heating system and households, the solar heater contributes to 4.3% as input exergy.

The comparison of primary energy input between Scenarios (A) and (B) is summarized in Table 4. Note that this comparison assumes that the power consumption by energy devices except for cooling and heating systems is 319.3kW so that the two scenarios become comparable. That is, since CGS provides extra power of 319.3kW in Scenario (B), we impose the same load on the primary power consumption of Scenario (A). In this case, the primary energy consumption of Scenario (B) (1,019.7kW) achieves 25.4% reduction from that of Scenario (A) (1,367.7kW).

4.3 Discussions on the results

The comparison between Scenarios (A) and (B) reveals that, as depicted in Table 4, Scenario (B) is more energy

Table 3: Power consumption and generation by cooling and heating systems of the apartment building

Item	Scenario		Remarks
	A	B	
Power consumption (kW)	77.4	74.6	Needed power for operating cooling and heating systems.
Power generation (kW)	0	393.9	Supplied power from the energy systems in the apartment building.

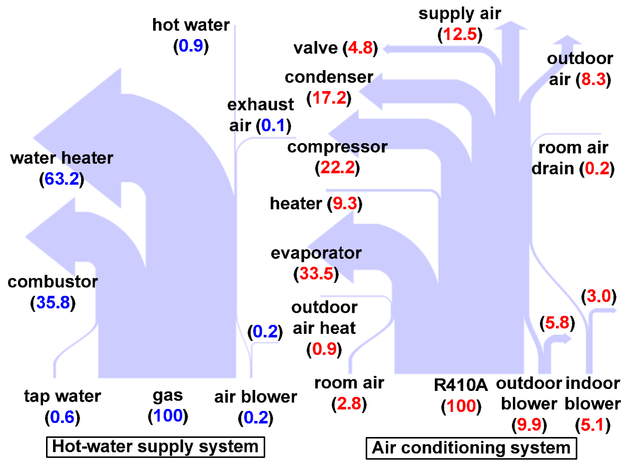

Fig. 4: Sankey diagram for Scenario (A)

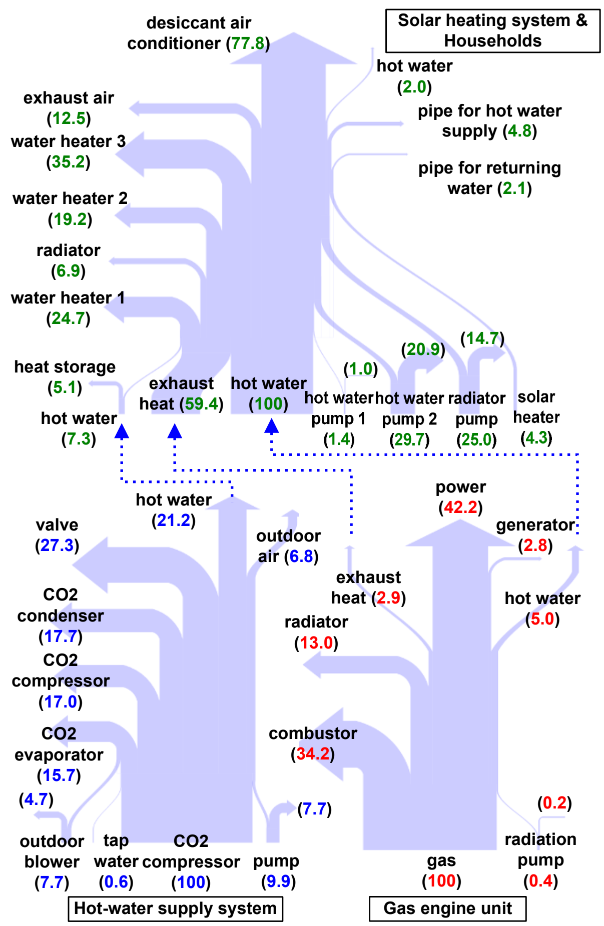

Fig. 5: Sankey diagram for Scenario (B)

efficient in terms of primary energy input. CSG of Scenario (B) does not generate much heat loss by the gas engine even in summer regardless of what existing studies on CGS pointed out (*e.g.*, [2]). Reasons for this improvement include (1) introducing a highly-efficient gas engine for apartment buildings (efficiency: 41.5%), (2) employing desiccant air conditioners, which requires much heat (77.8%, see Fig. 5) for operation, instead of conventional ones, and (3) installing solar heating systems on the rooftop. To make the energy system of Scenario (B) more efficient, the result depicted in Fig. 5 indicates that exergy loss of CO2 condenser, compressor, and evaporator should be reduced. In Scenario (B), while the hot water demand in this case study is 24.0m^3/h, extra hot water of 0.03m^3/h (see Table 4) is stored in the heat storage for night time, *e.g.*, for taking a shower after work.

Table 4: Comparison of primary energy consumption

Item	Scenario A	Scenario B	Remarks
Primary gas, power, and water input to the apartment building			
Primary gas consumption (kg/h)	19.2	66.9	
Primary power consumption (kW)	77.4	0	Used for cooling and heating
	319.3	0	Used for energy devices except for cooling and heating systems
Water (m^3/h)	24.00	24.03	
Primary energy consumption in the apartment building (in higher heat value; HHV)			
Gas (kW HHV)	292.7	1,019.7	HHV of gas:45MJ/Nm^3
Power (kW HHV)	1,075.1	0.0	Conversion efficiency of electric power: 36.9%
Total (kW HHV)	1,367.7	1,019.7	

However, Scenario (B) consumes 3.5 times larger amount of gas than Scenario (A). This implies that Scenario (B) might not be cost-effective in a long run. For further analyses of the scenarios described in the cases study, we should assess, at least, costs (including fixed and running costs) and CO2 emissions of each scenario. This is one of our future works. Another problem is that this case study presents only two scenarios. To expand a range of possible images of future energy systems, we should design a wide variety of alternative scenarios based on the proposed framework. In this context, we also should create several scenario variants from Scenarios (A) and (B) by changing assumptions. For example, by modifying assumptions in regional level, we can examine different lifestyles or different regions to install energy systems as scenarios. We are planning to design various scenarios in accordance with various configurations of energy systems as well as various social, political, and economic systems, using Scenarios (A) and (B) as a prototype.

5 CONCLUSIONS

This paper presented a framework for describing scenarios of various energy systems, classifying scenario elements into three levels – social, regional, and technological levels. Base on this framework, we described two scenarios called (A) BaU Scenario and (B) CGS Scenario in order to analyze the effect of introducing cogeneration systems (CGS). The results revealed that CGS is a promising means for improving energy efficiency as it provides both power and heat. In particular, it was indicated that there is a possibility of saving primary energy consumption by installing desiccant air conditioner together with CGS. Future works include:

- Conducting further analyses on CGS, such as assessing the described scenarios from the viewpoints of cost and CO2 emissions.
- Designing a variety of scenarios by assuming various configurations of energy systems as well as social, political, and economic systems.
- Developing system for supporting scenario design by connecting 3S Simulator and VMGSim.

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Exergy Design of Energy Conversion System Using Internet Technology

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Abstract

Exergy evaluation system with cloud computing technology has been developed for anyone to perform exergy analysis on a homepage for various energy conversion systems, such as gas engine, desiccant air conditioner, and fuel cell, etc. In this system, parameter studies on each system can be conducted on the homepage, changing initial conditions. The calculation results are obtained in the form of some tables, graphs, and sankey diagrams so that users can experience a process of minimized exergy loss without any paid software. To provide an example of exergy design, SOFC (Solid Oxide Fuel Cell) cogeneration system for domestic use is described. The results show that exergy loss of the cell stack and some heat exchangers are mainly reduced, increasing power generation efficiency by the fuel utilization ratio.

Keywords: Exergy, Energy conversion system, SOFC, Process simulation, Cloud computing

1 INTRODUCTION

The accident of the nuclear power plant triggered the increasing of energy concern, so that the development of cogeneration system and renewable energy technology of solar heating and wind power are accelerating. The improvement of total system efficiency and cost reduction are important to popularize the cogeneration and natural energy system in addition to the improvement of each component efficiency. Thus, the exergy have been attracting attention to evaluate energy quality and to specify the energy waste in system.

Exergy is defined by using second law of thermodynamics, and can evaluate the thermal energy as equivalent energy of power. The system evaluation can be achieved by use of exergy, considering the energy quality difference of natural and fossil energy. Furthermore, exergy can evaluate loss based on a increase of entropy, which enthalpy cannot evaluate. The system design method to minimize these exergy loss is called “exergy design”. It is superior in terms of identification of devices that should be improved in an energy conversion system. The exergy was attracting attention several times [1][2], but exergy has not been widely popular, because great procedure is required to perform exergy analysis and exergy efficiency is smaller than enthalpy efficiency in most energy conversion system. However, it is easy to conduct an exergy analysis with developing computational devices and process simulator

In this study, the exergy analysis for the various energy conversion system to popularize the exergy design [3]. In this paper, the exergy design concept was described, and the exergy design was conducted for SOFC (Solid Oxide Fuel Cell) cogeneration system of domestic use. Finally, exergy evaluation system, which can perform exergy design for various energy conversion system on the homepage, was introduced.

2 EXERGY ANALYSIS AND DESIGN CONCEPT

Enthalpy is generally used to evaluate performance of energy conversion system, considering first law of thermodynamics. The energy defined by first law of thermodynamics is always preserved. On the other hand, exergy is defined as the maximum work that can be done by the system and a specified reference environment. The exergy of a system or a stream is composed of physical and chemical exergy.

$$E = E_c + E_p = E_c + (H - H_0) - T_0 (S - S_0), \qquad (1)$$

where E is exergy, E_c is chemical exergy, E_p is physical exergy, H is enthalpy, S is entropy, T is absolute temperature, subscript 0 is reference state, respectively.

The difference of enthalpy and exergy analysis are shown to consider heat transfer process in a heat exchanger. The input and output of enthalpy and exergy are a following relationship without heat loss from the heat exchanger,

$$\sum H_{in} - \sum H_{out} = 0, \qquad (2)$$

$$\sum E_{in} - \sum E_{out} = EL \geq 0, \qquad (3)$$

where EL is exergy loss, subscript in and out are input and output, respectively. The total of enthalpy is always preserved, but that of exergy is not preserved due to irreversible process of heat transfer.

Figure 1 shows schematic diagram of a heat exchanger for enthalpy and exergy analysis. The working fluid is water, the input water pressure is atmosphere, flow rate is

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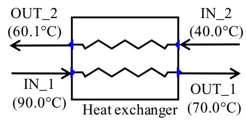


Fig.1 Schematic diagram of Heat exchanger.

Table 1 Enthalpy and exergy analysis of heat exchanger.

Stream	F[kg/h]	T[°C]	H[W]	E[W]
IN_1	1.0	90.0	104.7	7.22
IN_2	1.0	40.0	46.6	0.42
OUT_1	1.0	70.0	81.4	3.59
OUT_2	1.0	60.1	69.9	2.22
(Input - Output)	---	---	0.0	1.83

Table 2 Comparison of enthalpy and exergy evaluation.

Contents	Energy conversion criteria	
	Enthalpy	Exergy
Energy amount	○	○
Energy quality	×	○
Reference state	×	○
Pressure evaluation	×	○
Composition evaluation	×	○
Exhaust gas and heat loss	○	○
Mixing loss	×	○
Combustion loss	×	○
Rotation loss	×	○
Heat transfer loss	×	○
Decompression loss	×	○

1.0 kg/h. The pressure drop of the heat exchanger is not considered. The reference state is temperature of 25 °C and atmosphere pressure.

Table 1 shows calculation results. The total of enthalpy is preserved, but that of exergy is not preserved. The exergy loss of 1.83 W occurred in the heat exchanger.

Table 2 shows the comparison of enthalpy and exergy analysis. Enthalpy can consider amount of energy and exhaust loss, but cannot consider the quality of energy, composition, etc. Exergy can evaluate all terms including amount of energy, energy quality, composition, irreversible process loss of combustion, mixing, decompression, etc.

Figure 2 shows PDCA (Plan-Do-Check-Act) cycle of exergy design. First, a target system is modeled (Plan: Process modeling). Secondly, exergy analysis is done to evaluate the exergy loss of each device and exergy efficiency(Do: Exergy analysis). Then, a scheme minimizing the exergy loss is devised from the result of exergy analysis (Check: Loss evaluation). Finally, the scheme is done if there is a potential to get a return of investment. Consequently, that PDCA cycle is repeated, so that the system efficiency is improved. Designers without exergy design improve a system, considering similar process unconsciously. The exergy design is effective to quantify and visualize the system loss that can not be visualized using enthalpy analysis.

Fig.2 PDCA cycle of exergy design.

3 CLASSIFICATION OF ENERGY SYSTEM

The exergy evaluation system [5] for 5 classification energy conversion system has been developed in our homepage to popularize exergy design, using process simulator [4] and cloud computing system. Cloud computing is the delivery of computing over network or internet, whereby users can use a software or service without installing any software in a local computer. The detail of exergy evaluation system is described later. The released exergy evaluation systems are listed bellow;

- Classification A : Cogeneration system with town gas
  - Gas turbine
  - Gas engine
  - Fuel cell (SOFC: Solid Oxide Fuel Cell)
- Classification B: Power generation system from thermal heat
  - LNG power generation system
  - Rankine cycle system
- Classification C: Heat supply system of hot water and air heating
  - Gas hot-water heater
  - Heat pump heater with natural refrigerant
  - Vapor re-compression (Future plan)
- Classification D: Air conditioning
  - Air conditioner
  - Desiccant air conditioner
- Classification E: Natural energy utilization
  - Water spray cooling

In addition these system, the physical property estimation software with thermodynamics and physical property software [6] has been released on our homepage. This software allow the user without any paid software installation get physical property of natural gas, hydrogen, oxygen and nitrogen, carbon oxide, and carbon dioxide, etc.

4 EXERGY ANALYSIS OF SOFC SYSYTEM

To provide an example of exergy design with our homepage, the exergy analysis of fuel cell cogeneration is introduced. The target fuel cell is SOFC. The operation temperature of SOFC is as high as 600-900 °C, so that SOFC can operate without noble metal catalyst.

Furthermore, fuel can be reformed with thermal exhaust heat, and carbon oxide can be used as fuel. SOFC has been expected to use as electric power generation of a combined cycle and coal gasification system in the past, but the development of SOFC for the cogeneration system of home appliance is recently accelerating.

The exergy analysis is carried out for SOFC of which generation capacity is 700 W. The exergy analysis of a large scale device SOFC [6]-[8] has been performed, but there are few studies in terms of a minimized exergy loss. Figure 3 shows the schematic diagram of SOFC cogeneration.

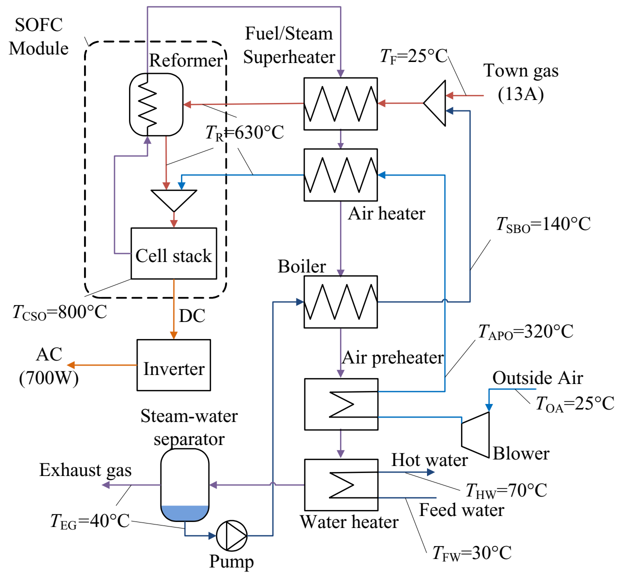


Fig.3 Schematic diagram of SOFC cogeneration system.

In this system, town gas (13A) is reformed to generate hydrogen and carbon oxide in the reformer. Then, hydrogen and carbon oxide are reacted on the electrode in the cell stack to generate power. The unreformed town gas in the reformer can be reformed in the cell stack to generate hydrogen, so that the reform efficiency of town gas in the SOFC module is approximately 100 %. DC electricity from the cell stack is converted into AC with the inverter. The hot exhaust gas from the cell stack is used for absorption heat of reformer and for heating source of fuel, air, and water. The water used for steam-reforming reaction is obtained from water in the exhaust gas. Thus, the SOFC can operate without supply of outside water.

The SOFC model is calculated using the process simulator [4]. The water flow used for fuel reforming is determined using steam to carbon ratio *S/C*,

$$F_{H_2O} = S/C \times \left(F_{CH4} + 2F_{C2H6} + 3F_{C3H8} + 4F_{C4H10}\right), \qquad (4)$$

where *F* is mole flow [kgmole/h].

The fuel reforming is calculated, using steam reforming reaction (R1) and water gas shift reaction (R2) at a given reforming temperature,

$$C_nH_{2(n+1)} + nH_2O = nCO + (2n+1)H_2, \qquad (R1)$$

$$CO + H_2O = CO_2 + H_2. \qquad (R2)$$

For the simplicity, the equilibrium calculation is conducted with (R1) and (R2) for initial fuel composition, where all composition except methane are completely reacted using reaction (R1), in order to estimate fuel composition after fuel reforming.

The electric generation reaction of hydrogen and carbon oxide at electrode in the cell stack is given,

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O, \qquad (R4)$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2. \qquad (R5)$$

The methane that is not reformed in the reformer is reacted before the calculation of the electric generation (R4) and (R5). The consumption amount of hydrogen and carbon oxide in the reaction (R4) and (R5) is determined, using fuel utilization ratio U_f,

$$U_f = \frac{(F_{H2})_{ele}}{F_{H2}} = \frac{(F_{CO})_{ele}}{F_{CO}}, \qquad (5)$$

where $(F_{H2})_{ele}$ and $(F_{CO})_{ele}$ are the consumption flow rate [kgmole/h] of hydrogen and carbon oxide, respectively.

The power generation efficiency of SOFC η_{AC} is defined, assuming that fuel is methane,

$$\eta_{AC} = \eta_{DC} \times \eta_{inv} = \frac{\Delta G_{H2} \times 4}{\Delta H_{CH4}} \times \eta_{ref} \times U_f \times \frac{V}{V_0} \times \eta_{inv}, \qquad (6)$$

where η_{AC} is power generation efficiency, ΔG_{H2} is Gibbs free energy of hydrogen at a given operation temperature of the cell stack, ΔH_{CH4} is heat of formation [kcal/kgmole HHV] of methane at the fuel supply temperature 25 °C, η_{ref} is the fuel reforming efficiency, V_0 is theoretical voltage [V], V is operation voltage [V], η_{inv} is the inverter efficiency. The fuel reforming efficiency is a hundred percent, because it is assumed that methane unreformed in the reformer is reformed in the cell stack. The theoretical voltage is defined as the following equation,

$$V_0 = \frac{-\Delta G_{H2}}{\left(4.60984 \times 10^4\right)}. \qquad (7)$$

The theoretical voltage is 0.98 V at the operation temperature of 800°C.

The hydrogen and carbon oxide that are not reacted in (R4) and (R5) are converted into water and carbon dioxide though the combustion reaction.

Table 3 shows the calculation conditions. The air to fuel ratio is 23, operation voltage is 0.75 V, operation temperature is 800 °C, heat loss to higher heating value of fuel is 0.05 [W/W HHV], the inverter efficiency is 0.90, reforming temperature is 630 °C. The input fuel and fuel utilization ratio are set as 1700 W and 0.70 to reproduce

η_{AC} of 41 % HHV at the power generation of 700 W that is corresponding to the rated operation condition of the typical SOFC cogeneration for home appliance. Table 4 shows fuel composition of town gas (13A). The town gas is composed of methane, ethane, propane, and isobutane.

Exergy of streams shown in Fig.3 are defined by equation (1). The temperature and pressure at the reference state are 25 °C and ambient pressure, respectively. The chemical exergy is estimated using the following equation,

$$E_c = \sum_i \left(E_i^{\circ} \times F_i \right), \qquad (8)$$

where E° is standard chemical exergy [kcal/mole], subscript i indicates chemical component shown in table 5.

Table 3 Calculation conditions of SOFC.

Outside air temperature T_{OA} [°C]	25
Fuel temperature T_F [°C]	25
Exhaust gas temperature T_{EX}[°C]	40
Feed water temperature T_{FW}[°C]	30
Hot water temperature T_{HW}[°C]	70
Cell stack operation temperature T_{CSO}[°C]	800
Reformer temperature T_R[°C]	630
Steam temperature at boiler output T_{SBO} [°C]	140
Air temperature at air preheater output T_{APO} [°C]	320
Input fuel [W HHV]	1700
Air fuel ratio [-]	23
Steam to carbon ratio S/C [-]	2.5
Electricity output [W]	700
Operation voltage V [V]	0.75
Fuel utilization U_f[%]	70
Inverter efficiency η_{inv}[%]	90
Heat loss ratio from module [W/W HHV]	0.05
Environment temperature [°C]	25

Table 4 Fuel composition.

Fuel	Town gas (13A)
CH_4 [Vol. %]	88.9
C_2H_6 [Vol. %]	6.8
C_3H_8 [Vol. %]	3.1
iC_4H_{10} [Vol. %]	1.2

Table 5 Specific chemical exergy.

Compounds	Phase	E°[kcal mol^{-1}]
CH_4	gas	198.41
C_2H_6	gas	357.02
C_3H_8	gas	513.62
iC_4H_{10}	gas	669.47
CO	gas	65.81
H_2	gas	2.05

Figure 4 (a), 4 (b) shows the enthalpy and exergy sankey diagrams illustrated from calculation results. The enthalpy sankey diagram of Fig. 4 (a) shows that electricity efficiency is 40.9 % HHV, the thermal recovery efficiency (Hot water) is 37.8 % HHV, so that total efficiency is 78.7% HHV. Enthalpy analysis can evaluate the exhaust gas loss, heat loss, and inverter loss. The highest loss is the exhaust gas of 11.9 %. The exergy sankey diagram of Fig. 4(b) indicates exergy loss of cell stack, reformer, fuel and steam mixing, every heat exchanger in addition to loss evaluated by enthalpy analysis. The highest exergy loss occurs at the cell stack of 19.8%. The exergy loss of the reformer is 2.5%, which is much smaller than that of the cell stack. This is because the chemical exergy is regenerated in the process of the fuel reforming by use of the physical exergy of the exhaust gas from the cell stack.

To improve the cell stack performance for reduction of the exergy loss, high fuel utilization rate and heat loss reduction are desirable [9]. In this study, the exergy analysis is performed with varying the fuel utilization ratio from 0.70 to 0.90 for the fixed heat loss ratio. There is increase in the amount of electricity as the fuel utilization

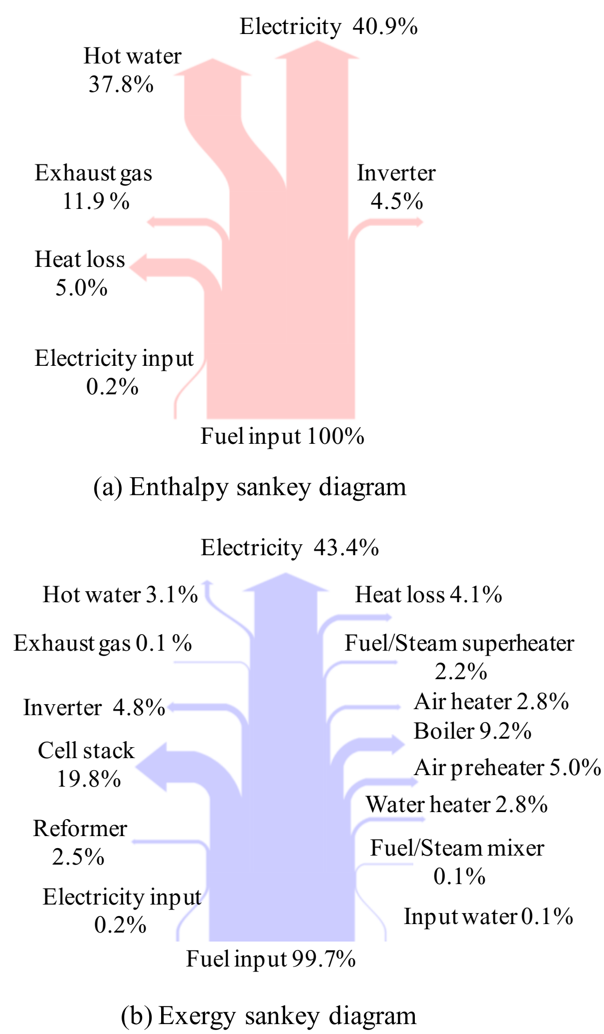
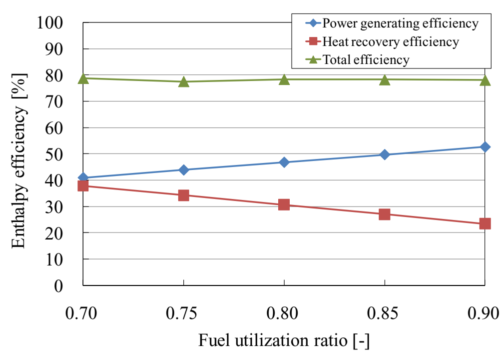


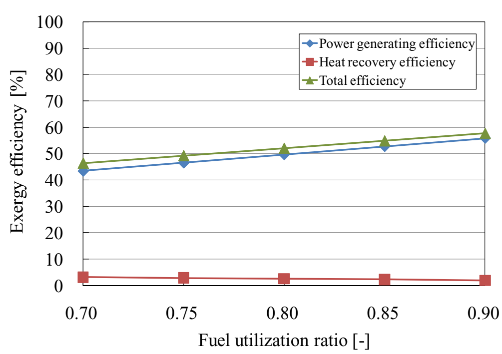
Fig.4 Sankey diagram.

rate increases. Thus, the amount of the input fuel is varied to maintain the amount of electricity of 700 W.

Figure 5 shows the effect of the fuel utilization ratio on power generation, heat recovery, and total efficiency. Figure 5 (a) is the result of enthalpy analysis, while Fig. 5 (b) is that of exergy analysis. The total efficiency of the enthalpy analysis is almost the same value 79% with increasing the fuel utilization ratio, but the total efficiency



(a) Enthalpy analysis



(b) Exergy analysis

Fig. 5 Effect of the fuel utilization ratio on generation, heat recovery, and total efficiency.

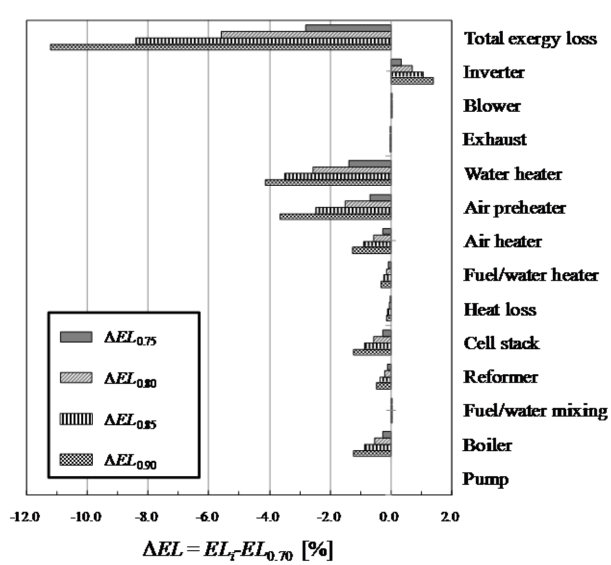


Fig. 6 Effect of fuel utilization on exergy loss.

of the exergy analysis is increased with increasing the fuel utilization ratio. When the power generation efficiency is increased, the heat recovery efficiency is decreased without relying on the analysis method. But the thermal heat of hot water has low quality of energy, so that there is increase in total efficiency of exergy as power generation efficiency increases.

The amount of exergy loss change is shown in Fig. 6 in order to specify which exergy loss are decreased with increasing the fuel utilization. The amount of exergy loss change is defined,

$$\Delta EL_j = EL_j - EL_{0.70} \quad (9)$$

where ΔEL is the amount of exergy loss change, $EL_{0.70}$ is exergy loss at the fuel utilization ratio of 0.70, subscript j indicates fuel utilization ratio of 0.75, 0.80, 0.85, and 0.90.

Figure 6 shows ΔEL of total exergy loss at fuel utilization ratio of 0.90 is dropped to 11.1%. This is achieved mainly by the exergy loss change of the heat exchangers of the water heater, air preheater, air heater, and boiler in addition to that of the cell stack. Therefore, this figure indicates that heat transfer performance of heat exchangers should be improved to increase fuel utilization ratio.

5 CLOUD COMPUTING SYSTEM FOR EXERGY EVALUATION

Figure 7 shows that the screenshot of our homepage for the SOFC cogeneration system that is developed in Japanese. Users input initial conditions and push calculation start button to get calculation results of a result table, enthalpy and exergy sankey diagrams, and some graphs, while graphs are not installed in the calculation page of SOFC.

Figure 8 shows the schematic diagram of cloud computing system for enthalpy and exergy analysis. Users push calculation start button, WEB server performs enthalpy and exergy analysis with the initial condition that users input, calling the process simulator via excel. The calculation load occurs at WEB server, not local computers of users. To realize this system, ASP.NET with IIS (Internet Information Service) is installed in WEB server. The sankey diagram is illustrated at user's local computer with Microsoft®Silverlight™. The connection between local computer and WEB server is conducted by asynchronous communication with AJAX (Asynchronous JavaScript and XML) in order to update only an essential portion in the page for improve of user availability. The calculation time from calculation start to displaying result is a few second. By the use of this system, the exergy analysis for various energy conversion system can be achieved, without any paid software, from local computer and Smartphone in which web browser of internet explorer and Firefox, etc. is installed.

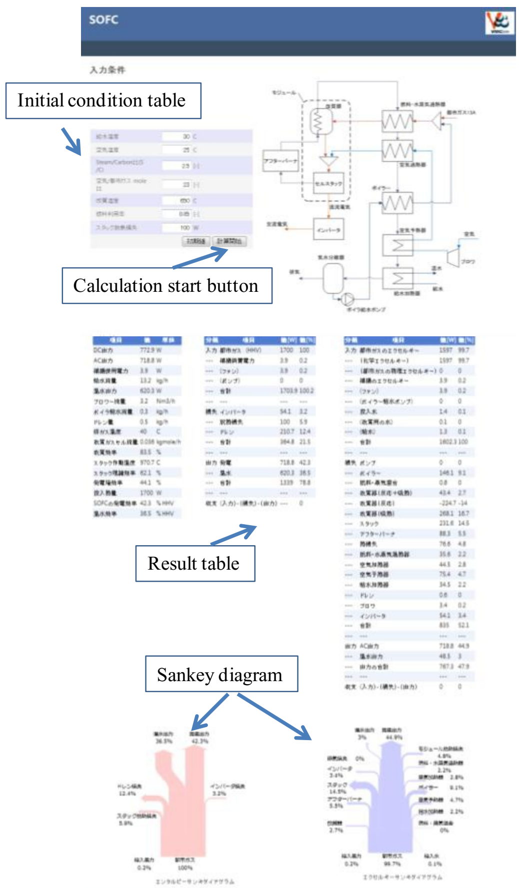


Fig. 7 Screenshot of exergy evaluation system for SOFC.

6 SUMMARY

In this study, the exergy analysis for various energy conversion system has been conducted to popularize a system development with exergy design. Thus, the exergy evaluation system on our homepage has been developed and released using a cloud computing technology for anyone to use exergy analysis program that we developed. In this paper, the exergy analysis of SOFC cogeneration system for home appliance is descried to provide the example of exergy analysis by use of exergy conversion system on our homepage. The result shows that the maximum exergy loss occurs at the cell stack. To minimize the exergy loss of the cell stack, the calculation is performed with varying the fuel utilization ratio. The results show that the exergy loss of the cell stack and some heat exchangers are reduced with increasing fuel utilization ratio. This indicates that heat transfer performance of some heat exchangers should be improved to increase fuel utilization ratio. In the future, we are going to increase the number of the energy conversion system that can perform exergy analysis on the homepage, and to develop English version of our homepage. Furthermore we will develop the energy conversion system, using exergy design.

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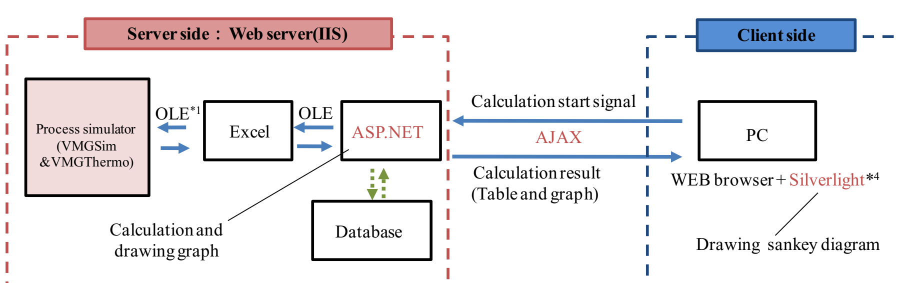

Fig. 8 Schematic diagram of exergy evaluation system with cloud computing system for enthalpy and exergy analysis.

Challenges of Advanced Utilization of LNG Cold in Osaka Gas Senboku LNG Terminals

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Abstract

In this paper, we report the outline of the Senboku LNG terminals, with a focus on Terminal 1, and the facilities using the LNG cold. In addition, by evaluating the efficiency of the facilities in terms of exergy, we consider the vision to improve utilization of LNG cold.

Keywords:

LNG Terminal, LNG Cold, Exergy, CO_2

1 INTRODUCTION

1.1 Increase in global demand for LNG

These days, it has been required to reduce the amount of CO_2-emission in every business. Natural gas (NG) has been more and more important because it emits, when burned, less CO_2 than other kinds of fossil fuel such as oil and coal.

There are two ways to transport NG. One way is to transport NG through pipelines from a production site to a city. Another way is to liquefy NG in a production site and then transport the Liquefied Natural Gas (LNG) by tankers offshore. About 28% of NG consumed is transported in the latter way. In recent years, more and more LNG has been transported to many countries around the world[1]. Fig. 1 shows what percentage of global trade volume of NG each of the two transportation ways account for in 2009. Fig. 2 shows what percentage of global import volume of LNG each country account for in 2009. Fig. 3 shows the trend in global trade volume of LNG from 1999 to 2009.

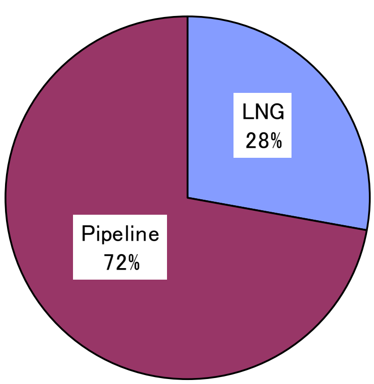

Fig. 1: The percentage of global trade volume of NG which each of the two transportation ways accounts for in 2009 [1].

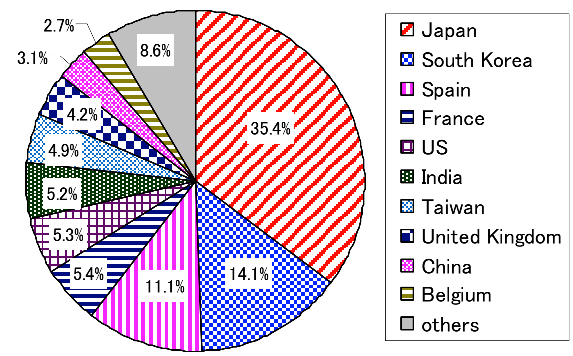

Fig. 2: The percentage of global import volume of LNG which each country accounts for in 2009 [1].

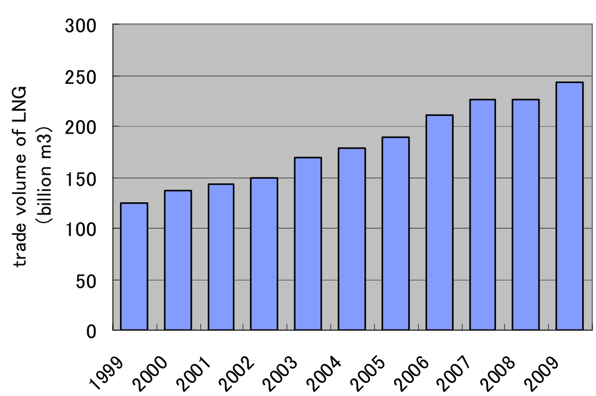

Fig. 3: The trend in global trade volume of LNG from 1999 through 2009 [1].

1.2 Cold energy of LNG

The temperature of LNG is approximately -160 degrees Celsius with higher energy density than that of wind

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power or solar energy. We can reduce electric power for cooling a substance when we cool it by heat exchange with LNG. We call this way "LNG cold energy utilization". When LNG is composed of Methane 89vol%, Ethane 6vol%, Propane 4vol% and Butane 1vol%, for example, available chemical energy of LNG is 14,400kWh/LNG-t and available cold energy of LNG is 240kWh/LNG-t(that is equal to approximately 2% of the chemical energy) [2]. If we aim at energy saving, it is essential to make effective use of the cold energy in addition to the chemical energy.

Today, Japan, which imports over 60 million tons of LNG a year (that is approximately 35% of total imports in the world [Fig. 2]), is the world's biggest importer of LNG. If we could convert about 15% of the cold energy of LNG annually imported into electricity, the amount of the electricity would be equal to the power consumed by about 400 thousand houses for a year [3].

2 THE FEATURES OF OSAKA GAS' LNG TERMINALS

2.1 Introduction of Osaka Gas

Osaka Gas is one of the city gas companies in Japan and started to import LNG in 1972. Today Osaka Gas has long-term contracts with 6 countries, namely Brunei, Indonesia, Malaysia, Australia, Qatar and Oman, and imports about 7 million tons of LNG from those countries and others in 2010. Osaka Gas will newly start to import LNG from Russia in 2011, and from Papua New Guinea in 2013 by long-term contracts.

Osaka Gas has three LNG terminals, namely Senboku LNG Terminals (Terminal 1 and Terminal 2) and Himeji LNG Terminal. Osaka Gas supplies city gas, which is produced in these three terminals, to about 7 million customers in the 6 prefectures of Kansai Region [Fig. 4].

2.2 Utilization of LNG cold energy in Osaka Gas

In Senboku LNG Terminals (Terminal 1 and Terminal 2) and Himeji LNG Terminal of Osaka gas, we make good use of LNG cold energy with many types of facilities, including plants such as air liquefaction and separation [Fig. 5], carbon dioxide liquefaction [Fig. 6], cryogenic power generation, and BOG re-liquefaction with cold energy storage system [Table. 1]. For example, the air liquefaction and separation plant with LNG cold energy has saved 50% of the amount of electric power consumed in other plants without LNG cold energy.

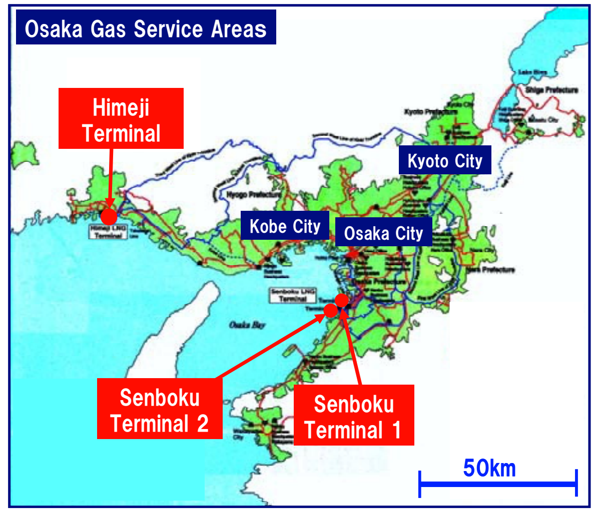

Fig. 4: Osaka Gas service areas.

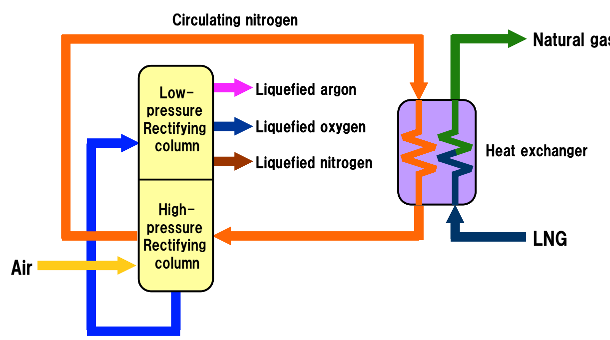

Fig. 5: Flowchart of the air liquefaction and separation facility using LNG cold energy.

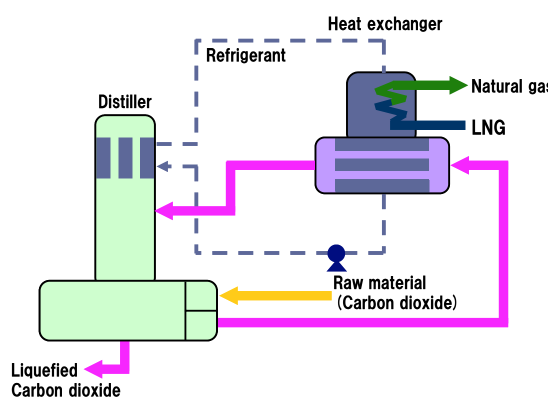

Fig. 6: Flowchart of the carbon dioxide liquefaction facility using LNG cold energy.

Table. 1: The facilities using LNG cold energy in each LNG terminal of Osaka Gas.

Senboku Terminal 1			
The facility using LNG cold	Start of operation	Installation site	The LNG cold utilization rate*
Air-condition with LNG cold	1978	in the terminal	approximately 100 %
Carbon dioxide liquefaction	1980, 2004	in the terminal	
Warm water chilling	1987	in the terminal	
Brain chilling	1987	in the terminal	
Expansion turbine	1989	in the terminal	
Air liquefaction and separation	1993	in the terminal	
Ethylene plant	2011	in a neighboring factory	

Senboku Terminal 2			
The facility using LNG cold	Start of operation	Installation site	the LNG cold utilization rate*
Cryogenic power generation	1979, 1982	in the terminal	approximately 50 %
Air liquefaction and separation	1983	in the terminal	
BOG re-liquefaction with cold energy storage system	1997	in the terminal	

Himeji Terminal			
The facility using LNG cold	Start of operation	Installation site	the LNG cold utilization rate*
Cryogenic power generation	1987	in the terminal	approximately 50 %
Expansion turbine	2000	in the terminal	
Intake air cooler	2004	in the terminal	

*This is the ratio of the volume of LNG vaporized at facilities using LNG cold to total volume of vaporized LNG in each terminal.

In Terminal 1 (Senboku LNG Terminal 1), in particular, we have achieved effective use of LNG cold energy, connecting the plants with those of neighboring factories, taking advantage of the location in industrial complex.

2.3 Efforts towards advanced utilization of LNG cold energy in Senboku LNG Terminal 1

Fig. 7 shows the outline of the utilization of LNG cold energy in Terminal 1. In every vaporization processes shown in Fig. 7 except for Open Rack Vaporizer (ORV), we can use LNG cold energy effectively. However, in ORV, we can't use it because LNG cold is wasted to sea by heat exchange with sea water.

In Terminal 1, in January 2011, we started to supply LNG cold to the neighboring factory's ethylene plant [Fig. 8] and this has enabled us to save energy and reduce CO_2-emission considerably with some improvements on operation in Terminal 1. As a result, we could accomplish the 100% (volume-based) utilization of LNG cold in Terminal 1. This means that now we don't have to use sea water to produce city gas in Terminal 1.

Thanks to the electric power reduction through this use of LNG cold energy, the amount of CO_2 reduction for a year in Terminal 1 has reached about 113 thousand ton. This amount of CO_2 is equivalent to that of CO_2 absorbed by coniferous forest in the area of one-quarter of Kyoto city.

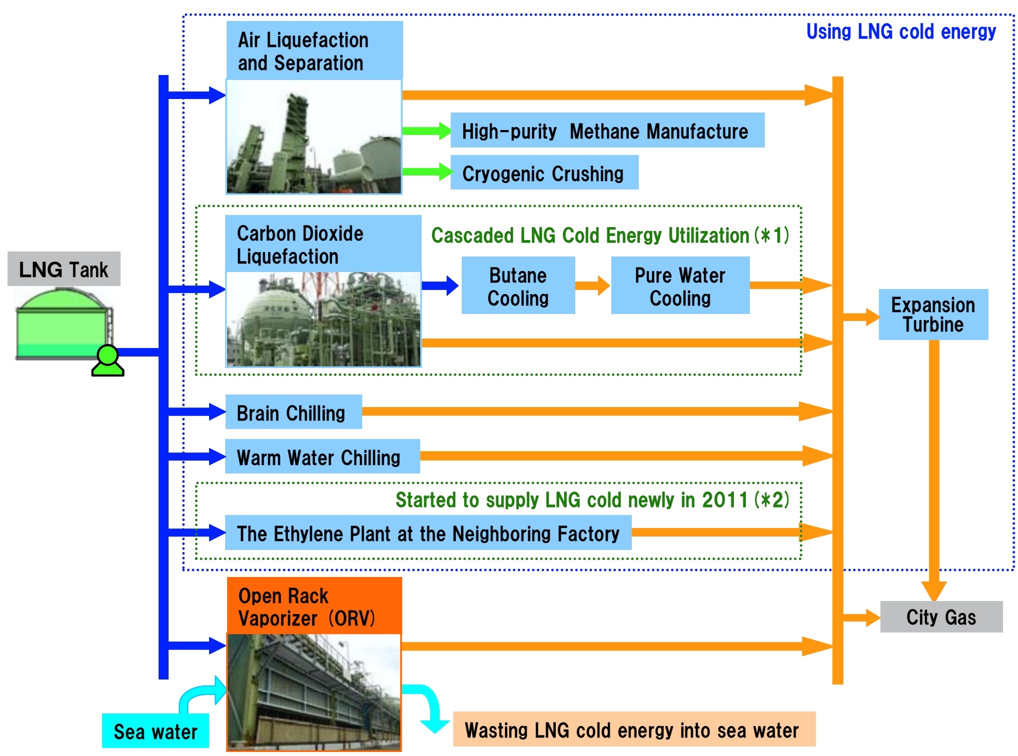

Fig. 7: The outline of the utilization of LNG cold energy in Terminal 1.

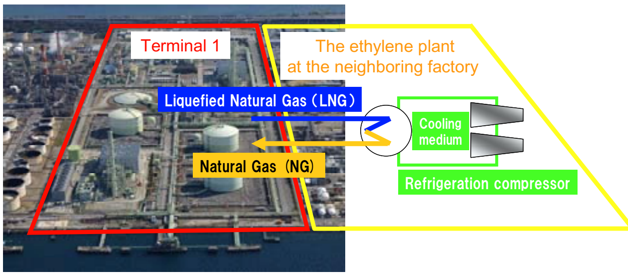

Fig. 8: LNG cold supply from Terminal 1 to the ethylene plant at the neighboring factory.

3 EVALUATION OF LNG COLD ENERGY FROM A NEW STANDPOINT

3.1 Application of exergy-based evaluation

In the past, we've evaluated the utilization of LNG cold energy in terms of volume (the ratio of the volume of LNG vaporized at facilities using LNG cold to total volume of vaporized LNG), because this way of thinking is simple to understand. However, in order to make more efficient use of LNG cold energy, we need to improve the quality of the utilization of LNG cold energy. So, in this paper, we try to evaluate the quality of the energy by applying exergy-based evaluation.

The exergy of a system is the maximum useful work possible during a process in which the system reaches the condition for equilibrium with environment. This is expressed in the following formula [formula. 1].

$$E = (H - Ho) - To(S - So) \qquad \text{[formula. 1]}$$

E : the value of the exergy

H : the value of the enthalpy

S : the value of the entropy

T : the Temperature

The variable with subscript 'o' means the value 'on the condition for equilibrium with environment'

By applying exergy-based evaluation, we can evaluate not only heat energy but also energy as pressure of LNG cold [4].

In 3.2 and 3.3, we report the case of evaluating the efficiency of LNG cold utilization in Teminal 1 in terms of exergy.

3.2 Evaluating the efficiency of the facilities using LNG cold in terms of exergy

"Exergy efficiency" is considered to be one of the indicators representing how efficient LNG cold is transferred to the targeted material [4]. In this paper, we define "20 degrees Celsius (Temperature), 101.3kPa (Pressure)" as the condition for equilibrium with environment. Under the condition, we calculate the exergy efficiency of existing facilities using LNG cold in Terminal 1 or supplying LNG cold to the ethylene plant [Fig. 9]. Exergy efficiency is defined as below [formula. 2].

$$\eta^i = \frac{\Delta E^i{}_{user}}{\Delta E^i{}_{LNG}} \times 100 \qquad \text{[formula. 2]}$$

η^i : the exergy efficiency of the facility i (%)

$\Delta E^i{}_{user}$: amount of the exergy the targeted material obtains at the facility i $(kWh/LNG-t)$

$\Delta E^i{}_{LNG}$: amount of the exergy of LNG cold energy consumued at the facility i $(kWh/LNG-t)$

The bottom of the fraction [formula. 2] represents the value when the exergy of LNG at outlet of the facility is subtracted from that at inlet of it. The top of the fraction [formula. 2] represents the value of the exergy which the targeted material obtains in the facility. Table. 2 shows the values of $\Delta E^i{}_{user}$, $\Delta E^i{}_{LNG}$, and η^i in each facility using LNG cold.

Table. 2: Information on the exergy efficiency of each facility using LNG cold.

	$\Delta E^i{}_{user}$ (kWh/LNG-t)	$\Delta E^i{}_{LNG}$ (kWh/LNG-t)	η^i (%)
Ethylene Plant	82.41	111.64	74
Air Liquefaction and Separation	77.14	112.85	68
Carbon Dioxide Liquefaction	37.45	102.76	36
Brain Chilling	9.29	89.85	10
Warm Water Chilling	0.00	102.28	0
Expansion Turbine	33.22	45.59	73

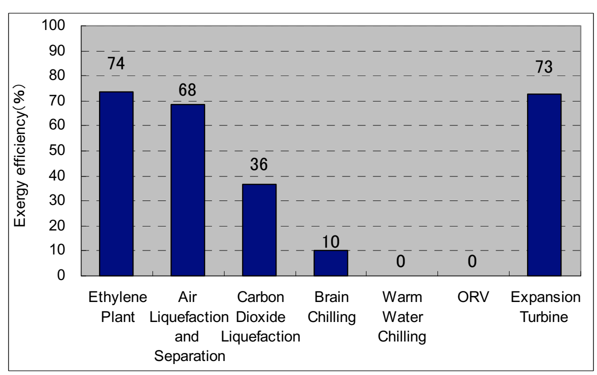

Fig. 9: Exergy efficiency of each facility vaporizing LNG.

In general, the smaller the difference between temperature of a targeted material and that of LNG, the higher exergy efficiency is.

At water chilling facility using LNG cold, LNG cold contributes to reducing electricity used for cooling tower.

But, the exergy efficiency is evaluated negatively by Formula.1, because the temperature of cooling water is higher than 20 degrees Celsius as the condition for equilibrium with environment. However, the value of the exergy in the water chilling facility case is so small that we approximately regard the exergy efficiency as zero in this paper.

Fig. 9 shows that the exergy efficiency in supplying LNG cold to the ethylene plant is the highest in Terminal 1. This means that LNG cold is the most efficiently used there. This high efficiency is achieved by installing heat exchangers in series for exchanging heat between LNG and targeted materials at six stages between low temperature (-100 degrees Celsius) and atmosphere temperature (20 degrees Celsius).

3.3 Evaluating the comprehensive quality of LNG cold utilization in the LNG terminal in terms of exergy

We try to understand how the quality of LNG cold used in Terminal 1 comprehensively has changed by starting to supply LNG cold to the ethylene plant. In this paper, we defined "the exergy efficiency of LNG cold utilization in Terminal 1". Fig. 10 shows the concept of the exergy efficiency.

Table. 3: The value of exergy of LNG (NG) in each condition.

Condition (Temperature, Pressure)		The value of the exergy (kWh/LNG-t)
LNG	-160 degrees Celsius, 106.4 KPa	239.8
NG	20 degrees Celsius, 0.75 MPa	70.6
NG	20 degrees Celsius, 2.35 MPa	109.5

We need to make use of some of LNG exergy as pressure energy to supply city gas to pipelines. After LNG is gasified to natural gas through a LNG cold utilization facility, a part of the vaporized gas is introduced to the expansion turbine and then supplied to a trunk line at 0.75 MPa and the rest of the gas is directly supplied to another trunk line at 2.35 MPa. Table. 3 shows the value of exergy of LNG (NG) in each condition.

So, we calculate "the exergy efficiency of LNG cold utilization in Terminal 1" by formulas below [formula. 3 ~ formula. 5]. The top of formula. 3 (i.e.formula. 4) means sum of the exergy obtained by the targeted materials at each facility inTerminal 1. The bottom of formula. 3 (i.e.formula. 5) means the available exergy of total LNG cold in Terminal 1, except the exergy used for supplying city gas.

In this paper, we take no account of the effect of LNG pump on exergy of LNG cold because the effect is very small.

$$\eta^{all} = \frac{E_{used}}{E_{utilizable}} \times 100$$ [formula. 3]

$$E_{used} = \sum_{all\ i} \Delta E^{i}{}_{user} \times LNG^{i}$$ [formula. 4]

$$E_{utilizable} = 239.8 \times LNG^{total} - \{70.6 \times LNG^{\exp ander} + 109.5 \times (LNG^{total} - LNG^{\exp ander})\}$$ [formula. 5]

η^{all} : *the exergy efficiency in Terminal 1 (%)*

$E_{utilizable}$: *total amount of available exergy of LNG cold energy in Terminal 1 (kWh)*

LNG^{i} : *volume of LNG vaporized at the facilitiy i (ton)*

LNG^{total} : *total volume of LNG (ton)*

$LNG^{\exp ander}$: *volume of LNG supplied through Expansion Turbine (ton)*

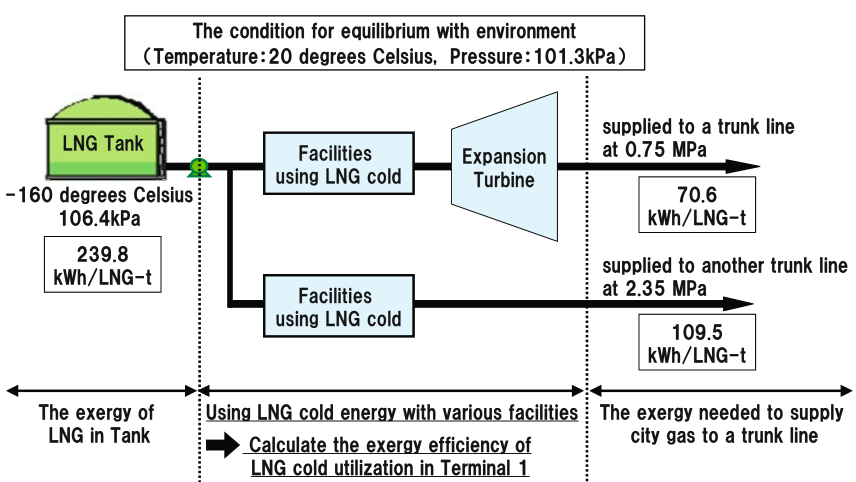

Fig. 10: The concept of "the exergy efficiency of LNG cold utilization in Terminal 1".

Table. 4: Comparison of "the exergy efficiency of LNG cold utilization in Terminal 1" between before and after starting to supply LNG cold to the ethylene plant.

LNG cold energy utilization facilities and LNG vaporizer	The value of the exergy the targeted material obtains in each facility (kWh/LNG-t)	Total LNG mass of each facility for two months (t) LNG cold energy utilization in Ethylene Plant	
		before	after
Ethylene Plant	82.41	0	75805
Air Liquefaction and Separation	77.14	75129	72268
Carbon Dioxide Liquefaction	37.45	9222	8105
Brain Chilling	9.29	4951	7531
Warm Water Chilling	0.00	34645	28035
Open Rack Vaporizer (ORV)	0.00	466	0
Expansion Turbine	33.22	74069	96951
The exergy efficiency in Terminal 1 (%)		45	54

Table. 4 shows the comparison of "the exergy efficiency of LNG cold utilization in Terminal 1" between before and after starting supply LNG cold to the ethylene plant. ("before": February to March in 2010, "after": February to March in 2011)

As shown in Table.4, the value of the exergy efficiency of LNG cold utilization in Terminal 1 has been increased from 45% to 54% after we started to supply LNG cold to the ethylene plant. Thanks to the supply of LNG cold to the ethylene plant, the rate of using LNG cold at the facilities with the high exergy efficiency was increased. As a result, we could accomplish more advanced utilization of LNG cold in Terminal 1 from the view point of not only "volume" but also "quality" than before.

In Terminal 1, the rate of LNG cold utilization is already 100% (volume-based), but the exergy efficiency has not reached 100% yet. So, from now on, it is important to make more advanced utilization of LNG cold by improving the quality of the utilization.

4 SUMMURY

Today, we need to make more efficient use of LNG cold in LNG terminals because it is very important to save energy.

In this paper, first, we remarked the purpose of evaluating the efficiency of the LNG cold utilization in terms of exergy, and then we introduced the case of such evaluation in Terminal 1.

We understand that we can make more efficient use of LNG cold in Terminal 1, mainly by following two ways. One way is improving the quality of the LNG cold utilization at the facilities with low exergy efficiency, such as the water chilling facility. The other way is increasing the ratio of the amount of LNG vaporized at the facilities using LNG cold with high exergy efficiency, such as the ethylene plant.

From now on, we will make positive efforts to save energy by comprehensively evaluating the effects of the LNG cold utilization in terms of exergy and cost.

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(*1) This is the method for using LNG cold efficiently. Research and development of this method has been implemented as an effort by the Research Association of Refinery Integration for Group-Operation (RING).

(*2) This project was implemented with the support of the New Energy and Industrial Technology Development Organization (NEDO).

Parameters with Eco-performance of Solar Powered Wireless Sensor Network

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Abstract
The life cycle framework and flow charts for select of energy budget and battery parameters are proposed. The required battery capacity and charging circuit are arranged by local weather conditions. Then, the placement configuration is arranged based on physical structures. From the system reliability point of view, MTBF becomes shorter as the temperature increase. Avoiding high temperature situation can extend sensor node's life. Green design considerations at early stage of system design are helpful to build a proper system framework and technology implemented.

Keywords:
wireless sensor network, solar cell, energy budget

1 INTRODUCTION

The wireless sensor network is researched recently for mobile and distributed network application. A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, pressure, motion or pollutants. It is now used in many industrial and civilian application areas. Limitation of energy supply has constantly impeded the progress of WSN towards large scales and true autonomous operations [1].

The advantage of wireless sensor network is the flexibility; each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a micro-controller, and a battery. Owing to the distributed nature of WSN, the battery replacement and maintenance is a very time-consuming process.

Compact and integrated WSN is currently developed to minimize power consumption and energy providing problem. Smaller size implies less raw material and lower environmental impact during manufacturing process. The transceiver with minimum bandwidth and suitable electromagnetic wave coverage range also implies fewer requirements for battery replacement.

The wireless sensor network also brings environmental impact during manufacturing, product use or at the end of product life. For example, batteries may contain cadmium, mercury, copper, nickel, and lithium, which may create a hazard when disposed incorrectly. Although each wireless sensor node is a small component, it operates as a clustering network system. For proper estimation of the environmental impact during life cycle, the boundary of the scenario needs to extend to the whole system operation. Therefore, it is important to consider the possible design parameters and related environmental impacts in early design phase.

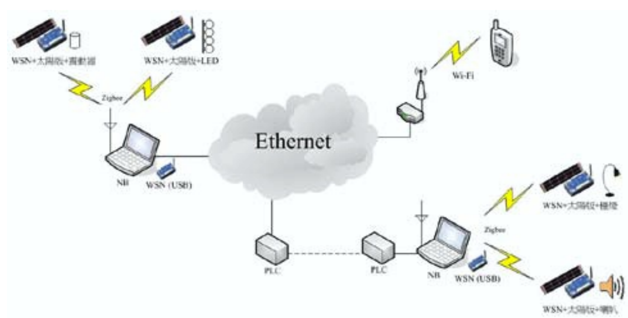

Fig. 1 Wireless sensor node

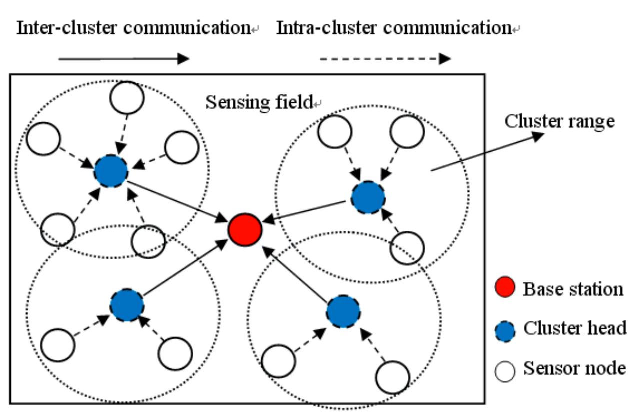

Fig. 2 Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors

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2 TECHNOLOGY

Sensor networks are designed especially for deployment in adverse and non-accessible areas without a fixed infrastructure. Therefore, energy conservation plays a crucial role in the proper operation of these networks. Solar powered wireless sensor network had been proposed and demonstrated [2] with various combination of technical attributes. Depending on the parts and technology chosen, there are many factors that will affect the system performance and environmental impact of WSN.

2.1 Solar powered Wireless Sensor Network

Several network protocols that perform solar-aware routing were proposed [3]. Proper network protocols while utilizing solar power can improve system flexibility and provide significant energy savings. Incorporating the solar status of nodes in feasible routing decision making results in reduced overall battery consumption.

Corke [4] discussed hardware design principles for long-term operation solar-powered wireless sensor networks. The assumptions and principles appropriate for long-term operation from primary cells are quite different from the case of solar power with its abundant energy supply and regular charging cycles. The system used NiMH battery technology which does not require complex charging circuitry. In the presented outdoor environments, it allowed significant relaxation of the severe energy constraints. The presented data from field measurement illustrated the use of solar energy and rechargeable batteries to achieve 24×7 operations for over two years, in March 2005.

Small size compact and integrated WSN was developed to minimize energy supply problem [5], the size of sensor node circuit is only 20×20×6 mm, and the pilot study shows reasonable application potential in outdoor environments. Some system also utilized indoor light to generate electricity [6], but it must leave the lights on to get the energy needed to partially charge device over night. The energy wasted from the indoor lights is much greater then the energy obtained.

2.2 Solar panel and LCA data

While power from the sun itself is renewable and green, the equipment necessary to capture and convert solar energy into usable electricity still have a carbon footprint during its life time.

A life cycle analysis study proved that solar cells are cleaner than conventional fossil fuel power generation [7]. Amorphous silicon had shown successful operation in normal conditions, the process step is simpler than mono-crystalline cell, therefore the panel requires less energy consumptions in production phase.

Mono-crystalline silicate cells have the highest energy conversion efficiency of 14 percent, but it requires the most energy to produce. It emits 55 grams of global warming pollutant per kilowatt-hour, which is only a fraction of the near one kilogram of greenhouse gases emitted by a coal-fired power plant per kilowatt-hour. From the carbon emission's point of view, solar powered systems are 90 to 300 times lower than those from coal powered plants [8].

Four most common types of PV cells: multi-crystalline silicon, mono-crystalline silicon, ribbon silicon and thin-film were reviewed by [8]. Even taking into account the low efficiency of thin-film solar cells or the energy needed to purify silicon for the other types of PV, the results proved significantly fewer emissions in their entire life cycle than the fossil fuels needed to produce an equivalent amount of electricity.

Energy-related acid emissions of m-Si modules are 16× less with PV electricity generation than with the average Dutch electricity supply system [9]. The non-energy-related releases of SO_2 are about 5% of the energy-related emissions for the base case. The energy requirement and emissions per amount of electricity generated are in the same order of magnitude as those found for amorphous silicon modules. This is caused by a two times higher solar cell conversion efficiency for m-Si modules which compensates the two 2 times higher energy requirement during manufacture.

Materials that dominate the material requirements of m-Si modules are the bulk materials like glass and aluminum. The study suggested that module design has to be reconsidered in order to facilitate recycling of module components. The process step contributes dominantly to the emissions that occur during the life-cycle of the PV module. Due to the 100-fold thicker Silicon layer in m-Si cells (150-300 μm for m-Si vs. 350-500nm for a-Si cells), the emissions of (non-energy-related) CO_2 and SO_2 are about 200 times larger than the values for amorphous silicon solar cell modules [9].

2.3 Charging circuit

Design considerations for battery charger includes designing the circuit, loading, impedance and panel structure. Some solar charging circuits were selected and implemented for field trial of different WSN applications. It includes the charging circuit, switching, protection circuit, and the leveling circuit. In [10], the iron phosphate type lithium-ion batteries were safely charged to their maximum capacity and the thermal hazards associated with overcharging were avoided by the self-regulating design of the solar charging circuit. The solar energy to battery charge conversion efficiency reached 14.5%, including a PV system efficiency of nearly 15%, and a battery charging efficiency of approximately 100%. This high system efficiency was achieved by directly charging the battery from the PV system with no intervening electronics, and matching the PV maximum power point voltage to the battery charging voltage at the desired maximum state of battery charge.

2.4 Battery and environment

Major Parameters of battery selection includes cost of battery, energy density stored within battery which dominated the physical size of battery, the permitted cycle of recharge and the side effects of end of life. The rate of degradation of Lithium-ion batteries is strongly temperature- dependent. Operating at high temperatures can result in the destruction of the cell. The Arrhenius effect helps to get higher power out of the cell by increasing the reaction rate, but higher currents give rise to higher I^2R heat dissipation and thus even higher temperatures. Unless heat is removed faster than it is generated, it possible causes thermal runaway [11].

The first stage is the breakdown of the thin SEI layer on the anode, due to overheating or physical penetration. The initial overheating may be caused by excessive currents, overcharging or high external ambient temperature. The breakdown of the SEI layer starts at the relatively low temperature of 80ºC.

The data [11] shown that starting at about 15 ºC cycle life will be progressively reduced by working at lower temperatures. Operating slightly above 50 ºC also reduces cycle life but by 70 ºC. The battery thermal management system must be designed keep the cell operating within its sweet spot at all times to avoid premature wear out of the cells. The cycle life quoted in specification sheets provided by manufactures normally assumes operating at room temperature. This would be unrealistic for harsh environment applications.

3 GREEN DESIGN CONSIDERATIONS

While powering from the sun itself is renewable and green, the equipment necessary to capture and convert solar energy into usable electricity have a carbon footprint. The wireless sensor network also brings environmental impact during manufacturing, product use, or end-of-life. It is important to consider the technology available and related environmental impacts in early design phases.

The life cycle framework had been applied to photovoltaic module design. These metrics are based on energies used during material production, manufacturing, and transportation. Although the energy data of each phase of product life vary over a wide range, low and high values can be used to do a basic estimation

As a WSN application designer, the major parts that can contribute within the life cycle are the use phase. The manufacturing phase impact can also be minimized by proper selection of technology and parts.

3.1 Procedure & Overview

Small changes at the design stage can have a far greater positive effect than trying to mitigate impact during and after production. The general wireless sensor network consists of four different devices; the PV generator, the control electronics, the battery and the mechanical frame. Environmental impact is related to factors such as PV module size, battery size, frame and electronic packaging material required and control electronics. Minimized environmental impact can be achieved through properly choosing the parameters of those variables. Flow chart for selecting solar panel parameters is shown in Fig. 3. Based on scenario and weather conditions of WSN application, we can select panel type and size. With the LCA data and supporting analysis tools, the judgments can be made based on environmental impact, weight, installation and cost. Firstly, the required battery capacity is determined. Secondly, the charging circuit and usage condition is arranged. Thirdly, the placement configuration is arranged based on actual physical structures.

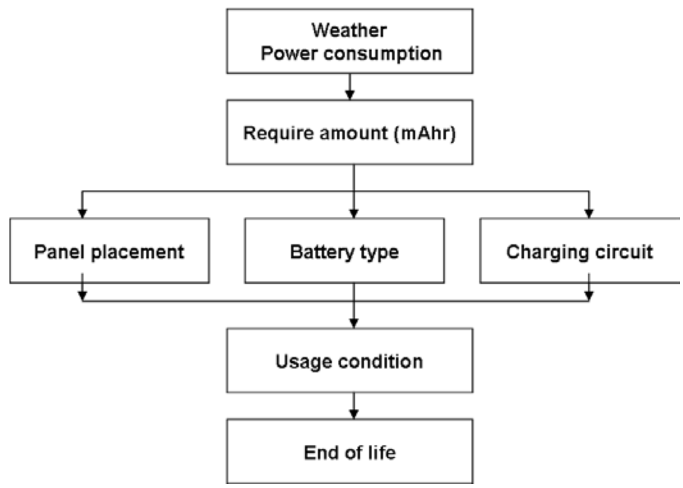
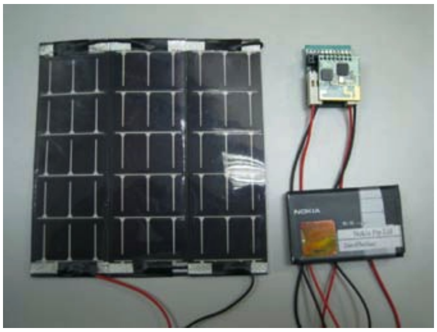


Fig. 3 Flow chart for select of energy budget and battery parameters

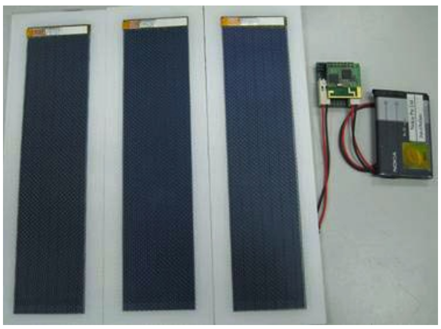
3.2 WSN and panel chosen

The WSN under study is a small size compact and integrated wireless sensor node, which was developed to minimize energy supply problem [5]. While operating in normal mode, it consumes only 29mA/27mA. The voltage tolerance is 2.7 to 3.6V DC, it means it also can survival in worse energy conditions. The battery used the Li-ion battery from NOKIA (3.7-volts), the charging capacity is 1020 mAh.

Due to its reasonable dimension, it can easily apply in environmental parameters monitoring and many outdoor networking situations. The compact size also benefits power usages and battery life.



(a)



(b)

Fig. 4 IP-Link 1223 outdoor solar charging system

For solar panel we choose Solar Focus 1SC1, as shown in Figure 4. The three-layer composite amorphous-silicon solar technology can effectively absorb different spectrum of solar light. Using three layer hierarchical stack, red, green and blue in the solar spectrum can be efficiently absorbed through different layers.

3.3 Charging circuit

During designing the circuit, loading, impedance, some of solar charging circuits were selected and implemented for field trial. Design parameters are adjusted and compared from both cost and efficiency. For example, reduction of switch counts and driving circuits can achieve the advantages of compact size, low cost and high efficiency. For simplicity, the basic diode and capacitor charging circuit (Fig. 5, 6) was implemented. There are no active parts in the charging circuit; consequently, it consumes less power while in operation.

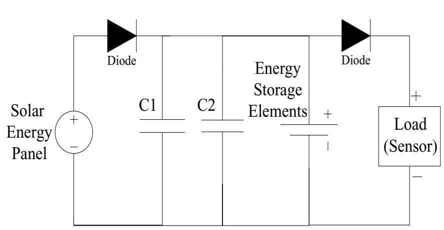
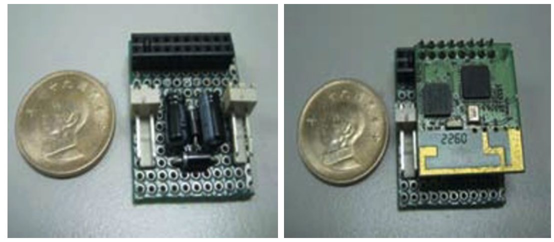


Fig. 5 Charging circuit diagram of solar charge control



(a) (b)

Fig. 6 Physical implementation of the solar powered WSN (a) the charge control circuit board (b) wireless sensing node and charging protection circuit board

To minimize the space required and packaging dimension, the WSN and charging circuit board was attached by socket. During the chassis design, three dimensional placements were checked with battery and components. The design concerns of system frame are the fixing of solar panel with different kinds of basement, electronic packaging dimension and the adjustment of panel skew angle based on available space.

4 MEASUREMENT AND ESTIMATION

The small size compact and integrated wireless sensor node were built and measured its performance to verify possible energy supply problems.

4.1 Measurement facility

For long term evaluation of system performance, Onset HOBO U12 standalone data loggers were utilized. It provides 12-bit resolution for detecting data, direct USB interface, and a 43K measurement capacity. It could monitor voltage, temperature, humidity, light intensity for several weeks.

Figure 7 indicates the battery voltage is strongly dependent on the ambient light intensity. The temperature sensor locate within U12 does not directly contact with the solar panel, therefore it indicate the local ambient temperature around the panel. The measured temperature increases at noon, and can reach as high as 45° C. With three solar panels in series, it produces electricity for 5.8V-6.4V and charging current 80mA-235mA. The battery voltage increase rapidly as the ambient light intensity increased. Normally the charging process reaches 95% of capacity within two hour period of time.

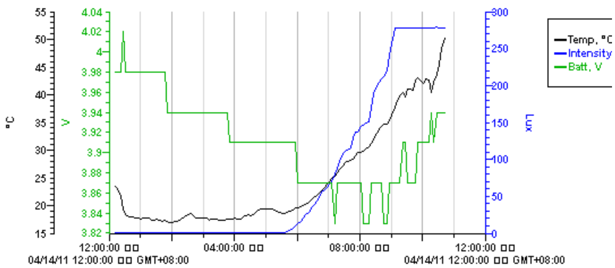


Fig. 7 Charging voltage measurement during 12 hours (light intensity, battery voltage, temperature)

According the weather conditions, energy absorbed by the solar panels will be very different. For example, on sunny days direct sunlight at noon time will give a maximum current of about 235mA, and during late afternoon, current drops to around 35mA. In this situation, WSN need operate by proper routing protocol which allows signal transmitted through the node with enough energy storage. The simple calculation of battery life and charging efficiency can be found in [13].

4.2 Reliability issues

Panel's temperature also affects power output of the solar panel. The mechanism is related to the complex cell chemistry. To estimate temperature related effect, we measure the solar panel output voltage and current under load while the temperature rises.

Table 1 Effect of temperature variation

			
Temperature Panel	**voltage**	**Temperature Panel**	**voltage**
26℃	7.50 V	26℃	5.45 V
28℃	7.28 V	28℃	5.35 V
30℃	7.17 V	30℃	5.30 V
32℃	7.20 V	32℃	5.22 V
34℃	7.23 V	34℃	5.16 V
36℃	7.25 V	36℃	5.09 V
38℃	7.22 V	38℃	5.03 V
40℃	7.19 V	40℃	4.97 V

A power resistor was used across the positive and negative outputs of the solar panel. The projecting light was utilized to heat up the surface of solar panel. Previous experiments had shown us that the peak power output of these panels is obtained with a load resistance of around 56 Ohms. A Pasco data acquisition device was used to take voltage, current, and temperature readings. The relationship between temperature and the solar panel power output voltage, between 26 and 40 degrees there was a drop in power output from a peak of 7.5V down to 7.19V (Table 1). The total power loss due to the increase in temperature reaches almost 5%. It means by maintaining a lower temperature, the system failure rate will decrease and output power can also be increased.

4.3 Solar Panel Configurations

Solar panel configurations also influence the WSN temperature that attached on the panel. From the system reliability's point of view, MTBF becomes shorter as the temperature increase. Higher temperature during component assembly or usage leads to component life reduction, thermal fatigue, plastic IC popcorn effect, delaminating of multi-layer PCB, etc. Reducing the temperature can reduce the need of maintenance requirement of both WSN nodes and system.

The progress of WSN towards large scales and true autonomous operations need the flexibility of installation. Once installed people can not easily change the reception angle by adjusting skew angle of the panel surface. Based on the situations of surrounding environment and the sunshine conditions, the actual installation maybe varied. To estimate the effect of installation and surrounding environment, two kinds of configurations are shown in Fig. 8, with RC concrete wall (-c) or thermal insulated material (-i). The thermal insulated material can reduce heat conduction through the structure.

(a) (b)

Fig. 8 Installation configurations

The measured temperature variation of four kinds of configurations is listed in Table 2. The result of configuration (b)-i shows the lowest temperature, the reasons is low heat conduction from structure and panel's convection heat transfer efficiency is high (Fig. 9). Highest temperature is configuration (a)-c, therefore it needs more open space to improve convection heat transfer efficiency and reduce the heat transfer from structure.

Table 2 Measurement of penel temperature

Configuration	Temperature
(a)-c	42.3
(b)-c	37.8
(a)-i	39.4
(b)-i	37.3

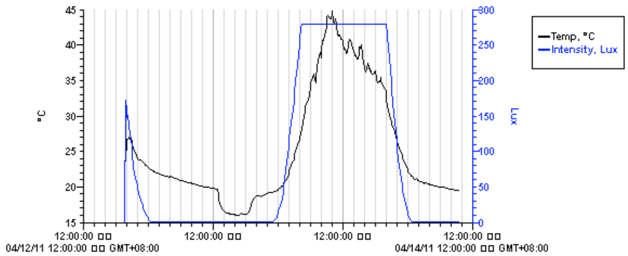


Fig. 9 Measured panel temperature while outdoor light intensity changed (ambient temperature is 30 $^{\circ}$ C)

4.4 Maintenance issue

To calibrate maintenance costs, we need information about expected failure rates of components. Each component of the sensor node has a different failure rate. The PV panel has an expected life cycle of 20 years, but without routine maintenance the panel may fail after 10 years. The battery has an expected life cycle of 4 years, but this can be reduced to a range of 1 years. The charge controller can last 5 years, depending on the level of misuse.

The highest rate of equipment failure occurs with the battery is most often the result of battery misuse. Overall projected system failure rates determine the required number of visits to an installed WSN. Routine maintenance by a trained technician is required to increase usage life time of sensor nodes. Frequency of required visits for normal WSN will be much higher than that of WSN with solar panel. Therefore, the cost of the solar panel can easily recover by the cost of maintenance.

By constantly monitoring the voltage level and smart routing protocol, the WSN with solar gives lower maintenance cost. The network can monitor the status of each node periodically to detect that if a WSN node fails or is defective. This reduces the cost of using WSN technologies and a more reliable distribution networks to ensure a successful implementation

5 CONCLUSIONS

Through the integration of wireless sensor network technologies and solar charging system, the development of low power, high performance, and long lasting nature of wireless sensor networks can be achieved. This will extend the life of nodes in wireless sensor network and the feasibility and effectiveness of the system. Firstly, we build a solar power system for green wireless sensor network platform, then, the solar charging efficiency of sensor networks node were measured.

In the future, a wide range of WSN application will make sensor networks an integral part of our lives. Solar energy reduced the problems of unstable power and loading effect. Although the life cycle impact from each phase of product life can vary over a wide range, design parameters can still be compared from both cost and system maintenance in early development phase.

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An Empirical Inquiry on the Effect of Cleaner Local Energy Production on Consumer Carbon Footprint

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Abstract

This study analyzes the effect of cleaner local energy production on the consumer carbon footprint. The results in consumption based carbon footprint assessments have traditionally indicated that a significant change in consumption patterns or lifestyles would be needed to achieve the often aspired, ambitious 50-80% cutoffs in the carbon emissions on a community level. However, it is also known that a majority of the emissions related to all goods and services derives from energy. Thus cleaner local energy would not affect only the emissions from housing in the consumer carbon footprint but also the carbon load from the consumption of goods and services produced with the same energy.

Keywords:

energy, lifecycle assessment, LCA, carbon, CO_2, greenhouse gas, GHG, consumption

1 INTRODUCTION

Numerous studies have demonstrated that emissions associated with energy production dominate the greenhouse gas (GHG) emissions caused by human activities [1-2]. A recent study of 18 European metropolitan cities found as much as 79 to 97% of the GHG emissions of the studied cities to derive from energy production.

Consumption based consumer carbon footprint calculations have traditionally estimated the shares as significantly lower [3, 4]. This is likely due to that only emissions derived from housing energy use have been allocated as emissions from energy production. In other words, it is ignored that energy production is accountable for a majority of emissions related to all consumables and services as well.

As the single most important source of GHG emissions from consumption, housing energy offers the largest mitigation potential [3, 5]. However, the share of housing energy of the GHG emissions of a consumer has been reported being substantially less than 50 % in many studies [3, 5, 6]. Since building energy consumption and energy production mode are the key decisions on a city level to affect the carbon footprints, often aspired ambitious 50-80% cuts in carbon emissions would only be possible through significant changes in the individual consumers' consumption patterns, as a significant share of the emissions derives from goods and services [3, 4]. This study suggests, however, that cleaner local energy production modes would affect, not just emissions from direct housing energy use, but also the emissions attributable to the consumption of goods and services, making this a substantially more effective way to mitigate the GHG emissions on a community scale. This applies especially to emissions from services consumption, the majority of which derive from local energy production.

This study presents a consideration of the effect of cleaner local energy production on consumer carbon footprint employing a scenario analysis. The primary aim is to demonstrate the significance of the choice of energy production mode. The effects of cleaner energy production on the GHG emissions are assessed with a consumption based hybrid LCA model. Besides direct housing energy consumption, the effect of the cleaner local energy production on the carbon footprints of locally produced services is assessed. This will create better understanding on the significance of cleaner local energy production on the consumer carbon footprint.

The Finnish capital city Helsinki is analyzed in the study. In the first stage of this paper the carbon footprint of an average resident of Helsinki is assessed and the distribution of the emissions is analyzed employing the hybrid LCA model developed earlier by the authors [3, 5, 7]. In the second stage, the carbon mitigation effect of cleaner local energy production is analyzed with the assessment model.

2 METHOD

This study examines the GHG emissions attributable to private consumption, e. g. carbon consumption, with an aim to incorporate all life cycle emissions into the inventory. This is achieved by employing a hybrid lifecycle assessment (hybrid LCA) model developed by the authors in previous studies [3, 5, 7].

The method is based on is a combination of the two prevailing assessment techniques, process life cycle assessment (process LCA) and input-output life cycle assessment (IO LCA). Of these two techniques, process-LCA is the traditional and the most utilized method [8]. In Process LCA the emissions attributable to a certain good are assessed process by process based on energy and mass

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flows. The accurateness of the method is potentially very high. However, the technique suffers from a couple of problems inherent to all process based LCAs. First, the amount of processes adding to the emissions inventory of a certain good is often very large in cradle to grave assessments. The assessments thus tend to be very laborious and time consuming to conduct. Second, related to the workload, the assessments suffer from truncation error from the boundary selection as all the processes cannot be assessed. These may potentially be very high even with inclusion of multiple production chain processes [8, 9]. Third, the energy and mass flow data needed for the assessments may not be easily available.

An alternative for process-LCA is input-output-LCA. The method assesses the emissions attributable to a certain good (the outputs) based on monetary flows (the inputs) [10]. The method is based on output tables that describe the industry interdepencies within an economy. Based on these, the tables add together all the emissions within an economy related to a monetary transaction on one sector. The method is similar to the input-output statistics of national accounts, but in this case the output tables include the emissions data in addition to the economic activity relations. In output tables an economy is divided into industry based sectors so that the economy is fully acknowledged. This is one of the primary sources of uncertainty in input-output-analysis. The output tables are averages that may include figures from very different industries, and the result thus may not describe well the object of the inquiry. In addition, possible temporal (inflation and currency rate differences) and regional (industry structure differences) asymmetries of data and the model, and the assumption of domestic production of imports [9] create possible sources of bias. However, the method is fast and rather easy to use. The inventory is also always complete, as no boundary cutoffs are needed. In addition, the monetary input data is often easier to obtain than data for process analyses.

The third category, hybrid LCAs, have emerged to combine the strengths of the two presented approaches and to reduce the inherent weaknesses related to them [9]. As was described above, the IO and process method have different uncertainties related to them creating space for a combining approach. The first hybrid approaches are from as far as from the 1970's, but the method has become more popular in environmental impact assessments since the late 1990's. In hybrid LCAs, full coverage of production and delivery chains can be maintained with the use of input-output tables, but the accuracy is raised with utilization of process data for the assessment of the most important processes.

The hybrid LCAs can be divided into three categories [9]. In tiered hybrid LCA the most important first order and lower stream processes are assessed with process data whereas the rest of the production and supply chain emissions are assessed with IO approach. The second option, input-output-based hybrid analysis can be utilized when detailed monetary data within the IO sectors are available. In input-output-based hybrid analysis the important IO sectors are further disaggregated to incorporate specific process data. The third alternative is integrated hybrid-LCA that incorporates detailed unit process level information in physical quantities into the input-output model representing the surrounding economy that embeds the process-based system.

The assessment model employed in the study is based on the tiered hybrid LCA method. The model follows the WRI scope three definition [11] in including the full lifecycle emissions of all private consumption. Furthermore, the perspective is consumer responsibility meaning that the GHG emissions are allocated to a consumer based on his/her consumption.

3 STUDY DESIGN

The study analyzes the annual consumption based carbon footprint, carbon consumption, of an average resident of Helsinki. Helsinki is the largest city in Finland with over 500,000 inhabitants, over 10% of Finnish population. The area is affluent in Finland [12] and represents divergent availability of services. The average resident of Helsinki purchases goods and services with 17,400 € annually. The table 1 presents the distribution of the consumption within five broad consumption areas. The local power generation is fossil fuels based [13], which increases the significance of improving the carbon intensity of the power production.

Table 2: Distribution of the annual consumption of an average resident of Helsinki

Consumption area	Amount
Tangible goods	5,200 €
Housing	5,900 €
Transport	1,900 €
Services	3,800 €
Air, Maritime and Package Travel	500 €
Total	**17,400 €**

The input data consist of the consumption survey of Statistics Finland which presents the consumption of an average inhabitant in very high detail, including roughly 1,000 categories of goods and services. For the GHG modeling the data are aggregated down to 59 consumption sectors, and further to the above mentioned five consumption areas to present the GHG assessment results.

The monetary inputs are converted into GHG emissions employing the Carnegie Mellon University economic input-output LCA (EIO-LCA) model [10]. In addition, in the first stage, the WRI scopes one and two [11] emissions of energy production for housing, the fuel combustion of private vehicles and public transport are assessed utilizing

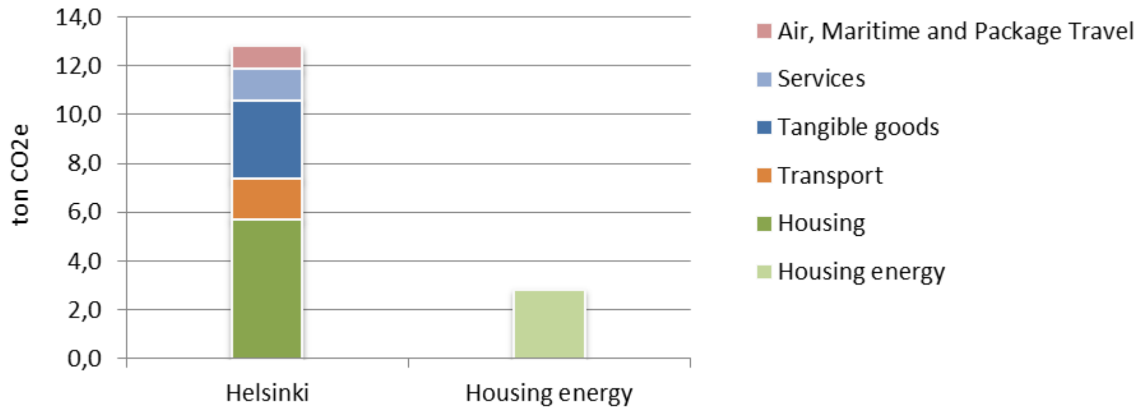

Fig. 1: The annual carbon consumption of an average resident and the share of the emissions of housing energy.

local emissions data, whereas for the rest of the emissions the EIO-LCA output tables are employed.

In the second stage the services produced predominantly locally are identified. After this, the effect of cleaner local power generation is analyzed with a 100% renewables scenario, in which zero production phase emissions are assumed, but the production chain emissions remain. While unrealistic in short term in the context of CHP production dependent Helsinki, the scenario demonstrates the potential related to cleaner local energy production. Furthermore, the decrease in the GHG emissions is linear respective to the share of renewables, the selected scenario thus being easily convertible to lower renewables' shares also.

4 RESULTS

The average resident of Helsinki purchases goods and services with 17,400 € annually. Based on the assessment model ,this results in GHG emissions, or carbon consumption, of 12.8 tons of CO2e.to. As Figure 1 depicts, housing is the dominating source of GHG emissions. The share of the sector is 5.7 tons, of which housing energy (heat and electricity) comprises a share of 2.8 tons. The housing sector is followed by the emissions from consumption of tangible goods (other than housing related) with 3.2 tons of CO2e, transport with 1.7 tons, services with 1.3 tons and air, maritime and package travel with 0.9 tons.

In addition to the housing energy, the carbon intensity (g CO2e/kWh) of local energy production affects directly the carbon load of local services. The services category in the assessment model includes 10 sectors altogether. The share of heat and electricity of these is 65% on the average ranging from 50% in health services up to 80% in culture, sports and recreation services.

In the 100% renewables scenario we assume zero production phase emissions. The downstream production and delivery chain emissions are assumed to remain constant and thus generate some energy related emissions.

Figure 2 depicts the change in the GHG emissions of an average consumer in the 100% renewables scenario including the 10 services sectors and housing energy.

Altogether the 100% renewables scenario would result in 3.2 tons of CO2e lower annual emissions on the level of carbon consumption of an average resident of Helsinki, and the annual carbon footprint would amount to 9.6 tons of CO2e. Of this, a majority, close to 2.5 tons, derives from housing energy related emissions and the remaining 0.75 tons from services. The overall mitigation effect of cleaner local energy production in the 100% renewables scenario is thus 25%.

5 DISCUSSION

This study was set to analyze the effect of cleaner local energy production on the carbon consumption (annual per capita GHG emissions) of a consumer. The study employed a consumer responsibility perspective [Norski väitös] allocating to a consumer the emissions related to all emissions attributable to the consumption of goods and services. The effect of cleaner energy was assumed to affect the housing energy and also the carbon load from services which predominantly utilize local energy.

In the study the carbon consumption of an average resident of Helsinki, the capital of Finland, was assessed. For this a hybrid LCA model developed previously by the authors [3, 5, 7] was employed. The effect of cleaner energy was examined through a 100% renewables scenario, in which the local fossils based fuel-mix was assumed to be replaced entirely with renewables.

The assessment of the annual carbon consumption of an average resident of Helsinki resulted in 12.8 tons of CO2e carbon load. The largest contributor was found to be housing with a share of 5.7 tons. Of this, 2.8 tons comes from housing energy. Consumption of tangible goods, other than housing related, adds 3.2 tons of CO2e, transport 1.7 tons, the object of the study, services, 1.3 tons and travelling abroad 0.9 tons.

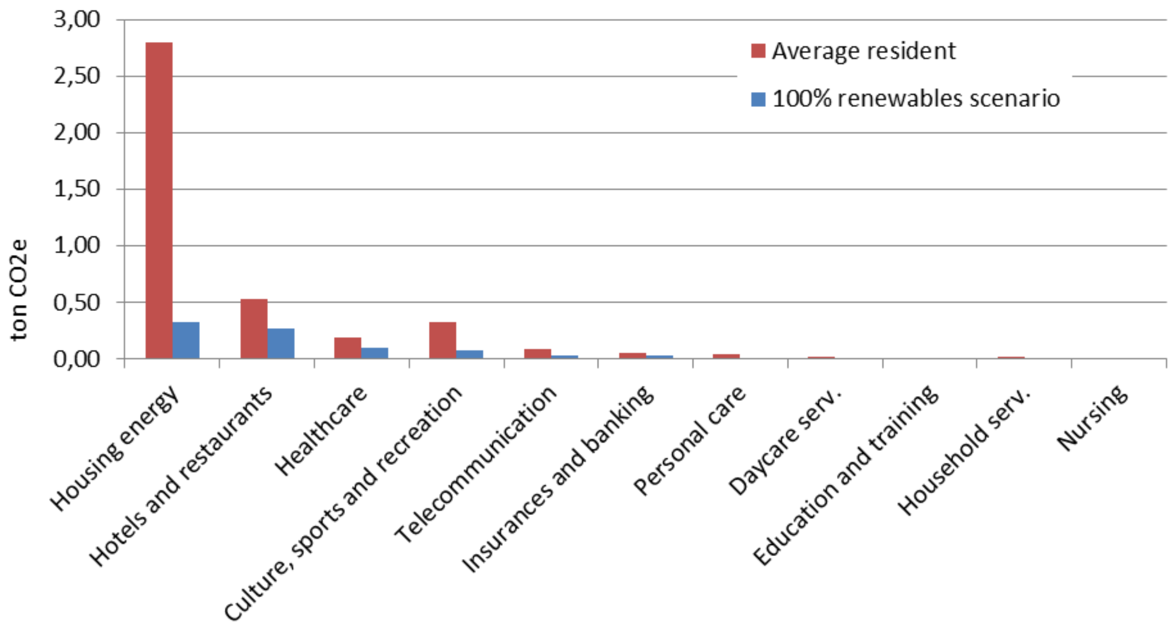

Fig. 2: The mitigation effect in 100% renewables scenario in housing energy and services sectors.

When the 100% renewables scenario was employed, the carbon consumption of an average resident was found to decrease by 3.2 tons of CO2e (25%). Of this, nearly 2.5 tons comes from housing energy and the remaining 0.75 tons from services. Within the 10 services sectors forming the Services consumption area in the LCA model, on average 65% of the GHG emissions were identified to derive directly from energy. However, the overall carbon load from many of the services is so low that the mitigation effect stays moderate. Thus it would still seem that not any single development is enough to achieve even the 50% GHG emissions reduction target mentioned in the Introduction of the paper. Such significant reductions would also require changes in the consumption patterns or significant reductions in the carbon loads of all goods and services.

The study has a few easily identifiable deficiencies. The utilization of the IO LCA method raises uncertainties inherent to all analyses with the method. In addition, new problems arise from the employment of US industry based EIO-LCA model in Finnish context. Employing hybrid techniques can decrease these in general, but also raise new possible sources of bias. However, in this study the model was taken as such based of earlier work of the authors. A detailed description of the qualities of the model as well as a profound discussion about the true deficiencies and their significance can also be found from earlier academic publications of the authors [3, 5, 7, 14].

One specific deficiency in the analysis of this paper is the narrow recognition of local services. In addition to the analyzed services, a majority of all tangible goods include local services in the form of sales facilities, customer service etc. Inclusion of these into the analysis would somewhat increase the effect of decreasing the carbon intensity of local energy production, but probably not be enough to significantly change the overall result.

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Domestication of small-scale renewable energy systems – A case study of air heat pumps, residential micro wind stations and solar thermal collectors in Finland

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Abstract

A thorough understanding of the user is crucial in technological design and development. The domestication framework has been used in sociology of consumption to open up technology adaptation processes where technology becomes part of the everyday life of people. This study applies domestication framework for air heat pumps, solar thermal collectors and micro-wind generator technologies. An experimental case study is based on semi-structured interviews and observation of residential household and summer cottages in Finland. Trialing of technology and incremental increase of usage and further investing demonstrate users to aim for smooth evolutionary approach in energy technology adaptation. Modularity, extendibility, interoperability with other energy systems are key design requirements to enhance adaptation.

Keywords:

renewable energy, sociology of consumption, domestication, air heat pump, solar energy, wind energy

1 INTRODUCTION

Historically energy provision became based on networked infrastructure and centralized systems, which has led to a passive role for the most energy end-users [1,2]. From residential housing viewpoint energy systems work in the background and provide air and water heating and cooling with minimal requirement of daily monitoring, configuring or maintenance by inhabitants. However, the need for low carbon solutions and rising energy prices are changing local residential energy consumption and renewable energy is increasingly produced locally on site, which makes production distributed, requires technology adaptation, learning of use and changes or considerations in inhabitants' daily life.

Domestication is a concept within studies of the sociology of technology that has been developed to describe and analyze processes of technology's acceptance, rejection and use. The concept [3–5] emerged from a series of studies, which sought to understand the appropriation of artifacts in the specific social setting of the home [6]. However, the sociology of consumption is not especially well equipped to deal with domestic infrastructures supporting the evolution of normal standards of daily material life [7]. Thus the framework has been rarely used for infrastructure type of technologies, such as residential energy systems. Now that residential renewable energy systems are breaking away from the infrastructure role and becoming more visible and meaningful for consumers, a new avenue opens up for researchers.

In this paper the domestication framework is applied for three different residential renewable energy technology, air heat pumps (AHP), micro wind stations (WS) and solar thermal collectors (STC). These technologies have significant differences regarding daily use and needed user involvement. Air heat pump technology is visible and designed for frequent user interaction. Wind station performance is subject to changes in wind conditions. In the optimal case solar thermal collectors work in the background without need of attention. The research question I ask is: *what kind of domestication processes are involved with residential sustainable energy production and use?*

The advancement of innovation research has lead to the blurring of the distinction between design, implementation and use [8]. Research on the social shaping of renewable energy technology in the context of residential housing provides valuable insights for designers and policy makers for understanding inhabitants' role when designing and regulating residential energy systems.

In the following, I will first elaborate on domestication framework used for empirical analysis. This is followed by a section explaining data sets and methods of this study. Three different technologies are analyzed within the domestication framework. Finally, a discussion of these findings, study implications and limitations of current study.

2 BACKGROUND OF THE STUDY

2.1 Domestication framework

Domestication as a concept originated in large part from anthropology and consumption studies [9]. The concept represented a shift away from models, which assumed the adoption of new innovations to be rational, linear,

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monocausal and technologically determined. It presented a framework and research approach, which is taking into account diversity and complexity of everyday life and technology's place within its dynamics, ritual, rules and routines [5]. Through domestication artifacts become invisible taken for granted elements of everyday life [6]. Silverstone and his colleagues have presented theoretical scheme to study use of technology by proposing four dimension or states in a household's dynamic uptake of a technology. After purchase an object goes through a process of appropriation (1), whereby it is taken possession of by its users. In this stage objects acquire a meaning and become authentic. During the objectification (2) an object is installed and finds its place in household. An object becomes incorporated (3) when it starts being integrated into routines and habits. In conversion (4) users display their ownership of a new product to the outside world both by displaying the object via discourse [10].

Domestication can be seen as period in the biography of artifact about its introduction into the domestic setting. The process of consumption and of embedding the object into the household is one of sense making, of transformation the alien object to ascribe it meaning in the symbolic reality of the household [5]. Biographies of things describe change and transformation of technology but at the same time they reveal the changing qualities of the shaping environments through which they pass [10,12]. In consumption consumed item is incorporated into the personal and social identity of the consumer [13,14]. At the same time people generate interpretations and application of technological systems that often diverge from the ones originally inscribed in them [15]. In this domestication represents a step away from the belief in the one-sided transformative power of technology: an area that the domestication approach clearly develops further was the study of innovation and diffusion [5].

The domestication of consumer goods has been relatively widely studied starting from 90's [9,16]. Previous studies have examined especially electronics and media technology in considering the contexts in which ICT were experienced [17,18,5,19,16]. But it has proved to be useful tool for analyzing for example e-learning technologies [20] and health technology [14]. Aune's study of energy use and metering are rare example of a domestication study concerning energy technology [21,22].

Before presenting domestication processes of residential renewable energy technology, I first briefly outline the Finnish market for the technology, provide basic descriptions of three case technologies and introduce data and methods.

2.2 Small-scale renewable energy production in Finland

The usage of renewable energy sources in Finland has steadily increased. Raising energy prices, progress in renewable energy technologies, energy regulation changes and changes in attitudes towards sustainable lifestyle are increasing demand of renewable energy systems such as air heat pumps, micro wind stations and solar thermal collectors. There are 1,1 million detached houses in Finland, which have over 100 000 Air Heat Pumps (AHP) and over 14 000 Exhaust Air Heat Pumps (EAHP) installed [23]. Solar thermal market is very small in Finland. In 2009 installation area was in total 26973 m2 which produces 18 881 KW(th) worth of energy [24]. Micro wind is very rarely used and statistics include only commercial projects and capacity.

An air heat pump is used for both cooling and heating. External unit of the device diverts heat from outside air in to heat up air, which is blown via internal unit into a building. In the process a pump can provide up to 2-4 COP (co-efficiency of performance) compared to direct electric heating. Air heat pump can usually be used for cooling purposes, which is electricity-consuming activity.

A solar thermal collector converts solar radiation into a more usable or storable form such as water. Water is stored to hot water cylinder. To prevent freezing of collector in Nordic climate, mixture of water and propylene glycol is used as heat exchange fluid that heats water in heat exchanger. Living area is heated by radiant heating where heated water is circulated in radiators or in underfloor heating.

Micro wind micro-wind generators can provide electricity for private use in both rural and urban environments. In Finland micro wind is often used to power up off-grid summerhouses, but it can be used to replace residential energy consumption by self produced renewable energy. Batteries are used to store generated electricity.

3 DATA AND METHODS

The study was organized around semi structured in-depth interviews. This article focuses on inhabitants who live in private homes and in summer cottages throughout Finland. Interviewed users were selected via Internet discussion forums and via personal networking. The data includes 3 air heat pump cases, 3 solar thermal collector cases and 2 micro wind cases. These seven 30-60 minutes interviews included 7 men and 2 women (one interview for couple).

The requirements for wanted users were: (1) Nonprofessional user who's work is not involved in commercial development of residential energy technology and systems (2) Is using case products in detached family house or summer cottage and has freedom to make decision regarding own energy system purchases and use

(3) Has been using the system over a year.

A screening of Internet forums was used for finding and selecting suitable persons for long interviews. The forums used were ilmalampopumput.info (discussion on usage experiences section) and ilmaisenergia.info (discussion on solar thermal general and own projects section). Analysis is based on triangulation of data sets from forums, interviews and observations. One user visit, observation, was carried out in northern Finland.

4 DOMESTICATION PROCESSES OF RENEWABLE ENERGY SYSTEMS

4.1 Appropriation

Why are the consumers bothering with their own energy production when there is a countrywide grid available and energy can simply be taken from a plug on a wall? There is motivation to save in energy cost, but surprisingly often a reason for renewable energy investments was convenience or easier use energy system. Combining renewable energy technologies with existing systems can make system use more convenient overall or help only in some parts of the year. User of wood pellet heating was satisfied to old system configuration on wintertime, but summer time solar thermal collector takes over and provides free energy without any maintenance and make energy provision very convenient.

According previous studies people who manifest strong environmental concerns have strong motivations to set up small-scale production plants [25]. In this study sustainability was not among main reasons to install renewable energy technology. For rather special and niche type of technology that is not widely adopted, such as solar thermal collectors or Solar PV in Palm and Tengvard study, people stress more environmental concern as motivation.

Different motivations and reasons associated with selecting renewable energy technology for domestic use can be recognized especially between permanent residence and temporary summer cottage. For adults primitive summer cottage conditions can be well thought choice. In Finland summer cottage conditions can be rather primitive, but this makes possible sensuously rich experience [26]. For teenagers living without electricity can be annoyance and balance is sought:

« When twins were teenagers, they wanted to have television in the summer cottage and solar panel was then installed. Later on I installed also wind generator to extend power availability for darker period on autumn (summer cottage 1) ».

Electricity availability is significant upgrade and brings possibility to add new appliances to summer cottage. However meaning of technology changes over time. For example a summer cottage wind generator user described how television for kids lost significance when they were not visiting the place, and new activities and needs took over. Charging a mobile phone became the most important utility electricity can do. Cost saving motivation was present in this case only via alternative cost of providing electricity. Grid can be extended to new locations, but connection fee is high and with own renewable energy production the cost can be avoided.

Table 1: Energy systems at case houses

Interviewee	Energy systems installed
Householder 1	AHP, electrical heating
Householder 2	AHP, electrical heating
Householder 3	AHP, oil
Householder 4	Wood pellets, STC, oil
Householder 5	STC, oil
Householder 6	STC, wood stove, AHP
Summer cottage 1	WS, PV solar
Summer cottage 2	WS, AHP, electrical heating

4.2 Objectification and incorporation

All air heat pumps and two solar thermal collectors and one wind generator case was installed by services companies. One solar thermal collector and Micro-wind station was an self-installation.

Installation of the system

In air heat pump cases placing of both internal and external unit required careful consideration. Noise and wintertime ice forming put requirements for external unit location. In countryside even insignificant metallic industrial noise can be considered annoying. Although units are relatively large, when asked, users said not to be bothered of aesthetics but at the same time they describe how they covered external unit with a hut.

In a similar way, solar thermal system has both internal and external parts. Solar collectors are installed on the roof on south or west side and unit is not visible internally in the house. With larger roof renovation embedding of collector is easy and flat collector becomes almost invisible. But even in most typical installation, where collectors are clearly visible on the roof, solar collectors on roof were not considered disturbing.

Good wind conditions are basic requirement in selection of wind station location. Area should be open, preferable from all directions. In principle higher the installation tower, better the wind condition is, but in real environment there are many factors that should be taken into considerations.

« Initially it was one block higher, but I removed 1 meter. I noticed that trees have fewer branches down here. I have also removed some branches (Summer cottage 1) ».

Local adaptations

The interviews reveal how people do small modifications to the systems. Following three cases are examples of micro innovations, adaptations and configuration done by users to increase usability the system, ease of use and comfort.

(1) In solar thermal collectors performance is not optimal early spring or late autumn. Additional valves are installed to improve performance (Householder 4).

(2) In a room with high ceiling reconfigurations for air heat pump is done by installing extension cord for for sensor to improve temperature metering accuracy (Householder 2).

(3) In Nordic climate winter is causing maintenance for air heat pump users. A pump creates frost and ice that cumulates and can cause damage for the unit. Plastic sledge is used to collect ice below the unit and make the removal of ice easier (Householder 3).

Technology metamorphosis of domestic energy technology is rather inflexible and has clear distinction to consumer goods. It is never considered as a toy and actual usage purpose can't change with most of renewable energy technologies. Unexpected usage purposes do not rise up. In this study air heat pumps is the only multipurpose product and it is used for both heating and cooling. It can be seen as device for consumption and production. Users may be starting from one end and move towards the other. In two cases air heat pump was purchased for summer purposes and cooling but later one usage was extended to heating. In one case usage extended usage to the other direction from heating to cooling.

Establishing maintenance routines

All case technologies require some maintenance, air heat pump most frequently when wind generator is almost self sufficient. Internal unit of heat pump has filters that require regular cleaning, however, frequency varies a lot. In minimal use cleaning period is up to two months. This seems to be difficult period to remember and take part of normal housing routines. House cleaning is done more often and cleaning of air heat pump can't be integrated to weekly cleaning and in less frequent cycles cleaning is often forgotten.

Solar collector and wind generator are minimally present in daily life routines. When enough collectors are installed or supporting sources are used for water heating, such as electricity, there is no need to take account reduction in solar generation. In some cases system is build on various local energy sources and other sources take over and keep water temperature on desired level when solar power is limited.

Solar collectors are monitored more on times when temperature is not high enough for full production i.e. during spring and autumn. Also changing settings may be done then concerning water circulation. In summer use only consumption water is needed and room heating is disabled.

Taking hot water sufficiency into account is rare when hot water availability can be guaranteed with electrical heating. Order of household activities is not changed because of cheaper operation, although inhabitants are aware of saving possibilities.

4.3 Conversion

All the users in this study considered new system with renewable energy sources improvement when compared to previous system. Data reveal how differently consumers create requirements for consumer goods and goods with production capabilities. In consumption (pleasure) consumer good ties always capital, it doesn't provide dividends, its monetary value rarely increases and thus people are not necessarily interested of the payback time. In case of production goods, the payback time and profitability arguments are required to rationalize purchases. One of the interviewees discusses this on her blog [27]:

« When do you get your money back? When are these solar collectors paying themselves back? Is this profitable system? I doubt that in normal renovations people need to answer similar questions: "when is your satellite antenna paying back, or swimming pool, or roof window ? »

The question is certain technology profitable in comparison to other commercial energy alternatives is not considered significant, especially if investment is considered reasonable.

An investment to energy production can be seen as capability building. It increases independence from the grid but also opportunities of the grid are started to be seen. As one interviewee write on the blog (Tuulahdus, 2011):

« Before I was dreaming about organizing a celebration where big tongs are used to cut lines to the national power grid. Now I dream about solar panels that are connected via inverters to the grid (Householder 6) ».

The sign of the successful integration of technology in the household sector is that the product has a symbolical aspect in addition to the utility-aspect. Aune claims this symbolic aspect lacks in energy technologies [22]. Findings of this paper mostly support Aune's findings. However, some signs of expression of identity can be noticed in case of solar thermal collector that are still relatively special in Finland and easily visible for neighborhood externally outside of house. This is inline with studies of PVs and wind power [25]. Air heat pump owners did not have special environmental beliefs or concern for the environment and thus having air heat pump visual outside of house can't be considered as communicating of meaning or lifestyle to externals via energy efficient product purchases (see motivations in [28] and Palm & Tengvard 2011).

5 DISCUSSION

5.1 From trials to trust

It's noteworthy that there is strong trial or experiment attitude towards renewable energy production. Expectation level is not necessary high before the purchase and beginning of the use. Users are not seeking for radical one solution that fixes whole system and all previous problems. They rather want to see what new technology is capable of and make further changes and energy system investments later on. T-K. Lehtonen writes about technology trials [29] in adaption, which indeed describe well process of decision making in renewable energy projects. Users describe technology purchase as test. It is not fully replacing old systems, it's acquired to support existing system, work with it and make it more cost efficient or convenient in use or both. Initial learning and adoption is a trial where technology's real performance is tested and new purposes can be found.

5.2 Intertwined energy production and consumption in domestic space

An household is more than a site for a consumption. Rather, especially in case of residential energy systems, it is a place that is turning back towards highly intertwined, inseparable site of both production and consumption. Understanding of residential energy systems and social change towards renewable energy use requires partial departure from consumption studies approach.

Changing role of energy consumer calls for introduction of micro entrepreneurship type of components into the research. There is a thin line from energy production for own use to over production and energy provision to the other users and market. Understanding energy production in local site creates important knowledge for future purposes when two directional energy grids, smart grids, become available. Users now have the possibility to produce their own power, but they still face difficulties when trying to resell extra power generated back to the grid. There is antipathy against large energy utility companies and dependency on centralized power grid and energy supply (See also Palm and Tengvard 2011 study and way to protest against energy companies motivation). Value of national distribution network seen from new direction. It's network for selling, as much as for buying.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

In this study I have focused on appropriation, configuring, daily using and conversing technology from consumer viewpoint. I have left out design process of goods and as a consequence, not included notion of script [30], which is widely used analytical tool inside science and technology studies and useful for comparing designers' conceptions of technology and actual user behavior. In renewable technologies, with relatively straightforward way of using the product, notion of script may provide meaningful analytical tool to provide interesting insights. Also, in wider scope, regarding understanding technology policy, I also recognize importance of social learning [6,] processes involving people, communities, companies outside of domestic site to the domestication processes described earlier. This are important future research opportunities but a wider framing and set of analysis together with format of conference paper would have negatively impacted to detail of description in this stage.

Environmental impacts arise through the interplay of technology, consumption and everyday life [31]. A better understanding of the role of end-users in processes of technology diffusion could help the development of environmentally friendly final products and enhance the adoption rate of these technologies and lifestyles. Renewable energy production in residential house context is mostly motivated by financial reasons, convenience and utility. There is strong variation between these requirements case by case and complacency is achieved already when key factor is well fulfilled. Although energy production investments are larger and less frequent than purchases of typical household consumer goods, switching from old system to new is not revolutionary. Trialing of technology and additional increase of use and investing to renewable technology demonstrate users to have smooth evolutionary approach in energy technology adaptation. Modularity of design to expand capacity of certain technology or combine different technologies conveniently should be high on manufacturers agenda.

The most advanced users see opportunities in co-generation of energy and are willing to additional investments when smart grid enables more open energy market for small producers. Detached houses and dispersed community structure provide favorable conditions for smart grid that should be tested in small scale trials before mass market operations.

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Co-creational Environmental Excellence in Socially Exchangeable Modular Energy System and its Leading Design Methodology based on System of Systems Viewpoint

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Abstract
This research discusses the co-creational environmental excellence focusing on a socially exchangeable modular home fuel cell co-generation system, and proposes its leading design methodology introducing a viewpoint of "system of systems" which broadens the scope of a design problem from the optimization of an individual system to the optimization of system of systems by integrating local optimization, multi-agent simulation, and scenario based planning. The design problem is decomposed into three sub problems i.e., (i) design optimization of variety of system modules such as a fuel cell unit and a heat exchanger which meets variety of energy demand of a residence, (ii) design optimization of a service system for introducing and exchanging fuel cell modules, and (iii) design optimization of a bounty system for popularization of a home fuel cell. A scenario is composed by combining alternative solutions of the sub problems, and is evaluated with a multi-agent simulation which predicts household behaviors for a introducing and exchanging a home fuel cell and then calculates social cost and consumed energy. The results show the possibility of co-creational environmental excellence in a socially exchangeable modular energy system, and the possibility of a system-of-systems approach for optimizing such an open-ended, complicated design problem toward the high-level environmental excellence.

Keywords:
Energy system, environmental excellence, system of systems, leading design

1 INTRODUCTION

Today's societal demand for environmental sustainability has been prompting all stake holders, such as governments, local communities, manufacturing companies, households, to simultaneously involve with its problem solving. They should cooperatively contribute to environmental excellence and gain any benefits through its total optimality. However, this is an extremely open-ended problem, since factors cannot be defined explicitly and all factors contain uncertainty. The high-level environmental excellence should be achieved through a co-creational mechanism in which each stake holder not only optimizes its problem locally but also coordinate with each other toward a total optimal solution.

This research looks at leading desing of socially exchangable modular houme fuel cell systems as an example, and proposes its design methodology to achieve high-level environmental excellence through co-creation of systems. This research introduces a viewpoint of "system of systems" which broadens the scope of a design problem from the optimization of an individual system to the optimization of systems by integrating local optimization, multi-agent simulation, and scenario based planning.

2 DEPLOYMENT OF SYSTEM THEORY AND EXPECTATION FOR CO-CREATIONAL ENVIRONMENTAL EXCELLENCE

2.1 Co-creational environmental excellence

System can be generally defined as "an aggregation of elements which depend on and interact with each other.[1]" In engineering domain, a word *system* is used to represent an artifact, e.g., a product system, a service system, a social system and so on. This research also uses the word in that meaning.

There are some approaches to enhance environmental excellence of an individual system, e.g., a manufacturer designs products with less environmental load materials or modularization for easy reuse and recycling, a customer buys environment-friendly products, a policy maker builds a bounty system to promote environment-friendly activities, and so on. A more high-level environmental excellence can be considered by incorporating those individual approaches. Generating such an effective value through interactions of autonomic stake holders is called *co-creation* [2]. A system built by co-creation can astronomically reconfigure its structure responding to changes of environment, such as changes of customers' demand, and then show high-level optimal performance.

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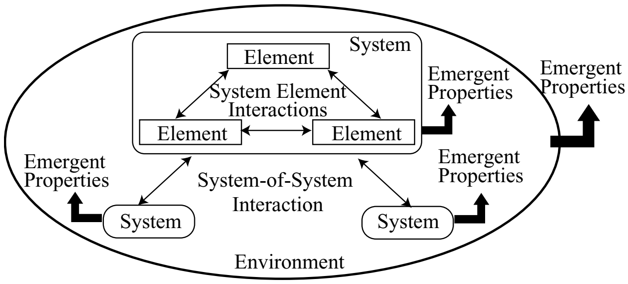

Fig. 1 : System of Systems

2.2 Viewpoint of "system of systems"

Co-creational environmental excellence is an answer to expanding system design theory. A range of today's system design has been expanding. That is not only because an individual system becomes large-scaled and complicated, but also because a society now demands that a system should be designed considering both of system performances and the affects to its environment. An expanded object of system design is called *system of systems* (abbreviated to SoS in the rest of this paper). Its necessity is noted especially in aerospace industry and defense-related industry in the United States. SoS is a large-scaled system consisting of multiple autonomic systems as shown in Fig. 1. A range of design is not limited to an individual system but expanded to various systems which have complicated interrelationships. Therefore, design problem of SoS requests any new approach other than conventional methods of system design, e.g., top-down system analysis, top-down system modeling, top-down formulization, and optimization based on them.

2.3 Emergent approach

Emergent is one of effective approaches to design of SoS, to which it is difficult to adopt conventional system design methods [2]. In philosophy, systems theory, science, and art, emergence is the way complex systems and patterns arise out of a multiplicity of relatively simple interactions of autonomic system as shown in Fig. 1. The behavior of each system is bound by the emergent properties. In emergent theory, an autonomic system is called agent. The emergent causes co-creation.

This research adopts an emergent approach and proposes a design method for SoS as shown in Fig. 2. Firstly, systems elements concerning with a design object and interrelations among them are enumerated. A system model of the whole of design problem is built based on the clarified elements and interrelations. It is decomposed into sub design problems. Each sub problem is solved locally to obtain a set of solution candidates. In this local problem solving, an optimization is performed for some sub design problems, which can be mathematically formalized and any optimization method can be adopted. A set of solution candidates for the whole design problem, each of which is called scenario, is composed by enumerating combination of alternative solution candidates of sub problems. A multi-agent simulation is performed under each scenario to evaluate the solution candidate.

Because SoS design is open-ended, any new approach is required for evaluation of its solution candidate. This research proposes that ideal situation should be assumed before the evaluation, and it is used as a target. A designer compares scenarios with the ideal situation, critiques them based on the comparison, and decides whether or not the scenario is good enough as the solution. If necessary, he/she should go back to the previous phases to refine sub problems, system modeling, and system element definition.

Based on the emergent approach introduced in this subsection, the rest of this paper focuses on the leading design of exchangeable modular home fuel cell systems and discusses its methodology toward co-creational environmental excellence.

3 SOCIALLY EXCHANGABLE HOME FUEL CELL SYSTEM

3.1 Home fuel cell cogeneration system

Distributed generation, also called on-site generation, is one of probable solutions for sustainable society. In industrial countries, most of their electricity is usually

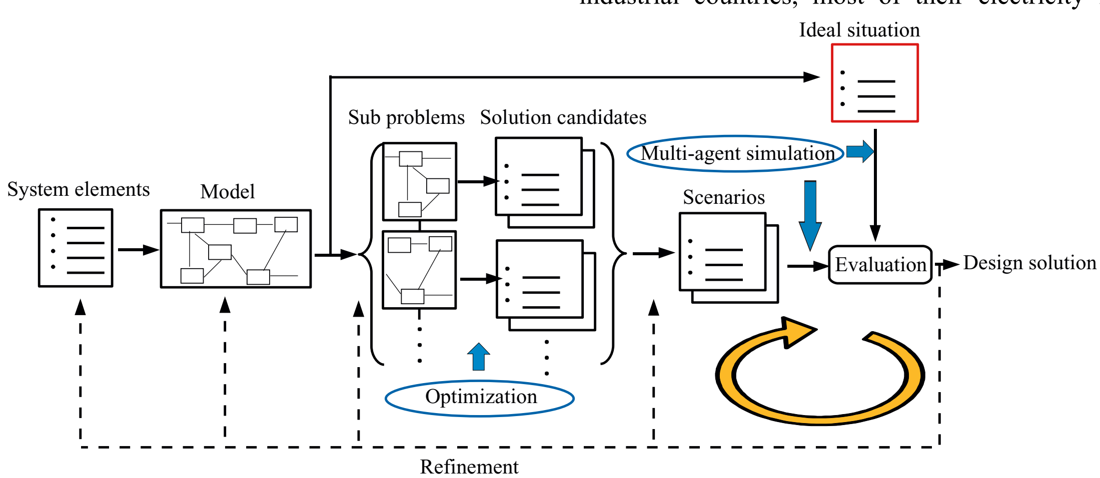

Fig. 2 : Emergent approach for SoS design

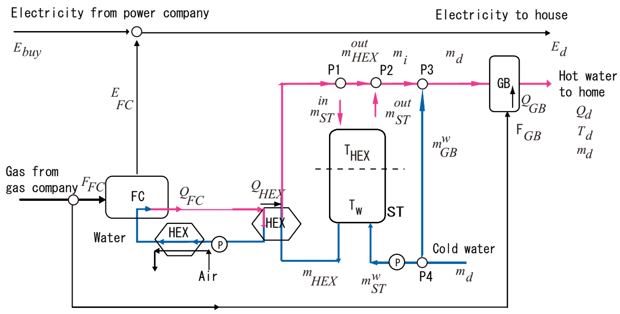

Fig. 3 : System architectmre of home fuel cell

generated in large centralized facilities. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. Distributed generation is another approach. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed.

A home fuel cell co-generation system (CGS) is a representative example of popularizing distributed generation systems. CGS is a system that simultaneously generates two useful secondary energies [4], usually electricity and useful heat. It generates electricity by a power station, such as gas turbine or fuel cell, captures by-product heat emitted during electricity generation, and uses it for boiling water or air-conditioning. Fig. 3 shows system architecture of home fuel cell. It generally consists of three modules, e.g., fuel cell power station (FC), gas boiler which works as a backup heat engine, and hot water tank (T_{HEX}). A fuel cell co-generation system is being noticed as a probable energy system because of its high energy efficiency. However, it has not yet been popularized, because its introduction cost and running cost is high although a government supports its popularization by a bounty system.

3.2 Fluctuation of energy demand

Rated output of a home-use energy system should be designed corresponding to energy demand of a household which introduces the system. If rated output of an introduced CGS is larger than energy demand, it causes redundant running cost. If it is smaller than energy demand, energy efficiency becomes lower.

The number of household members, on which the energy demand depends, changes through life stages, such as marriage, birthing and independence. That change takes place everywhere in a society, and causes fluctuation of energy demand. Because an energy system's life span is long enough, it should be designed considering the fluctuation. This research assumes that energy demand of different household will fluctuate differently, but distribution of energy demand in the whole society will remain largely stable.

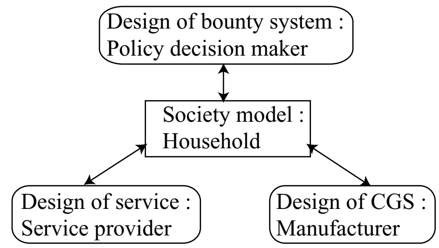

Fig. 4 : Sub problems

3.3 Possibility of co-creational environmental excellence with socially exchangeable modular home fuel cell

Total performance of CGS depends on its modules' performance. It is expected to respond to fluctuation of energy demand by exchanging some modules properly. It is also expected to respond to physical deterioration with a low cost by exchanging a deteriorated module instead of replacing the whole system.

If various energy demands distribute among society, and distribution of energy demand in the whole society will remain largely stable, it can be considered that each household shares the modules and exchanges them when the energy demands changes. A household can choose an optimal one corresponding to its energy demand. An exchangeable module will reduce introduction and operation cost of home fuel cell will reduce, and then promote its popularization.

4 LEADING DESIGN METHODOLOGY OF SOCIALLY EXCHANGABLE MODULAR HOME FUEL CELL CGS

4.1 Leading design

This research supposes that a socially exchangeable home fuel cell CGS is popularized, and that co-creational environmental excellence is achieved by it. That is a near future scenario. Toward designing such an advanced system, a concept of leading design is important. Leading design is a concept to support designing a highly advanced artifact for which necessary technical seeds are not sufficiently developed [5]. This research is based on the concept, and proposes leading design methodology of to-be energy systems.

4.2 Definition of sub problems

It is not feasible to solve the whole leading design problem as a single problem considering factors stated in the previous section. This research decomposes it into the following three sub design problems.

1. Design of CGS, that is, design of CGS module, its variants and operation schedule corresponding to energy demand.
2. Design of services of introducing CGS and exchanging modules.
3. Design of a bounty system.

Those three sub problems are integrated by a social model that is implemented by a multi-agent simulation considering interrelationships among the systems as shown in Fig. 4.

4.3 Steps of leading design

The leading design is performed in the following steps based on the approach stated in Subsection 2.3 considering the sub problems and their interrelationships.

(i) Modeling fluctuation of household energy demands and household behaviors of introducing/exchanging CGS

A multi-agent simulation that simulates energy demand fluctuation is built considering four life events which change the number. Household behavior of introducing or exchanging CGS is also modeled.

(ii) Design optimization of CGS

An optimal product family of CGS is designed under energy demand fluctuation given by a multi-agent simulation built in step (i).

(iii) Design of service system, design of bounty system

Multiple alternative solution candidates of a service system and a bounty system are obtained.

(iv) Computing cost and energy efficiency

Scenarios are composed by combining the solution candidates given in step (ii) and (iii). Each scenario is evaluated by total cost in a society and social energy efficiency calculated by a multi-agent simulation.

The following subsections of this section explain the details of those steps. The detail of step (iii) is explained by a design example in Section 5.

4.4 Modeling fluctuation of household energy demand and household behaviors of introducing/ exchanging CGS

Modeling fluctuation of household energy demand

Energy demand consists of electricity demand and gas demand. Household energy demand depends on the number of household members as shown in Fig. 5 [6]. It can be roughly classified into three patterns, i.e., single person household (S1), two to four person household (S2) and over five person household (S3).

This research considers four life events which change the number of household members, i.e., birth, marriage, independence and death. A nominal probability distribution is given to each factor. A model that simulates human life based on the four factors is built with a multi-agent simulation. A life model can predicts change of the number of household member, and fluctuation of energy demands based on the data shown in Fig. 5. Random numbers r_E and r_Q are multiplied to electricity demand and gas demand, respectively, in order to consider that different household has different energy demand because of difference of its lifestyle even if the number of household members is same. r_E and r_Q are given by two-

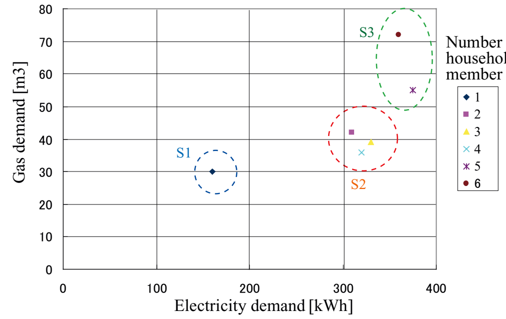

Fig. 5 : Patternized energy demand

dimension normal distribution with covariance, because electricity demand would correlate with gas demand.

Modeling household behaviors of introducing/exchanging CGS

It is assumed that household introduces CGS if the sum of its introducing cost and its running cost is less than the sum of electricity cost and gas cost in the case of no CGS. Introducing cost of CGS is modeled by a monotonically decreasing function of the number of manufactured fuel cell, because its manufacturing cost will decrease because of economy of scale.

A fuel cell of CGS should be exchanged in the future, because of its physical deterioration and energy demand change. This research assumes that a household decides to exchange a current fuel cell module for new one which meets energy demand when any of the following conditions is true.

(i) A fuel cell comes to the end of its physical life.

(ii) The other module comes to the end of physical life. That is, a fuel cell can be exchanged in the opportunity of exchanging the other module.

(iii) The following inequality is satisfied; $C_1 - C_2 > C_t$, where C_1 is annual running cost of current fuel cell, C_2 is annual running cost of new optimal fuel cell, and C_t, is exchange cost.

4.5 Design optimization of CGS

Design of modules and product family

A variety of rated output of CGS is needed in order to meet a variety of energy demand. This research defines two factors as design variables of CGS family design problem, i.e., maximum amount of gas inputted to fuel cell [kW], which controls rated output of fuel cell power station, and capacity of boiled water tank [L]. It is assumed that the common gas boiler is used regardless of energy demand, and its rated output of gas boiler is 17.5[kW], because a gas boiler is just a backup heat generator. An objective function is the sum of annual write-off of introduction cost, annual running cost and annual energy cost, which sums electricity cost and gas cost,. A mathematical model of electricity amount and heat amount generated by a fuel cell power station, and a mathematical model of heat amount generated by a gas boiler are needed to calculate necessary amount of electricity and gas corresponding to energy demand. This research uses liner approximated models of them [4][7].

Optimization of operation schedule

A daily schedule of operating fuel cell power station should be optimized when CGS is designed. This research assumes a daily fluctuation of electricity demand and gas demand [6], and obtains an optimal operation schedule in advance, which minimizes daily energy cost under the daily fluctuation of energy demand. That optimal schedule is given to the design optimization of CGS modules stated above.

4.6 Computing cost and energy efficiency

An objective function of total cost C is an annual cost of each household, which sums introduction cost and running cost. It is given by the following equation;

$$C = \frac{\sum_{t=1}^{T}\sum_{i=1}^{N}(IC_i^t + EC_i^t + TC_i^t)}{\sum_{i=1}^{N} n_i} \quad (1)$$

A subscript t and i denotes a value of t th year of i th household. T is years of simulation span. IC^t_i is annual writing-off of CGS introduction cost. EC^t_i is annual energy cost. TC^t_i is module exchanging cost. n_i is the length (years) that i th household exists. N is the total number of household that exists in T years.

An objective function of energy efficiency E is given by the following equation;

$$E = \frac{E_{out}}{E_{in}} \times 100 \quad (2)$$

$$E_{out} = \sum_{t=1}^{T}\sum_{i=1}^{N}(ED_i^t + QD_i^t) \quad (3)$$

$$E_{in} = \sum_{t=1}^{T}\sum_{i=1}^{N}(FP_i^t + FFC_i^t + FGB_i^t) \quad (4)$$

E_{out} is total energy output, that is, total energy consumption in a society. E_{in} is total energy input in a society. ED^t_i is electricity demand. QD^t_i is gas demand. FP^t_i is primary energy amount inputted to a power plant in order to cover household electricity demand. FFC^t_i is gas amount inputted to a fuel cell power station. FGB^t_i is gas amount inputted to a gas boiler.

5 DESIGN EXAMPLE

5.1 Overview

This section demonstrates an example of leading design based on the methodology stated in Section 4. A span of a multi-agent simulation is 30 years. As proposed in Subsection 2.3, values of objective functions at the ideal situation are used as a design target. Scenarios are evaluated by comparing with that target. Fig. 6 shows values of objective functions and outlines of Pareto optimal solutions under the scenarios introduced in the design example, and transition of Pareto optimal solutions corresponding to refinement of scenarios. A horizontal axis of Fig. 6 is a value of Eq. (1), and a vertical axis is a value of Eq. (2). A data label in Fig. 6 denotes a scenario number.

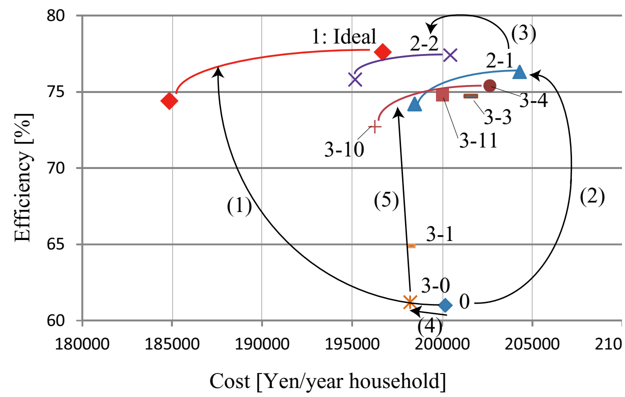

Fig. 6 : Evaluation of scenarios

5.2 Scenario of ideal situation

Firstly, a situation that CGS has not been popularized is considered. All energy demand of household is covered by buying electricity from a power company. All heat demand of household is covered by a gas boiler of household. This situation is named scenario 0. The results of a multi-agent simulation show that C will be 200,176 yen and E will be 61.0% as shown in Fig. 6.

Next, realization of socially exchangeable modular home fuel cell CGS is assumed as an ideal situation. It is assumed that the number of CGS lineup is 100, module exchange cost is zero, and manufacturing cost of CGS lowers to asymptotically stable value. This situation is named scenario 1. In order to obtain an outline of Pareto optimal solutions with a small computation cost, this research obtains two extreme Pareto optimal solutions with a single objective function, i.e., a cost optimal solution and an energy efficiency optimal solution. Comparison between the results of scenario 1 and the results of scenario 0 shown in Fig. 6 reveals that cost reduction of about 15,000 yen and efficiency improvement of about 15% can be expected by realization of socially exchangeable modular home fuel cell CGS (Fig. 6 (1)).

5.3 Scenarios of CGS family design and operation system design

Scenarios of CGS family design and its operation system design are composed under the assumption that all household will introduce CGS.

Case of designing three CGS variants

This subsection firstly considers a situation that a manufacturer designs three CGS variants each of which covers each of patterned energy demand S1, S2 and S3 explained in Subsection 4.4. This is named scenario 2-1. The optimization is performed with genetic algorithm (differential evolution) powered by OPTIMUS. Table 1 shows specs of fuel cell power station and boiled water tank as the results of the optimization. A multi-agent

Table 1 : Optimization results of three fuel cells

	Fuel cell output [kW]	Tank capacity[L]
S1	0.28	53.0
S2	0.43	53.0
S3	0.57	53.0

simulation is performed under that scenario. The results reveal that energy efficiency comes up to the target level, but cost is 10,000 yen higher than the target (Fig. 6 (2)). One explanation for the results is that CGS which many households introduce has higher rated output than household energy demand. That is because the number of CGS variants is too few to cover distributed household energy demand. It is also revealed that only 85% of households have never exchanged modules because of high exchange cost. Those results show that socially exchangeable modular home fuel cell CGS cannot be realized by this scenario.

Case of designing three CGS variants

Next, the other situation is considered. A manufacturer modularizes a cell unit of a fuel cell power station such that its rated output can be easily configured by combining proper number of cell units. This design example assumes a cell unit which rated output is 0.2 kW, and its exchange cost is 50% of exchange cost of the whole fuel cell module. This situation is named scenario 2-2. Comparison between its results and the results of scenario 2-1 reveals that efficiency comes up to the target level, and cost comes close to the target (Fig. 6 (3)). 96.4% of households have exchanged modules. Those results lead to the conclusion that scenario 2-2 is probable.

5.4 Scenarios of bounty system

In a design of bounty system, a household is assumed to decide introduction of CGS based on the rule defined in Subsection 4.4. The situation of scenario 2-2 is assumed as for CGS family design and its operation system design. Scenarios are composed assuming some situations of bounty, e.g., no bounty is paid (scenario 3-0), a certain amount of bounty is paid every year to a household which introduced CGS (scenario 3-1 to 3-4), bounty is paid every year but its amount is reduced every five years (scenario 3-5 to 3-13). Table 2 shows the details of representative scenarios, values of objective functions and percentages of household which introduces CGS. Cost includes government's expense for bounty. When there is no bounty, only 1.8% of households introduce CGS. Improvement of cost and efficiency is fractional (Fig. 6 (4)). Any bounty system can promote energy efficiency, and cost increase is not so large (Fig. 6 (5)). It is revealed that about 13% improvement of energy efficiency can be expected by the same amount cost as scenario 3-0. That is because bounty promotes popularization of CGS, and it causes manufacturing cost reduction. According with the results shown in Table 2, scenario 3-10 is cost optimal, where initial amount of bounty is large but it is reduced

Table 2: Evaluation of bounty system design

Scenario	Bounty system: Yearly	Bounty system: Reduction	Cost	Efficiency	Intro. ratio
3-0	0	0	198,221	61.2	1.8
3-1	1,000	0	198,126	64.9	18.0
3-3	5,000	0	201,590	74.7	89.1
3-4	7,000	0	202,649	75.4	93.5
3-10	5,000	3,000	202,649	72.7	81.1
3-11	7,000	1,000	200,025	74.8	86.6

after five years. Scenario 3-4 is efficiency optimal, where larger amount bounty promotes more popularization.

6 CONCLUSION

This research proposed a design methodology to achieve high-level environmental excellence through co-creation of systems focusing on leading desing of socially exchangable modular houme fuel cell CGS. This research introduces a viewpoint of "system of systems" which broadens the scope of a design problem from the optimization of an individual system to the optimization of systems. The design example shows that some probable design solutions can be found by the proposed method incorporating local optimization, multi-agent simulation, and scenario based planning.

This research used "artisoc," which is a multiple agent simulator provided charge-free by Kozo Keikaku Engineering Inc. We are deeply grateful to it.

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Eco Design and the Optimization of Passive Cooling Ventilation for Energy Saving in the Buildings: A Framework for Prediction of Wind Environment and Natural Ventilation in Different Neighborhood Patterns

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Abstract

The idea of utilizing natural ventilation for passive cooling and hence reducing the energy for air conditioning systems of buildings has increasingly attracted the attention of researchers. In urban areas however, a kind of comprehensive approach considering simultaneously the outdoor wind environment and the natural ventilation has been mostly neglected. This study firstly investigates, the effective criteria on the resulting wind environment at pedestrian level, in the outdoor spaces, and secondly defines criteria and indicators in different residential neighborhood patterns which led to an assessment of the resulting ventilation potential of the neighborhood blocks. The results of parametric three-dimensional modeling studies, using Computational Fluid Dynamics (CFD) have been used to identify criteria more precisely. In the context of Iran, by focusing on Tehran, this article aims to indicate the application of the effective criteria in several configurations of neighborhoods, each represent a kind of typology, in order to assess wind environment around the neighborhood blocks. Finally, the article developed a framework which may be used as a guide for urban designers/planners to create a more ecologically and environmentally sustainable urban form.

Keywords:

Ventilation, Pedestrian-level wind environment, Neighborhood patterns, CFD

1 INTRODUCTION

Considering wind environment effects on urban spaces such as Dispersion of pollutants, diffusion of heat, comfort and safety of pedestrians, and also the energy related effects such as natural ventilation of buildings, indicates the necessity of understanding the wind behavior and its environment to be taken into account in the sustainable urban design approach.

Apart from which of the above effects are prior regarding the geographic situation and climatic conditions of site, it is essential for an urban designer, to have knowledge of the effective criteria forming a wind environment. The necessity will be also multiplied regarding the increase in world's urban population[1] and hence the need of high rise buildings and skyscrapers on the one hand, and the cost of a conventional wind environmental advice (wind tunnel), which led it to being postponed to the quasi-final design steps, on the other; although the use of computational models has been noticeably increased in recent years which makes the wind environment analysis easier, faster, and also more affordable.

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions [2].

The main purpose of this study is to suggest a framework which can be assumed as one of the environmental consideration an urban designer should have in his mind, in order to improve the urban spaces' environmental quality as well as buildings' energy efficiency. This article does not aim to investigate the parameters related to the CFD method and interpret the dynamical equivalent. Rather it seeks the main results of previous studies which have been carried out using CFD analysis and tries to clarify their relationship with the basic factors which are used in urban design in order to organize the effective criteria by definition of a framework which can be used by the urban designers not only in new urban development but also in reconstruction of the existing urban texture.

1 The world's urban population was 2.9 billion (47.2%) in 2000 and is expected to rise to 5 billion (60.2%) by 2030. During 2000–2030, the world's urban population is projected to grow at an average annual rate of 1.9% [1].

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2 BACKGROUND

Computational Fluid Dynamics, or CFD, uses advanced computer software to model the flow of fluids through a processing facility. The fluid may be in liquid, gas or loose particle form, or a combination of them. Using computer simulation a wide range of variations in physical design and operational parameters can be tested and refined until a set is identified which gives optimum performance[2]. One of the software uses the CFD method, is the software "Fluent". Since it is mechanical software and deals with the small size obstacles and objects, it requires a huge amount of computations in order to analyze wind behavior at the scale of an urban.

Recently, Meteodyn has developed "UrbaWind", which is automatic CFD software for computing the wind in urban environment for small wind turbines. The model used in UrbaWind allows taking the wind effects into account by solving the equations of Fluid Mechanics with a specific model that can represent the turbulence and the wakes around buildings as well as the porosity of the trees and the effects of the ground roughness (asphalt, water or grass). In comparison with the software Fluent, Urbawind's advantage is that it has been dedicated for the analysis at urban scales, which led to a less time-consuming computational process. In order to validate UrbaWind's results, different study cases proposed by the Architectural Institute of Japan have been set up[3]. Urbawind's output and input data can be illustrated as fig.1. There are several input types needed to get the 3D plan output. This paper aims to develop a framework used in the 3D site plan as the input.

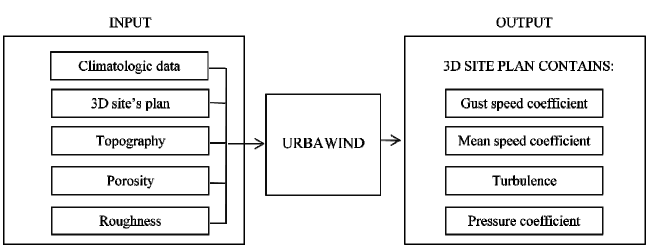


Fig. 1: Scope of Urbawind software(by author based on [3])

UrbaWind solves the equations of Fluid Mechanics, i.e. the averaged equations of mass and momentum conservations (Navier-Stokes equations) When the flow is steady and the fluid incompressible.

3 DEVELOPING A FRAMEWORK

There are several studies based on wind tunnel tests or numerical models which examine wind environment around buildings [4],[5],[6],[7],[8]. They suggest that apart from site's situation (i.e. porosity and vegetation) and local wind characteristics, there are several criteria regarding buildings which form the characteristics of the wind over an actual ground surface. Building configuration, e.g. its height, width, building arrangements and density are some of the significant factors affecting wind velocity near the ground level [4, 9].

Many studies has been focused on street canyons and indicate how the ratio of building height to the width of street (called aspect ratio) affects the wind environment [10], [11],[12],[13],[14]. Bottema [15] after introducing the wind amplification factor which links local mean wind speed to mean wind speed at an ideal meteorological site, defines topography and surrounding terrain, building or building groups and details of site as the effective criteria on wind amplification factor at various scales(i.e. region, city, district)[15]. Kubota et al [4]suggests the gross building coverage ratio and gross floor area ratio as the criteria to reveals the relationship between the building density and the average wind velocity at pedestrian level. It indicates that an increase of the gross building coverage ratio decreases the mean wind velocity ratio. It also concludes that the average pedestrian-level wind velocity of cases can be explained well by the gross building coverage ratio rather than by the gross floor area ratio. Fig.2 shows some effective criteria on wind environment which have been mentioned by previous studies.

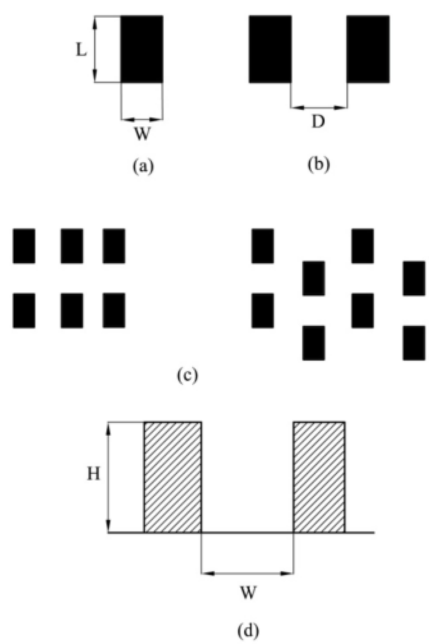
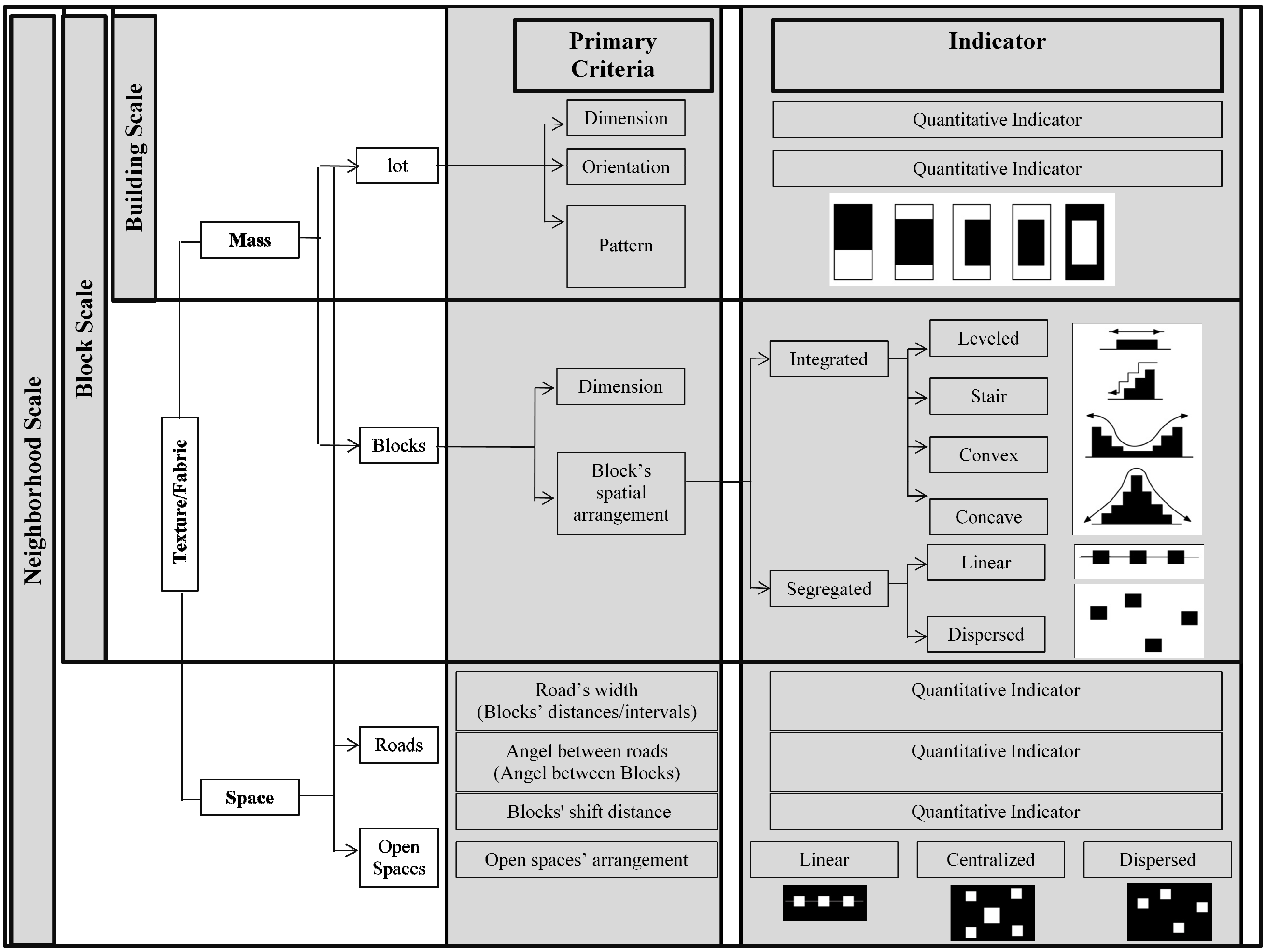


Fig. 2: Scope of effective criteria on wind environment mentioned by previous studies (a) building's dimensions (b) block's distances (c) blocks' arrangement (d) aspect ratio

Considering these studies the main effective criteria on the airflow behavior according to the CFD method can be illustrated as Diagram1. In the diagram, three scales ranging from building to neighborhood are shown. A kind of fabric can be identified for each scale by means of mass and spaces (voids). Therefore each scale has its own criteria and indicator categorized regarding whether they concern the mass or the space. The building scale's main criteria as far as it considered as a lot are, dimension (i.e. orientation, and pattern which indicates how the building is being arranged in a lot. The first two criteria can be identified by the quantitative indicator and the last one, by qualitative indicator. As the upper scale and formed by standing a row of lots in a vicinal way, a block can be defined by its dimension and spatial arrangement.



Diag. 1: Conceptual Framework: Effective Criteria and quantitative and qualitative indicators on wind environment in various scales from building to neighborhood (by authors)

Because of the obstacle's height effect on wind behavior and also inevitable existence of buildings with various heights in a block, it should be considered blocks' profile and the height changes rhythm (that is whether it's increasing, decreasing, and constant or …). Containing all the previous criteria, the neighborhood has its own spaces containing roads and open spaces. Roads criteria are road's width, angel between roads and its continuity which can be construed as the blocks' overlapped distance or blocks' shift distance which all can be identified by the quantitative indicator.

Some notes are worthy to be mentioned regarding the above diagram. Some criteria (i.e. the ratio of building height to the width of street, area's foot print, gross floor area ratio …) which have been mentioned by the previous studies can be assumed as secondary criteria which can be derived from the primary one above. The quantitative indicators in the diagram 1 should be identified by local regulation, building's codes, and per capita standards or by the urban designers' suggested guidelines through the results and observation of computational simulation of CFD. Nonetheless a quantitative range for them can be defined as indicated in table1.

4 NEIGHBORHOOD TYPES

There are two divergent views about the size of city quarter or neighborhood. There is that view represented by Jacobs which stressed the political function of the quarter. Another view held mainly by physical planners relates the size of the quarter to a comfortable walking distance from its center to periphery[16].

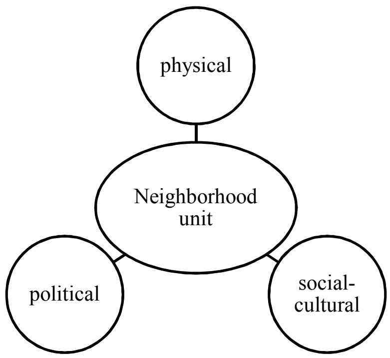
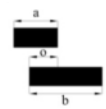


Fig. 3: Scope of Neighborhood's aspects (by authors based on [16])

Focusing on the physical aspects of the neighborhood unit, this paper regards neighborhood as an urban unit which one can reach within 10 to 15 minutes' walk from center to periphery.Surveying different existing neighborhood patterns in Tehran according to their urban fabric, open spaces pattern and the roads network and hierarchy led to identification of three main neighborhood types as following:

Table 1: Quantitative indicators of effective criteria on wind environment

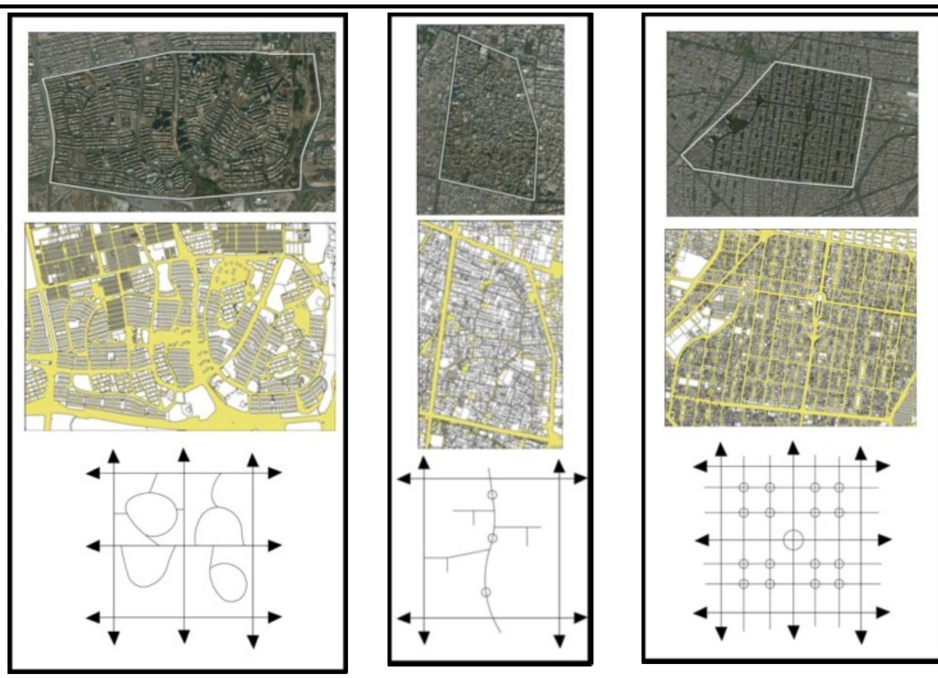
Primary Criteria	Quantitative Range	
Lot 's orientation	0-180 degree	
Roads' width (meter)	Major arterial	45
	Minor arterial	30
	Collector-feeder	18
	Local street/ cull de sacs	10
Angel between roads	0-90 degree	
Block shift distance 	o≤a	

Type A: The main square at center, main roads deriving from that, continuing through the surrounding fabric, high building density at center decreasing toward surroundings.

Type B: clustered model, roads with the well defined hierarchy, open spaces mostly arranged in the main road, fine fabric.

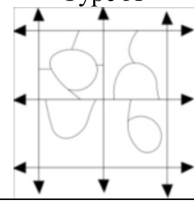
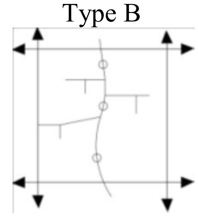
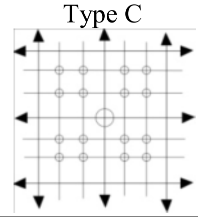
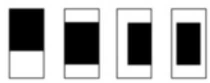
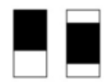
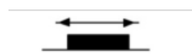
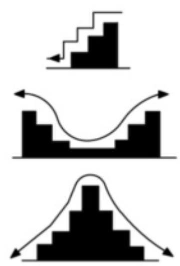
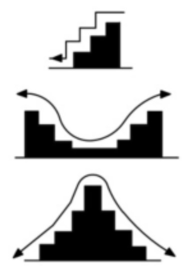
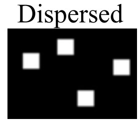
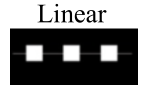
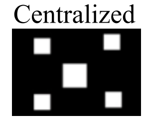
Type C: Grid model, hierarchy of roads and open spaces (fig.4).

Fig.4: Different neighborhood types, Tehran (by author, 2011)



Type A: *Shahrak e Gharb* Type B: *Oodlajan* Type C: *Haft hoz*

Table 1: Neighborhoods' indicators of effective criteria on wind environment

			Type A	Type B	Type C
					
Scale	Criteria		Indicators		
Lot	Dimension (meter)	Length	45	20-30	30
		Width	20	10	15
		Height	6-12	9	15
	Orientation(degree)		0-180	0,30,90,150,180	90
	Pattern				
Block	Dimension (block's length(meter))		120-250	70-100	80-200
	Spatial arrangement				
Neighborhood	Roads' width(meter)		15-45	1.5-8	10-30
	Angel between roads		0-180	0,30,90,150,180	0,90
	Open spaces arrangement		Dispersed 	Linear 	Centralized 

One important note regarding neighborhood types defined above is, their land use intensity scale which defined by the quantitative indicator between 0 and 1. It also can be regarded as the area's footprint criterion (mentioned as secondary criterion before), that as it approaches the value 1, it means that the neighborhood fabric get much more compact and dense. Among the neighborhoods above, Type B with the intensity scale value of about 0.8 can be respected as a dense neighborhood. Although this is needed to be proved by the results from computational model, it can be expected that such a dense neighborhood would be impenetrable facing the local wind and it would play a huge obstacle role against that.

5 CONCLUSION

Considering different types of necessary input data for computational fluid dynamic (CFD) analysis, and focusing on the geometric data which is "3D site plan", this paper reviewed the previous studies on wind behavior which have been held by the CFD method. Therefore the primary effective criteria on wind behavior regarding the geometric characteristic of building and blocks have been recognized and a framework of effective criteria on wind environment, quantitative and qualitative indicators, categorized by building, block and neighborhood scales has been suggested. As shown in the diag.1, in the building scale, lot's dimension, orientation, pattern, in the block scale, in addition of building scale's criteria, block's dimension and its spatial arrangement and finally in neighborhood scale, in addition of lower scales' criteria, roads' width, angel between roads, blocks' shift distances and open spaces arrangement, are the primary criteria. Then some ranges, can be assumed for the quantitative indicators have been suggested in the table1. Finally the developed conceptual framework has been applied for the three most common neighborhood types in selected systematically Tehran city; then each neighborhood type's character has been introduced by the qualitative and quantitative indicators of the suggested criteria in the framework. So the urban designer can use it as a primary assessment in the early stages of design and before the 3D plan analysis stage by CFD. This framework can be used by the urban designers not only in new urban development but also in reconstruction of the existing urban texture and it introduces and generates a knowledge of effective criteria as tools which can be applied by an urban designer to control the environmental quality of urban areas toward urban sustainability in a favorable way. This article took the first step in the process of an approach which tries to assume wind as an environmental factor in the early steps of design and before the application of computational model; further studies can be dedicated to next steps by a definition of the quantitative ranges for the suggested indicators which led to a safe and favorable wind environment.

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Energy Harvesting for Distributed Microsystems – The Link between Environmental Performance and Availability of Power Supply

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Abstract

Efforts in reducing power consumption of microelectronic components and developments in the area of energy harvesting devices have led to technically feasible solutions for autonomous power supply of distributed microsystems. Reliability by means of availability of the required energy is a fundamental constraint for replacement of batteries. At the same time environmental impacts of the technical solution need to be kept low. In this paper we will present a framework for modeling energy budgets depending on non-ideal environmental loads. A new indicator describing availability and risk of materials implemented is introduced, which is then applied to compare environmental performance of different design decisions.

Keywords:

Energy harvesting, system-oriented design, resource availability and risk indicator (RARI)

1 INTRODUCTION

The interest in microsystems integrating own power conversion units using energy from the surrounding environment is steadily growing. Main application fields can be found in industry because of the chance to save significant maintenance costs due to extended system lifetime without the need to change batteries on a regular basis. Moreover, reduction of battery use in wireless application is desired from an environmental point of view. Trade-off considerations comparing environmentally critical materials of both, energy harvesting devices and batteries vs. operation time were previously conducted [1][2]. The first step towards an environmentally conscious solution is the comparison of technologically feasible options. Ambient conditions as well as the ability to buffer deviations from ideal operating conditions will finally determine the choice of components, overall dimensions and therefore amount and composition of materials implemented. The developed framework for modeling and optimization of the energy conversion chain provides a foundation for further considerations regarding energy budgets and environmental impacts.

2 SYSTEM-ORIENTED MODELING APPROACH

The idea behind the modelling concept for energy harvesting devices is shown in Fig. 1 for the example of thermoelectric energy harvesting systems converting temperature gradients into electricity. In order to model the complete conversion chain of the harvesting system, components are first categorized corresponding to their functionality and split into parameterized sub-models. In case of the thermoelectric energy harvesting chain this comprises the thermoelectric converter itself as well as peripheral electronic devices for voltage conversion and energy storage.

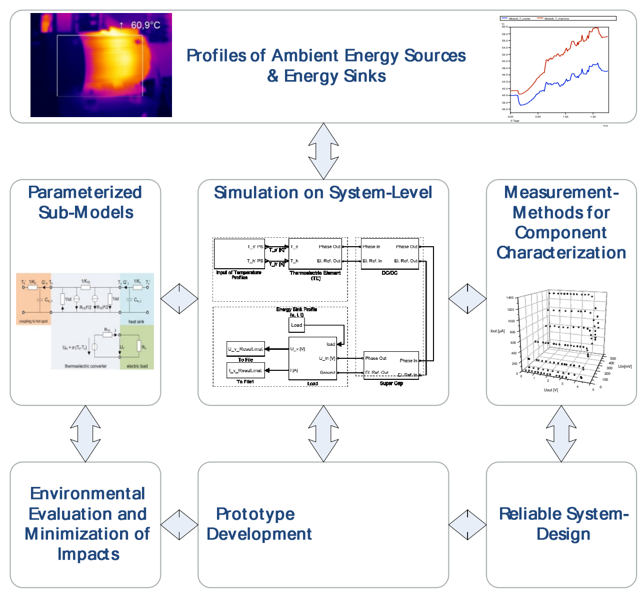

Fig. 1 – Concept of system-oriented modeling approach

The sub-models are then transformed into a common modelling platform with defined interfaces for coupling of the single modules describing the relevant physical domain. Parameters to sufficiently describe these components with regard to their effect on the power conversion path are identified. Parameter sets for specific, interchangeable devices are generated from measurements in case information provided by datasheets is not sufficient. Typical examples are thermoelectric devices,

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Where specifications usually only partially contain the required data for simulation of energy flows in the proposed framework. This is especially true for simulation of system behavior at other than room temperature levels, requiring temperature-dependent parameter curves of the module. For analysis of dynamic processes, time-dependent parameter sets might also be required, e.g. leakage current of capacitors. Moreover input profiles of ambient energy available as well as output profiles of the energy consuming devices (energy sinks) need to be coupled to the simulation environment. On the basis of the provided framework, feasibility of energy harvesting setups in varying environments can be evaluated in an early development phase. System optimization by identification of critical parameters becomes possible as effects of changes in design on module-level can directly be linked to overall system performance. From the model, acceptable parameter deviations or drifts can be derived for the system to be working within targeted specifications. For environmental analysis firstly technological alternatives can be compared on a common basis. Secondly effects of elimination, minimization or replacement of environmentally critical components can be investigated. A suitable, optimized solution of components chosen is finally turned into a hardware test setup.

3 APPLICATION SCENARIO

Maintenance and repair are significant expense factors for operating a facility, plant or machine. Efficiency and profitability can be increased by applying intelligent concepts of condition monitoring, cutting down expenses caused by unscheduled downtimes or complete engine breakdowns. Moreover, by applying condition based maintenance, operating time between service intervals can be increased significantly. Recent studies at Technical University of Berlin and Fraunhofer IZM focus on the design of condition monitoring systems for industrial applications. Within the frame of the project 'ECoMoS' (Energy-autarkic condition monitoring system) a sensor network of self-sufficient micro systems is currently developed for condition monitoring purposes of machine parts in paper plants. The wireless sensor system proposed within the framework of the project 'ECoMoS' represents such an innovative approach for applied condition monitoring (Fig. 2). The developed system includes an acceleration sensor which is attached to the vibrating machine being monitored. A digital signal processor performs hardware-based algorithms to complete a Fourier transformation of the acceleration signal and does further analysis of the characteristic spectrum. A first diagnose of the systems condition is carried out onboard. In case of a warning a protocol with the attached FFT is sent to a base station via proprietary communication standard. Further steps can then be decided by operating staff of the paper mill. Minimum threshold value for operating voltage was defined 3.3V corresponding to the specifications of the IC solutions implemented. In order to keep energy demand low, duty cycle operation of the system was chosen with current pulses below 50mA over periods of 10s for each measurement. While the first prototype already proofed to be fully functional [2], a second generation integrating all electronics of the sensor system as well the thermal path for thermoelectric energy conversion will be introduced (Fig. 2).

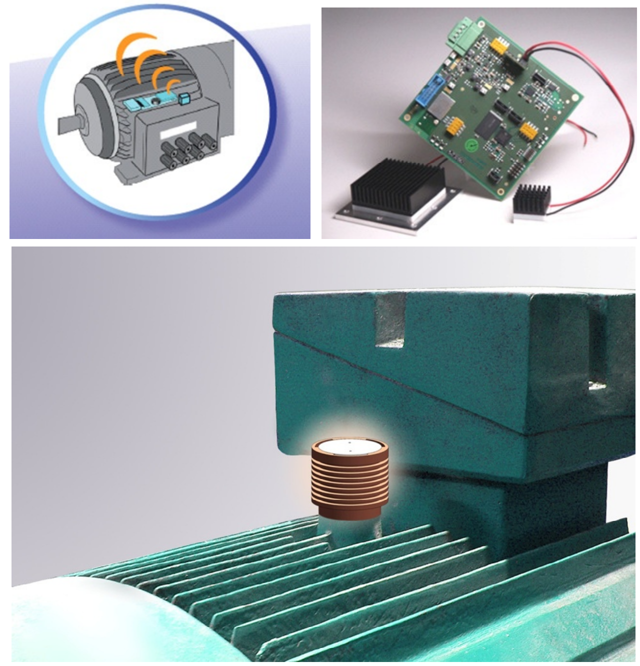

Fig. 2 –Self-sufficient sensor node: System study (top, left), first prototype from discrete components (top, right), final integrated concept (bottom)

4 SYSTEM SIMULATION

The setup of the electronic subsystem for voltage conversion and buffering including parameters of the chosen components was fully described in [2]. Sub-models described were implemented in Matlab/Simulink, using predefined SimScape components from electric and thermal physical domain.

Properties	TEG A	TEG B
Dimensions [mm·mm·mm]	20,0·20,0·3,4	30,0·30,0·3,6
Weight [mg]	6,19	14,74
α [mV/K]	12,7	54
Rth [K/W]	5,92	3,19
Ri [Ω]	0,37	3,41

Table 1 – Properties of thermoelectric devices investigated

The complete energy harvesting model consists of the thermo-electric modules (TEG) opposed to a temperature gradient, a Linear Technologies DC/DC converter, LTC3108, and the energy storage, a CAP-XX ultracap, HS230, as central module blocks. As for the thermoelectric devices, two options were compared in the latter thermal simulations, Type A and Type B (Table 1), without changing the electronic voltage conversion and energy buffer. Both modules significantly differ regarding Seebeck-coefficient α, thermal resistance R_{th}, electric resistance R_i, weight and size therefore determining system behavior in conjunction with the chosen thermal path.

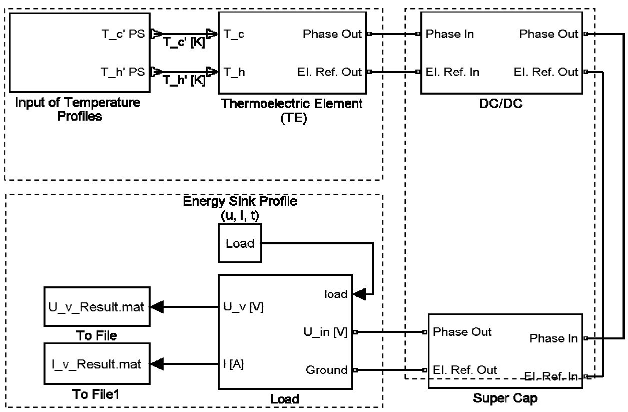

Fig. 3 – Simulink block diagram of the harvesting system

As central multi-physics modeling platform a Simulink model (Fig. 3) was developed. Input connections are provided by two interface blocks for coupling of ambient temperature profile data into the model. These inputs require the temperatures at the thermoelectric elements hot and cold side. From these profiles the temperature gradient is calculated and fed into a controlled heat source in a heat flow network consisting of thermal resistances and capacities describing the thermoelectric device as well as heat conducting layers for mounting between hot and cold side. Parameters are adapted in dependence of the average operating temperature applied to the system using look-up tables providing temperature dependent parameters of the modules. Thermal voltage is linked to the temperature difference via the Seebeck-coefficient and is used to control a voltage source in the electrical path of the thermoelectric element. The output of the DC/DC converter is modeled as a voltage source being controlled from input and output voltages defining the operating point as discussed. For the energy buffer, the ultracap is represented by an ideal capacity and an electric series resistance. Moreover, the leakage current was taken into account being modeled as an additional current source in parallel to capacitor and resistance. The load profiles of the consuming electronics of the sensor system can be applied by an additional block within the platform. Fig. 12 shows the block diagram with interconnections between the modules. The use of parameterized building blocks that can easily be adapted and extended to the targeted application leads to a modeling framework as a starting point for an efficient design of self-sufficient energy supplies for sensor networks. The model was then fed with input data of hot and cold side of data for both TEG options A and B simulated in combination with the newly developed housing concepts using ANSYS Icepak computational fluid dynamics (CFD) software. Hot spot temperature of 61°C on the motor blocks' surfaces as well as ambient temperature of the surrounding air of 35°C in the machine hall were determined from field measurements at the paper mill. Average power provided to the consuming electronics at a constant voltage of 3,3V at the output terminals of the harvesting chain was calculated for the different housing setups discussed below.

5 CONSIDERED HOUSING OPTIONS WITH INTEGRATED THERMAL PATH

While the first prototype consisted of discrete, separate components, the idea of a fully integrated self-sufficient electronic system is introduced in Table 2.

Part	Function	
1	Lid	1
2	Location electronics	8 2
3	Thermoelectric module	
4	Therm. isolating ring	
5	Therm. isolated screws	3 4
6	Location sensor	5 6
7	Coupling hot spot	
8	Surrounding medium (air)	7

Table 2 – Housing of integrated self-sufficient sensor system

The Bi_2Te_3-based thermoelectric device (TEG A or TEG B) is mounted in between a bottom mounting base, attached to the hot surface, and a top cooler with integrated cavity for inclusion of the electronic system. Both metal parts are fabricated from either aluminum or copper. They are screwed together using thermally isolating sleeves around the screws and an isolating spacer defining a fixed height for thermoelectric module inclusion. Silicone-based heat-conductive pads are included on hot and cold sides of the thermoelectric modules accounting for height tolerances by the manufacturer and damping when opposing the module to mechanical loads. There are significant advantages regarding the construction. Firstly including the electronics into the cooler of the thermal path will increase lifetime of the components and reduce parasite effects, e.g. leakage currents at the ultra cap by lowering operation temperature. Secondly, housing the thermoelectric device will prevent it from direct exposure to humidity and chemicals applied in industrial environments. Driven by design restrictions concerning overall dimensions and mechanical robustness preventing usage of conventional cooler designs, modules M1 to M4 described in Table 3 were analyzed regarding its suitability for power conversion as well as its environmental impacts in the following chapters. Modules M1 – M3 include thermoelectric element TEG A, featuring a smaller footprint, thus higher thermal resistance compared to TEG B, whilst Seebeck-coefficient is significantly lower. This is the maximum footprint of a standard peltier device chosen for the metal housing with diameter 45mm applied in modules M1 and M2. Thermal conductivity of the thermal path was increased in M2 by using Cu instead of Al (M1). With M3 and M4 the outer dimensions of the housing were increased to allow for larger surfaces opposed to the surrounding, cooling air, thus increasing heat transfer at higher velocities of air flow around the device. Effects of adding functional thermoelectric material was increased in construction M4 by implementing TEG B.

Module	Main components		Design
M1	Housing	Al	
	h [mm]	58,4	
	Ø [mm]	45	
	m [g]	160,1	
	TEG	Type A	
M2	Housing	Cu	
	h [mm]	58,4	
	Ø [mm]	45	
	m [g]	529,9	
	TEG	Type A	
M3	Housing	Al	
	h [mm]	68,9	
	Ø [mm]	55	
	m [g]	313,0	
	TEG	Type A	
M4	Housing	Al	
	h [mm]	69,1	
	Ø [mm]	55	
	m [g]	313,0	
	TEG	Type B	

Table 3 – Design alternatives considered for power conversion

6 CFD-SIMULATION OF TEMPERATURE DISTRIBUTION

For simulation of temperature distribution within the design alternatives, geometry models of M1 – M4 were set up in ANSYS Icepak using simplify operations for transfer of complex geometries from CAD-files. The thermoelectric devices TEG A and TEG B were modeled as homogenous building blocks allocating the specific heat conductivity of the module in the direction of the major heat flow to the system properties. Material properties of metals and isolators were taken from Icepak library for the specific components chosen. Boundary conditions were set after applying standard hexahedral mesh to the model. All modules were aligned orthogonal to the z plane with the main direction of heat transfer in z-direction. A constant temperature of 61°C resembling available hot surfaces at the application scenario was applied to the lower x-y-plane of the cabinet. The opening option was chosen for all remaining walls of the cabinet allowing for open heat exchange with the environment. Ambient temperature of surrounding medium at initial state was set to 35°C, according to measurements at the paper mill. For simulation of natural convection effects, activation of gravity in –z direction was activated. In x direction flow of fluid (air) particles was increased in four steps. 0m/s (solely natural convection) accounts for worst case, rather unlikely situations, when no circulation of air flow is guaranteed around the sensor node. A typical velocity of 0,2m/s was then followed by values of 0,5m/s and 1m/s resembling forced convection through devices, e.g. fans in the motor block found within immediate distance from the mounting base. Fig. 4 demonstrates the exemplary result of a simulation applied to M4, using forced convection of 1m/s.

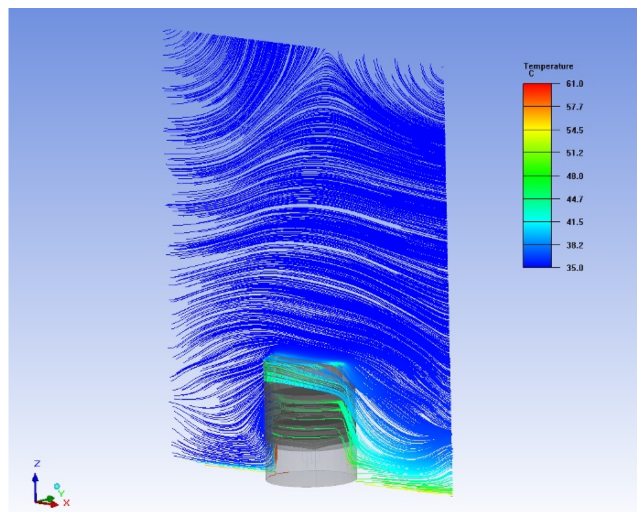

Fig. 4 – Exemplary simulation result of forced convection [1m/s] applied to M4

At distributed locations at hot and cold side of the simulated TEGs within the models, temperature values were determined as input parameters for the previously described simulation workflow in Simulink.

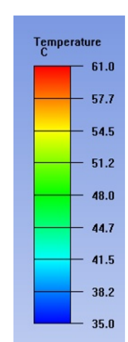

Fig. 5 – Temperature distribution in y-Plane at M4 at natural convection (left) and forced convection at 1m/s (right)

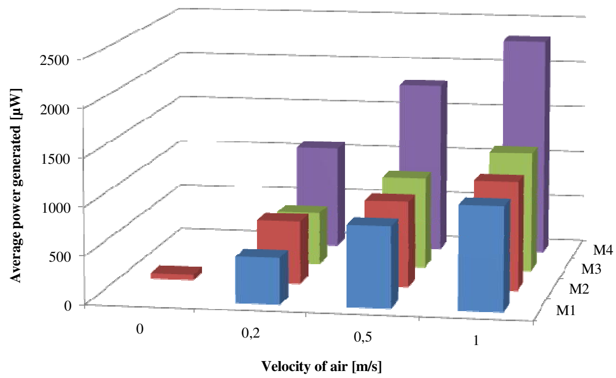

Fig. 6 – Average power available vs. module and air flow

Results for the available energy budgets are shown in Fig. 6. From this overview it can be shown, that natural convection effects will only be sufficient to start the sensor node when using the copper-based housing frame (M2), allowing for optimum heat transfer within the thermal path. Available temperature gradients at designs M1, M3 and M4 will not be sufficient to start the DC/DC converter without forced convection. With increase of air velocities all options will provide sufficient electricity to start-up the system. The copper-based frame will improve heat conductance through the device in comparison to the Al housing. Still, with rising values for air flow around the device, there will be hardly any gain in temperature difference. In this case, increasing the cooler size in comparison to M1 will have a much stronger effect on energy conversion. Finally, for all cases of forced convection, applying the larger thermoelectric element in conjunction with the larger cooler option will lead to a significant rise in average output power that cannot be achieved by merely changing the properties of the thermal path.

7 ENVIRONMENTAL ASPECTS OF ENERGY HARVESTING SYSTEMS – INTRODUCING THE RARI 2011 INDICATOR

As previously conducted studies in [1][2] have shown, each harvesting technology bears materials that have the potential to be environmentally critical, requiring study of environmental impacts already in early design stages.

RARI 2011 in the Periodic Table of the Elements

Legend: Al — 2,76 RARI_2011; 3,38 Risk Indicator; 0,84 Concentration on Countries (Herfindahl Index); 2,33 Need for Innovation; Symbol

H																	He
0,51 Li 1,09 1,52 0,63	15,43 Be 0,00 5,33 2,91											6,35 B 4,11 1,67 3,32	C	N	O	F	Ne
Na	3,55 Mg 3,75 2,13 0,85											2,76 Al 3,38 0,84 2,33	Si	P	S	Cl	Ar
K	Ca	Sc	1,22 Ti 1,50 0,76 2,57	3,98 V 3,85 2,05 1,58	10,95 Cr 2,23 1,29 4,99	3,31 Mn 2,46 0,61 3,59	5,84 Fe 3,42 1,22 3,96	77,25 Co 7,00 1,14 2,92	5,10 Ni 3,65 0,30 3,58	3,57 Cu 1,35 0,61 3,87	7,67 Zn 1,87 0,38 4,65	Ga	65,91 Ge 2,95 3,42 6,81	9,89 As 3,36 1,75 4,70	3,67 Se 0,37 1,75 3,87	Br	Kr
Rb	11,69 Sr 2,44 2,74 4,97	84,27 Y 4,56 7,00 3,31	3,08 Zr 1,12 1,75 3,63	32,22 Nb 3,04 6,01 3,66	2,87 Mo 2,43 1,45 3,33	Tc	Ru	Rh	3,70 Pd 3,78 2,13 1,16	7,10 Ag 2,34 0,30 4,53	5,41 Cd 2,52 0,38 4,20	2,38 In 2,48 1,75 2,93	40,10 Sn 6,14 1,60 4,71	43,19 Sb 4,52 5,86 5,21	0,90 Te 0,49 1,67 2,08	I	Xe
Cs	8,73 Ba 4,18 2,05 4,01	Lantha-nides	3,08 Hf 1,12 1,75 3,63	0,98 Ta 1,20 1,60 2,06	15,67 W 4,56 4,57 3,60	2,76 Re 1,22 1,67 3,50	Os	Ir	6,58 Pt 2,87 4,34 1,07	8,20 Au 2,47 0,00 4,68	11,74 Hg 4,59 2,82 4,03	Tl	8,82 Pb 2,47 1,29 4,74	8,84 Bi 4,25 2,82 3,77	Po	At	Rn
Fr	Ra	Acti-nides	Rf	Db	Sg	Bh	Hs	Mt	Uum								

One basic value for these Rare Earths:
Ce, Dy, Er, Eu, Gd, Ho, Nd, Pr, Sm, Tb, Tm

Lantha-nides →	La	62,53 Ce 4,56 6,70 0,00	62,53 Pr 4,56 6,70 0,00	62,53 Nd 4,56 6,70 0,00	Pm	62,53 Sm 4,56 6,70 0,00	Eu	62,53 Gd 4,56 6,70 0,00	62,53 Tb 4,56 6,70 0,00	62,53 Dy 4,56 6,70 0,00	62,53 Ho 4,56 6,70 0,00	62,53 Er 4,56 6,70 0,00	62,53 Tm 4,56 6,70 0,00	Yb	Lu
Acti-nides →	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Table 4 – RARI 2011 in the Periodic Table of Elements

However, use of energy harvesting technologies can lead to a significant reduction of toxic environmental impacts in comparison to conventional battery-based solutions in case reasonable system dimensions and operating times can be achieved. As a consequence a stable power-output needs to be guaranteed even under non-ideal ambient conditions whilst dimensions and use of environmentally harmful materials need to be minimized in early phases of the design process. With the application of self-sufficient sensor nodes in so-called 'mount-and-forget' applications, a deeper look at possible dissipation of materials used for energy harvesting components gains in importance. Therefore in this publication, scarcity of materials used for the previously introduced energy harvesting system will be discussed. For this purpose the newly developed method of the 'Resource availability and risk indicator (RARI 2011)' is applied in order to analyze the effects of design decisions on environmental performance. The indicator was developed and introduced in [5] motivated by rising demand for resources by a continuously growing world population. On the contrary limited availability and finite nature of resources, esp. in the electronics sector, ask for a more careful usage of these materials. In practice evaluation of resource criticality is complex as electronic products contain several materials, most coming from highly branched suppliers all over the world. Thus, there was strong need for an easy-to-handle indicator, enabling the designer to do a first screening of the product in early design stages. The RARI 2011 covers typical electronic metals esp. when drawn from ores, as close to 100% of these are imported in Germany [6] leading to a strong dependency on foreign distributors. Moreover, mining of metals is in general a severe intrusion in environmental processes. Plastics will remain out of consideration within this first version of the indicator.

The following aspects were included in the RARI 2011:

- Requirement for innovation, evaluating the statistical range of coverage, based on the U.S. Geological Survey [7]
- Origin, evaluating concentration (and therefore possible monopolies) on countries based on the Herfindahl-index
- Origin, evaluating the political stability of producing countries based on a study published by BMWi [8]

Each substance can be attributed a substance-specific RARI value on a scale of 0 (not critical) to 100 mg-1 (extremely risky) as an aggregated value calculated from inputs of the studies mentioned above. In the RARI 2011 indicator model updated input data from the latest USGS is included. For calculating the total RARI-value for the evaluated product, masses of the substances included are multiplied by the substance specific RARI and then aggregated to the $RARI_{Total}$ value. Table 4 includes an overview of RARI2011 values in the periodic table of elements. Modules M1 – M4 were then evaluated using the RARI2011 method. As can be seen from the exemplary study of module M1 in Fig. 7, the metal Al used for building the housing significantly counts for the overall $RARI_{Total}$ due to it's high contribution to the total mass of over 95%.

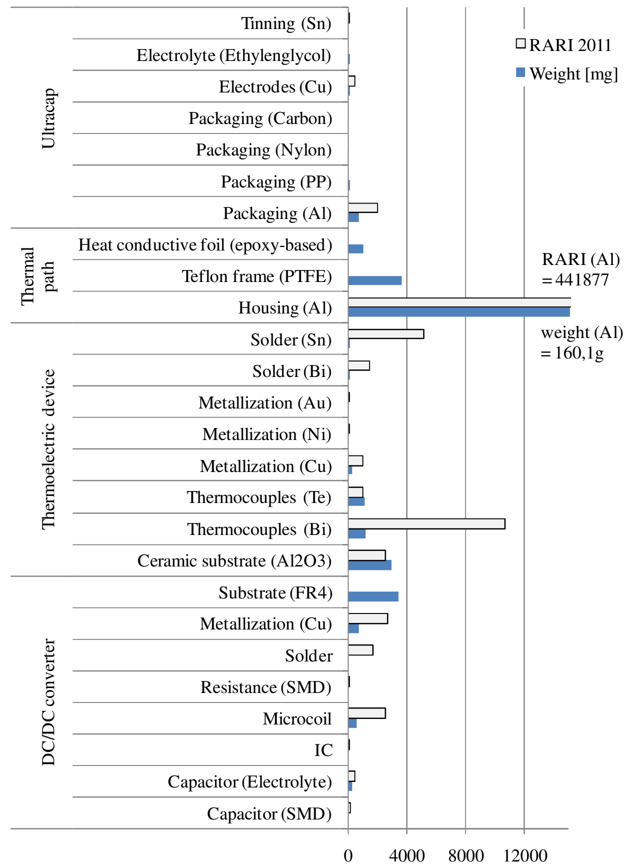

Fig. 7 – Weights and equivalent RARI values for module M1

In case of the copper housing option, there will be a vast rise of $RARI_{Total}$. Not only leads the high density of copper base material to an increase of the total risk indicator. Also ist the specific RARI larger then for aluminum, as production is concentrated in Chile. Thus, for further comparison, choice of either copper or aluminum as well as the size of the cooling concept will almost exclusively determine the total RARI indicator. For 'mount-and-forget' applications this will directly reflect dissipation of resource critical materials – In cases where recycling, esp. of the pure metal blocks building the housing, is an option, a closer look at materials contained in minor amounts of weight is necessary. Although only contained in small amounts, bismuth as part of the active thermoelectric material will exhibit the second largest contribution to the $RARI_{Total}$. This is due to the fact, that production mainly takes place in China (about 62%) and Peru, limiting access to these materials. Moreover, range of coverage is comparatively low. Tin used in soldering material of the thermoelectric legs as well as the electronics is regarded the most critical material within the device regarding the substance specific RARI. China, Indonesia and Congo account for most parts of the production, also exhibiting the risk of possible political instabilities. In comparison to the remaining electronic subsystem, the thermoelectric device thus provides the most critical substances within the designs when neglecting the housing metal. Also these will be the materials to be dissipated most likely at end of life, as recycling options will be scarce for these compounds of non-homogenous materials.

8 DISCUSSIONS: AVAILABILITY OF POWER VS. RESOURCE CRITICALITY

In Fig. 8 gain of average power by changing the design is compared to changes in RARI resource indicator.

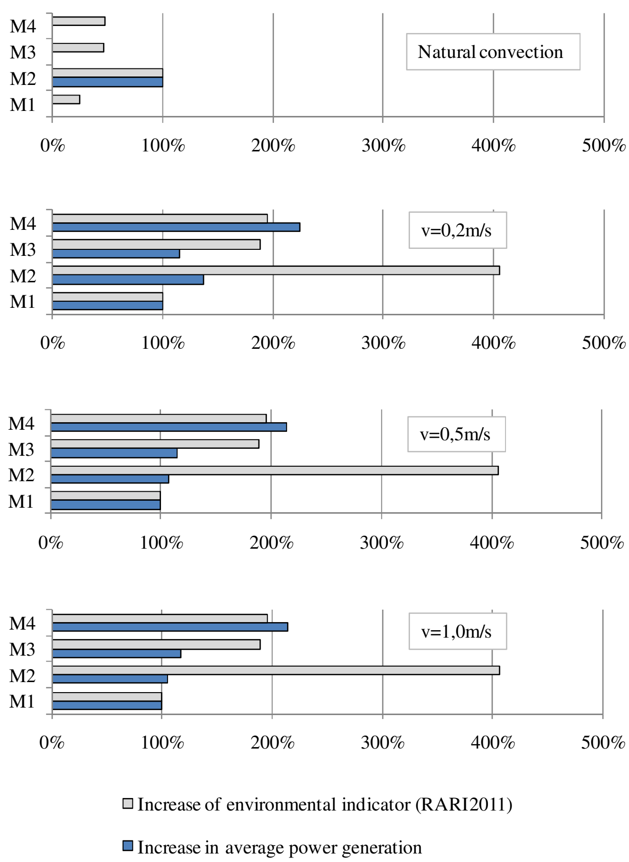

Fig. 8 – Gain of average output power vs. increase in resource indicator

At natural convection, the environmentally critical Cu-based solution is the only technical feasible option – thus applicable at locations were no or only low air flow is available. Even if flows of 0,2m/s can be detected, the Cu-based option will provide more energy than the extended Al-based cooler dimension in conjunction with the smaller thermoelectric device TEG A. This will be necessary if small system dimensions need to be achieved or in case copper will be returned to recycling processes even after long-time usage. For air flows of 0,5m/s or more, switching to the larger Al-based cooler geometry will lead to even slightly higher temperature gradients at significantly lower environmental expenses compared to the Cu-based solution. Increasing the active materials by exchanging the thermoelectric device will lead to a significant rise of average power output whilst merely influencing the $RARI_{Total}$.

9 CONCLUSION

Design decisions and their effect on system performance from both, an environmental as well as technical point of view were studied for a thermoelectric energy harvesting systems. The relations between an increase in system capacity to account for deviations from standard working conditions, the necessary over sizing and the shift in environmental impacts were discussed. The proposed approach can support eco design of energy harvesting based solutions by determining a reasonable degree of robustness for the targeted application and evaluate different design options of how to get there. For the conducted example of thermoelectric energy harvesting systems the choice of the best solution strongly depends on the boundary conditions: A design approach with optimum performance at natural convection might not necessarily be best suited at forced convection szenarios from technical as well as environmental perspective. Moreover, recycling options need to be evaluated upfront – In case solid metal parts that can easily be recycled will be returned to recyling processes at end of life, extending the range of a given thermoelectric device by increasing cooler dimensions or thermal conductivity will be an environmentally conscious solution. Instead, if dissipation of all included materials can be foreseen, increase of active materials for power generation can lead to lean design by minimizing large amounts of passive materials for cooling. Systems studies as carried-out in this paper need to be conducted over the broad application range in order to determine reasonable trade-offs. The presented method for evaluating resource criticality proofed to be suited for a first evaluation of energy harvesting systems and will be further applied also for complex szenarios, e.g. when comparing to battery-based solutions.

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How Policies Stimulate Innovations– Evidence from Dioxin Emissions and Home Appliances Recycling

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Abstract

How environmental policies affect technological developments and economic competitiveness has been an enduring question among engineers as well as economists. This paper attempts to clarify the impact of Japanese waste management policy on technological innovation using dioxin emissions from incineration and the recycling of home electric appliances in Japan as two case studies. We discuss the policy relevance of streamlining push-pull relationships between knowledge creators and technology users. We found that technological innovations usually start with social concerns regarding environmental issues (demand pull). The government then introduces policies to meet those concerns and the industry develops new technologies to comply with such policy requirements (technology push). For our case studies, relevant Japanese patent data were gathered for the period 1990–2008. To demonstrate that environmental regulations induce technology innovation, we conducted statistical analysis to compare the number of patents related to each regulation between the period under regulation and period outside the regulation. In order to control for the potential exogenous effects of factors such as business cycles and demand changes on technological development, we compared the ratios of the case studies related patents to the total number of environment-related patents. The results show that the number of related patents for most technological types is larger after the regulations were introduced. The results also show a decreasing pattern in patent citations once the targets have been met suggesting a possible weakness in these types of regulations due to lack of incentives for further innovations.

Keywords:

environmental policy, induced innovation, patent data, lock in.

1 INTRODUCTION

Technology innovation has played a central role in providing safer and comfortable lives for people. However leaving technology innovation to the market alone has been one of the causes of technological lock-in, which has prevented the emergence of sustainable technologies [1]. There have been many studies that challenged the belief that environmental regulations would affect the industrial competitiveness of countries. Porter for instance argued that stricter environmental regulations would trigger innovations and increase the competitiveness of firms [2]. On the other hand there have also been studies that didn't find any significant impact of environmental regulations on innovation [3].

This paper analyzes the impact of policies and regulations on technology innovation using the Japanese experience in dealing with dioxin emissions from incineration and the recycling of specific wastes as case studies. We found out a pattern regarding the environmental technology innovations in Japan. Usually these innovations start with social concerns regarding environmental issues or resource scarcity (demand pull). The government then introduces stricter regulations to meet those concerns (policy push) such as emission standards for dioxin, SO2, etc, or recycling targets for end-of-life products. Finally the technology community and industrial sector develop the innovations necessary to comply with those regulations.

2 INDUCED INNOVATION: DEALING WITH TECHNOLOGICAL LOCK IN

2.1 Overcoming lock-in

Induced innovation states that changes in the relative price of the factors of production will spur innovation to economize the use of that factor [4]. Technological lock-in refers to the difficulty in escaping the specific paths followed by technologies and technological systems [5]. To explain the lock-in mechanism Dosi [6] introduced the term technological paradigm i.e. technological progress shaped by the following of specific rules and principles in the way of thinking. Arthur [7] argued that the increasing return to adoption mechanism enhances the attractiveness of adopting a specific technology once it has secured an initial lead and will eventually lock in the market. Moreover such technologies create barriers that will try to prevent the emergence of new alternatives. By supporting specific technologies, institutions also show increasing

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return to adoption and the interaction between both systems will reinforce their lock-in [8]. Other mechanisms such as policies and regulations could also trigger environmental innovations by breaking lock in, promoting niche markets, encouraging feedback from market formation, etc. In the case of environmental technology innovation process, for instance, in order to address the social concerns regarding environmental problems (demand pull), the government introduces environmental policy or regulations (policy push). The technology development sector then develops the innovations to comply with the policy requirements.

2.2 The use of patents to measure innovations

There have been several studies that focus on the impact of environmental policy and regulations on technological innovations with mixed results. Jung et al [9] analyzed the incentive effects of environmental policy instruments to promote advanced pollution abatement technology and found out that auctioned permits and emission taxes and subsidies have the greatest impact on innovation. Fischer et al [10] analyzed the impact of auctioned permits, emission taxes and free permits on innovation and found out that either one can induce innovation but neither one has a stronger effect on innovation. Jaffe et al [11] found empirical evidence consistency with theoretical findings in the sense that market-based instruments are likely to have greater impacts than command and control approaches on environmental technology innovations. With the more ready availability of proxies for measuring innovation trends like patent data, there have been increasing research initiatives on analyzing the effect of policy on innovation. When analyzing technological innovation patent data provides many advantages [12, 13]:

- Patent classification provides useful information on the different types of R&D and hence track the advances in specific technological fields more accurately;
- The date of application of patents can give us information on the level of R&D activity;
- International patent data provides information on the level of diffusion of technologies across countries;
- Patent citation can be used as an indicator of further knowledge development or knowledge flow; and
- The rate of assigned patents will provide information on their commercial or market potential.

3 INDUCED INNOVATIONS IN JAPANESE WASTE MANAGEMENT POLICIES

3.1 The case of dioxin emissions from waste incineration

The Waste Management and Public Cleansing Law of 1970 promoted waste technologies with high and rapid volume treatment capacity such as incineration. Incineration technology has been important in Japan because of its capacity to reduce waste volume significantly Since the amount of daily wastes was relatively small in the 70's, local governments operated mostly small scale and batch-type incinerators. The change in lifestyle of the 80's due to higher living standards was the main driver for not only the increase in the amount but also the nature of wastes. This change increased the demand for products in small packages which in turn increased the amount of plastic waste generation [14]. Public health concerns related to dioxin emission associated with plastic incineration started to increase from the early 90's. Various studies found that dioxin emissions were higher in low-combustion and batch-type incinerators (see [15] and [16]). To address this public health concern the government introduced the Law Concerning Special Measures against Dioxin in 1999 [17]. As shown in Fig. 1, the law, which set the target to reduce dioxin emissions by 90% by 2003 taking as a base the year 1997, proved to be effective since the target was surpassed by phasing out small scale and batch incinerators with continuous type ones and introducing dioxin trapping technologies [18].

3.2 The case of electric home appliances recycling

Japanese policies have basically focused on promoting effective use of resources and minimize the environmental and health impacts of production and consumption systems (Japan is a resource-dependent country). Since the early 90's the government enacted various laws based on the 3R approach: the Containers and Packaging Recycling Law (1995); the Home Appliance Recycling Law (1998); the Construction Materials Recycling Law (2000), the Food Recycling Law (2000); and the End-of-Life Vehicles Recycling Law (2002) [19]. These laws targeted specific wastes including containers and packaging (plastic, glass and paper), electric and electronic home appliances, cars, construction materials and food-related wastes. In the case of electric and electronic home appliances, for instance, the law targeted four key products: air conditioners, refrigerators, televisions and washing machines. In this case all the recycling targets were met and surpassed.

4 THE IMPACT OF POLICIES ON INNOVATIONS

4.1 Analysis of patent trends

In order to determine whether the environmental policies where the actual drivers of specific innovations or not we analyzed the Japanese patent database. For the identification of the relevance of patents we first analyzed the related Japanese technological processes for both the dioxin emission reduction and home appliances recycling. Table 1 and Table 2 show the summary of the identified patent groups. (We used the International Patent Classification Codes and assigned shorter specific codes for the sake of simplicity). Figure 2 shows the patent number trends for both dioxin and home appliances respectively for the period 1990-2008. To demonstrate that environmental regulations (the presence of law) affect environmental R&D, we conducted a t-test analysis to compare the number of patents related to the regulations between the periods under and without the law presence. In the case of dioxin we divided the period terms into: 1990-1996, 1997-2003 and 2004-2008. The rationale for this classification is that the Dioxin Law was enacted in 1997, the plan was enforced in 1999 and the emission standards were met in 2003. In the case of the home appliances we divided the trends into two periods: 1990-1998 and 1999-2008. In this case we selected this division because the Home Appliances Recycling Law was enacted in 1998 and enforced in 2001. Table 3 presents the t-test results. During the period under the regulation, the number of related patents for most technological types is larger than in the period in which there is no regulation or the regulation targets have been met. These results indicate that proper regulations possibly induce the development of environmental technologies.

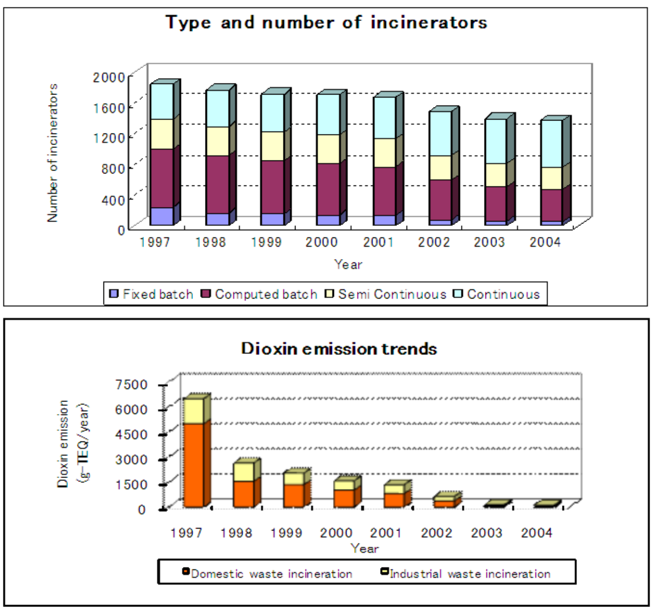

Fig. 1 Trends in incineration types and dioxin emissions

Table 1: Patents related to dioxin emissions

Patent Code group (IPC)	Assigned code	Outline of the patent group
F23G5/027	P1	Incineration of waste: pyrolising or gasifying stage
F23G7/06	P2	Incinerators or other apparatus for consuming industrial waste: of waste gases or noxious gases, e.g. exhaust gases
F23J1/00	P3	Removing ash, clinker, or slag from combustion chambers
F23J3/00	P4	Removing solid residues from passages or chambers beyond the fire
F23J15/00	P5	Arrangements of devices for treating smoke or fumes
F23J15/00*	P6	Arrangements of devices for treating smoke or fumes (* Without considering SOx and NOx)
F23N5/00	P7	Systems for controlling combustion
B01D46/00	P8	Filters or filtering processes specially modified for separating dispersed particles from gases or vapors
B01D53/00	P9	Separation of gases or vapors; Recovering vapors of volatile solvents from gases; Chemical purification of smoke, fumes, or exhaust gases
B09B3/00	P10	Destroying solid waste or transforming solid waste into something useful or harmless
B09B3/00*	P11	Destroying solid waste or transforming solid waste into something useful or harmless (*Related specifically to plastics and rubber)

Table 2: Patents related to home appliances recycling

Patent Code group (IPC)	Assigned code	Outline of the patent group
B01D21/00	R1	Separation of suspended solid particles from liquids by sedimentation
B03C1/00	R2	Magnetic separation
B03C1/00*	R3	Magnetic separation (* solid-solid separation)
B03C1/02	R4	Magnetic separators
B03C7/00	R5	Separating solids from solids by electrostatic effect
B03C7/02	R6	Separators (solid-solid)
B03B5/00	R7	Washing granular, powdered or lumpy materials; Wet separating
B03B5/28	R8	Sink-float separation
B07B1/00	R9	Sieving, screening, sifting, or sorting solid materials using networks, gratings, grids, or the like
B07B4/00	R10	Separating solids from solids by subjecting their mixture to gas currents
B07B7/00	R11	Selective separation of solid materials carried by, or dispersed in, gas currents

Table 3: Statistical analysis comparing patent trends inside and outside regulation period

Patent type	t-test hypothesis	Patent type	t-test hypothesis
Dioxin emission reduction	$H: \mu^{law}-\mu^{non\text{-}law}>0$	Recycling	$H: \mu^{law}-\mu^{non\text{-}law}>0$
Type P1	***	Type R1	**
Type P2	***	Type R2	**
Type P3	***	Type R3	*
Type P4	**	Type R4	***
Type P5	***	Type R5	**
Type P6	***	Type R6	**
Type P7	*	Type R7	**
Type P8	*	Type R8	**
Type P9	**	Type R9	**
Type P10	***	Type R10	Reject
Type P11	***	Type R11	Reject

Note: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The regulation period for the dioxin law is 1997-2003. The regulation period for the recycling law is 1999-2008.

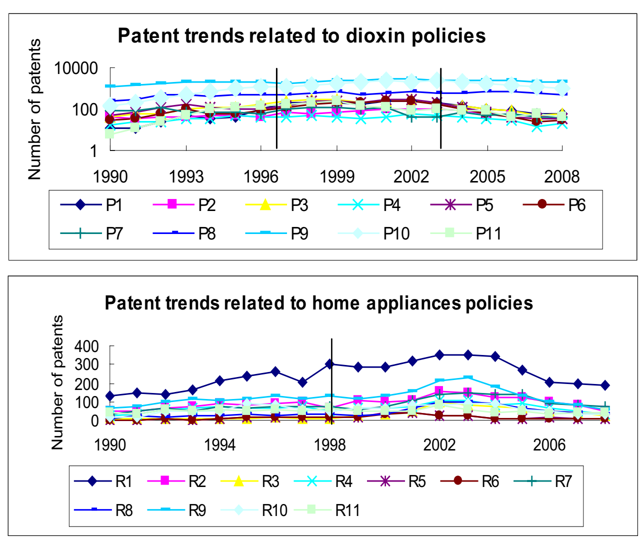

Fig. 2: Patent trends of case studies

Furthermore, in order to control for the potential exogenous effects of factors such as business cycles and demand changes, we compared the ratios of the case studies related patents to the total number of environment-related patents. From the results the ratio of dioxin-related patent to the total was 0.33 under the regulation period and 0.29 under the unregulated period. Likewise, the ratio of recycling-related patent to the total patent was 0.06 under the regulation period and 0.04 in the unregulated period. Again, we conducted the t-test, obtaining the results that the ratios of the environment-related patents were statistically higher under the period in which regulations were effective.

5 SUMMARY

This paper attempted to clarify the impact of Japanese waste management policy on technological innovation using dioxin emissions from incineration and the recycling of home electric appliances in Japan as two case studies. For our case studies, relevant Japanese patent data were gathered for the period 1990–2008. To demonstrate that environmental regulations induce technology innovation, we conducted statistical analysis to compare the number of patents related to each regulation between the period under regulation and period outside the regulation. In order to control for the potential exogenous effects of factors such as business cycles and demand changes on technological development, we compared the ratios of the case studies related patents to the total number of environment-related patents. The results show that the number of related patents for most technological types is larger after the regulations were introduced. The results also show a decreasing pattern in patent citations once the targets have been met suggesting a possible weakness in these types of regulations due to lack of incentives for further innovations. Furthermore the study also demonstrates the policies not only helped achieve specific end-of-pipe targets but also promoted further innovations such as the innovations at the design and production phase. In the case of home appliances we found that the environmental policies have pushed for the design of easier to recycle components and the design of parts and products with minimal use of hazardous substances such as chlorine-based components in plastic production which is associated with dioxin generation.

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Cluster Analysis of Investment Behavior to Companies' Environmental Activities with Questionnaire

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Abstract

This report describes investors' decision-making related to environmental Socially Responsible Investment (SRI) by administering a questionnaire with virtual stock-selection conditions and information related to both financial and environmental performance. Our findings are as follows: First, prospect theory is not valid with decision-making over environmental achievement. Second, a person's level of environmental consciousness has little effect on decision-making related to environmental performance. Third, four clusters with each different decision-making property were found using cluster analysis. Finally, significant differences were found in behaviors related to negative and positive financial performance. These findings are expected to be an aid in managing SRI funds, which requires consideration of both financial and social objectives.

Keywords:

socially responsible investment, behavioral finance, prospect theory

1 INTRODUCTION

In recent years, companies have been required to consider corporate social responsibility (CSR). Corresponding to this trend, numerous socially responsible investment (SRI) funds have emerged over the past decades.

Renneboog et al. provide an overview of the state of academic literature on SRI. They refer to the multi-task nature of SRI: SRI portfolio managers pursue both financial goals and social objectives [6]. Then how should they manage SRI funds? To solve this problem, it is necessary to discuss two SRI stakeholders: firms and investors.

Regarding firms, the question is whether CSR profits firms or not. For this question, numerous studies have been conducted. For example, Pava and Krausz review over 21 empirical studies [5]. Hamilton et al. investigate the performance of 32 SRI funds and 320 non-SRI funds. These empirical studies do not demonstrate that SRI funds perform worse than conventional funds [2]. Mackey et al. propose a theoretical model and argue that socially responsible activities undertaken by firms do not maximize the present value of their firm's future cash flows yet still maximize the market value of the firm [4].

With respect to investors, the question is how investors make choices related to economic efficiency and social objectives. Bollen claims that a conditional multi-attribute utility function can represent SRI investors. Such a function is derived from conventional fund performance and socially responsible attributes, especially when SRI funds deliver positive returns [1]. This is the first step to the theory of decision-making over social achievements.

In analyzing decision-making under risk such as investment, the academic field of behavioral finance cannot be ignored. Kahneman and Tversky propose prospect theory to explain human decision-making under risk using questionnaires, in which respondents, given two choices, choose a lottery to join [3].

To analyze decision-making in SRI, we extend Kahneman and Tversky's questionnaires to decision-making under information of both financial returns and environmental efforts by companies, which served as a CSR-representative activity.

This study particularly examines investors' behavior related to environmental performance, which has not been clarified theoretically.

2 QUESTIONNAIRE

This section explains the questionnaire we administered. The questionnaire was administered in December 2009 to 4843 Japanese people who were in their 20s to 60s: 2961 men and 1882 women. Of the respondents, 3335 had some investment experience.

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Q1 You are going to invest 100 thousand yen in either of company A or B. Both companies have emitted 10 million tons of carbon dioxide gas in last accounting period. The following is a prospect of monetary return of investment and effort for the environment in this period for each company. Which company do you want to invest in? Choose one company, and you must choose either of the two.

Company A

Financial return: You will certainly gain 100 thousand yen.

Effort for the environment: This company will reduce its carbon dioxide emission by 2 million tons and emit 8 million tons with probability of 60%, and increase the emission by 2 million tons and emit 12 million tons with probability of 40%.

Company B

Financial return: You will certainly gain 100 thousand yen.

Effort for the environment: This company will certainly emit 10 million tons, the same amount as the last period.

Fig. 1 Sample of Stock-selection Question.

Choose a suitable answer for the following questions from strongly agree, agree, disagree and strongly disagree.

Q01 I always try not to harm the environment.

Q02 I am not interested in environmental issues.

Q03 Although I think it is better to be green, I don't want to spend money for it.

Q04 Companies should reduce carbon dioxide emissions.

Q05 I sometimes feel effects of global warming in daily life.

Fig. 2 Environmental Consciousness Questions.

2.1 Questions with virtual stock-selection situations

The questionnaire mainly comprised 24 questions, each of which was set in a virtual decision-making situation of stock selection. From two names, a respondent chooses a stock in which to invest, considering their stated prospects of both financial and environmental performance.

The prospects of financial performance are represented as combinations of probability and the amount of monetary gain/loss. Those of environmental performance are combinations of probability and the amounts of carbon

Table 1 Conditions of Stock-Selection Questions and Results

	Name	Financial Performance		Environmental Performance				Results[1]	Expected value of environmental achievement (million tons)
		Probability	Amount of gain (thousand yen)	Probability	Amount of reduction (million tons)	Probability	Amount of reduction (million tons)		
Q1	A	1	100	0.6	2	0.4	-2	58.8%*	0.4
	B	1	100	1	0			41.2%*	0
Q2	A	1	100	0.6	2	0.4	4	47.7%*	2.8
	B	1	100	1	2.5			52.3%*	2.5
Q5	A	1	100	0.4	2	0.6	0	49.2%	0.8
	B	1	100	0.3	3	0.7	0	50.8%	0.9
Q6	A	1	100	1	2			62.7%*	2
	B	1	100	0.75	3	0.25	0	37.3%*	2.25
Q10	A	1	100	0.6	-2	0.4	-4	34.8%*	-2.8
	B	1	100	1	-2.5			65.2%*	-2.5
Q15	A	1	-100	0.6	2	0.4	-2	59.1%*	0.4
	B	1	-100	1	0			40.9%*	0
Q16	A	1	-100	0.6	2	0.4	4	48.9%	2.8
	B	1	-100	1	2.5			51.1%	2.5
Q22	A	1	-100	0.6	-2	0.4	-4	34.4%*	-2.8
	B	1	-100	1	-2.5			65.6%*	-2.5

* 5% Level of significance

[1] Ratio of respondents who chose the name in the same column.

dioxide emissions. One question is presented in Fig. 1.

Each of the 24 questions has different probabilities and amounts for financial returns and environmental efforts.

2.2 Questions on environmental consciousness

In the questionnaire, we also asked respondents their level of environmental consciousness: how much they care about the environment. The questions are shown in Fig. 2.

3 SCOPE OF ANALYSIS

As stated in section 1, this study specifically assesses investors' behavior toward the environmental performance of a firm. A respondent's behavior toward financial performance is assumed to be consistent with prospect theory. Therefore, we analyzed 8 of the 24 stock-selection questions showing no uncertainty in the prospects of financial returns. Table 1 presents conditions of the eight questions and their results.

4 RESULTS

4.1 Comparison with prospect theory

First, we verified whether prospect theory is valid with decision-making over environmental performance.

Based on the results shown in Table 1, we compared the choices that are expected to be the majority if prospect theory were valid with environmental achievement to those which actually are the majority in the questionnaire. Table 2 presents the comparison.

Table 2 Comparison with Prospect Theory

	Expected	Actual
Q1	B	A
Q2	B	B
Q5	A	-
Q6	A	A
Q10	A	B
Q15	B	A
Q16	B	-
Q22	A	B

-: No significant difference is found.

According to Table 2, actual results are not consistent with expectations implied by prospect theory, meaning that prospect theory is not valid for people's behavior related to the environmental performance of a firm.

4.2 Environmental consciousness and investment behavior

A main concern of the SRI study is whether decision-making of SRI investors differs from that of conventional investors. From this viewpoint, a hypothesis is raised that a respondent's level of environmental consciousness affects investment behavior related to environmental performance. To verify this, we analyzed results of environmental consciousness related questions, as introduced in section 2.2.

For each question, we put respondents into two groups with respectively differing levels of environmental consciousness: respondents who answered 'strongly agree' or 'agree', and those who answered 'strongly disagree' or 'disagree'.

Then we made up 40 pairs consisting of each stock-selection question and environmental consciousness question and compared the results between the two groups using a McNemar test.

Table 3 Number of stock-selection questions that show significant and non-significant differences

	Significant difference	No significant difference
Q01	1	7
Q02	3	5
Q03	1	7
Q04	4	4
Q05	1	7
total	10	30

As Table 3 shows, significant differences were found between the two groups in only 10 pairs; no significant difference was found in the remaining 30 pairs. We therefore infer that a person's environmental consciousness has little effect on that person's decision-making related to environmental performance.

4.3 Cluster analysis

We conducted a cluster analysis of the results for questions in Table 1 using the group average method. Respondents are divided into four clusters. Table 4 shows results of stock-selection questions from each cluster.

For convenience, we now classify the eight questions into the following three groups to discern each different property of decision-making.

Group 1 (Q1, 5, 6, 15): PREFERENCE FOR CHANGE

Questions in this group determine whether a respondent has a preference for change in environmental performance: a tendency to avoid investing in a company whose carbon dioxide emissions in the current period is expected to be equal to that in the last period.

In these questions, one firm in the alternative is expected to emit the same amount of carbon dioxide gas as in the last period with some possibility, whereas the other is expected to either reduce or increase its carbon dioxide emissions.

Table 4 Results from each Cluster

	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
	A	B	A	B	A	B	A	B
Q1	92.6%*	7.4%*	1.9%*	98.1%*	84.8%*	15.2%*	11.0%*	89.0%*
Q2	25.5%*	74.5%*	29.5%*	70.5%*	86.3%*	13.7%*	64.9%*	35.1%*
Q5	56.2%*	43.8%*	45.8%*	54.2%*	48.3%*	51.7%*	31.4%*	68.6%*
Q6	66.3%*	33.7%*	77.1%*	22.9%*	52.8%*	47.2%*	24.7%*	75.3%*
Q10	34.2%*	65.8%*	15.5%*	84.5%*	48.5%	51.5%	59.9%*	40.1%*
Q15	76.1%*	23.9%*	20.4%*	79.6%*	84.1%*	15.9%*	23.4%*	76.6%*
Q16	22.8%*	77.2%*	22.6%*	77.4%*	94.9%*	5.1%*	88.0%*	12.0%*
Q22	40.9%*	59.1%*	19.0%*	81.0%*	41.5%*	58.5%*	35.8%*	64.2%*

*5% Level of significance

Table 5 Characteristics of Clusters

	Change	Certainty	Rationality
Cluster 1	++	+	
Cluster 2		++	
Cluster 3	++		+
Cluster 4			++

++: has the property

+: has the property, but dominated by another property

Group 2 (Q1, 2, 6, 10, 15, 16, 22): PREFERENCE FOR CERTAINTY

Questions in this group determine whether a respondent prefers certainty of environmental performance.

In these questions, one company is expected to reduce or increase carbon dioxide emissions by a certain amount with probability of 100%, whereas others have uncertainty related to the amount.

Group 3 (Q1, 2, 5, 6, 10, 15, 16, 22): PREFERENCE FOR RATIONALITY

Questions in this group ascertain whether a respondent makes choices based on the expected environmental achievement.

For all eight of these questions, the expected values of carbon dioxide emissions differ between the two firms.

The results exhibited in Table 4 reveal each cluster as having the following properties. Cluster characteristics are presented in Table 5.

Cluster 1 (1651 respondents): PREFERENCE FOR CHANGE AND CERTAINTY

In all four questions of group 1, larger numbers of respondents in cluster 1 show a preference for change. Additionally, in 5 of 7 questions belonging to group 2, larger numbers of respondents make decisions that show a preference for certainty. In the remaining questions, preference for change is dominant over that for certainty.

However, rational decisions are made in only half of the eight questions of group 3.

Therefore, the behavior of a typical respondent in cluster 1 is inferred as follows: if the question is a group-1 question, the subject makes decisions based on a preference for change. If not, the subject makes decisions based on a preference for certainty.

Cluster 2 (1409 respondents): PREFERENCE FOR CERTAINTY

In all seven questions of group 2, larger numbers of respondents in cluster 2 show a preference for certainty.

However, the results are consistent with a preference for certainty in 1 of 4 questions that belong to group 1. In addition, rational decisions are made in only 3 of 8 questions of group 3.

Therefore, it is inferred that a typical respondent in cluster 2 makes decisions based on a preference for certainty.

Cluster 3 (1486 respondents): PREFERENCE FOR CHANGE AND RATIONALITY

In 3 of the 4 questions that belong to group 1, more respondents in cluster 3 show a preference for change. Regarding group 3, in 5 of the 8 questions, larger numbers of respondents show rationality. Furthermore, in one of the remaining three questions, preference for change was dominant over rationality. In contrast, in only 2 of 7 questions of group 2 do respondents show a preference for uncertainty.

Therefore, behavior of a typical respondent in cluster 3 is inferred as follows: for a group-1 question, the subject makes decisions based on preference for change. If not group-1, the subject makes decisions based on rationality.

Cluster 4 (299 respondents): PREFERENCE FOR RATIONALITY

In 5 of 8 questions belonging to group 3, greater numbers of respondents in cluster 4 show rationality. However, results of none of the 4 group-1 questions are consistent with preference for certainty and only 3 of 7 group-2 questions are consistent with rationality.

Therefore, it is inferred that a typical respondent in cluster 4 makes decisions based on rationality.

Table 6 Ratio of respondents who choose name A and results of McNemar test

	Cluster 1		Cluster 2		Cluster 3		Cluster 4	
Financial performance	(1, 100)	(1, -100)	(1, 100)	(1, -100)	(1, 100)	(1, -100)	(1, 100)	(1, -100)
Q2 – Q16	25.5%	22.8%	29.5%**	22.6%**	86.3%**	94.9%**	64.9%**	88.0%**
Q1 – Q15	92.6%**	76.1%**	1.9%**	20.4%**	84.8%	84.1%	11.0%**	23.4%**
Q10 – Q22	34.2%**	40.9%**	15.5%*	19.0%*	48.5%**	41.5%**	59.9%**	35.8%**

* 5% Level of significance

**1% Level of significance

According to this cluster analysis, three properties are identified as characteristics of human behavior toward environmental achievement: preferences for change, certainty, and rationality. Among them, preference for change—the inclination that people prefer either an increase or decrease of green house gas emissions to constant emissions—stands out because this is rarely observed in decision-making over monetary gains. It might suggest that, in SRI, a certain number of people appreciate companies' trial of activities, whether the company succeeds or not: they do not like doing nothing.

4.4 Behavior in negative financial conditions

It is often assumed that the financial performance of SRI funds is worse than that of non-SRI funds. How do investors consider this problem of social cost? To answer this question, we compared the results of two questions with the same environmental performance and opposite financial performance.

From the eight questions in Table 1, we paired results of Q2 and Q16, Q1 and Q15, and Q10 and Q22. Here we will write, "return of X thousand yen is expected with the probability of x" as (x, X) and "Y million tons of emission will be reduced with the probability of y" as (y, Y).

Between questions in these pairs, the conditions of environmental performance are common. However, the financial performance of both firms in the alternative is (1, 100) in one question of the pair, and (1, -100) in the other. Therefore, simply expecting the results between the questions in each pair should not differ because environmental performance is set in the same condition between the questions in the pair, and two firms do not differ in financial performance in both pairs. However, results of the McNemar test show that the null hypothesis––that no difference exists in respondents' decision-making between conditions of positive and negative financial returns—is rejected in most cases.

Table 6 presents the ratio of respondents who choose A in questions in the pairs and results of McNemar test.

Q2 (positive) and Q16 (negative)

Environmental performance in these questions is (0.6, 2) and (0.4, 4) for A, and (1, 2.5) for B; the environmental performance is positive.

According to Table 6 , in cluster 2, larger numbers of respondents choose B in Q16 than in Q2, which means that the preference for certainty is enhanced in negative financial conditions. In contrast, in clusters 3 and 4, the numbers of respondents who choose A are larger, meaning that a preference for certainty is weakened in a negative financial condition.

Q1 (positive) and Q15 (negative)

Environmental performance in these questions is (0.6, 2) and (0.4, -2) for A, and (1, 0) for B. The environmental performance is neutral.

According to Table 6, in cluster 1, larger numbers of respondents choose B in Q15 than in Q1, meaning that preference for certainty is enhanced in a negative financial condition. In contrast, in clusters 2 and 4, the numbers of respondent who choose A are greater, which means that the preference for certainty is weakened in a negative financial condition.

Q10 (positive) and Q22 (negative)

Environmental performance in these questions is (0.6, -2) and (0.4, -4) for A, and (1, -2.5) for B; the environmental performance is negative.

According to Table 6, in clusters 1 and 2, larger numbers of respondents choose A in Q15 than in Q1, meaning that the preference for certainty is weakened in a negative financial condition. In contrast, in clusters 3 and 4, the numbers of respondents who choose B is larger. Consequently, the preference for certainty is enhanced in a negative financial condition.

Table 7 presents a summary of the results presented above, which suggest that a person's preference for certainty is affected by negative financial conditions. Results also clarify that the effects of negative financial performance differ among positive, neutral, and negative environmental conditions for each cluster.

Table 7 Behaviors in Negative Financial Conditions

Environmental Performance	Positive	Neutral	Negative
Cluster 1		+	-
Cluster 2	+	-	-
Cluster 3	-		+
Cluster 4	-	-	+

+: Preference for certainty is enhanced

-: Preference for certainty is weakened

Blank: No significant difference is found

5 CONCLUSIONS

For this study, we conducted a questionnaire with virtual stock-selection conditions of SRI.

First, we verified whether prospect theory is valid with environmental achievement as well as monetary gains. Respondents' behavior related to environmental performance is not consistent with prospect theory.

Second, we investigated whether respondents' level of environmental consciousness affects their behavior related to environmental performance. Results clarified that the level of environmental consciousness has little effect on their decision-making about environmental performance.

Third, we conducted cluster analysis of respondents based on their answers. We obtained four clusters and identified three properties of decision-making related to environmental achievement: preferences for change, certainty, and rationality.

Finally, in negative financial conditions, respondents are affected according to the clusters to which they belong. Furthermore, the effects of negative financial performance differ among positive, neutral, and negative environmental conditions for each cluster.

The results reported herein can be an aid in establishing environmental SRI funds. Results described in section 4.2 implied that a person's level of environmental consciousness has little effect on a person's decision-making related to environmental performance. Therefore, in managing SRI funds, it might not be necessary to consider different environmental consciousness among customers. In addition, cluster analysis clarified that only 6.2% of respondents belong to cluster 4: respondents who make rational decisions. Rather, more respondents tend to prefer either change or certainty of environmental performance. Therefore, environmental SRI fund with names of firms with higher certainty or companies that take initiatives for the environment or other objectives in some way—irrespective of risk—are preferred to funds that are managed based on the expected value of environmental performance.

Finally, further studies are expected to address the question of why preference for change is observed in some of respondents and why different behaviors exist among clusters in negative financial conditions.

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Innovative Financing Mechanisms for Energy Efficiency Retrofits in Buildings – A Shift in the Traditional Paradigm

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Abstract

The retrofitting of existing buildings is no doubt an attractive means of saving energy, reducing greenhouse gas emissions and creating jobs in the process. Energy efficiency has been unanimously regarded as the fastest, lest expensive and lowest risk method of addressing carbon emissions all over the world. Most existing commercial buildings are significantly less efficient than new buildings, and modifications can be made to improve efficiency typically by 20% to 40% using commonly accepted practices and widely available technologies. For building owners this often translates into an increase in the property value, increased cash flows, the ability to attract and keep desired tenants and an added recognition of being a good corporate citizen. The investment required to make these changes typically can offer paybacks of 5-10 years, providing competitive investment returns, and ongoing operational and maintenance cost savings at the same time. Despite this potential, there remains a significant barrier – access to competitive financing which reflects the unique characteristics and complexities of both energy efficiency projects and building owners alike.

Key words: building retrofits, energy efficiency, energy performance contracting, financing, off balance sheet financing

1. Introduction

Property owners, in general, do not have the up-front funds or do not want to use existing funds to invest into energy efficiency projects no matter how attractive they may appear. For the average building owner, energy efficiency projects represent an investment that they are just not certain about. They don't necessarily know how to place a numerical value on the savings as they aren't as tangible or clear as other more traditional investments. They are also skeptical about whether the savings will really pay them back in the time frames promised or the proposed technologies and systems will really deliver as promised by vendors, and hence the returns on this specific investment become cloudy.

Commercial office building owners are even less incentivized to invest into energy efficiency projects as their tenants reap the benefits of any reduction of utility bills without having to share in the initial investment of the project and re-negotiating leases with multiple tenants in the building can be time consuming, complicated and unwelcome. Many building owners have covenants with lending institutions that do not allow their buildings to be further leveraged while others, especially institutional investors want the flexibility to sell their properties if they receive a bid above their threshold pricing and do not want to increase existing debt levels, especially when paybacks extend well over the projected hold period.

Recently, there has been an increasing willingness of commercial lenders to consider loans for energy efficiency retrofits. However, there are complications relating to the existing credit history. Most commercial assets are held by limited liability companies (LLCs) formed to hold single buildings or at most a portfolio of buildings. These LLCs may not have been set up for very long and hence would not have established a credit rating. This presents lenders with an unattractive client to begin with and is highly unlikely to lend without requiring the provision of fixed asset collateral or significantly high interest rates as an unsecured loan.

2. Current limitations in the financing sector

Despite the numerous barriers mentioned earlier, according to the Efficiency Valuations Organization (2009), "one of the most significant of these barriers is a lack of commercially viable financing, which is not caused by a lack of available funds per se, but rather an inability to access existing funding capacity at local banks and financing institutions on commercially attractive terms." There exists a very clear disconnect between the traditional banking sector and that which is needed to make an energy efficiency project take place.

Commercial banks are still approaching energy efficiency financing from either a corporate lending or a project financing perspective looking for the standard fixed asset collateral and limiting lending to 70% to 80% of the asset base. They have failed to accept the equipment installed as part of the project as sufficient collateral and are not willing to recognize the energy efficiency cost savings as acceptable cash flow as a

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reliable repayment source and hence assign no value to the cash flow generated.

But this is not all; unfortunately they still see energy efficiency projects as being relatively small investments and are not willing to invest into the development of internal capacity to enable them to understand the complexities of energy efficiency projects, the technologies involved, the different delivery models, and how to evaluate the risks associated with each one effectively and efficiently.

3. Self-Financing

Public and private entities with sufficient internal funds may consider self-financing their energy efficiency project. A building owner can fund such a project by drawing on its capital budget, or operating budget or by tapping funds for deferred maintenance. Depending on the building owner's financial position, self-financing often represents the least expensive means of financing a project because it avoids the need to pay interest and transaction costs on incremental borrowing. Internal financing also minimizes the "cost of waiting," or energy cost savings opportunities foregone as a project waits for funding to be approved and processed.

Attractive returns are possible if a building owner invests its own resources to pay for the up-front project costs in what is essentially a project equity investment to be paid back through energy savings.

4. "Off Balance Sheet" Financing

As a result of the slow pace at which the commercial banking sector (and institutional financing organizations) has addressed financing energy efficiency, there has been an increasing emergence of customized energy efficiency financing structures all over the world, mostly to overcome the initial capital outlay constraints faced by building owners. "For the first time in decades, dating back to the initial use of shared savings contracts in the 80's, new EE financing structures are emerging that allow end users to avoid the initial capital outlay associated with the installation of EE measures, thereby enabling the completion of efficiency projects that, absent outside funding, would go undone" (Hinkle and Kenny, 2010).

Hence, the ideal mechanism would be one which addresses most of the major barriers – no (or as little as possible) upfront capital required, no lien waiver needed from mortgagee, savings guaranteed by ESCO, in case the building is sold, the contract obligations can be assigned to the new owner, and there's no fixed asset collateral required to enable the project to take place.

One such financing structure is often referred to as Operating Lease Agreement (OLA). An operating lease commands that both legal and economic ownership of the equipment rests with the lessor indefinitely. From an accounting perspective, an operating lease obligation can be considered "off-balance sheet." In reality, the lessee is actually paying rent for the service that the equipment provides, rather than paying for the purchase of the equipment itself. Because the equipment legally belongs to the lessor, the lessor can take advantage of the tax benefits of ownership such as accelerated depreciation. Because the lessee is not considered to own the equipment, no asset or long-term liability rests on the organization's balance sheet, and lease payments can be allocated from the lessee's operating budget.

This type of an arrangement can benefit organizations that are at or near their borrowing capacity, or simply do not wish to use their existing credit facilities for energy efficiency as their focus is still on their core business activities. It also enables a simpler decision making process in a multiple ownership structure that needs to approve any new debt.

The investor is at peace of mind as the organization's responsibility for making timely payments under the operating lease are absolute, and not contingent upon whether sufficient guaranteed savings materialize. Under this agreement the building owner's regular payment obligation is to the lessor.

The actual energy efficiency project details and contract, including the guaranteed savings and shortfall payments (the EPC) are a separate agreement and rest between the building owner and the ESCO.

5. Methodology - Energy Performance Contracting

There are numerous models utilized to retrofit buildings from the traditional 'bid-spec' model to the more complex procurement methodologies traditionally used by public authorities. However, one such model which is seen to provide the most attractive structure for financing, (and the least risk to both building owner and investor) is the Energy Performance Contract (EPC) where the ESCO develops, designs, implements, commissions and guarantees the outcome of a turn-key energy efficiency project. In this model the ESCO assumes the performance risk component of the project and agrees to either repay the building owner for any shortfall in savings or invest into additional equipment/modifications to the energy efficiency project in order to deliver the guaranteed savings. This model provides assurance to the building owner (and financier) that the project will deliver a certain amount of savings which can then be allocated to repaying any financing that was taken out for the project.

Energy Performance Contracting has been widely used as a method for contracting building retrofits for several decades, particularly in the U.S. public and institutional building sectors. By guaranteeing a minimum amount of energy savings, EPC allows all building owners to assess the payback and thus the financial returns on their energy efficiency project. Some owners may be able to finance the entire cost of new equipment and technologies by using the energy savings alone, negating the need for initial capital expenditure.

While in other cases it may be possible to structure the debt repayments so that the minimum required payments are less than the actual cost savings, hence providing a positive cash flow that can be reinvested into other initiatives such as cosmetic renovations or expansion activities. In this approach building owners immediately realize the positive impact energy efficiency can have on operating budgets without having to wait for the actual return on investment to occur. Other main characteristics include:

1. *Turn-Key Project* - EPCs focus on a turn-key process of delivering a project whereby one ESCO is responsible for design, documentation, installation, project management, commissioning, and ongoing monitoring and verification (M&V) of energy conservation measures. This methodology takes a comprehensive and holistic approach to a building (HVAC, lighting, building envelope, control and management systems, on-site generation) and calculations, recommendations and measures are based upon a life-cycle analysis (operational costs over the equipment life) rather than the initial upfront 'purchase price' as being the deciding factor behind decision making.

2. *Performance Guarantee* - EPCs are based upon a 'performance guarantee' whereby the ESCO provides a guarantee on the performance of the Energy Conservation Measures (ECMs) that the ESCO is recommending to implement. This performance guarantee is usually presented as a guaranteed amount of energy (kWh) to be saved. The basis for these calculations in a project are usually a combination of efficiency gains as well as operational and maintenance savings.

3. *Leveraging/Bundling* – The EPC methodology enables a project to be based upon one final project profile which means that a number of Energy Conservation Measures (ECMs) can be combined together within the project to make up this final profile. Hence, ECMs which have high energy savings potentials and shorter payback periods can be used to leverage larger, more complex ECMs which may not have such attractive financial characteristics. This results in larger total project savings (and hence greenhouse gas emission reduction) and a lower combined or 'bundled' project payback period, with the only downside often being a larger required initial investment.

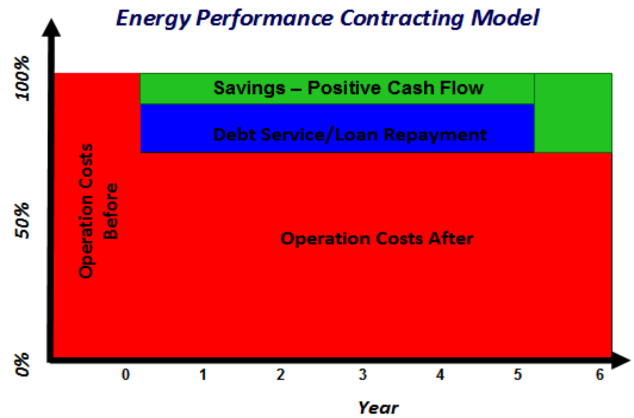

Figure 1: Energy Performance Contracting

6. The Structure

The actual energy efficiency component of the whole project is still undertaken by the ESCO and project activities such as the preliminary assessment and the Investment Grade Audit are kept separate from the 'investor'/financier. The ESCO will bear responsibility for any delays in implementation and completion.

When the project is ready to be implemented, the building owner and the financier will enter into an agreement which outlines the terms and conditions of the provision of capital, and the repayment obligations. The financier will own all assets related to the project that are installed into the building, with an emphasis on the specific location of the (main) equipment. This equipment will be defined as being owned by the investor with a specific agreement to allow this equipment to be used (and operated) by the building owner (lessee). The investor will hold a first priority security interest on these assets. For equipment that may be installed in various locations throughout the building, the investor will hold a subordinated security interest.

Payment obligations will fall under the OLA between the building owner and financier and are usually set out in either monthly or quarterly repayment schedules. The repayment structure is usually set up to reflect the minimum energy cost savings guaranteed by the ESCO, however there is often the option of making either higher or more frequent repayments or on the other hand, prolonging the repayment agreement to enable the building owner to take advantage of a positive cash flow scenario.

Upon making the final repayment, the ownership of all energy efficiency assets will be transferred to the building owner at a pre-agreed price.

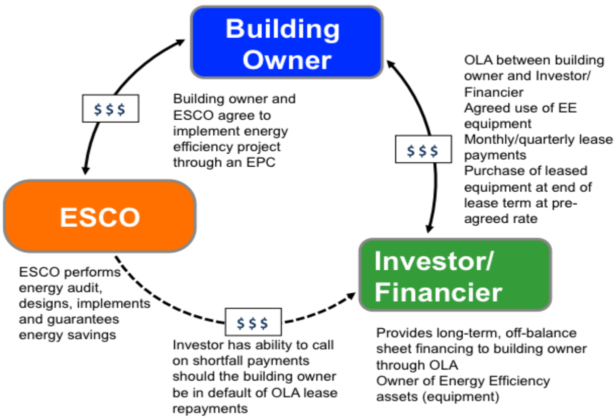

Figure 2: The Operating Lease Agreement

7. Establishing a proven track record

It is well accepted that energy efficiency has tremendous potential to contribute to the mitigation of greenhouse gas emissions all over the world, especially in cities with a large number of existing buildings. At the same time however, the commercial banking sector has remained conservative in their approach, attempting to fit energy efficiency into their standard corporate lending practices and lack the knowledge and innovation to meet the unique characteristics and complexities of energy efficiency projects. They have not invested sufficient resources to develop the internal capacity required for this market.

On the other hand, there has been a significant increase in the development of customized financing mechanisms from non-traditional lenders to cater to the financial conditions and preferences of building owners to address the barriers that they face when contemplating undertaking such projects. As these sector specific financing models become more established, well proven and more widely utilized, it is likely that the commercial banking sector follows suit in a much larger scale than what is being seen at the moment.

"For sustainable and sizeable channels of financing the local banking sector is ultimately the key in most every country. Where the local banking sector is too weak, immature or simply uninterested, any of a variety of arrangements may be worthwhile to provide initial energy efficiency project financing or begin to introduce the energy efficiency lending business into the market" (Taylor et al, 2008)

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Successful Eco–Sustainability
Toward a Company–related Environmental Labeling

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Abstract
Today, eco-design is an important goal for many companies in the world. And this for various reasons: environmental legislation, a company's green image, protection of the environment. These motives require companies to consider different aspects of eco-design: the environmental impact of a product, the legal requirements to be compliant, a confusing number of existing labels worldwide and customers' resistance to pay more money for a sustainable product. To succeed on the market with sustainable products requires a defined sustainability strategy that goes beyond existing regulation. An important aspect to achieve exceptional green products might be to certify the company as a whole for its environmental performance, instead of certifying a single product. The presentation will offer an assessment of product versus company related eco-strategies.

Keywords:
Eco-design, ErP Directive, Green image, Eco-label, Eco-certification

1 BACKGROUND

In 2005 the European Union put into effect the first framework directive for creating eco-design criteria targeting energy-using products (EuP Directive 2005/32/EC). The directive was reviewed and newly published in 2009 with the new name of ErP Directive on energy-related products (Directive 2009/125/EC).

What are these directives aiming at? They want to establish a framework for the setting of eco-design requirements for energy–related products. These requirements are going to be defined by so-called "implementing measures" which the EU Commission issues after consultation with stakeholders. The work of the EU Commission currently focuses on energy efficiency. The list of implementing measures already published and those under preparation may give an overview about the scope of this new legal provision.

Table 1: Overview of existing implementing measures (Status: 2011/09/22)

Regulation	Product Group	Date of Application
Regulation (EC) No 1275/2008	Standby and off-mode losses	7/1/2010, **7/1/2013**
Regulation (EC) No 107/2009	Simple set-top boxes	25/2/2010, **25/2/2012**
Regulation (EC) No 244/2009	Non-directional household lamps	1/9/2010, 1/9/2010, 1/9/2011, **1/9/2012**, **1/9/2013, 1/9/2016**
Regulation (EC) No 245/2009	Tertiary sector lighting products	13/4/2010, 13/10/2010, **13/4/2012, 13/4/2015, 13/4/2017**
Regulation (EC) No 278/2009	External power supplies	27/4/2010, **27/4/2011**
Regulation (EC) No 640/2009	Electric motors	16/6/2011, **1/1/2015, 1/1/2017**
Regulation (EC) No 641/2009	Circulators	**1/1/2013, 1/8/2015**
Regulation (EC) No 642/2009	Televisions	1/7/2010, 20/8/2010, 20/8/2011, **1/4/2012**
Regulation (EC) No 643/2009	Domestic refrigerators and freezers	1/7/2010, **1/7/2012, 1/7/2013, 1/7/2014, 1/7/2015**
Regulation (EU) No 1015/2010	Household washing machines	1/12/2010, **1/6/2012, 1/12/2012, 1/12/2013**
Regulation (EU) No 1016/2010	Household dishwashers	**1/12/2011, 1/6/2012, 1/12/2012, 1/12/2013, 1/12/2016**
Regulation (EU) No 327/2011	Fans	**1/1/2013, 1/1/2015**

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Table 2: Overview of coming implementing measures (Ongoing preparatory studies not included, Status: 2011/09/22)

Lot	Product Group	Working Document/ Consultation Forum	Reg. Committee	EU Parlia-ment/ EU Council
10	Air conditioners and comfort fans			X
1	Boilers	X		
2	Water heaters	X		
3	Computers and monitors	X		
4	Imaging equipment	X (voluntary agreement)		
8/9	Tertiary lighting	X (amendment)		
10	Domestic ventilation and kitchen hoods	X		
11	Pumps	X		
12	Commercial refrigerators and freezers	X		
16	Household tumble driers	X		
17	Vacuum cleaners	X		
18	Complex set-top boxes	X		
19	Domestic lighting part II "directional lamps"	X		
26	Networked standby losses	X		
ENTR Lot 5	Machine tools	X (voluntary agreement)		
	Medical imaging equipment	X (voluntary agreement)		

How does the EU identify the products for which implementing measures are going to be prepared? The directive itself stipulates the selection criteria:

- more than 200,000 units sold per year in the EU,
- significant environmental impact,
- significant potential for improved ecological performance because the current performance of the product is widely spread among competitive products on the market.

Implementing measures apply uniformly everywhere throughout the 27 EU member states, as they are issued as EU regulations. The ErP Directive makes manufacturers or their authorized representatives or importers responsible for ensuring conformity. Conformity must be proved by the CE mark.

2 THE GREEN IMAGE

What are the effects of the ERP directive?

2.1 The customer's view

Political institutions and industry are getting mixed messages from markets. On the one hand side, customers are answering questions about the importance of environmental product attributes positively. On the other side the customer's willingness to pay more for a product which combines price-performance with improved environmental attributes is still low.

The situation may have changed with the steep rise in energy prices. European private households appreciate the energy–label – so far e.g. for washing machines and dishwashers, and since 2011/11/30 also for television sets. But there is no evidence yet that other eco–design criteria are also getting on the radar screen of the consumer.

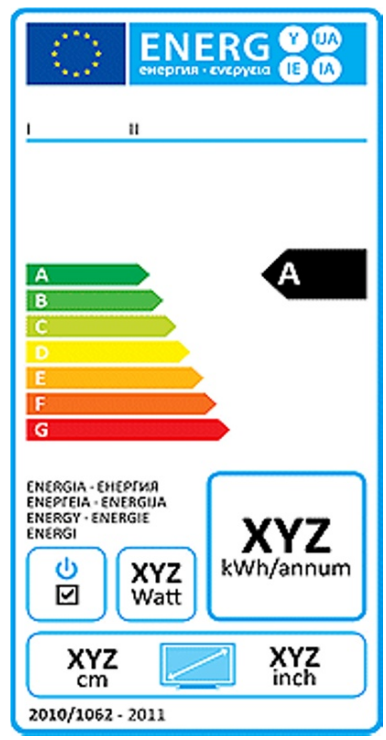

Fig. 1: New energy-label for televisions

2.2 Enforcement

Every piece of environmental legislation requires government enforcement. Otherwise there will be a distortion of competition between the good and the bad boys. The good boys will suffer from higher manufacturing and other costs compared with the bad boys saving money simply by non-compliance.

Therefore, industry was requesting the EU and the member states to improve systematic enforcement activities covering the environmental legislation of the last 10 years which includes the ERP Directive, too. As the more systematic approach to government enforcement started only recently and not in all 27 EU member states simultaneously, there is no reliable evidence available about industry's compliance behavior.

2.3 Industry's challenge

Independently from consumer's behavior and government enforcement activities, the launch of the eco–design legislation influenced companies asking questions about how to build or how to improve a green image. There are a couple of answers to this question:

2.3.1 Compliance with mandatory legislation does not help building or improving a green image. Legal provisions are making all products falling under the scope of the legislation "me too". Therefore compliance is positioning companies among the pack, but not ahead of the pack.

2.3.2 The only other way that governments and NGOs are offering for creating and improving a company's green image are eco-labels. Most eco-labels, in fact, are including a big number of challenging eco-design criteria which companies must fulfill in order to get it. In conclusion and in theory, eco–labels like the Blue Angel for instance do have the potential to improve the green image of a company. However, it is questionable if eco-labels are a good way to present a green image in particular from a global perspective. Firstly there is a confusing number of different eco-labels in the industrialized regions of the world. Please see examples from Europe and Asia.

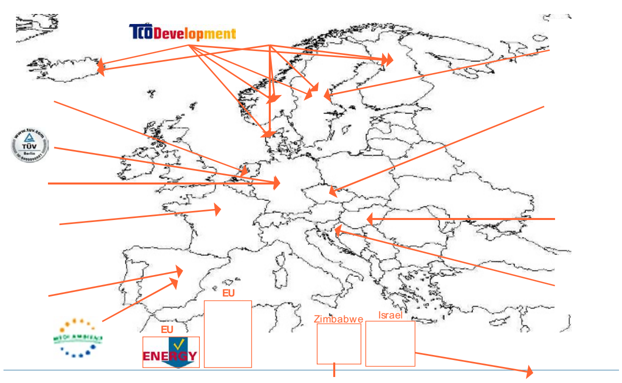

Fig. 2: EMEA – all known eco–labels

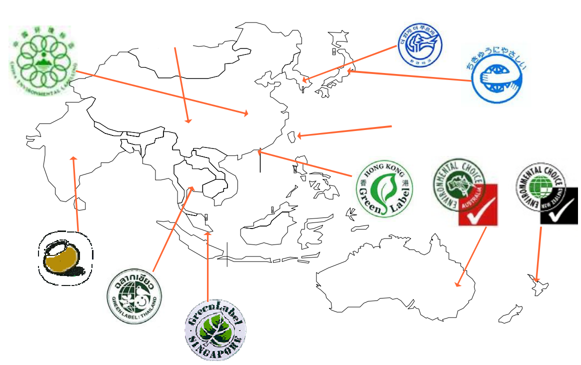

Fig. 3: Asia Pacific Japan – all known eco–labels

In addition, eco-labels are more or less of local importance only. They may satisfy national or regional markets. But there is no way to use an Asian eco-label for proving environmental product performance on the European or American market and the other way round to use the Blue Angel for the Asian markets. Companies and even NGOs like Greenpeace acknowledge this weakness of eco–labels.

3 A NEW PROPOSITION FOR A PROVEN GREEN IMAGE

With the background of the existing legislation and the variety of eco–labels industry requires an answer to the question whether there is a way to prove environmental performance on the global markets in a less confusing way compared to the situation today. It would be extremely desirable for globally acting companies to demonstrate environmental performance uniformly with the same tools on all markets.

There seems to be a new answer to this question of industry: a label certifying the company's environmental sustainability and not the company's products, one after the other. Why could such label be an instrument for demonstrating environmental performance without confusing markets and customers? There are a couple of answers to that question:

- A label which applies to a company reduces the number of necessary labels dramatically. A label for a single product does not allow the conclusion that all the other products of that company are equally environmentally friendly. However, a company cannot be environmentally sustainable without having environmentally friendly products as well as an overall environmental performance. If this wasn't the case, the company would not earn the label.
- A company certificate makes it easier for customers to compare competitors: as far as environmental performance is concerned, the comparison takes place on the company level and not on the level of the single product.
- The process for certifying the company does not hinder the launch of new products. In other words: the company must not worry about time to market. As the certification process covers a variety of environmental aspects, the company can run it independently from its key processes (R&D, manufacturing, marketing and sales).

An example of such company-related eco–certification is the ULE 800 standard. It covers the following areas (domains):

Table 3: Company related eco-certification with ULE 800 – the domains

Governance for Sustainability	sustainability strategic planning, board oversight, internal stakeholder engagement, ethics policies, and creating the infrastructure and fostering the behaviors that create a culture of sustainability
Environment	product stewardship, sustainable resource use, environmental management systems, energy efficiency and carbon management, materials optimization, facilities and land use, habitat restoration, and waste prevention
Work Force	professional development, workplace integrity, employee satisfaction and retention, workplace safety, and employee health and well-being
Customers and Suppliers	fair marketing practices, product safety, customer support and complaint resolution, and sustainable supply chain management, monitoring and improvement
Community Engagement and Human Rights	community impact assessment, community investment, and human rights issues

Designing-in Sustainability in Industrial Projects and Processes

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Abstract

Industrial projects represent significant potential for economic development in their host countries. Likewise, they also present the potential to cause significant social and environmental impacts. While much consideration has been put into the design for sustainability of products, there is still a significant gap in the integration of sustainability considerations into industrial projects and processes. Moreover, there is an additional need to bridge the theory of sustainable design and the "on-the-ground" needs of the designers of such projects. This paper discusses one framework which has been developed to help bridge this gap, as well as the results and learnings from its application to high impact "real world" projects. The paper discusses the problem from a range of perspectives including: what the gap between current and ideal practice is, what needs to be incorporated in a sustainable industrial project, what methods have been applied, and the relative theoretical and practical success of the current framework.

Some of the key outcomes from the case studies to date have included the development of plans for the roll-out of integrated social and environmental initiatives to reduce cost and environmental impact while improving societal acceptance and resilience. Research learnings have indicated the need for a structured framework for identifying potential opportunities and risks, as well as the importance of timing and integration with existing project management systems.

Keywords:

sustainable development, design, industrial, process, project

1 INTRODUCTION

Sustainable development is a challenging concept for the designer of industrial processes to incorporate – especially when these projects tend to involve extreme processing conditions, high throughputs and large footprints on multiple scales. However, sustainable development (SD) principles are often touted by the corporate leadership of companies without full consideration as to how these can be incorporated in the design of new processes or projects (e.g. [1]). Furthermore, the literature on design of industrial projects and processes to meet principles of sustainability is highly porous [2] (in contrast to the literature on sustainable design of products).

The object of this paper is to provide a brief overview of the state-of-play of industrial process design for sustainability, and describe recent work that has taken steps towards filling some of the gaps in both academic understanding and practical application.

2 SUSTAINABILITY IN DESIGN

2.1 Approaches from industry

As an example of industrial design, the minerals industry may be seen to be quite highly performing in the area of sustainability at the corporate level, having undertaken significant global stakeholder dialogue and committed to sustainable development at the highest level [1, 3]. However, when it comes to actualizing these commitments, the industry has not found it easy. In regards to the approach of project developers and designers in this industry, decisions on resource projects are traditionally based on the answer to three fundamental questions: (a) is it technically feasible?, (b) does it make financial sense? and (c) will government/community allow it?

This approach may be broadly comparable across heavy industrial projects. The practical application of these aspects means, respectively, that (a) tried-and-tested technology or processes are applied and reapplied with little innovation from project to project; (b) financial investment in sustainability is seen as non-core, and therefore typically avoided or omitted; (c) the lower limit of acceptability is the benchmark for projects – as typified by environmental regulatory processes. These approaches neither support the integration of sustainability principles nor, it may be argued, enhance the ultimate feasibility, financial performance or acceptability of the project.

Additional to these limitations, project design and management processes typically work to reduce the possibility of integrating innovation to improve contribution to sustainable development through the drive for: (a) KPI's that do not include or reward sustainability;

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(b) projects being divided-up into design silos that communicate too infrequently, thus limiting cross-pollination of sustainability initiatives; (c) highly compressed timeframes and budgets; (d) standards and regulations that create “low bar” goals and do not incentivize higher performance; (e) task-orientation and separation that leads to design conflict, sub-optimal solutions and a lack of broader perspective on the project from the majority of the design team; (f) limitations on spending at the early stages of design, which is where the best opportunity for improving the project can be obtained.

It must be noted that some companies are trying to bring greater integration of sustainability, but that these efforts tend to be marginal in relation to the overall project.

A special note for environmental impact assessment (EIA) and social impact assessment (SIA) must be made. These potentially highly useful and effective tools have been integrated into the regulatory system of many countries, in order for project approval to be granted. However, these studies are often outsourced or tendered to companies that are not undertaking the major design. This can give a useful legal separation that may impress regulators with the perception of non-bias, however it also means that the effort undertaken in EIA / SIA is not immediately or directly fed-back into the design process. In addition, these tasks are often undertaken too late in the design process to make much more than end-of-pipe or superficial changes.

2.2 Tools from academia

There have been a number of tools developed through academic effort over the past decades which are receiving some industrial uptake, although often mistimed. Key tools include environmental footprinting, life cycle assessment (LCA) and a variety of principles and methodologies for cleaner production, waste minimization [4], green engineering [5]. There have also been a large number of associated assessment tools and metrics developed (e.g. [6]).

As these tools have been integrated into software packages, they have received some level of uptake by industrial process designers. However, most of these tools are based on post-design assessment, rather than guiding or assisting the design in a proactive manner. Thus, although important, they lack an element of creative input to enhance design for sustainability (DfS).

2.3 Design methodologies from academia

A number of DfS methodologies have been proposed for process design [7-11], but no industrial take-up has been reported. While this could in part be the result of a lack of reporting of such applications by industry, it is considered more likely to be an indication that take-up has not occurred. There are known to be other in-house methods or tools that have been indicated in the literature, but not thoroughly explained due to confidentiality and commercial advantage [12]. Other tools and approaches are mentioned on many engineering consultants’ websites (e.g. http://www.ghd.com/global/about-us/sustainability/) and some have been made publically available [13]. Despite the mention by industrial players, there is little indication of their application, which is a vital element in the success of such methodologies.

One frequently cited approach [8] adds: an initial scoping of sustainability criteria, identification of alternatives, and assessment on these criteria, before the traditional design process. This occurs at an early stage of the project, prior to preliminary design. Further additional steps involve assessment of sustainability after each iteration of design (or at the end of each project stage). This iterative approach, and the integration with the project management cycle is vital, as described in the next section.

The remaining cited methodologies focus specifically on the design phases of the project and involve mathematical or computer-based optimisation of a number of indices or metrics representative of sustainability of the alternative process flow sheets [9-11]. Stewart, et al. [9] include a preliminary step of comparing possible raw materials or products however, the remainder of these methodologies is quite similar. Alternatives are generated by application of standard design methods and assessed or evaluated using tools mentioned in section 2.2. These assessment processes are limited to environmental impacts, and largely ignore the location-specific aspects that make each project unique, and ultimately affect sustainability of an industrial installation [14]. The integration of social and location-specific aspects is a complex issue which is not well treated by existing design methodologies or tools such as LCA.

2.4 Importance of the project cycle

In “real world” industrial design projects, as opposed to academic design exercises, the project management system typically dictates the time, data and scope for innovation that is available at each process stage (Fig 1). It is vital to match any DfS strategy with the project management system, in order to enable timely and appropriate integration of sustainability.

If there is no correlation between a DfS methodology and the project cycle, then the methodology will not be successful. Two examples follow: (a) the use of highly detailed flowsheet anaylsis or optimization at the conceptual stage of a project. This will not succeed because the required data is not available and uncertainties are too high. (b) the attempt to introduce new flowsheets or processes in the detailed design stages. This will be rejected on the basis of the timing and required cost to rework the project.

The importance of correlation with the project management system goes further, in that existing tools such as LCA need to be applied appropriately in order to gain support of internal stakeholders and to provide appropriate information to the design team.

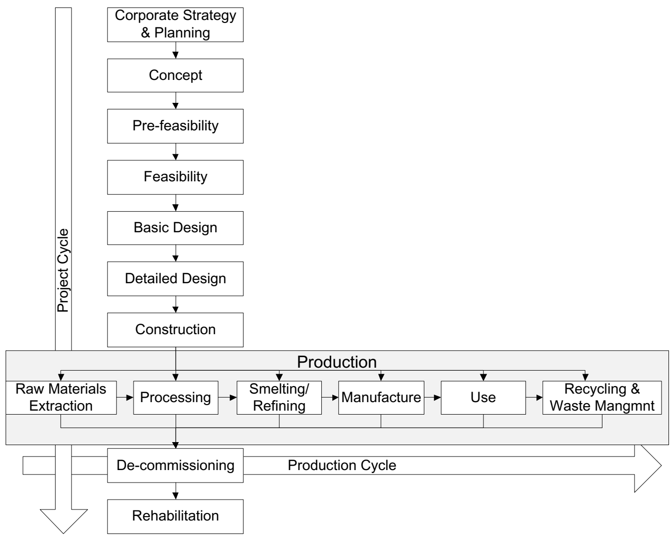

Fig. 1: Project-production cycle

The following sections describe a methodology that has been developed to overcome these gaps.

3 THE SUSOP® MECHANISM

3.1 Development

Recognising that most of the proposed DfS methodologies have been academically-derived, the SUSOP® (SUStainable OPerations) mechanism took a different approach, being a collaboration between industrial and academic partners. This has led to a DfS methodology that acknowledges and incorporates industrial realities, while still aiming to provide an academically rigorous solution for integrating sustainability considerations in design. Moreover, due to this collaborative arrangement, the methodology was able to be tested on actual, ongoing minerals industry projects.

3.2 SUSOP® components

The mechanism comprises three major components that form the backbone of the framework:

1. Sustainability opportunities and risks identification (SUSID™). A significant characteristic of this element is that it includes 'new ideas' generation.
2. Sustainable Development (SD) Assessment – to conduct a detailed evaluation of the shortlisted or high-priority opportunities and risks.
3. Decision Support - to provide assistance with decision-making at project toll gates.

A schematic of the main elements of SUSOP® are presented in Fig 2. With recognition of the different stages of the project cycle, the particular elements applied at each stage are tailored to the available level of data and the key tasks required for normal project delivery.

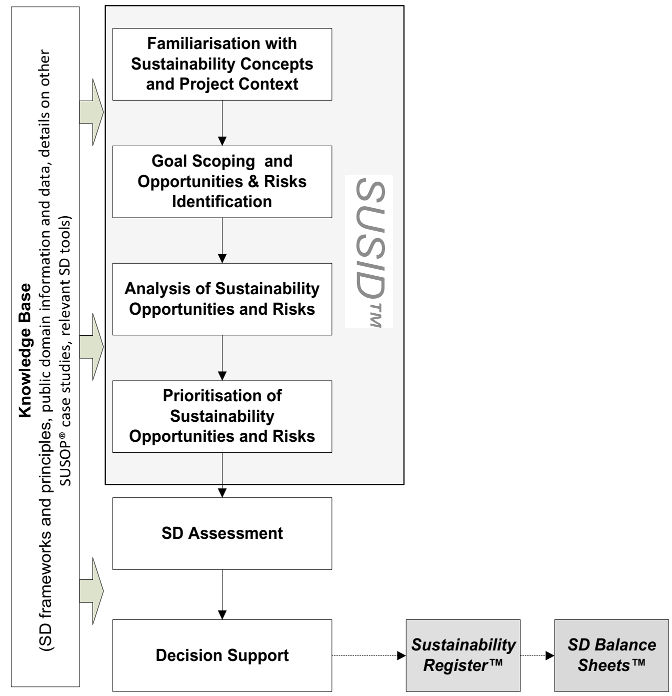

Fig. 2: SUSOP® Framework

Sustainability Opportunities and Risks Identification (SUSID™)

There are four steps in SUSID™:

1. Familiarisation with Sustainability Concepts and Project Context;
2. Goal Scoping and Opportunities & Risks Identification;
3. Analysis of Sustainability Opportunities & Risks;
4. Prioritisation of Sustainability Opportunities & Risks.

The first two steps and the last step are run in a workshop environment while the third step is analysis conducted by SUSOP® Practitioners.

The aim of the Familiarisation step is to create a common understanding of the project context (key technical and financial characteristics, local environment and the social context at the local and regional levels) and core sustainability principles and frameworks for the workshop attendees. The attendees draw out the linkages between the project context and the sustainability framework and relevant sustainability principles, such as the ICMM's ten principles [1], or corporate sustainability policies. By discussing and formalizing the designers' knowledge of the project and sustainability principles from the beginning, design and innovation can start to be driven based on a new paradigm.

The Goal Scoping and Opportunities and Risks Identification step comprises two key activities. The first activity is the generation of project-specific sustainability goals based on the company's corporate sustainability principles or policy. It is an extension of the Familiarisation process and provides the seeds for the second activity, Opportunities and Risk Identification.

Opportunities and Risk Identification is one of the key elements of SUSOP®, distinguishing it from alternative methodologies. Specifically designed prompting questions and key words based on widely accepted sustainability concepts are employed to identify sustainability opportunities that could potentially improve the SD contribution of the project. Risks caused by the project to SD are also identified and, if possible, solutions are suggested to mitigate these risks. Innovative solutions typically emerge when participants understand and appreciate the connections between the proposed project and the broader societal and environmental context. Both sustainability risks and opportunities are listed in the Sustainability Register™ which is then carried forward by the project team across the project development cycle for further attention in subsequent phases.

Analysis of Sustainability Opportunities and Risks is undertaken by specialized SUSOP® Practitioners to further analyse and verify the outcomes from previous steps, and investigate the potential for other opportunities or identify additional risks. An important part of this step is establishing clusters, connections or linkages between opportunities and risks, to develop a preliminary understanding of the overall sustainability impacts. Based on the analysis in this step, an initial shortlist of opportunities and risks is produced.

The outcomes from the Analysis step are then presented to the project team in the Prioritisation of Sustainability Opportunities and Risks step to validate (based on sustainability considerations) and confirm a shortlist of opportunities and risks for future evaluation and assessment. By the end of this step, the project team agrees on a prioritised list of opportunities and risks, including those that require immediate action.

SD Assessment

The SD Assessment involves the detailed evaluation of the prioritised sustainability opportunities and risks. Where possible, quantitative tools are used to investigate and evaluate the top ranking opportunities and risks on the basis of their sustainability impacts (positive and negative). It must be noted that the level of quantification, and the tools used must reflect the available data and project stage.

Decision support

The final component is decision support. This is an important area of consideration in DfS, with so many (often conflicting) areas of priority and impact. This step draws on existing techniques, such as multi-criteria analysis techniques, to provide substantive guidance on the selection of initiatives that will deliver enduring sustainability benefits as well as satisfy key business performance criteria.. An SD Balance Sheet™ is used to graphically demonstrate the different SD impacts and benefits of alternative design options, and is also useful in the decision support situation. The "Five Capitals" model [15] is used as the default framework – as shown in Fig 4. In addition, the Sustainability Register™ presents the outcomes from applying SUSOP® in a format that feeds into the standard project management systems.

4 CASE STUDIES

4.1 Concept phase – site selection

Two case studies are discussed in this section. The first was a concept phase study that was to assist the client in making a decision on plant location based on criteria beyond their usual risk and cost metrics. The project was in a developing country with minimal domestic infrastructure, poor access to cheap energy, low technical or skilled labour force.

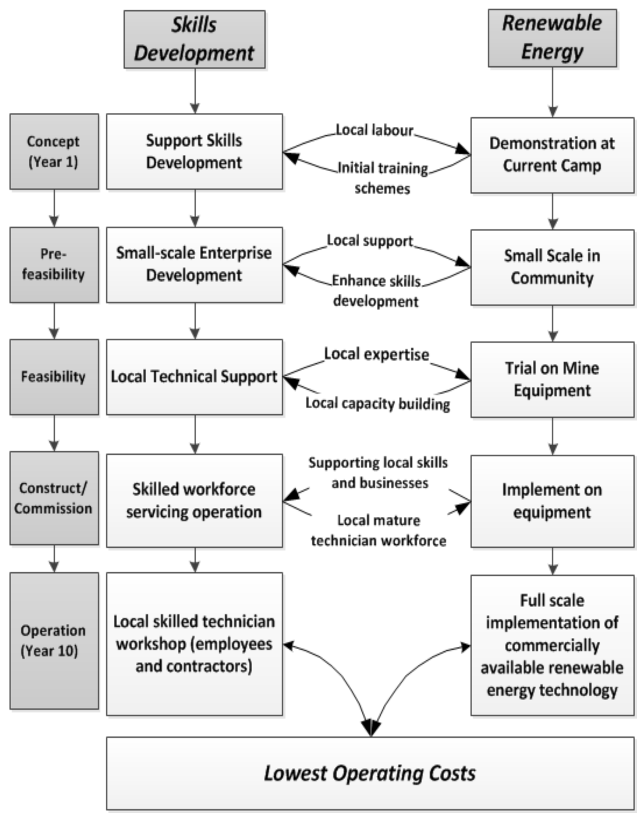

Fig. 3: Integrated development plan.

Applying the SUSOP® methodology identified more than 70 opportunities for improving SD contribution through waste reuse, community initiatives and low impact processing options. These were further analysed and grouped into a number of clustered opportunities that could be integrated on a whole-of-project scale.

One of the key outcomes from this case study was the development of a plan for progressively bridging the skills and energy gaps over the subsequent project phases, so as to ultimately reduce project costs. The savings in project operational costs, which could be derived by training local workmen rather than importing expensive expatriates and by reducing dependence on imported energy sources, were a key "selling" point for the plan.

4.2 Pre-feasibility study – waste treatment

The client was at the pre-feasibility stages of a minerals processing expansion, in a developing country. The project was to compare a variety of existing options for effluent treatment on a sustainability basis, and to suggest further improvements.

From this study, sustainability opportunities to support effluent management were identified, such as creating local enterprises to provide consumables, producing 'green' by-products and implementing a small-scale wetland to replace a conventional effluent treatment facility. These outcomes will deliver significant improvements to social and natural capitals compared with the base case option, and substantially satisfy key elements of the corporate sustainability policy.

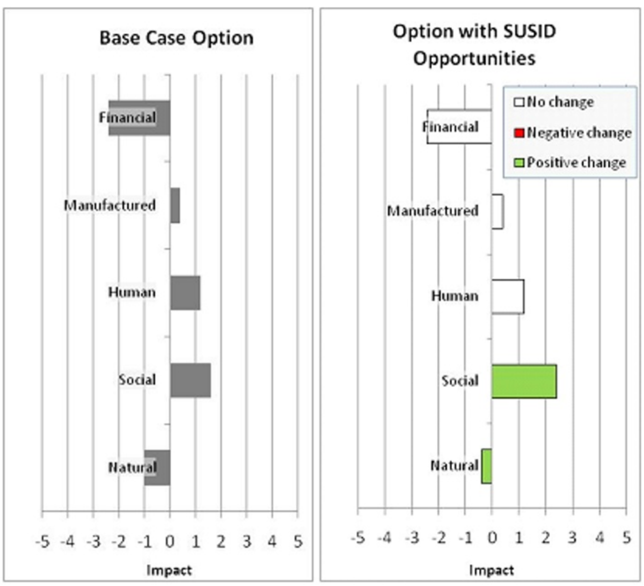

Fig. 4: SD Balance Sheet™ – applying the "Five Capitals" SD framework

Being at the pre-feasibility stage, sufficient data was available to complete a quantitative estimate of the potential of the different options, as well as to produce SD Balance Sheets™ for each option before and after the integration of sustainability initiatives (Fig 4). Significant positive change was found to be possible for social and natural capital, while manufactured and human capital were not significantly improved. Furthermore, financial capital remained negative, but this was consistent with the required expenditure for effluent treatment – a non-profit generating activity.

4.3 Learnings

A number of key learnings have emerged from the application of SUSOP®. Firstly, a number of key elements must be included in order to drive more sustainable design – including multi-stakeholder innovation sessions, assessment and decision-making tools with a consistent SD framework throughout. Secondly, the DfS process must integrate into the existing project management system, acknowledging the limitations of data and scope that give boundaries to the potential for innovation. Thirdly, the identification of opportunities and risks requires a structured approach – in some cases essential to prompt ideas, and in other cases essential to limit or restrict ideas to within project scope. Without these elements, a DfS methodology is unlikely to receive uptake or perform its purpose satisfactorily.

5 CONCLUSIONS

This paper describes some of the challenges for designers attempting to integrate sustainable development principles into industrial process design. It describes key elements of one structured mechanism, and the relative success that the process has achieved in application.

Unlike most existing approaches, the SUSOP® framework attempts to integrate closely with existing project management systems, and to fit with the limitations of scope that each project stage delivers.

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Industrial design accolades: Do they support socially sustainable product innovation?

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Abstract
This paper looks for evidences of socially sustainable product innovations amongst the entries recognized in international industrial design awards. The winning designs for the last four years in three of the most popular mainstream accolades were investigated and profiled. The analysis shows that attention to socially sustainability in design is gradually picking up. Several special awards that pay special attention to social sustainability issues were found, suggesting that support for this type of innovation in the design profession is growing.

Keywords
Industrial design awards, socially sustainable product innovation, socially responsible design

1 INTRODUCTION

Industry accolades recognize the efforts of design practitioners and manufacturers in offering highly innovative products and outstanding solutions in the marketplace. They stimulate the understanding of the business and public realms about the impact that excellent design could bring to the quality of human life everywhere and to the national and global economies.

1.1 Product design accolades

Accolades for industrial design creations can be generally categorized generally into two types. One is an endorsement scheme for well designed products, whereby submitted entries are given commendations depending on how they conform to the assessment criteria and benchmarked with similar products in their particular category. In this mode the design award functions like a seal of design quality. The entrants do not compete with other products but instead demonstrate that they are exemplars of good design. Many products receive equal recognition, and there can be multiple winners at various levels. Commonly the designs entered in these endorsement schemes are required to be already in production and available for usage or purchase in the market. Most of the long-running mainstream industrial design awards are of this type.

The other type is based on an open contest where products vie for the honor of being named the best among the submitted products in meeting the competition brief. In this category only one product is adjudged the best and awarded the highest accolade, such as a gold prize. The second best gets the silver prize, the third best the bronze, and there can be a few honorable mentions or highly commended works too. In this award system, only one or a few products emerge as winners. The great majority of designs entered into this award type are conceptual.

Unfortunately many of the ground-breaking ideas entered in the competition-type design awards do not get realized into actual production, perhaps due to lack of financial viability, practicality or manufacturing resolution. Often as a concept progresses during the iterative process of new product development, several technical constraints are imposed along the way, causing the idea to reshape, sometimes significantly, to address the production and other requirements; the project could also ultimately be shelved if a feasible business model cannot be assured.

The criteria for evaluating products for design accolades vary, but in general they assess the following product qualities and keywords:

- Innovation, novelty, originality.
- Aesthetics, styling, semantics, emotional content.
- Functionality, usability, ergonomics.
- Quality, durability, finish, material, construction.
- Safety, user protection, standards compliance.
- Sustainability, real need, environmental impact reduction, long lifetime; resource efficiency, end-of-life consideration, disassembly, maintainability.

The above adjudication criteria successfully distinguish good design and design excellence in the marketplace from bad design and dull, unexciting products. Ecological sustainability is now being addressed by all major awards as a prerequisite to entry, in recognition of the need to minimize the overall lifecycle impacts of manufactured products.

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1.2 Socially Sustainable Product Innovation

In 1971 the activist professor Victor Papanek wrote that "much recent design has satisfied only evanescent wants and desires, while the genuine needs of man have often been neglected by the designer" [1]. He advocated that market-oriented designers go beyond "appearance design, styling, or design cosmetics", and use their talents to solve the pressing needs of the disadvantaged minorities in society: the disabled, the elderly, the developing countries, people surviving under marginal conditions, and others often ignored by the design profession [1].

Papanek's pleas for designers and creative professionals to contribute to real change in the world through good design provided the impetus for the emergence of "socially responsible design", defined as "the use of design to address social, environmental, economic and political issues" [2]. This ideology campaigns for all humans to acknowledge their moral obligation to act for the betterment of society and life in general. A proposed model for socially responsible design, based on the management approach of corporate social responsibility, identifies crime, education, government, health, fair trade, ecology, social inclusion and economic policy as the eight socially significant domains to which designers can direct their creative problem solving skills [2].

Many recent design movements and philosophies can be linked to socially responsible design. There is "socially responsive design", which "takes as its primary driver social issues, its main consideration social impact and its main objective social change" [3]. Analogous to this is "humanitarian design", which upholds the universal and egalitarian rights and dignity of every human being through appropriate solutions. These include such approaches as "design for the bottom of the pyramid" [4], "design for the millennium development goals" [5], "design for the other 90%" [6], "design for the majority" [7], and "design for development" [8]. "Ethical design" is grounded in principles that are popularly accepted in society as morally right values. Another relevant but ambiguous principle is "democratic design", which suggests that good design should not be reserved for the affluent few but rather made accessible to everybody; it could also refer to participatory design in which stakeholders are actively involved in identifying problems and in co-creating the right answers to their needs. Universal or inclusive design represents another ethos, promoting non-discriminatory products that are inherently usable by as many people as possible, whether able-bodied or physically challenged. All these movements allude to an emerging stream of "design activism" among people who passionately want to "use the power of design for the greater good of humankind and nature" [9].

Socially sustainable product innovations, as used in this paper, includes all product-based solutions that empower individuals and groups to advocate, facilitate, catalyze, and realize positive change in the present and future of their community and that enrich their quality of life and wellbeing without sacrificing environmental or economic sustainability. They are long-term practical solutions that foster societal cohesion, promote the public good, repair the "social fabric", and build the trustful "social capital" needed by neighborly networks in shaping their communal destinies. They endorse social justice and tackle social ills in global society. They save and promote human lives, and equip people with the capabilities to develop themselves and to look after their own livelihood. They accelerate the adoption of sustainable everyday behaviors or lifestyles and facilitate the efficient delivery of socially beneficial services to the community. They allow design to penetrate to disadvantaged groups in human society.

Socially sustainable product innovation differs from "social innovation". With regards to their approach of using creative and design-led thinking to meet varied social needs and to enhance civil society, they are similar; however, the results of most "social innovations" [10] are intangible collaborative service blueprints, capacity-building strategies and social value creation activities rather than tangible product designs for supporting sustainable social systems. Many social innovations tend to be outcomes of rethinking of services to be more responsive, pleasurable, experience-enriching, and behavior-changing. Bottom-up initiatives of "creative communities" [11] demonstrate that social innovation can indeed occur without any material product development. Socially sustainable product innovation, on the other hand, highlights the contribution that traditional product-oriented designers can make in boosting the impacts of design to the benefit of global society.

This study focuses on product designs that can potentially trigger, support and orient sustainable social innovations. While it is accepted that less product centricity is highly likely to reduce environmental loads significantly [12], this paper argues that industrial designers are well placed through their training in object-oriented product development to contribute to the enhancement of less resource exhaustive solutions that work well in the communities they are intended to benefit. They have successfully demonstrated their capability in designing product components that facilitate the efficient and effective delivery of user benefits through product-service systems [13], as well as enrich the experiences of participants in these systems.

2 METHODOLOGY

This paper investigates the accommodation of social sustainability within international industrial design awards. Design awards and competitions are viewed here as public venues where practitioners display their abilities in offering meritorious solutions to a range of design issues, and where organizers demand the most notable outcomes in the industry through the evaluation criteria that they establish.

The research was firstly narrowed down to the popular awards (Table 1) which most designers aim to be recognized in. The archives of these awards were consulted, and a content analysis was conducted against the definitions and conditions for socially sustainable product innovation set out in the preceding section; this method follows another research done by the author on Australian design awards [14]. After tabulating the number of awards given out yearly, it became evident that the study will entail analysis of an exceedingly huge number of winning designs, even when student entries and conceptual proposals have been excluded (Table 2).

Table 1. Mainstream industrial design awards in the study.

Award	Accolades	First award	Web site	Operator
Good Design | Product Design, USA	Good Design	1950	www.chi-athenaeum.org	Chicago Athenaeum Museum of Architecture and Design
iF | Product Design Award, Germany	iF Award	1953	www.ifdesign.de	International Forum Design GmbH
Red Dot Award | Product Design, Germany	Red Dot, Honorable Mention	1955	www.en.red-dot.org	Design Zentrum Nordrhein Westfalen
G-Mark: Good Design Mark, Japan	Good Design Award	1957	www.g-mark.org	Japan Industrial Design Promotion Organization
AIDA: Australian International Design Awards	Design Award, Good Design	1958	www.designawards.com.au	Good Design Australia
IDEA: International Design Excellence Awards , USA	Gold, Silver, Bronze	1980	www.idsa.org	Industrial Designers Society of America

Table 2. Accolades awarded, excluding students and concepts.

Award	2007	2008	2009	2010
AIDA	42	61	73	111
G-Mark	1043	1067	1034	1110
Good D	400+	433	587	494
IDEA	49	157	118	152
iF-pd	742	811	785	756
RedDot-pd	666	863	926	1073

Due to time constraints, the study was further limited to the last four years of three mainstream awards: the Australian International Design Awards (AIDA), the International Design Excellence Awards (IDEA) based in the USA, and the International Forum Product Design Award (iF-pd) based in Germany. The G-Mark of Japan and the Red Dot Award of Germany had the most number of awardees; the analyses of these will be incorporated in a future publication. The Chicago Athenaeum Good Design Awards, while being the world's first accolade for industrial design, was excluded because the archives do not provide any explanatory text to describe the winning products. The other five awards provide rather detailed descriptive information about the winners, allowing deeper understanding of the design; IDEA, G-Mark and Red Dot even supply the jurors' rationales for awarding the most outstanding products.

3 RESULTS

Graphing the results of the analysis of the three award schemes in the study (Figure 1), it can be seen that the socially sustainable product innovations can be categorized into the following product groupings:

3.1 Designs for saving lives and fostering good health

Consistently outnumbering all other winning designs in the three schemes are products which are categorized as "medical", "scientific" and "health care". Clearly these products are directly involved in saving lives and promoting good health, safety and wellbeing that would enable people to participate and contribute to society. Most of these were items for in-hospital patient care, and many were also for home use. These include

- In-hospital bedside care: universal trolley stretchers, vital signs monitors, intravenous containers, electric beds, neonatal incubators, infusion workstations, respiratory ventilators, bedpans, catheter handsets.
- Emergency rooms: knee bandages and braces, ultrasonic nebulizers, asthmatic inhalators, pressure garments, hypothermia cooling kits, obstetric forceps, orthopedic braces, spinal immobilization backboards, cold compression therapy.
- Clinical diagnostics: portable ultrasound tools, breast volume scanners, ECG, MRI, lung function screeners, melanoma detectors, sleep study, prostate exam chairs; analyzers for blood chemistry, cancer and infections in tissue samples, cell metabolism.
- Surgery: operating tables, instruments for surgery and laparoscopy, workstations for organ recovery and transplantation, touch-free faucets, surgical lights.
- Domestic use: forehead thermometers, blood pressure monitors, blood glucose testers, breast pumps, asthma puffers, infrared heaters, sleep apnea masks, hearing aids, eating aids, wheelchairs, prefilled syringes, body fat scales, walking frames, HGH injectors.

The majority of these award winning medical products are not necessarily groundbreaking; indeed they are mostly incremental innovations in a mature market. Interestingly, some of the rather radical innovations come from Philips:

- Philips Lifeline PERS (personal emergency response service), a cordless phone system with a wearable medical alert button and back-to-base station for immediate assistance and emergency coordination, to enable frail elderlies to maintain their independence and continue living at home.

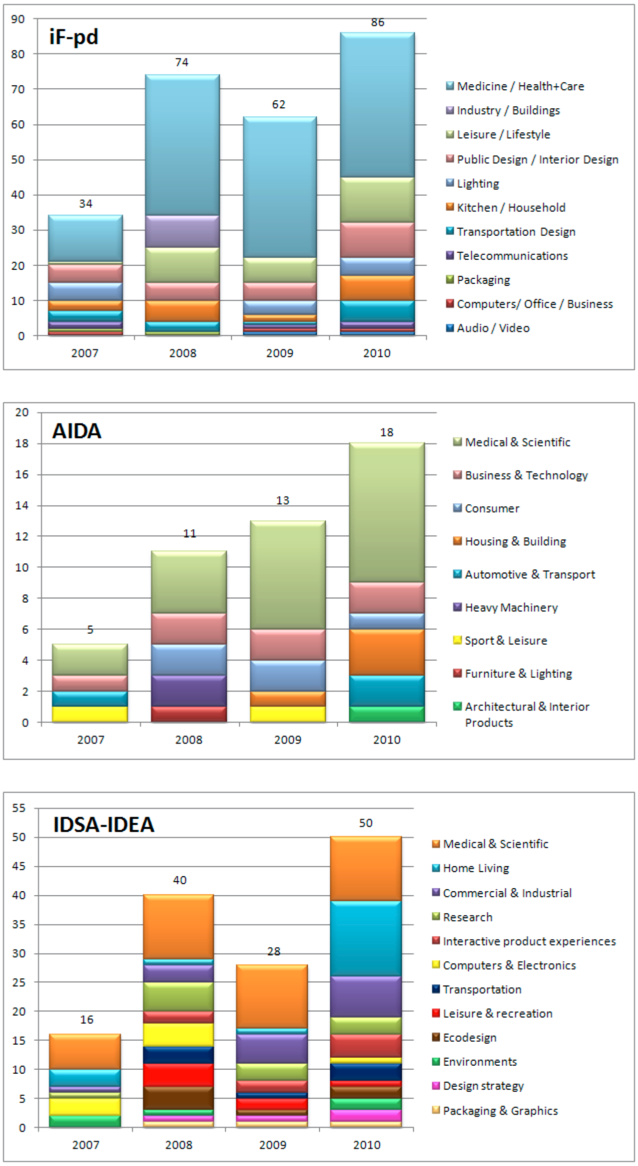

Figure 1. Breakdown of socially sustainable product innovation by categories in design awards.

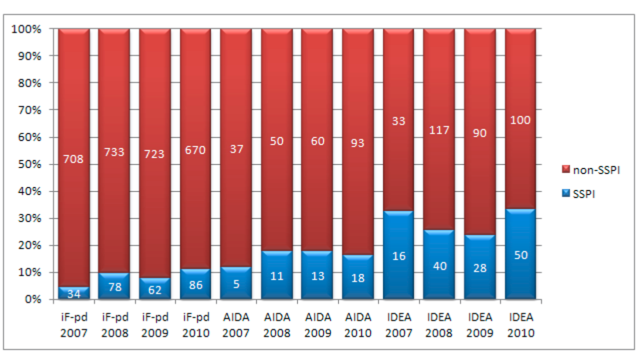

Figure 2. Proportion of socially sustainable product innovations.

- Philips' interactive toy CAT (computerized axial tomography) scanner, also known as "kitten scanner", designed to help lessen children's anxiety about the scanning procedure by using role play and storytelling to learn what to expect.
- Philips Breath Counter, a solar-powered respiration-monitoring device to enable health-care workers in developing countries to detect pneumonia and accurately and reliably identify and classify cases of the disease in just 60 seconds.

Relevant to this category also are products used to save lives and improve human living conditions during disasters and emergencies. These include rapidly deployable shelters (RDS), rapid deployment flood walls (RDFW), firefighting devices, fire sprinklers, vehicle crash extrication tools, and winches.

3.2 Designs for low-impact recreation and lifestyles

Products that enable participation in behavior-changing recreational activities constitute the second largest number of socially sustainable product innovations, although only 1/3 the number of medical and scientific products.

- Products which enable and enhance participation in sustainable mobility and commuting. These include folding bicycles, city bikes, road bikes, electric bikes, as well as cycling accessories such as safety lights, handlebar grips, tire levers, helmets, pannier bags, water flasks, security locks, and parking stands.
- Products which afford safe and pleasurable participation in healthy outdoor activities. These include life jackets, rechargeable flashlights, backpacks, amphibious lanterns, head lamps, snow shovels, educational tennis gloves, portable solar panels, hedge shears, watering cans.
- Products which promote sustainable procurement. These include personal shopping trolleys, handy grip for plastic bags, reusable shopping bags.

Again most of these were incremental innovations. Some of the far-reaching innovations here include:

- Kiddie's Paradise Wavy Tactile Path, an educational sensory and tactile toy inspired by trails in a rice field, helping children to improve their coordination, balance and ability to adapt to different environments.
- Yakkay bicycle helmet with hat covers, where safety and style are united and equally valued, encouraging the design conscious to consider commuting by bike.
- Stelton Shopper, a reusable nylon shopping bag with designer graphic prints; while not in use, it folds and hides away into its own plastic handle.

3.3 Designs for pleasurable public and work spaces

The third largest group is comprised by products categorized in the various awards as "public design", "environments", "architectural and "interior products", "commercial and industrial products".

- Products which promote enjoyment of public outdoor spaces. These include modular street and park furniture systems, information kiosks, litter bins, self-cleaning city toilets, smokers lobby, recycling kiosks.
- Products which enhance sustainable transportation. These include modular public transport shelters, smartcard load rechargers, ticket validators, e-ticketing terminals, and electric car fast charging points.
- Products which enhance safe working environments and conditions. These include construction safety harnesses, vibration control gloves, Optalert™ eyewear for managing driver fatigue and drowsiness.

More revolutionary innovations in this category include:

- Wall AG Dog Service Station encourages dog owners to clean up after their dogs; system includes waste bag dispenser and pedal-operated odorless disposal unit.
- NYC Condom Dispenser, an initiative of the New York City Department of Health which offers free condoms in public places as an effective measure against HIV infections and unwanted pregnancies.
- Better Place Charge Spot provides fast-charging power outlets for electric vehicles in public places.
- Mobility Vision Integration Process, deck of creativity cards and online brainstorming tool to investigate how expert designers can support and accelerate dialogue about the future of sustainable mobility.

3.4 Designs for healthy everyday living

This group incorporates those in the "consumer products", "household", "residential", "home living", "kitchen" and "personal" categories in the three awards.

- Products which provide a healthy and safe living environment. These include: allergy-free vacuum cleaners, air ionizers, water purifiers, child safety gates, modular planters and hydroponics for apartment kitchen gardening.
- Products which prevent wasteful consumption. These include battery chargers, water saving shower heads, trash compactors, non-electric ice pop maker, reusable shipping containers, air multiplier fans, and kitchen sink water reuse bucket.
- Products which follow universal design principles. These include the One Touch™ can opener, easy-to-use corkscrews, kitchen aids, padlocks, scissors.

The more disruptive innovations in this category are

- Makedo, a reusable connector system that enables construction and creation with found materials.
- Stacket, a space-efficient square bucket for places where storing rationed water is the norm.
- Easy Latrine, an affordable household sanitation solution for developing countries. This simple design was awarded the IDEA Best in Show in 2010.
- Philips Chulha, a low-smoke biomass stove designed for households in rural India. Reducing indoor air pollution that causes fatal respiratory diseases, this project is a demonstration of Philips' "Philanthropy by Design" approach.
- IDEO Human-Centered Design Toolkit, a free innovation guide that empowers NGOs and social enterprises in the developing world to address needs of those living on less than $2 a day.

3.5 Other socially sustainable innovations

The other product categories showed only a few good examples of social sustainability. Computer and office equipment could be represented by the Motion C5 mobile clinical assistant, the Perkins mechanical Braille typewriter and the One Laptop per Child (OLPC), a revolutionary $100 laptop to bring learning, information and communication to children in developing countries.

In the Packaging and Graphics category the best examples were "Design for Democracy: Ballot + Election Design", a book which set the national guidelines for designing clearer ballots and polling place signage; and "Out of the Box", a design study to investigate and find solutions to the increasing divide between older Europeans and digital mobile communications.

4 DISCUSSION & CONCLUSIONS

It should be noted that sometimes the winning designs are not placed in the most suitable product category, and there are probably too many product groupings; it would be desirable in future studies to reconsider combining some categories and re-categorizing some products.

While it may appear that the iF product design award has more socially sustainable product innovations than the other schemes, Figure 2 shows that, relative to the number of awards given out, the socially sustainable fraction of iF-pd is in fact the smallest among the three. The four-year average on the proportion of socially sustainable designs for iF-pd is only 8.4%; in comparison AIDA has 16% while IDEA has a 29% mean.

It was also found that most of these awards recognize sustainable design through a special award or by running a parallel awards scheme. However, they all focus on ecological aspects and do not really promote social sustainability (Table 3).

Table 3. Sustainable design accolades within mainstream awards.

Award	Design for Sustainability accolade
AIDA	Design Award | Sustainability for the single most environmentally conscious design of the year. Started in 2007.
G-Mark	Long Life Design Award for products which have a history of at least 10 years of production and distribution. Sustainable Design Award for products which contribute to lasting values in the future. Multiple winners every year. Started in 2008.
Good Design	Green Good Design Awards, separate scheme. Started in 2009. €300 entry fee. 34 recipients in 2009, 64 in 2011.
IDEA	Designs of the Decade, separate scheme. Subcategories: solutions to a developed world social problem, developing world social problem, most responsible design solution, best

	sustainable design solution, and others. Ran in 2000, 2010.
	IDEA Ecodesign Category. Ran from 2006 to 2010.
iF-pd	iF Ecology Design Award. Ran from 1997 to 2001.

This study also found that the financial cost to participate in these design awards can be very high. The lowest charge was US$ 390, for entry into the Good Design Award (see Table 4). The Best of the Best winners in the Red Dot shell out at least US$ 6808, which includes use of the label, a double page on the yearbook and design diary, and a one-year exhibition in the Red Dot museum for small objects such as mobile phones; large appliances, vehicles and furniture systems pay up to US$ 10,140.

Table 4. Participation costs in design awards.

Award	Charge	Cost US$
AIDA	Entry (yearbook & exhibition free)	$1089
G-Mark	1st screening	$130
	2nd screening	$649
	Yearbook	$390
	Exhibition	$260
Good D	Entry	$350
IDEA	Entry (yearbook & exhibition free)	$100 ~ $350
iF-pd	Registration	$488 ~ $646
	Winner	$3734
Red Dot	Registration	$287 ~ $345
	Excess size	$72 ~ $216
	Winner & honorable mention	$3232~$6104
	Best of the best	$6808~$10140

Some of the mainstream design awards have categories which invite concepts, explorations or projects still at proposal stage. Some of these conceptual winners show promise in addressing social sustainability issues, but because this paper is only interested in realized solutions, these unrealized entries were excluded from the analysis.

Relevant to this study, competitions specifically celebrating socially responsible design were also found. The INDEX: Award "Design to Improve Life" in Denmark is the most prestigious, rewarding its five winners with €100,000 each. The Saatchi & Saatchi Award for World Changing Ideas gives $50,000 cash plus $50,000 marketing consultancy to one winner. Other schemes include the ICSID World Design Impact Prize, the Victor J Papanek Social Design Award "Design for the Real World Redux", the Spark Design & Architecture Awards, and the Core 77 Design Awards which has a "Design for Social Impact" category. Some of these require that the entries must have been realized in production while some are open to conceptual proposals.

Product design accolades do their job well in highlighting the excellent work of industrial designers and the manufacturers they work with. However, given the urgency of climate change and environmental disasters that are attributed to the impacts of not-so-responsible designs, it is sensible to rethink whether designers and manufacturers should continue pursuing the market-oriented approach of offering consumers endless streams of award-winning material "stuff" to own.

As the analyses show, designers and manufacturers are indeed capable of designing excellent solutions that are socially sustainable. While the proportion of such innovations is still low in comparison to the rest of the awards, it is promising to see growth in this area. BusinessWeek noted that in 2008 a "strong sense of social responsibility ran through most of the winning entries" [15], and that this trend was repeated in 2009 [16].

That mainstream design accolade schemes are so costly to enter might be one reason why we see relatively few socially sustainable product innovations entering and winning. Indeed the financial investment in participating could be better spent on supporting the product to reach more intended beneficiaries in society. Social designs do not necessarily gain the commercial advantage that traditional industrial design objects get from winning these mainstream awards. It is more practical for them to gain recognition through the special design competitions on social impact, which are either free or low-cost to enter and also could offer huge monetary prizes for winners. The other reason, of course, for lack of social design presence in the awards is that the humanitarian innovations are not seen to have enough visual appeal to be worthy of such design awards.

The successful examples of socially sustainable product innovations in this paper prove the stimulating and empowering agency that industrial design has in helping usher a world that is more equitable and beneficial for more people. As evidenced by the charts, more designers and manufacturers are increasingly embarking on endeavors that advance the betterment of humanity; this is commendable, and we hope to see this trend continue in the future. Sustainability is a relatively new ballgame for designers [14], and the attempts of the design industry worldwide to engage in this challenge should be supported and encouraged, particularly in strengthening its capacity to contribute towards a truly sustainable future.

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The Teaching-Research Nexus in the Rise of Sustainability Science: Scope and Approach

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Abstract
Fundamental changes in the way research is approached and conducted, together with continuous changes in economics as it moves towards a weightless economy where knowledge and technological innovation replace mass production, together with developments and efforts worldwide aiming towards sustainability, are challenging institutions of higher education to rethink their missions and to re-structure their research and education programs. Post-modern societies now seem about to introduce mass education, due to the new orientation of the economy towards knowledge and innovation. This is a situation unprecedented in the entire history of higher education, and it offers both tremendous opportunities and considerable drawbacks if mishandled. In this first part of a two part paper, several important issues are examined in relation to the approach to and scope of research and teaching from the viewpoint of synergy between them on an interdisciplinary and multidisciplinary basis.

Keywords:
sustainability science, green engineering, teaching-research synergy, higher education

1 INTRODUCTION

The rise of post-modernism and the provision of higher education to the masses have gradually changed the ways and places in which knowledge is produced in contemporary society. This is also reflected in a wide range of scientific and scholarly activity, as well as in the next generation and application of technology. In [1], this change is described as a transition from *Mode 1 science* to *Mode 2 science*. Mode 1 science describes scientific and scholarly activity which is disciplinarily homogeneous, and organized in a hierarchical form featuring a strong tendency to preserve this structure. Problems targeted and solved are usually within the realm of interest of a specific scientific community. In contrast, Mode 2 science features a problem-solving methodology that is much broader and is placed in a transdisciplinary social and economic context. Here knowledge is acquired in a more exploratory way in the context of application, providing a strong problem-driven and practice-oriented approach. Various actors and stakeholders from different disciplines and fields of expertise provide a participative mode of knowledge production within a heterogeneous network that is extended to various locations beyond the limits of familiar traditional institutions of higher education and research (see also [2]). This Mode 2 science is similar in nature to what has been identified as *science for the post-normal age* in [3]. Along with intensifying concerns for sustainability among the general public, in science, and in various societal, political and economic sectors, and the rise of what is known either as Mode 2 science or as post-normal science, a new research program has begun to emerge, currently referred to as *sustainability science.* Sustainability science focuses on the dynamic interactions between nature and society, employing a new methodology for knowledge production, which is demand driven, with consideration given to uncertainties, and is subjective and exploratory in nature, thus featuring a more heuristic approach to acquiring insight into and providing solutions for complex problems of sustainability.

A lot of pedagogic research in higher education concerned with the nature and evidence of synergetic relationships between research and teaching still tends to take place at a generic level, considering traditional approaches, methods, and (infra)structures, as related to domain specific research and education, without adequately taking into account current developments in how, where and by whom knowledge advancement is carried out employing which methods and tools according to which paradigms. The purpose of this paper is not to provide yet further evidence of a teaching-research nexus in current education models but to point out and bring to the attention of a wider academic community potential and opportunities that could foster synergy between research and teaching if concepts and models of curriculum design are adapted to current modes of knowledge advancement, and the demands of educating future generations of graduate students are drawn from the requirements of current efforts in problem-solving and professional practice within the context of sustainability science.

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The paper is structured as follows. In section 2 some background is given along with a discussion on related work. In section 3 the context of sustainability science is briefly outlined from the viewpoint of development regarding its principles, recognition in academia and practice, and body of community, research, and education. In section 4 basic ideas and concepts of the approach are presented and discussed, and this is followed by a summary given in the last section. Additional issues related to higher education in the context of sustainability science, regarding infrastructure and method of conduct, will be examined in the second part of this paper (in [4]).

2 BACKGROUND AND RELATED WORK

2.1 Education as an activity

From an activity-based viewpoint, education is regarded as the process by which society transmits a part of its accumulated values, knowledge and skills from one generation to another. The term *education* is derived etymologically from the Latin word *educare*, which means *to bring up*. The modern system of education is subdivided into primary, secondary and tertiary education. Within the given context of this paper the focus will be on the last, which is also referred to as higher education. The process of education consists of three sub-processes, usually identified as teaching (the activity and efforts of teachers to impart learning to the students), learning (the process by which knowledge and skills are obtained by those who study or are taught), and instruction (the facilitating of learning by a teacher). Currently, the most commonly identified learning styles or learning modalities are auditory learning based on listening to instruction, visual learning based on observation, and kinesthetic learning based on engaging in activities and hands-on work (cf. [5]). Within pedagogic research regarding the research-teaching nexus in higher education, the instructional relevance of learning styles is not so much a concern, due to new teaching strategies related to new paradigms of research and teaching. These put the teacher more into the role of an inquiry and discussion facilitator and guiding coach for individual knowledge discovery. The students become more engaged in active learning, and thus play an active part in the development of their own knowledge and patterns of understanding.

2.2 Concepts of the teaching-research nexus

Within work on defining concepts that allow for the investigation and linking of the research-teaching nexus to knowledge production and curriculum design, a three-dimensional model space for curriculum design has been constructed by Healey [6] partly based on the work by Griffith [7]. The basic three model directions (dimensions) are linked to emphasis (on research content vs. research processes and problems), focus (on teacher vs. student), and treatment of students (as audience vs. participants). This model can be used for the classification of the different curriculum designs currently either considered or employed in most colleges and universities, as briefly outlined in the following.

A *research-led* curriculum design follows a teacher-focused model that is based on traditional knowledge transmission with students as a more passive audience featuring an emphasis on research content rather than methods and research processes. The *research-oriented* curriculum represents another teacher-focused model with students as audience, though with an emphasis on research methods and processes, thus facilitating learning and understanding of both knowledge and the methods and techniques that produce and advance knowledge. In this context, teaching also considers skills relating to scientific inquiry and research experience per se. *Research-tutored* curricula feature a strong emphasis on both research content and active student participation in the learning process through tutorials, i.e. small group classes where subject matter related to student essays and papers is discussed collaboratively. Note that this particular curriculum design is peculiar to the Oxbridge tutorial system (cf. [8]). A *research-based* curriculum design is largely oriented on inquiry-based learning with a focus on students, who, in the ideal case, literally act as participating junior researchers, thus minimizing or even eliminating the classical division of roles between teacher and student. In this model, the research skills and experience of teachers can best be integrated into the processes of teaching and learning with a high potential for benefit for both teacher and students. And finally, from the viewpoint of the scholarship of teaching (cf. [9]), if teachers are actively involved in researching not only their own domain, but also pedagogical issues relating to inquiry into teaching methods and the learning process itself, their curricula are identified in [7] as *research-informed*. Within this curriculum model, ideally the design and contents of each curriculum will be regularly updated as new results of either a pedagogical or a domain specific nature become available.

Two different models are proposed in [10]. One describes the current practice in many institutions of higher education, while the other is considered a much better alternative, and is aimed at fostering synergy between teaching and research. The latter, though only gradually beginning to take shape in tertiary education, is based on the concept of research and the teaching process from the viewpoint of academics. Within the former model, teaching is regarded a mere transmission of mostly propositional knowledge, which in turn is generated and advanced using resources that actually in part compete with their counterparts in teaching, and thus rather decrease the chances of any synergy. Within the latter model, teaching is a student-focused process aimed at the development of sophisticated levels of intellect and skills within students who are destined to become members of academic communities of practice where knowledge is advanced in a socio-political context.

Yet another alternative model used to build a framework for analyzing the teaching-research nexus is described in [11]. This model employs a three-level nexus consisting of the *tangible*, the *intangible*, and the *global nexus* relating to knowledge acquisition through research. It examines the attitudes of students towards knowledge while also considering the academic milieu, and departmental influences on undergraduate education through research agenda and policies. Additional views and experiences relating to issues within teaching and research in the context of higher education for the 21st century can be found, for example, in [12,13].

3 SUSTAINABILITY SCIENCE ON THE RISE

3.1 Early developments

Over the past two decades, the concept of sustainability has become increasingly important both locally and globally, and has influenced the decision making and activities of all communities and of humanity as a whole as it works towards a future which offers increased harmony between human activities and the systems of the biosphere. It was during the early 1980s that the term *sustainable development* first came into use. It gradually began to replace earlier concepts within what had been known in the 1970s as the philosophy of *ecodevelopment*. The latter had featured a heavy focus on scientific principles rather than practical and political applicability, and thus had limited its potential to gain a more widespread acceptance. An important milestone for the role of sustainable development came in 1987, when the term was adopted in the UN-initiated Brundtland Report entitled *Our Common Future*. This crucial step prompted the elevation of sustainable development into a guiding principle during the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, when 180 nations signed a protocol named *Agenda 21* that encompasses it. A little more than a decade ago, the emergence of a new type of science and engineering then begun to be discussed explicitly, both in national academies and at international conferences (cf. [14,15]).

3.2 Efforts at establishment

About a decade ago, recommendations and policies such as those of the National Research Council of the United States of America and the International Council for Scientific Unions [16,17] began to address central issues related to sustainability science, such as the complex and dynamic interactions between nature and society that are reflected in the problems addressed by research and development priorities. International efforts to establish and advance sustainability science and engineering in different forms and places display in many cases a rather ad hoc approach resulting in different directions and approaches. For example, in Asia, most prominently in Japan, a technology-based approach is prevalent, with more human aspects being integrated into the approach only recently. In the United States of America, by contrast, interdisciplinary research on complex human-environment systems is favored. On the other hand, approaches in Europe are more transdisciplinary and implementation oriented, with a strong tendency to move towards participatory and iterative processes. Along with those efforts, small communities have developed which are actively pursuing sustainability science and engineering, though these are often oriented towards specific topics relating to the environment, economy or technology. To overcome the barriers of isolation often faced by those communities, sustainability science networks began to develop, in the form of alliances, science partnerships and forums such as the *Network for Transdisciplinary Research*, the *Resilience Alliance*, and the *Science and Innovation for Sustainability Development Forum*. Along with the formation of these networks and organizations, in academia there came the foundation of international journals such as *Sustainable Development*, *Sustainability Science*, and *Current Opinion in Environmental Sustainability*, while efforts in integrative scholarship produced the first books in this new field (for more details and references see the latest discussions, for example in [18,19]).

In higher education, issues of sustainability were initially introduced through aspects of green engineering, a discipline that actually spans all of the traditional engineering specialties, combining natural science, engineering practice, and technology, with environmentally conscious values and principles. However, green engineering does not usually include societal issues and the opinions of all stakeholders involved within its basic concepts and approaches. Later, these efforts were extended according to the nine principles of sustainability engineering, which unfortunately were overdue and were developed only belatedly at the Sandestin conference in 2003 (cf. [20]). Recently, new undergraduate and graduate curricula in many industrial nations all over the world have been dedicated directly to the concepts and principles of sustainability science and engineering. Some universities have even established whole departments or even institutes dedicated to sustainability. These developments have been motivated and reinforced by many national professional engineering accreditation bodies, which demand from engineering programs at institutions of higher education the production of new student generations with an understanding of the basic skills and know-how related to concepts of sustainability as well as sustainable technology and development. For a more detailed overview with concrete examples and further literature references, the interested reader is referred to [21,22,23].

4 DEVELOPMENTS AND NEW DEMANDS

Early efforts to include green engineering, and later sustainability science and engineering, in the traditional education of science and engineering at institutions of higher education were mostly carried out without the benefit of any systematic guidance such as concrete principles that could be used to design appropriate curriculum models, letting alone having models to analyze and assess their efficiency or even to identify any synergy between research and teaching in higher education. Definitions of green engineering and sustainability science do not actually provide any substantial support in this matter. Another problem is that curriculum design is still not taking full advantage of many results in pedagogic research on higher education. The integration of all types of scholarship, as presented in [9], is still far from becoming reality in academia. And to make matters worse, recently introduced research assessment systems, such as the research assessment exercise (RAE) in the United Kingdom, actually increase the difficulties in adapting and improving curriculum design to meet current demands and the essential requirement of higher education for a broader mass in a society where knowledge is growing rapidly and changing constantly. This is due to the inappropriate way of measuring research with a focus on a particular type of knowledge generation. In addition, one should not neglect the fact that, along with all these trends, the student profile has also changed. Today's new generations of students are more industrious and expect their higher education, which tends to become ever more expensive, to facilitate the acquisition of skills and know-how that will enable them after graduation to get the job done in practice at work.

4.1 Efforts in curriculum design

With the introduction and development of sustainability science and engineering, and new modes and approaches regarding research and knowledge advancement, major shifts related to focus, context, content and processes are undeniable. The focus has shifted from pursuing curiosity in phenomena of the physical world to solving problems in the real-life world. Along with this shift in focus, the context of research has shifted from disciplinary to multidisciplinary. These shifts in turn induce shifts in the content of research and its related processes. Within such a scenario, a re-conceptualization of education is indispensable for the future analysis and advancement of synergy between research and teaching in higher education. In particular, an adjustment of current curriculum models is necessary for analyzing the research-teaching nexus that has been developed within the focus and context of disciplinary research and education.

Now, as a first step towards determining the direction and nature of such an adjustment, it seems to be an elegant, promising and straightforward approach to take a closer look at the individual concepts and components used to define and classify the curriculum designs discussed earlier. In this way, we may be able to locate and analyze a possible synergy between research and teaching and relate it to an extension of the horizontal curriculum model defining main domains, namely research content and research processes, as discussed in the scenario above. In particular, within the former, disciplinary depth needs to be regarded as intertwined with the principles of sustainability science and engineering, and we must also take into consideration the knowledge, principles and methods of different disciplines that come along with multidisciplinary breadth. The structure of the latter is extended according to the overall nature of processes and problems within sustainability science and engineering, namely interdisciplinarity and transdisciplinarity. This requires us to include the acquisition of skills and know-how related to interdisciplinary integration and the development of transdisciplinary competencies.

Within such extended model dimensions and context, curriculum designs that emphasize research content, such as the research-led curriculum design, need to consider, besides their disciplinary subjects, additional subjects related to the principles of sustainability science and engineering such as life cycle assessment and systems approaches. Of course, modifications in disciplinary depth, multidisciplinary breath, and the resulting total content volume need to be carefully tuned regarding time constraints relating to the overall length of current undergraduate and graduate education. Curriculum designs that emphasize research processes and problem solving require even more complex rethinking and restructuring. For example, research-oriented curriculum design needs to take into account the same considerations as research-led curriculum design. However, additional skills related to interdisciplinary approaches and integration also need to be considered. These include being able to locate and work with pertinent information, identify and compare different approaches and methods, and develop a holistic understanding of a complex problem within an integrative framework. For research-oriented curriculum designs where processes of inquiry and problem solving are highly integrated into the student learning activity, additional skills, know-how, and competencies are required, relating to both interdisciplinary and transdisciplinary research and education. Since the nature of problems usually designates the methods and tools employed to solve them, this approach stands quite in contrast to curiosity-driven and traditional discipline-based inquiry [24]. In particular, as identified and pointed out in [25,26,27], various skills need to be taken into account. These include the ability to analyze complex problems from real life, hermeneutical abilities to interpret correctly not only readings on scientific instruments but also the meanings of identical terms used differently in individual disciplines, knowing how to participate in projects with interdisciplinary and/or transdisciplinary structures, knowing how to connect to various internal and external stakeholders, and knowing how to communicate across academic disciplines. These skills can be seen as an extension of student skills relating to working together in teams, communications, and presentations, commonly regarded as generic graduate skills [28] within a traditional disciplinary context.

4.2 Open issues related to curriculum design

In the following, some additional issues related to the discussion in the previous sub-section, and considered important, are examined briefly. To foster a critical attitude towards knowledge as part of the scientific disposition in students (cf. intangible nexus in [11]), courses on philosophical aspects of the discipline should be included along with domain-specific lectures. However, in the case of sustainability science, this approach is of limited use since a philosophy of sustainability has not been established yet. The only choice is to consider suitable topics within the philosophy of science and the philosophy of technology as interim substitutes. Another quite important issue, though still widely neglected, is the loss of valuable insight, experience and know-how gained during sustainability research. During the problem-solving process in a research project, a multidisciplinary team usually works together on an interdisciplinary / transdisciplinary basis. However, after project completion, each project member leaves and moves on to a new task in a different project. Within this context, for example by employing a research-based or at least a research-oriented curriculum, valuable synergy between research and teaching could be created by trying to pass on to students this valuable gained insight, experience and know-how, that is otherwise lost. At this point, to minimize the loss, it is recommended that we should at least implement measures and support for documenting the essentials of such insight and experience in the form of textbooks that can be used in courses to support the building of capacities and competencies in future generations of students. Related to this issue, in sustainability science and engineering in general, the scholarship of integration (cf. [9]), which includes the writing of textbooks, still lags far behind other disciplines. There are few good textbooks currently available. Moreover, advances in knowledge and innovations made during the course of problem solving within a research project need to be well integrated into both the disciplinary context to which they belong and the larger pattern of science, technology and society.

5 SUMMARY

After briefly outlining the nature and goals of sustainability science while taking a whirlwind tour through its short history of development, the author hopes to have made it clear that, among several dominant themes, two central issues gave rise to related research concepts and approaches, such as interdisciplinarity and transdisciplinarity. These two central issues are the linking and dialogue between knowledge and content on the one hand and process and activity on the other, along with mutual learning by all stakeholders, while considering new demands regarding the tertiary education, skill acquisition, and competency building of science and engineering students. The resulting interdisciplinarity and transdisciplinarity have been applied in sustainability research to the concepts and models of traditional domain-based curriculum design, and developed in order to identify and analyze relationships and synergies between research and teaching in higher education. The given approach will hopefully stimulate those involved in education and proliferate in further research in this direction on a multidisciplinary level. We need to employ the most suitable conceptual and theoretical components, skills and know-how from within sustainability science and pedagogic research in higher education to provide a constructive impetus to nurture the next generation of scholars, experts and practitioners to advance, as well translate into practice, sustainability research and teaching.

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The Teaching-Research Nexus in the Rise of Sustainability Science: Infrastructure and Way of Conduct

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Abstract
Economic trends and the nature of current economic and educational policies in most advanced industrial nations, and in the transnational organizations which they support, are signaling a transition from a mass production economy to a knowledge economy and towards sustainability. As a result, society worldwide is facing challenges and pressure to move towards increased knowledge generation and technological innovation as a means of economic activity, which will also support sustainable development. Within this scenario demands on higher education to provide appropriate education and lifelong learning pose a tremendous challenge that is further complicated by the obvious contradiction between the intellectual viewpoint and the economic viewpoint regarding the nature of a true knowledge society. In this second part of a two part paper, several issues are taken up from within this context by focusing on the synergy between post-modern research as a form of problem-solving oriented knowledge generation and the development of new forms of teaching aimed at fostering active learning with a student focus.

Keywords:
sustainability science, knowledge society, teaching-research synergy, higher education

1 INTRODUCTION

The latest stage of development in global economic restructuring is a move from post-industrial mass production to the emerging knowledge economy. This has brought a globally competitive need for innovation in new products and processes developed by the research community, whether it be a research and development department at a commercial enterprise or an institute in a university. The need to get human activities in balance with the biosphere is becoming as pressing as the need for producing a specialized labor force which is computer literate, sustainability literate and well trained in handling data uncertainty and complex information and relationships, as well as in developing digital models, respecting different opinions, and innovating on processes and systems in respect to sustainability.

Taking these developments one step further, it seems that at some stage in the post-modern society of an advanced industrial nation everybody will become some kind of sustainability-oriented knowledge worker. This means that in turn many organizations will need to become sustainability-oriented knowledge institutions, with knowledge itself then being not merely diffused by traditional knowledge-producing institutions such as universities, but rather suffused throughout the entire society. Since knowledge in itself is reduced in value if kept contained, only its wide distribution can provide for an increase in value. Within such a scenario many challenges arise regarding the role of traditional institutions accepted as authorities in the fields of both knowledge production and knowledge dissemination, as all institutions of higher education are assumed to be, and the role of the professional knowledge producer and knowledge forwarder and distributor. The nature of the latter is becoming fuzzier with the advent of new curriculum models and information technology-based educational support and management tools (see also discussions in [1,2,3,4]). At the same time, with a demand for new teaching strategies fostering a student-focused active learning mode with an emphasis on scientific inquiry, research processes and problem-solving (cf. [5,6]), the traditional well-defined boundaries between teaching and research are gradually diminishing.

Let us combine the central implications of this development with the developments in research, which are continually widening both the concept and the practice of research from the modern highly empiricism-influenced process of scientific inquiry to an interdisciplinary problem-solving process of generating knowledge in the form of solutions accountable to field specific, socio-economic and ecological domains, and taking into account uncertainty while also considering the interests of a variety of stakeholders. Then, more than ever before, we find that research and teaching now feature overlapping elements. This situation makes efforts to facilitate and foster the research-teaching nexus not only promising in many directions, but literally an appealing must. Unfortunately, as current practice shows, this potential is recognized by only a few, and in general not well understood. This is particularly evident if one takes a

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deeper look at the current policies of advanced industrial nations, and the transnational organizations which they support, regarding their approach to and conduct of higher education and their evaluation and rewarding of research and teaching within it.

This is the second part of a two part paper structured as follows. In section 2 some background is given along with related work on issues concerning the emergence of the knowledge economy and factors concomitant to the development of knowledge and sustainability in the societies of advanced industrial nations. In section 3 issues related to higher education are dealt with in the context of sustainability science, with particular emphasis on information and communication technology (ICT) as infrastructure and on how the research-teaching nexus is regarded from the viewpoint of emerging knowledge economies. Lastly, some conclusions are drawn in the last section.

2 POST-MODERN ECONOMY AND SOCIETY

The second and, more so, the third industrial revolution facilitated the rise of powerful economic societies based on an unprecedented, ever increasing consumption of all forms of energy. This was made possible by technological innovation, which eventually provided an energy form that is clean and can be made available efficiently and cheaply to consumers at any time and almost anywhere (cf. [7]). Now electricity, as one driving power of modern information technology, together with information per se, brought about newly emerging forms of society and of economies, all struggling worldwide to cope with the problems of their generation: storage, distribution and protection of energy and information.

The developments of the past three decades causing global economic and technological changes in advanced industrial economies have been conceptualized and described as the emergence of knowledge/information societies and their respective knowledge/knowledge-based economies [8,9,10]. Due to the difficulty of defining the term knowledge itself, the above terms are unfortunately still used interchangeably in the current literature. However, some basic distinctions can be made. For example, within a knowledge economy, knowledge itself becomes a property in the form of an economic good, whereas in a knowledge-based economy knowledge is merely treated as a tool. Moreover, since information is not identical to knowledge, perhaps the term information society should not be equated with the term knowledge society. The term *knowledge economy* was popularized in the late 1960s by Peter Drucker in reference to the application of knowledge to spur economic development (cf. [11], p. 263). This conforms with most contemporary views that knowledge is about to become the most important production factor in advanced industrial economies, replacing the traditional factors of land, labor and capital. According to some studies (for example, see [12]), it is assumed that in the foreseeable future knowledge-based industries and organizations might be in a position to provide over half of total employment while generating more than 50% of total gross domestic product (GDP). From a conceptual viewpoint this implies that, besides knowledge, also the higher education of knowledge workforces is becoming a kind of human capital that is seen as a new type of productive asset, which can be employed as or turned into an economic good seeking a high value return for the provision of services.

Within this scenario, as rightly argued in [9], information technology provides the technological basis for a knowledge economy. However, as the infrastructure technology that it has now become, it is also increasingly becoming the technological basis for research in almost any scientific and engineering discipline, thus being intertwined with the processes of knowledge generation and dissemination. It even transcends the role of a mere technological base when it is combined with vast amounts of information and know-how in order to facilitate new ways of knowledge generation that had never even been imagined not so long ago (cf. [13]).

3 UNFALTERING TRENDS AT CROSSROADS

Knowledge economies are on the rise and with them come the concomitant trends outlined earlier. Current public opinion holds that all individuals and societies have to adjust to this new global reality, and the concept and need for lifelong learning as one means to secure it are strongly promoted by most governments, professional associations, and transnational organizations. This in turn is leading to an ever increasing student population expanding in both heterogeneity and size, facing a still small and quite traditional and somewhat homogeneous faculty population. Such a situation has been unprecedented in higher education for centuries and is putting further demands and concerns on how higher education is approached and planned, which methods and tools should be used, and how research, teaching and learning should be conducted and related to each other. Besides age, social and educational background, and work experience, the most significant difference in the current student population is the way they approach technology, in particular ICT, a phenomenon referred to in the literature as the *digital divide*. The younger student generation born within the last two decades, sometimes referred to as the *Millennials*, has had the opportunity of growing up with the technology which is now found almost everywhere in our lives, a situation very different from that of older generations. These *Millennials* are said to be the student generation, which is composed of *digital natives* (see [14]). Being a digital native, however, does not automatically imply that a person has any knowledge of computational thinking or true computer literacy, or possesses any know-how regarding methods of data intensive knowledge generation. As several studies suggest, being a digital native, at least for the current generation of younger students, means that certain communication and interaction habits and patterns have developed, while related attitudes, methods, and means of operation have changed (see also discussions in [15,16,17]).

3.1 ICT as infrastructure

Besides physical structures, infrastructure includes organizational structures and the facilities required for the operation of a society or organization within a given context. Due to its ubiquity and dominance, in the following the main focus will be on information and communication technology. In this situation, the traditional approach of one size fits all regarding curriculum designs does not apply any more. If one is to facilitate and foster synergy between research and teaching, one of the challenges is now to analyze and relate the actual research, experience and competency of the faculty to the expectations, background and experience of the growing heterogeneous student population. At the same time, one must put the latter into perspective in relation to the requirements of higher education, as a means of forming responsible, well-educated citizens who in turn will reinvigorate, correct and improve this cycle for the good of future generations.

New generations of curriculum designs, aimed at enabling and benefiting from the research-teaching nexus, also need to be refined in regard to the potential of the paradigms, methods and technology used in current research, in particular ICT and data intensive knowledge generation, which increasingly influence research in most science and engineering disciplines. For example, one may consider a real small piece of contemporary research for a particular curriculum within a research-based curriculum model (cf. [18,19]) relating to sustainability science and engineering and aimed at including as many aspects and dimensions as possible, as discussed in part one of this paper [20]. Insofar as the domain knowledge, expertise and competencies of the faculty and research teams involved go, inquiry and problem-solving attempts from the real world must form a part of what faculty and research teams know and do. Otherwise this endeavor becomes reduced to a formal exercise with predetermined results which have already been produced many times by previous student generations. Due to the problem complexity, the high dynamics of changing parameters and states, the variety of stakeholders, fluctuating data, varying uncertainty in information, developments in technology, etc., the nature and demands of problem-solving within sustainability science and engineering can hardly be captured by a student-focused research-based teaching approach except when it is placed on an authentic base. Another very important issue that needs to be made explicit here is the fact that, when the nature and structure of a selected problem are determined, not only is part of the context of discourse selected, but also a tentative scope regarding the tools, data, domain knowledge, skills, etc. is defined. Again this can be done efficiently and competently only in regard to real research, experience, and the competency of the faculty. Perhaps in other forms of curriculum design such as the research-led model [18,19], where the emphasis is more on research content, with the student audience more or less passive, the research considered can be either the faculty's own research or research with which the faculty is very familiar but which was carried out by others and which is used in reference material, such as a well-documented case study.

Even if no concrete solution can be produced to a particular course assignment, because the problem was too complex and difficult, or because there was not enough time, or because the students' knowledge, skills and competencies were wrongly estimated, or for any other reason, still the journey to that point, i.e. the learning and evolving as both an individual and a group within the environment of a community of mutual learners and guiding scholars, will have been as important as, perhaps even more important than, reaching the destination, i.e. actually producing a genuine contribution to the advancement of knowledge. Of course, in this context, concepts such as progress, success and failure and their proper interpretation/evaluation need to be carefully reconsidered. For example, does failure refer to a situation where an individual or a group gave up somewhere in the middle of the journey, and thus did not reach the destination, or, in the worst case, does it mean that they did not even take the first step with which any journey, no matter how long, begins?

Within such a scenario, ICT infrastructure provides tremendous potential for support. For example, many aspects of real faculty research can be made available to students for active learning during a course at a level of presentation, completeness, integration and access mode unprecedented before. Results documented in reports or scholarly publications could be viewed simultaneously with their data, while either basic charts or sophisticated interactive data visualization displays could be chosen as the data representation mode. Such visualization displays even offer the means to facilitate hands-on experience, suitably monitored by the faculty, in partial interactive manipulation of data in order to trace and reproduce how certain theories have been verified and how new results and insights have been discovered based on those data. Access to data repositories or software tools that were used to obtain such data in the first place could also made available online in a limited form for educational purposes through, for example, a dedicated portal. Contact with the faculty and with classmates using ICT and its infrastructure also offers great potential for fostering additional curricular communication and greatly assisting in reducing the time required for feedback by removing many of the difficulties of traditional interpersonal interaction by defying the limits of time and space, thus making physical location and presence less relevant to communication. However, as it is with many technology-mediated activities, we must not have unrealistic expectations of the newly opened possibilities, nor should we abuse them. Today's ICT infrastructure can offer information access on an almost ubiquitous 24-7 base, supporting on-demand service and information for user-driven access, referred to in [21,22] as *demand pull*. These features have already become a matter of course in our emerging network societies, and particularly so for the digital native student generation. In the given context, this means that an ever-increasing amount of information is available in digital form at any time and in any place. Access to and retrieval of information is now less of a problem or concern, but evaluation of its value, quality and authenticity certainly is a problem. As a matter of fact, most of the knowledge most individuals possess is not personally verified. The most common way to accept newly acquired information as truth or particular type of knowledge is to have verified the source, or simply to trust the source due to its competency in this matter or its authority. This is exactly where institutions of higher education, faculties, and higher education per se come in. In our technology-mediated world of information deluge, information and knowledge generated from within and provided by them comes from a source where scholarship, experience in inquiry, research and teaching, and competency have been developed and refined uninterrupted for a long period of time. For centuries, institutions of higher education have been respected authorities in the advancement and dissemination of knowledge and they still are so.

An increasing number of online courses offered by many institutions of higher education worldwide already seem to exploit some of the abovementioned features, while relating to certain patterns in service expectancy and interaction habits of the current student population. However, more research is required regarding the design of those online courses in order to find ways to include the value of research and faculty experience on one hand and of student experience and learning progress on the other, so that we can facilitate and foster the generation of synergy, while improving the effectiveness and quality of distance learning per se. All this can be used and translated into practice within higher education for the benefit of all, both for current society and for future generations yet to come. However, certain rules regarding approach and method of conduct need to be taken into account. These relate to respect, responsibility, accountability, scholarship and the cultivation of active mutual learning within dedicated communities and will help to avoid issues such as those discussed in the following sub-section. If such rules are not taken seriously, they may actually destroy the possibilities and potential offered to us by the modern advances in technology.

3.2 Knowledge and the concept of property

Current practice in higher education tends increasingly to adopt the business view that education and knowledge are some sort of commodity with students as customers. This is especially so in newly established institutions of higher education, and the trend, which challenges the traditional concept of learning per se, actually has an inhibiting effect on the research-teaching nexus. If the notion of knowledge and ideas as property is taken seriously, one also has to face the matter of copyright law, the primary purpose of which is to protect an author's intellectual property and ideas. What is mostly overlooked is the fact that copyright law was originally enacted to balance the limited property rights of authors with the long-term rights of the public to promote learning through the spread of ideas. However, due to a continued movement of copyright law towards increased protection for an author's intellectual property without any additional benefit for the public, the original intention of promoting access and learning is gradually becoming lost. And along with this trend, unfortunately, the nature and understanding of what ideas and knowledge are, is also shifting, which negatively impacts the advancement of both learning and knowledge. Coming back to the context of the research-teaching nexus, for particular student-focused curricular designs such as the research-based curriculum, there is ideally and theoretically a high potential for benefit for both teacher and students. In these designs, the students literally act as participating junior researchers, thus minimizing or even eliminating the classical division of roles between teacher and student, while actively participating in a sort of guided and limited generation of new knowledge. The domain knowledge, research skills and experience of teachers can best be integrated into the processes of teaching and learning, facilitating not only the transfer of propositional knowledge but also ways of developing competencies, know-how and problem-solving skills that later partially translate into what is sometimes referred to as *tacit knowledge* [23].

However, various problems arise with the current view of knowledge and education as commodities. First, the student is becoming a co-producer, contributing to the generation of economic goods, thus reinventing the role of learner in higher education (cf. [24]). In this new context, the current copyright law, which actually protects every manuscript, note, presentation and e-mail, obviously limits any creative work and collaboration, thus greatly reducing or even preventing any synergy between research and teaching. Actual cases reported in [22] cite student inquiries about copyright ownership for work developed in collaboration with their supervisors and teachers. That, in turn, prompts faculty members to fear that they might lose control or even ownership of their intellectual property. Students are asking their professors to sign non-disclosure forms before submitting their class projects, due to concerns that some of the content of their work, ideas and knowledge now seen as their own property, might be stolen by their teachers for their own research, or patented afterwards without their consent. In other words, the generation of new knowledge is now seen as a form of economic production, and this is further evidence of a worrisome trend. However, there are some positive developments, such as the *Creative Commons* (see http://creativecommons.org), which aims at providing mechanisms to adjust the current copyright law towards a notion of "some rights reserved". This provides a means for sharing, i.e. allowing non-profit use of work by others, while reserving for-profit use to the author, thus creating a balance that ought to work for both views, the traditional academic view of free thought and knowledge advancement through inquiry, sharing and discussion of ideas and theories, and the emerging knowledge economy which sees knowledge as an economic good.

Another concept arriving with this view of knowledge commoditization is that of a *shelf life* for knowledge. For conventional economic commodities, the shelf life defines the length of time for which an item remains usable or fit for consumption or sale. Now in principle these measures can also be applied to a certain extent to knowledge, the newly emerging economic good. Taking a closer look at the current trend and at literature dedicated to this development, we find that the rise of network societies, along with ever faster developing ICT, clearly signals that higher education and its institutions are no longer in the traditionally exclusive position of providers and portals of declarative or propositional knowledge. That is to say that they are no longer simply able to disseminate information generated within their own walls or accumulated and advanced or forwarded by others. This they have been accustomed to do through scholarly publications or by employing the models of teacher-focused curricula with students mostly acting as a passive audience. This change is due to several factors, with rapidly developing technology certainly being one of the most influential, further increasing the speed of knowledge generation on one hand, while rendering what we know outdated almost as quickly. On the other hand, an increase in online learning, in order to reduce costs (cf. [25]), and the shortsighted and biased funding for higher education which is now common practice in all industrialized nations worldwide seem to work against efforts to facilitate active learning in richer and more sophisticated environments and against curriculum designs that actually value and promote skill acquisition, the development of competency, and the understanding of the methodology of learning as well as the content of what is learned.

4 CONCLUSION

It is becoming evident that changes stemming from demands on higher education are influenced most by policies paying tribute to the emerging knowledge economy in advanced industrial nations. It seems that disintegration rather than integration of scholarship is now the norm at institutions of higher education. This is evidenced by the way in which, for example, research, teaching and dissemination of knowledge in the form of scholarly publications are separately evaluated and rewarded. Such a development is actually counterproductive to the epistemic and intellectual nature of a true sustainable knowledge society.

On the other hand, because of the fundamentally changing way in which research is carried out with the support of information technology as both an infrastructure technology and a means for the provision and analysis of data and information in quantities and quality never seen before in science and engineering in the history of mankind, actually many of the tools are becoming more like those used in research. This is also true of infrastructure technology, and the nature of some elements and activities within the scholarship of teaching. At the same time, some of their counterparts in research are becoming more like those in teaching. In other words, teaching and active learning in higher education are about to become more like post-modern research. Thus the potential and possibilities for synergies between research and teaching are also becoming greater in quantity and stronger. One approach to this might be to find ways of improving integrated scholarship in concrete cases, based on the idea of fostering the research-teaching nexus, trying to identify the apparently increasing number of common elements, and analyzing their nature and contribution in respect to the four dimensions as outlined. This approach, of course, will show its strength only if translated into practice and put to the test.

Taking up again the metaphor of traveling used earlier in this paper, if we consider the current state of the art in pedagogical research, post-modern knowledge generation, and information and communication technology, the potential for higher education to provide means to let our minds reach for places they have never been before is tremendous and fascinating. However, this potential and the current developments in our society should not be misunderstood, or even perhaps misused, so that we confuse or gradually replace higher education with a kind of higher apprenticeship as in vocational training. Vocational training actually has different goals and concepts operating under different aspirations, where the acquisition of basic domain knowledge and skills is usually traded in exchange for early, mostly underpaid or even unpaid, participation in the production of economic services and goods. As pointed out, great potential and fascinating possibilities exist despite the many current challenges we face and the worrisome trends we see rising and gaining momentum at different levels and in different directions. But there are also many options still available to us. The choice is within the responsibilities of each individual, though in the end the journey on the long and difficult road to a truly sustainable knowledge society with green infrastructures and technologies is a collective one.

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Environmental Policy and Environmental Change in a Three-Sector Growth Model

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Abstract
This paper proposes a three-sector economic growth model with physical capital accumulation and environmental change on the basis of the neoclassical growth theory with an alternative approach to household behavior. The model synthesizes Uzawa's two-sector economic growth model and the environmental change in some traditional dynamic models of environmental economics. Both labor and capital distributions among the three sectors are determined by market mechanisms under the government intervention. We simulate the model to demonstrate existence of equilibrium points and motion of the dynamic system. In particular, we demonstrate effects of changes in the government policy and preference upon both short-run and long-run economic behavior of the system. The simulation demonstrates that the dynamics shows the same pattern of economic growth as predicted by the Solow model and exhibits the same relation between the income and environmental change as depicted by the environmental Kuznets curve.

Keywords:
the environmental Kuznets curve, tax, capital accumulation, environmental change, labor distribution

1 INTRODUCTION

The purpose of this study is to examine interactions between environmental change and economic growth. In recent years environmental issues have received more attention than ever. Global warming threatens living conditions of mankind and local environmental catastrophes are daily reported in TVs. It is challenging for economists to explain economic mechanisms and consequences of environmental changes. Environmental issues have increasingly caused attention in the literature of economic growth and development [1, 2, 3]. As mentioned in [4], one can find three effects that are important in explaining the level of environmental pollution and resource use. The three effects are: (i) increases in output tends to require more inputs and produce more emissions; (ii) changes in income or preferences may lead to policy changes which will affect production and thus emission; and (iii) as income increases, the economic structure may be changed which will causes changes in the environment [5]. It is argued that the net effect of these effects tends to result in the environmental Kuznets curve. It is well known that Kuznets [6] postulated that economic growth and income inequalities follow an inverted U-curve. The environmental Kuznets curve refers to the same relation between environmental quality and per capita income. Nevertheless, a large number of empirical studies on the environmental Kuznets curve for various pollutants find different relations - for instance, inverted U-shaped relationship, a U-shaped relationship, a monotonically increasing or monotonically decreasing relationship - between pollution and rising per capita income levels [4].

Economic growth often worsens environmental conditions. On the other hand, as a society accumulates more capital, more resources may be used to protect environment. Issues related to interdependence between economic growth and environment have been examined from different perspectives. This paper is concentrated on tradeoffs between economic growth, consumption, and pollution. This study attempts to make a contribution to the literature by examining interdependence between savings and dynamics of environment with an alternative approach to consumers' behavior. It is an extension of the growth model with environment proposed by Zhang [7]. The paper is organized as follows. Section 2 introduces the basic model with wealth accumulation and environmental dynamics. Section 3 examines dynamic properties of the model and simulates the model, identifying the existence of a unique equilibrium and checking the stability conditions. Section 4 studies effects of changes in some parameters on the system. Section 5 concludes the study. The appendix proves the analytical results in Section 3.

2 THE BASIC MODEL

This paper reexamines dynamics of the two-sector economic model proposed by Uzawa [8], by adding the environment and environmental sector to the model. The economy has two production sectors and one environmental sector. The Uzawa model extends the Solow model by a breakdown of the productive system into two sectors using capital and labor, one of which produces capital goods, the other consumption goods. Households own capital of the economy and distribute their incomes to consume the commodity and to save.

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Exchanges take place in perfectly competitive markets. We assume a homogenous and fixed population. The labor force is distributed among the three sectors under perfect completion in labor market. We select commodity to serve as numeraire (whose price is normalized to 1), with all the other prices being measured relative to its price.

In the literature of environmental economics, pollution may affect productivity through the channel that pollution directly affects production technology or the productivity of any input. Let subscript index, i and s, stand for capital goods and services respectively. We assume that production is to combine labor force, $N_j(t)$, and physical capital, $K_j(t)$. We add environmental impact to the conventional production function. The production functions are specified as follows

$$F_j(t) = A_j \Gamma_j(E) K_j^{\alpha_j}(t) N_j^{\beta_j}(t), \quad A_j, \alpha_j, \beta_j > 0,$$
$$\alpha_j + \beta_j = 1, \quad j = i, s, \tag{1}$$

where $F_j(t)$ is the output level of sector j at time t, $\Gamma_j(E)$ is a function of the environmental quality measured by the level of pollution, $E(t)$, and A_j, α_j and β_j are parameters. It is reasonable to assume that productivity is negatively related to the pollution level, i.e., $\Gamma_j(E) \le 0$.

Markets are competitive; thus labor and capital earn their marginal products. The rate of interest, $r(t)$, and wage rate, $w(t)$, are determined by markets. The marginal conditions are given by

$$r(t) + \delta_k = \frac{\alpha_j (1 - \tau_i) F_i(t)}{K_i(t)}, \quad w(t) = \frac{\beta_i (1 - \tau_i) F_i(t)}{N_i(t)},$$
$$w(t) = \frac{\beta_s (1 - \tau_s) p(t) F_s(t)}{N_s(t)},$$
$$r(t) + \delta_k = \frac{\alpha_s (1 - \tau_s) p(t) F_s(t)}{K_s(t)}, \tag{2}$$

where δ_k is the given depreciation rate of physical capital and τ_j is the fixed tax rate on sector j, $0 < \tau_j < 1$, $j = i, s$.

Consumers make decisions on choice of consumption levels as well as on how much to save. We apply an alternative approach to preference structure of consumers over consumption and saving. We denote per capita wealth by $k(t)$, where $k(t) \equiv K(t)/N$. Per capita current income from the interest payment $r(t)k(t)$ and the wage payment $w(t)$ are given by

$$y(t) = r(t)k(t) + w(t).$$

We call $y(t)$ the current income. The per capita disposable income is given by

$$\hat{y}(t) = y(t) + k(t). \tag{3}$$

The disposable income is used for saving and consumption. At each point of time, a consumer would distribute the total available budget between saving, $s(t)$, and consumption of services, $c(t)$. The budget constraint is given by

$$c(t) + s(t) = \hat{y}(t). \tag{4}$$

It should be noted that this study does not explicitly take account of consumers' awareness of environment. For instance, consumers may prefer to environment-friendly goods when their living conditions are changed. With regard to how much money the economic agent should spend on environmental improvement, As argued in [9], at a lower level of pollution, the representative agent does not care much about environment and spends his resource on consumption; however, as the environment becomes worse and income becomes higher, more capital will be used for environmental improvement. We may take account of changes in consumers' behavior, for instance, by assuming that the representative consumer spends a proportion of the disposable income on environment or the tax rate on the consumer's consumption is explicitly related to income and consumption level.

At each point of time, consumers have two variables, $s(t)$ and $c(t)$, to decide. We assume that consumers' utility function is a function of $s(t)$, $c(t)$, and $E(t)$, as follows: $U(t) = U(c(t), s(t), E(t))$. For simplicity of analysis, we specify the utility function as follows

$$U(t) = c^{\xi_0}(t) s^{\lambda_0}(t) E^{-\chi_0}(t), \quad \xi_0, \lambda_0, \chi_0 > 0,$$

where ξ_0 is called the propensity to consume and λ_0 the propensity to own wealth. A detailed explanation of the approach and its applications to different problems of economic dynamics are provided in [7]. It should be noted that in [10] and [11], it is assumed that utility depends negatively on pollution, which is a side product of the production process. As reviewed [12], "environmental economics has been slow to incorporate the full nature of the household into its analytical structures. … [A]n accurate understanding household behavior is vital for environmental economics." Our approach to household behavior is still over-simplified as, for instance, we analyze an economy with a single good and a single pollutant. We will deal with household behavior more realistically by, for instance, introducing multiple goods into the utility functions and each good has distinct features with regard o pollution (and may be subject to different environmental policies). We may also take account of family structure in the modeling. How to take account of different aspects of reality is illustrated in [7], even though it may be difficult to construct practically meaningful and analytically tractable models. Maximizing $U(t)$ subject to budget constraint (4) yields

$$c(t) = \xi \hat{y}(t), \quad s(t) = \lambda \hat{y}(t), \tag{5}$$

where

$$\xi \equiv \rho \xi_0, \ \lambda \equiv \rho \lambda_0, \ \rho \equiv \frac{1}{\xi_0 + \lambda_0}.$$

We now find dynamics of capital accumulation. According to the definition of $s(t)$, the change in the household's wealth is given by

$$\dot{k}(t) = s(t) - k(t). \quad (6)$$

The equation simply states that the change in wealth is equal to saving minus dissaving.

Demand and supply balances

The demand for services equals supply of services

$$c N = F_s(t). \quad (7)$$

Let N and $K(t)$ stand respectively for the (fixed) the population and total capital stock. The labor force is allocated between the three sectors. As full employment of labor and capital is assumed, we have

$$K_i(t) + K_s(t) + K_e(t) = K(t),$$
$$N_i(t) + N_s(t) + N_e(t) = N. \quad (8)$$

We now describe dynamics of the stock of pollutants, $E(t)$. We assume that pollutants are created both by production and consumption. We specify the dynamics of the stock of pollutants as follows

$$\dot{E}(t) = \theta_f F_i(t) + \theta_c C(t) - Q_e(t) - \theta_0 E(t), \quad (9)$$

in which q_f, q_c, and q_0 are positive parameters and

$$Q_e(t) = A_e \Gamma_e(E) K_e^{\alpha_e}(t) N_e^{\beta_e}(t), \ A_e, \alpha_e, \beta_e > 0, \quad (10)$$

where $N_e(t)$ and $K_e(t)$ are respectively the labor force and capital stocks employed by the environmental sector, A_e, α_e, and β_e are positive parameters, and $\Gamma_e(E)$ (≥ 0) is a function of E. The term $\theta_f F$ means that pollutants that are emitted during production processes are linearly positively proportional to the output level [13]. The parameter, θ_c, means that in consuming one unit of the good the quantity θ_c is left as waste [14]. The parameter θ_c depends on the technology and environmental sense of consumers. The parameter θ_0 is called the rate of natural purification. The term $\theta_0 E$ measures the rate that the nature purifies environment. The term, $K_e^{\alpha_e} N_e^{\beta_e}$, in Q_e means that the purification rate of environment is positively related to capital and labor inputs. The function, $\Gamma_e(E)$, implies that the purification efficiency is dependent on the stock of pollutants. It is not easy to generally specify how the purification efficiency is related to the scale of pollutants. For simplicity, we specify Γ_e as follows $\Gamma_e(E) = \theta_e E^{\upsilon}$, where $\theta_e > 0$ and $\upsilon > 0$ are parameters.

We now determine how the government determines the number of labor force and the level of capital employed for purifying pollution. We assume that all the tax incomes are spent on environment. The government's tax incomes consist of the tax incomes on the production sector, consumption, wage income and wealth income. Hence, the government's income is given by

$$Y_e(t) = \tau_i F_i(t) + \tau_s p(t) F_s(t). \quad (11)$$

Ono [15] introduces tax on the producer and uses the tax income for environmental improvement in the traditional neoclassical growth theory. For simplicity, we assume that the government's income is used up only for the environmental purpose. As there are only two input factors in the environmental sector, the government budget is given by

$$(r(t) + \delta_k) K_e(t) + w(t) N_e(t) = Y_e(t). \quad (12)$$

We need an economic mechanism to analyze how the government distributes the tax income. We assume that the government will employ the labor force and capital stocks for purifying environment in such a way that the purification rate achieves its maximum under the given budget constraint. The government's optimal problem is given by

$$\text{Max}\, Q_e(t) \quad \text{s.t.: } (r(t) + \delta_k) K_e(t) + w(t) N_e(t) = Y_e(t).$$

The optimal solution is given by

$$(r(t) + \delta_k) K_e(t) = \alpha Y_e(t), \ w(t) N_e(t) = \beta Y_e(t), \quad (13)$$

where

$$\alpha \equiv \frac{\alpha_e}{\alpha_e + \beta_e}, \ \beta \equiv \frac{\beta_e}{\alpha_e + \beta_e}.$$

We have thus built the dynamic model. We now examine dynamics of the model.

3 THE DYNAMICS AND ITS PROPERTIES

We now show that the dynamics of the economic system can be expressed by the two-dimensional differential equations system with $k_i(t)$ and $E(t)$ as the variables.

Lemma 1

The economy is governed by the following 2-dimensional differential equations

$$\dot{k}_i = \Lambda_{k_i}(k_i, E),$$
$$\dot{E} = \Lambda_e(k_i, E), \quad (14)$$

where the functions in (14) are only dependent on $k_i(t)$ and $E(t)$ which are given in the appendix. Moreover, all the other variables can be determined as functions of $k_i(t)$ and $E(t)$ at any point of time by the following procedure: k by (A11) $\rightarrow K = k N \rightarrow k_s$ and k_e by (A1) $\rightarrow N_i$, N_s and N_e by (A8) $\rightarrow$ $K_i = k_i N_i$, $K_s = k_s N_s$ and $K_e = k_e N_e$ by (A8) $\rightarrow r$, w and p by (A3) $\rightarrow F_i$ and F_s by (1) $\rightarrow$ Q_e by (10) $\rightarrow \hat{y}$ by (3) $\rightarrow c$ and s by (11).

As the expressions of the analytical results are tedious, it is difficult to explicitly interpret the results. For illustration we specify the parameter values and simulate the model. We specify the parameters as follows

$$\Gamma_i = E^{-b_i},\ \Gamma_s = E^{-b_s},\ \Gamma_e = E^{b_e},\ b_i = 0.1,\ b_s = 0.05,$$
$$b_e = 0.3,\ N_0 = 5,\ \alpha_i = 0.3,\ \alpha_s = 0.35,\ A_i = 1,\ A_s = 1.1,$$
$$\alpha_e = 0.5,\ \beta_e = 0.3,\ A_e = 0.5,\ \lambda_0 = 0.4,\ \xi_0 = 0.2,$$
$$\delta_k = 0.05,\ \tau_i = \tau_s = 0.05,\ \theta_f = 0.2,\ \theta_c = 0.25,\ \theta_0 = 0.05. \quad (15)$$

The population is fixed at 5. The propensity to save is much higher than the propensity to consume the commodity. Under (15), the dynamic system has a unique equilibrium point. The equilibrium values are given as in (16)

$$K = 7.58,\ E = 13.63,\ F_i = 1.19,\ F_s = 3.79,\ Q_e = 0.50,$$
$$N_i = 1.46, N_s = 3.39,\ N_e = 0.15,\ K_i = 1.76,\ K_s = 5.14,$$
$$K_e = 0.68,\ k_i = 1.21,\ k_s = 1.51,\ k_e = 4.69,\ f_i = 0.81,$$
$$f_s = 1.12,\ r = 0.14,\ w = 0.54,\ p = 0.79,\ k = 1.52,$$
$$c = 0.76. \quad (16)$$

The two eigenvalues are -0.25 and -0.07. This guarantees the stability of the steady state. Hence, the dynamic system has a unique stable steady state. We identified that the dynamic system has a unique stable equilibrium under (15). With the initial conditions, $k_i(0) = 1.4$ and $E(0) = 13.8$, we plot the motion of the system as in Figure 1. The length of the simulation period is 40, which is long enough for the system approach its unique equilibrium point. The national capital stock and capital stocks employed by the two sectors fall over time. The current income, the output level of the industrial sector, the wage rate and consumption level are all reduced. The labor force shifts from the service sector to the environmental and industrial sectors over time. The rate of interest rises as the capital intensity is falling. The level of pollution rises initially and then falls.

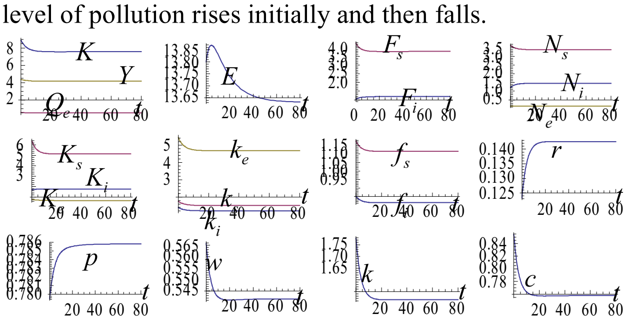

Figure 1: Motion of the economic system

4 COMPARATIVE DYNAMIC ANALYSIS

This section examines effects of changes in some parameters on the motion of the economic system. First, we study the case that all the parameters, except the speed that consumption pollutes the environment, are the same as in (15). We increase the parameter in the following way: θ_c: $0.25 \Rightarrow 0.30$. The simulation results are demonstrated in Figure 2. In the plots, a variable $\overline{\Delta} x_j(t)$ stands for the change rate of the variable $x_j(t)$ in percentage due to changes in the parameter value. We will use the symbol $\overline{\Delta}$ with the same meaning when we analyze other parameters. The rise in the speed that consumption pollutes the environment, reduces the national and two sector's capital stocks, wage rate and level of the consumption good, the interest rate. The labor force employed by the environmental sector is affected slightly. The level of pollution is increased over time. Hence, if the consumers have less awareness of environment, all aspects of the living conditions are deteriorated. When the consumers more intensively pollute environment, there are more pollutants. As the environmental condition is deteriorated, the productivity becomes lower, which leads to less capital and lower wage rate. As the dynamic system has a unique stable equilibrium, it approaches its steady state.

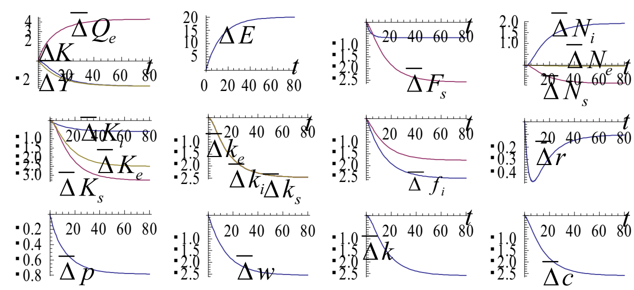

Figure 2: The pollution by consumption becomes stronger

If we raise the environmental tax rate on consumption as follows: τ_i: $0.05 \Rightarrow 0.07$, then the dynamic path of the economic system is shifted as illustrated in Figure 3. Initially, the economic system suffers and the environment deteriorates. But soon the economic conditions are improved and the environment becomes better.

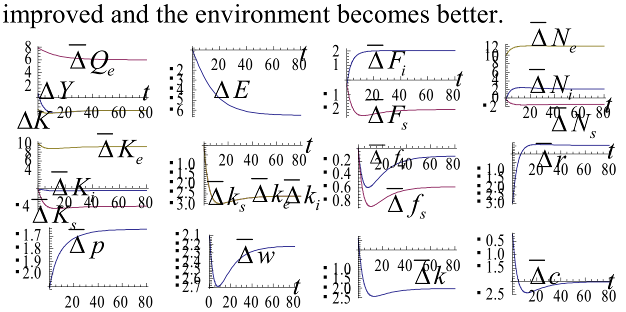

Figure 3: The environmental tax rate on the industrial output is increased

5 SUMMARY

This paper proposed a dynamic economic model with physical capital accumulation and environmental change on the basis of the neoclassical .growth theory. The model is a synthesis of the neoclassical growth theory and the traditional dynamic models of environmental change with an alternative approach to household behavior. This paper re-examined the Uzawa two-sector growth model with an alternative utility function. Different from the two-sector growth models with the Ramsey approach in the literature, we used a utility function, which determines saving and consumption with utility optimization without leading to a higher dimensional dynamic system like by the traditional approach. The model describes dynamic interactions among physical accumulation, environmental change, economic structure and division of labor with different environmental policies. We simulated the model to demonstrate existence of equilibrium points and motion of the dynamic system.

6 PROVING LEMMA 1

We now show that the dynamics can be expressed by the two-dimensional differential equations. From (2) and (13), we obtain

$$k_i = \bar{\alpha}_i k_e = \bar{\alpha}_s k_s, \tag{A1}$$

where we omit time index and

$$k_i \equiv \frac{K_i}{N_i}, \; k_e \equiv \frac{K_e}{N_e}, \; k_s \equiv \frac{K_s}{N_s}, \; \bar{\alpha}_i \equiv \frac{\beta_e \alpha_i}{\alpha_e \beta_i},$$

$$\bar{\alpha}_s \equiv \frac{\beta_s \alpha_i}{\alpha_s \beta_i}. \tag{A2}$$

By (A1) and (2), we solve

$$r = \alpha_i (1 - \tau_i) A_i \Gamma_i k_i^{-\beta_i} - \delta_k, \quad w = \beta_i (1 - \tau_i) A_i \Gamma_i k_i^{\alpha_i},$$

$$p = \frac{\bar{\alpha}_s^{\alpha_s} w}{\beta_s (1 - \tau_s) A_s \Gamma_s k_i^{\alpha_s}}. \tag{A3}$$

We see that k_e, k_s, r, w and p are functions of k_i and E. From $w N_e = \beta Y_e$ in (13) and (11), we have

$$N_e = \beta \tau_i \frac{F_i}{w} + \beta \tau_s \frac{p F_s}{w}. \tag{A4}$$

By this equation and (2), we have

$$N_e = \frac{\beta \tau_i N_i}{\beta_i (1 - \tau_i)} + \frac{\beta \tau_s N_s}{\beta_s (1 - \tau_s)}. \tag{A5}$$

From (A5) and (7), we have

$$\bar{\tau}_i N_i + \bar{\tau}_s N_s = 1, \tag{A6}$$

where

$$\bar{\tau}_i \equiv \frac{1}{N} + \frac{\beta \tau_i}{N \beta_i (1 - \tau_i)}, \quad \bar{\tau}_s \equiv \frac{1}{N} + \frac{\beta \tau_s}{N \beta_s (1 - \tau_s)}.$$

From (A2), (A5) and $K_i + K_s + K_e = K$, we have

$$\tilde{\tau}_i N_i + \tilde{\tau}_s N_s = \frac{K}{k_i}, \tag{A7}$$

where we also use (A1) and

$$\tilde{\tau}_i \equiv 1 + \frac{\beta \tau_i}{\bar{\alpha}_i \beta_i (1 - \tau_i)}, \quad \tilde{\tau}_s \equiv \frac{1}{\bar{\alpha}_s} + \frac{\beta \tau_s}{\bar{\alpha}_i \beta_s (1 - \tau_s)}.$$

From (A5)-(A7), we solve the labor distribution as functions of K / k_i as follows

$$N_i = \left(\tilde{\tau}_s - \frac{\bar{\tau}_s N k}{k_i} \right) \tau_0, \quad N_s = \left(\frac{\bar{\tau}_i N k}{k_i} - \tilde{\tau}_i \right) \tau_0, \tag{A8}$$

where

$$\tau_0 \equiv \frac{1}{\bar{\tau}_i \tilde{\tau}_s - \tilde{\tau}_i \bar{\tau}_s}.$$

From $c = \xi \hat{y}$ and the definition of $\hat{y}$, we have

$$F_s = (1 + r) \xi K + \xi N w, \tag{A9}$$

where we use $c N = F_s$. Insert (1) in (A9)

$$\frac{A_s k_i^{\alpha_s} \Gamma_s(E)}{\bar{\alpha}_s^{\alpha_s}} N_s = (1 + r) \xi K + \xi N w, \tag{A10}$$

where we use $k_s = K_s / N_s$ and $k_i = \bar{\alpha}_s k_s$. Substituting N_s in (A8) into (A10), we solve

$$k = \Omega(k_i, E) \equiv$$

$$\left[\frac{\tau_0 \tilde{\tau}_i A_s k_i^{\alpha_s} \Gamma_s(E)}{N \bar{\alpha}_s^{\alpha_s}} + \xi w \right] \left[\frac{\bar{\tau}_i \tau_0 A_s k_i^{\alpha_s} \Gamma_s(E)}{\bar{\alpha}_s^{\alpha_s} k_i} - (1 + r) \xi \right]^{-1}, \tag{A11}$$

where r and w are functions of k_i. We express k as a function of $k_i(t)$ and $E(t)$. From (A2), k_s and k_e are functions of k_i. From (A8), N_i, N_s and N_e are functions of k_i. By the following procedure, we can express other variables as functions of $k_i(t)$ and $E(t)$ at any point of time: r, w and p by (A3) → Q_e by (10) → $\hat{y}$ by (3) → c and s by (5). By these results and from (9) we get the following differential equation

$$\dot{E}(t) = \Lambda_e(k_i(t), E(t)) \equiv \theta_f F_i(t) + \theta_c C(t) - Q_e(t) - \theta_0 E(t). \tag{A12}$$

We do not provide explicit expressions of the functions as it is straightforward to do so and the expressions are too tedious. Taking derivatives of (A11) with respect to t yields

$$\dot{k} = \frac{\partial \Omega}{\partial k_i} \dot{k}_i + \Lambda_e \frac{\partial \Omega}{\partial E}, \tag{A13}$$

where we also use (A12). From (3), (5) and (6), we have

$$\dot{k} = \lambda w - (1 - \lambda r - \lambda) k. \tag{A14}$$

Insert (A13) and (A11) in (A14)

$$\dot{k}_i = \Lambda_{k_i}\left(k_i(t),\, E(t)\right) \equiv$$
$$\left[\lambda\, w - (1 - \lambda\, r - \lambda)\Omega - \Lambda_e \frac{\partial \Omega}{\partial E}\right]\left(\frac{\partial \Omega}{\partial k_i}\right)^{-1}. \tag{A15}$$

We have thus proved Lemma 1.

7 AKNKOWLEDGEMENTS

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The Impact Analysis of Waste Plastic Trade between China and Japan－From Policy View

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Abstract

The 3R policy in Japan promoted the recycling of waste resources; however, at the same time, it also triggered a rapid increase in the export of waste plastics to China. As a result, domestic material recycling (MR) of waste plastics generated in Japan has been declining, which may lead to a hollowing out of Japan's waste plastic recycling business. In this study, we conducted a macro analysis of the effects of the 3R policy in Japan and the economic situation of Japan and China on the flow of waste plastics by following changes in trade volume of waste plastics between the two countries from the 1990s through 2010. From the results of this analysis, it can be seen that waste plastics exports from Japan have continued to increase, driven by the legal structure related to the 3R policy in Japan and the rapid increase in the demand for plastics in China. However, the export from Japan seems to be already reaching a limit. On the other hand, when viewed from China's perspective, China has been importing waste plastics not only from Japan but also from about 120 countries around the world. Total imports in 2009 amounted to approximately 7.3 million tons, while imports from Japan (1.35 million tons) accounted for only about 20% of total waste plastics imports. The immediate cause is the rapid economic growth of China; however, various policies in China have also further increased the demand for plastics. Therefore, the demand for waste plastics in China is expected to continue increasing in the future. In addition, among waste plastics imported to China, inappropriate items included among the waste plastics have been on the rise in light of the Basel Convention, and there are concerns about the effects of environmental pollution resulting from the recycling business in China.

Keywords:

waste plastics, waste trade, material recycling, 3R policy, the Basel Convention

INTRODUCTION

Currently, many countries in the world are pursuing their own policy of promoting the cyclical use of waste resources, with the aim of forming a sustainable society. As an initiative to promote the formation of a cyclical society in Japan, the Containers and Packaging Recycling Law was enacted in 1995, while at the same time, the demand for plastics has continued to increase in China due to its rapid economic growth. In particular, waste plastics including waste PET (polyethylene terephthalate) have been exported in vast quantities from Japan to China, starting at the beginning of this century.

Simultaneously, domestic material recycling in Japan, which is the highest priority in the three kinds of recycling methods (material recycling (MR), chemical recycling (CR) and thermal recycling (TR)) for the formation of a cyclical society in Japan (3R policy), has been gradually faded out, and material recycling has been maintained by exports to China.

On the other hand, China has imported vast quantities of waste plastics from around the world backed by its resource policies. As a result, however, improvement of the safety inspection of imported waste plastics and measures for prevention of environmental pollution at recycling plants are becoming important issues.

In this study, we analyze in detail the process of expanding trade in waste plastics between Japan and China after 1997 based on statistical trade data from Japan and China, and also, work to understand the state of nonconformity of waste plastics China imported from around the world to standards based on customs statistics. Through this analysis, we clarify the actual state of cyclical use of waste plastics between Japan and China, straighten out issues concerning international cyclical use of resources from an environmental, economic and political viewpoint, and consider how to deal with the issues that exist in the future.

1. STUDY METHOD

Based on export and import statistical data of waste plastics in both Japan and China during the period of 14 years from 1997 when the Containers and Packaging Recycling Law was enforced to 2010, we clarify a macro trend in the secular changes in waste plastics trade between Japan and China. In addition, we identify and

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count the cases of nonconformity among waste plastics imported from Japan to China during the period from 2003 to 2009 in light of the "Environmental protection control standard for imported solid wastes as raw materials - Waste and scrap of plastics" based on the materials released by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China to consider legally inappropriate waste plastics trade cases. Furthermore, based on the development of policies related to the promotion of cyclical use of waste resources in both Japan and China and economic trends in both countries, we give an analytical consideration of factors to promote waste plastics exports from Japan to China and clarify environmental protection-related issues.

2. BACKGROUND ON THE INCREASING DEMAND FOR WASTE PLASTICS IN CHINA

Currently, China has set environmental protection management standards for waste plastics recycling plants; however, the standards have not been fully complied with on site. China has promoted recycling waste plastics by offering preferential treatment such as tax breaks; its prior policy is to save the oil consumption and manage the price of plastic products. According to the observation analysis report of China Customs Statistics "Increase in Waste Plastic Imports via Tianjin Port in January 2011," recycling one ton of waste plastics saves about five tons of oil [1]. This is because the production of one ton of plastic requires nearly four tons of oil, if waste plastics are recycled once and ultimately used as fuel, it will save five tons of oil. The total amount of waste plastics recycled in China in 2009 was approximately 17 million tons, including imports. This translates into savings of about 80 million tons of oil. Therefore, recycling waste plastics has a significant meaning to China's national strategy.

2.1 Changes in the amount of plastic used in China

In China, demand for virgin plastic materials has been increasing since 1994. From 1995 to 2000, in particular, the annual growth rate of demand reached about 20%. Although the growth rate somewhat slowed thereafter, demand has continued to grow by about 10% annually after 2000. Imports of virgin plastics increased to meet demand until 2002; however, reflecting an increase in the domestic production capacity, virgin plastics imports have decreased since 2003. Meanwhile, waste plastic imports have rapidly increased since 2000, and their imports have maintained an upward trend throughout the period to date in spite of the global recession in 2008. Since around 2002, a surge in oil prices has further increased the demand for waste plastics.

Fig. 1 shows changes in the amounts of China's domestic procurement and imports of virgin plastic materials and

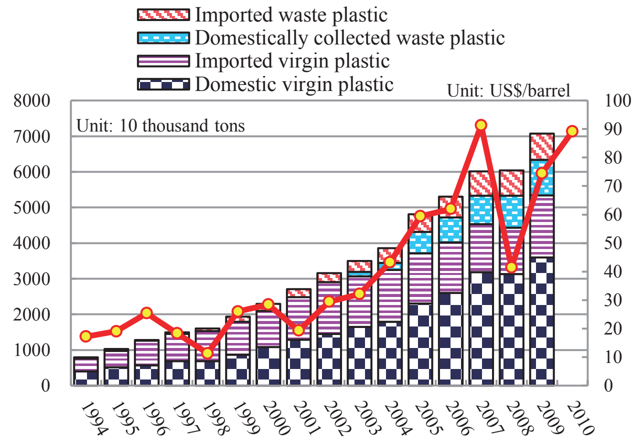

Fig. 1: Changes in the Amount of Plastic Used in China
* Data on the amount of domestically collected waste plastics is from 2003
Source: China Statistical Yearbook, China Customs Statistics, Changes in WTI Crude Oil Prices[2]

waste plastics and changes in oil prices (WTI crude oil prices) during the 15 years from 1994 to 2009. China's demand for plastics reached an all-time high of about 70 million tons in 2009, when the amount of domestic production was 36 million tons and imports of virgin plastic materials were 17 million tons. Meanwhile, imports of waste plastics totaled 7.3 million tons and the amount domestically collected totaled 10 million tons. Thus, waste plastics satisfy 25% of China's total current demand for plastics

2.2 Status of China's waste plastics imports

Imports of waste plastics totaled 3.02 million tons in 2003 and doubled to 7.3 million tons in 2009. China is now the largest importer of waste plastics in the world, and about 70% of total waste plastics shipped worldwide are imported by China. Of the 117 countries, the major countries and regions (Hong Kong, European countries, US, Japan, Taiwan, and South Korea) account for about 80% of total waste plastic imports [3]. However, as shown in Fig. 2, annual increase rate of waste plastic import in China dropped from the average of about 20% during 2003-2007 to 2% in 20008. In 2009, the rate slightly recovered to 4%.

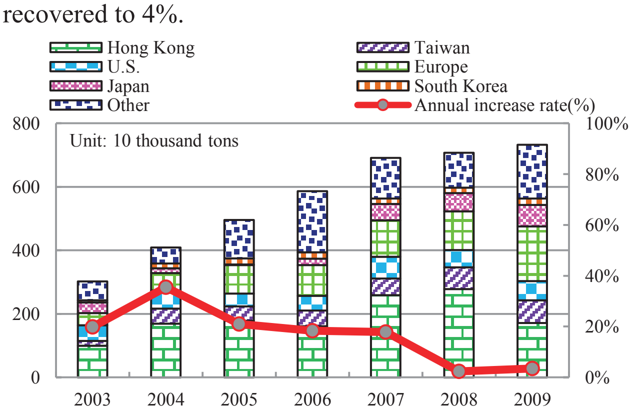

Fig. 2: Changes in Waste Plastic Imports by Country during 2003–2009
Source: Calculated from World Trade ATLAS

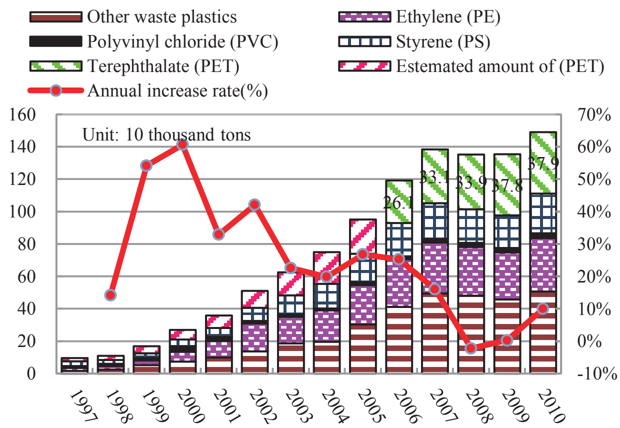

Fig. 3: Changes in Waste Plastic Exports from Japan to China
Source: Trade Statistics of Japan, Ministry of Finance, Government of Japan[4]
Note: Figures above differ from those in Figure 2 as they include exports through Hong Kong.

Furthermore, in 2009, the percentage of waste plastics imports through Hong Kong decreased, while there was an increasing trend in direct imports from overseas to the inland China. This is because direct shipments save time and reduces transportation costs more than import via Hong Kong as there are many waste plastics recycling plants in the inland China.

2.3 Import of waste plastics from Japan

As shown in Fig. 3, exports of waste plastics from Japan to China have rapidly increased since 2000, but due to the impact of the financial recession at the end of 2008, the demand for waste plastics in China temporarily decreased because of a decline in the export of Chinese plastic products to overseas markets, such as the U.S. and Europe in particular, and as a result, exports of waste plastics from Japan to China showed a slight decline. Along with the economy recovering in China in 2009, exports to China once again created an upward trend to reach a record high of 1.49 million tons in 2010, exceeding the record of 1.38 million tons in 2007 [4]. Among waste plastics, exports of only waste PET to China have maintained an upward trend in spite of the recession. However, it seems that plastic consumption has already peaked in Japan, and no substantial increase in the generation of waste plastics can be expected in the future. Therefore, the market of material recycling in Japan is expected to diminish further.

3. POLICIES OF BOTH COUNTRIES ON THE INCREASE IN THE FLOW OF WASTE PLASTICS

3.1 Factors attributable to the system of Japan's Containers and Packaging Recycling Law

The Containers and Packaging Recycling system imposes obligations on citizens to separate their waste, and municipal governments to carry out sorted collection and separate storage of waste and deliver the separated waste to the Japan Containers and Packaging Recycling Association free of charge. The Law also provides a system to impose obligations on producers and users to conduct recycling and pay recycling fees (commission). Furthermore, the Law imposes obligations on municipal governments to pay costs of sorted collection and separate storage as well as to pay commissions on behalf of small businesses. For this reason, the number of cases has been increasing where municipal governments that have to bear high costs sell the waste PET bottles they collected to China (Chinese buyers) for a fee in response to strong requests from China, without delivering them to the Japan Containers and Packaging Recycling Association.

Meanwhile, for recycling business operators, business conditions have worsened because of a rise in procurement costs due to a recent increase in exports to China and the sluggish growth in demand due to a rise in prices of products recycled from waste PET (flakes or pellets). According to interviews from the Containers and Packaging Recycling Association and some PET bottle recycling plant in Kawasaki Prefecture, Japan, although the company has world-class recycling technology, it is difficult for them to secure the product market because pellets recycled from waste PET bottles are more expensive than virgin materials.

To maintain the waste PET recycling market, a commission system for recycling business operators and a contribution scheme for municipal governments has been introduced as a result of a revision to the Law in 2006 [5]. However, because costs including those related to the collection of waste PET still remain high, the market for recycled products cannot expand in Japan. The immediate cause is that the cost of recycled products is relatively high compared to that of products made with competing virgin materials. Thus, it can be considered that high recycling costs are a major factor that hinders the growth of Japan's recycling system. The 3R policy has placed an emphasis on maintaining a stable recycling market without leaving it entirely to the highly fluctuating market. However, the growing waste plastics market in China is putting pressure on the management of Japan's waste plastic recycling businesses.

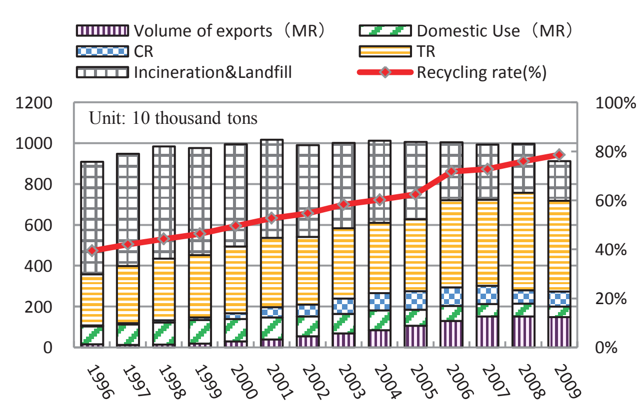

Fig. 4: Breakdown of Waste Plastic Treatment in Japan
Source:Plastic Waste Management Institute

Table 1 China's Policies to Promote the Use of Waste Plastics

Year	Policy	Contents
2006	The 11th Five-Year Plan	The plan to promote the use of plastic as an alternative material to steel and wood materials
2008	Corporate Income Tax Concessions for Enterprises Engaged in Comprehensive Resource Utilization [6]	This treatment imposes an obligation of 100% use of waste plastics, and provides the enterprises that have achieved the target with concessions for corporate income tax on 10% of their sales
2009	Circular Economy Promotion Law of the People's Republic of China	This law was enforced with the aim of minimizing the impact on the environment and improving resource efficiency by reducing and recycling waste
2010	Easing of Import Restrictions	Restrictions on the import of PET bales (plastic waste in the form of PET bottles) were lifted
2011	The 12th Five-Year Plan	The economic development policy was transformed from a traditional export-led policy to a domestic-demand expansion policy

Recent trend of waste plastic treatment, including recycling in Japan is shown in Fig. 4. Total recycling ratio is apparently very high, but, thermal recycling (TR) and chemical recycling (CR) are dominant and material recycling (MR) stays only about 20%. Material recycling within Japan is declining steadily since 2000, and in 2008, 75% of material recycling is conducted overseas, mostly in China. In other words, Japan actually depends on China for its material recycling, and as a result, the domestic material recycling industry for waste plastics is hollowing.

3. 2 China's resource recycling promotion policies

Besides the aforementioned economic reasons, China's recent policies shown in Table 1 serve as factors that accelerate China's demand for plastics and imports of waste plastics. The reason for this is that it will be more difficult for China to procure resources in the future. In concrete terms, policies to promote the use of plastics and import of waste plastics are as follows : (i) in the Circular Economy Promotion Law enacted in January 2009, China set a basic policy which prioritizes "reducing," "reusing," and "recycling" in the same way as in Japan [7]; (ii) in addition to the policy to increase the use of plastics announced in the 11th Five-Year Plan, a transformation from export-led economic revitalization to domestic demand expansion was announced in the 12th Five-Year Plan launched this year. This will further accelerate the use of plastics in China [8][9]; and (iii) in 2008, tax reduction measures were set forth to promote the use of waste plastics, and last year, it was approved to import waste PET bottles in the form of bales [10]. This enables direct import of bales to mainland China, which used to be imported through Hong Kong, and reduces transportation costs. According to the observation analysis report of China Plastic On Line "Plastics Market" [11], in the future 5 to 10 years, the demand for waste plastics is expected to grow at 10% to 20% annually.

4. ENVIRONMENTAL ISSUES ASSOCIATED WITH TRANS-BOUNDARY MOVEMENTS OF WASTE RESOURCES

4.1 Basel Convention and cross-border flow of waste plastics

Trans-boundary movements of waste resources such as scrap iron, waste plastics (excluding part of polyvinyl chloride (PVC)), waste textiles, waste rubber, etc. are not subject to the regulations of the Basel Convention. Polyvinyl chloride is also permitted for export if the percentage of lead content is 0.1% or less by weight [12]. For the past 21 years from 1988 to 2009, Japan exported PVC to 28 countries such as China, South Korea, Taiwan, and the U.S.A. When exported to contracting states such as China, a preliminary inspection is conducted based on the domestic law in Japan as an exporting country corresponding to the Basel Convention. In the same way, an inspection is also conducted of the trading partner based on its domestic laws. In the case of China, inspections are conducted based on the "Environmental protection control standard for imported solid wastes as raw materials - Waste and scrap of plastics" as well as the standards of the Basel Convention. The status of conformity to the standards of the Basel Convention and the domestic laws in China for waste plastics imports in China can be summarized as follows.

4.2 Cases of non-conforming waste plastic imports rejected by China

According to the materials released from the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, the number of waste plastics imports which failed to meet standards has been on the rise, as waste plastics imports by China have increased.

According to the report from China's Waste Resources Import Management Symposium held in Tokyo in 2008, the total number of lots of recyclable resources (scrap iron, waste paper, waste plastics, etc.) imported by China in 2007 totaled 287,602 [13]. As a result of random checks, 735 lots of waste resources failed to meet the "Environmental protection control standard for imported solid wastes as raw materials - Waste and scrap of plastics," which was approximately 0.26% of the total lots. Of the 735 non-conforming lots, 409 lots were waste

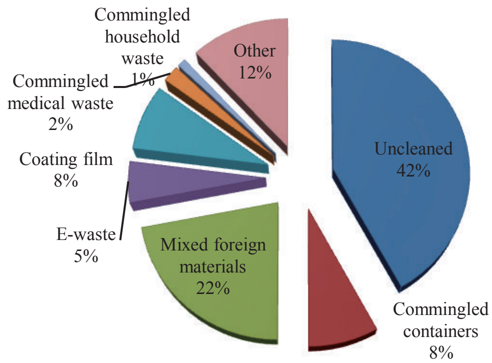

Fig. 5: Breakdown of 409 Lots of Non-conforming Waste Plastic Imports in 2007
Source: General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China[14]

plastics, which accounted for 56%, the largest percentage of the total.

As shown by the breakdown of reasons for the rejection of waste plastics imports in Figure 5, the number one reason for the lot being rejected was uncleaned plastic waste (42%), followed by mixed foreign materials (fibers, papers, etc.) (22%), coating films unremoved (8%), commingled containers (8%) (until restrictions on the import of waste PET bales were lifted in 2010, only the import of waste plastic scraps (flakes) were permitted), commingled electric and electronic parts (E-waste) (5%),

Table 2 Some Cases of Rejected Waste Plastic Imports

Importer	Year	Exporter	Reason for rejection
Shandong	2003	Japan	Commingled household waste
Liaoning	2004	South Korea	Radioactive materials in excess of standards
Liaoning	2006	South Korea	Commingled medical waste
Guangdong	2007	Hong Kong	Commingled medical waste
Shandong	2007	Japan	Mixed foreign materials in excess of standards
Guangxi	2008	Unknown	Commingled E-waste
Zhejiang	2009	U.S.	Commingled E-waste

Source: General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China[14]

commingled medical waste (2%), commingled household waste (1%), etc. Imports from the U.S. contained the largest number of non-conforming waste plastics totaling 150 lots, which was followed by 70 lots imported via Hong Kong, and 54 lots imported from Japan. The major non-conforming cases are shown in Table 2.

5. TRANS-BOUNDARY MOVEMENTS OF WASTE RESOURCES AND ENVIRONMENTAL POLLUTION

According to the Chairman's Summary Report of the Senior Officials Meeting on the 3R Initiative held in March 2006 in Tokyo, it was asserted that for the establishment of rules of trans-boundary movements of hazardous waste agreed in the international community (the Basel Convention), additional rules to restrict trans movements of recyclable resources were necessary [15].

However, obligatory restrictions should be left to each country. In addition, according to "Invisible Flow" and a Study Report on Recycling and Exports by Atsushi Terazono (2007), although the Basel Convention restricts trans-boundary movements of hazardous waste, it is currently easy to export such waste as long as there is an agreement between the seller and the buyer. It was also pointed out that even if a problem occurred, it would be difficult to ask who was responsible, and to what extent, for the problem [16].

The Basel Convention designates E-waste, PCB, residual agricultural chemicals, waste oil, medical waste, lead batteries, etc. as critically restricted items; however, it imposes no restrictions on waste resources which are not subject to the regulations of the Convention such as waste plastics, and the waste resources are being exported to many developing countries. Furthermore, in the recycling process of resources such as waste plastics, not a few countries may not have adequate technologies and economic capacities for environmental protection, which cause concerns about environmental pollution. Therefore, regarding such waste items mentioned above whose trans-boundary movements are increasing at a rapid pace, it would be desirable to inspect whether or not the Basel Convention is functioning effectively for the prevention of environmental pollution. In order to promote environmentally sound recycling of waste resources on an international basis, it must be said that exporting countries are required to thoroughly control their quality, and developing countries as well are also required to have a certain level of management ability as importing countries. When we visited an independently-operated small plant in Zhejiang Province, China in (August) 2010, where PVC pellets were recycled and processed, they had a low awareness for measures against environmental pollution. Sufficient environmental measures have not yet been implemented in the recycling and processing of waste plastics in China compared to Japan. In addition, adverse effects of environmental hormones such as plasticizers, including phthalates and bisphenol-A have been pointed out by many scientists of the world since 1990s. Although the scientific evaluation of their effects on human health has not been completed, the use of such substances for children's toys, etc. is restricted in Europe and other countries, and it has been pointed out that such restrictions may have an impact on the export of plastic products from China. In addition, there are some experts who point out the issue of "precocious babies" in China in recent years [17]. From the viewpoint of promoting environmentally-sound 3R policies on an international basis, an examination is considered to be necessary to prevent effects of such scientifically uncertain chemical substances on human health and ecology. In addition, administrative efforts will be increasingly important in the future to ensure that environmental regulations are properly implemented at recycling sites of waste plastics.

6. SUMMARY

i) Reason for the rapid increase in demand for waste plastics in China

(a) Due to reasons such as rapid economic growth in China and economic disparities between Japan and China, as well as the promotion of 3R policies in Japan, the outflow of waste plastics from Japan to China has been rapidly increasing in recent years, especially after 2000. China has been importing waste plastics not only from Japan but also from all over the world.

(b) Chinese government's circular economy promotion policies are serving as an underlying cause of the increase in the demand for waste plastics.

ii) Changes in waste plastics recycling in Japan

(a) Due to the obligation to separate and collect waste by citizens and municipal governments under the Containers and Packaging Recycling Law, material recycling of waste PET proceeded smoothly for a while after enforcement of the Law. However, the outflow of waste plastics to China has been putting pressure on the management of waste plastic recycling business operators in Japan and pressure to rationalize their management. As a result, some operators have gone bankrupt or closed business.

(b) The amount of material recycling of waste plastics generated in Japan is only 20% of the total, and more than half is recycled by thermal recycling. Moreover, the portion of material recycling set aside for exporting has risen year by year, and currently only 25 percent are for domestic use and 75 percent are exported to China and processed there.

(c) With the increase in demand from China, exports of waste plastics to China have been increasing. Although Japan exports 20% of its waste plastics imported by China at present, when the market size of Japan is compared with that of China, Japan's supply capacity of waste plastics is already reaching its limit.

iii) Basel Convention and concern about environmental pollution

(a) The Basel Convention prohibits trans-boundary movement of hazardous materials; however, it is questionable if it effectively functions to address the environmental pollution caused by the trans-boundary movements of resource materials which are not subject to the Convention such as waste plastics. Thus, it is necessary to further study the environmental pollution involved with the recycling process of waste plastics.

(b) Some specialists point out concerns over the effects of environmental hormone substances on human health, which requires a separate scientific study, in particular.

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Comparisons and Analysis on International Resource Recycling: A Case Study of Waste Disposal and Recycling between China and Japan

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Abstract

With rapid development of urbanization and industrialization, resources seem to be more and more important. All over the world, every country are paying more attention to resources conservation and recycle. At the same time, China and Japan, two large countries in Asia, share many similarities and have many differences. This paper, from the angle of sustainable development, compares various aspects of waste disposal and recycling in both China and Japan, including technologies, administrations, CSR (Corporation Social Responsibility), public attitudes and so on. By SWOT analysis, we can get to know merits and demerits of two countries' waste disposal and recycling, so as to better understand the differences between China and Japan and provide deeper suggestions to international resources recycling cause.

Keywords

International Resource Recycling, Waste Products, Comparisons, China and Japan

1 INTRODUCTION

Accompanied by ever-increase of international recycling development and the need for resources, resources recycling have been a hot-spot issue in contemporary society promoting ever-frequent international trade in this field. As to the issue of international resources recycling, not only does cooperation be indispensible, but deep understandings of different recycling systems in counters are also quite necessary. As a result, this paper, focusing on comparisons and analysis of waste disposal and recycling systems in China and Japan, aims at providing useful information to international resources recycling.

2 WASTE DISPOSAL AND RECYCLE SITUATION IN CHINA AND JAPAN

2.1 Solutions of waste disposal and recycle technologies in China

China enacted the Law of Prevention and Control of Environmental Pollution by Solid Waste in 2005. In the law, the definition of waste law was explicitly stipulated. As a result, according to the law, "waste" is a kind of product that coming from human daily life, manufacturing process, and natural environment as well. "Waste" itself contains solid and semi-solid two forms, and can be divided into three categories: industrial solid waste, municipal solid waste and hazardous waste. In many cases, this definition has the highest authority.

At present, the most common ways of urban waste disposal is land filling, occupying 70% of total quantity. The second way is high-temperature composting, which contains 20%. Very rare waste is disposed by incineration. By the end of 2006, there are 23 household waste disposal facilities in Beijing, including 6 household waste transferring stations, 13 landfill sites, 2 high-temperature composting sites and 2 incineration plants. The overall designed processing capacity is 15710t/d[1]. Since land filling sites are so important in end disposal that their operational state should be carefully detected. Though a large number of wastes are disposed by land filling, incineration has had more and more influences and effectiveness. More and more plants or factories prefer to use this method when handling waste disposal and recycle problems.

Land-filling

Land-filling is the cheapest way of waste disposal, as in China, the price for land-filling 1 ton of waste is about 40 RMB, much lower than any other technologies. That's why over 70% of household waste was handled that way.

However, despite its cost advantage, land-filling has many problems. A case in point is about land. In china, land is so expensive that it has already brought a series of problems, such as high cost, low benefit and consumers' heavy burden. While land-filling covers so large an area, making previous expensive lands much more expensive. Moreover, this method will also bring smelly to filled sites, especially in summer when temperature is a little bit higher than average. Dust, smell, bacterium and percolate will do great harm to human and surrounding areas,

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threatening people's life and health. As a result, the problems of landfill sites have become a tough issue over recent years.

High-temperature composting

Household waste when giving enough heat, they can be made into fertilizer, which can be used in agriculture. It indeed is a good way to dispose waste and realize recycle at the same time. But this method also has some inextricable problems. When household waste is made into fertilizer, it must be provided with enough heat, of which the process is difficult to control. It is the temperature that prompting this fermentation process. But usually the temperature is too hard to control and how to test the most suitable temperature is also a big question. Even if the temperature is suitable for fermentation, there is still one question left unsolved, that is low efficiency of fertilizer. Once the efficiency is very low, it cannot be easy to use in agriculture. Besides, how to fix a price is also a problem.

Incineration

Nowadays incineration seems to be the most effective way to handle waste disposal problems on one hand, and on the other hand, realizing the goal of recycle.

The merit of saving a lot of places is the most apparent and most remarkable one. By incineration, the average volume is greatly reduced. According to statistics, after incineration process, the reduction of volume is about 80% comparing to previous one[2]. Consequently, a landfill sites designed for 10 years' longevity can prolong its lifetime into 80 years. This is a very excited method when considering waste disposal. At the time of saving places, this method also will decrease the virus quantity of waste. What's more, heat energy released during incineration process is perfectly fit for generating electricity. This form of electricity generating way is considered to be pollution-free, high efficiency, environmental friendly, clean and sustainable approach.

As to the demerits, it is quite apparent—cost. Compared with domestic waste disposal method, incineration seems to be a little bit high than them, probably about 150 RMB/ton, almost 3 times than that of land filling. The second is CO_2 emission, which is much higher than land filling.

2.2 Solutions of waste disposal and recycle technologies in Japan

According to Japan's Waste disposal Law (enacted in 1970 and revised in1991), in Japan waste is defined as that "Waste is stuff that human needn't, usually is exited in the form of solid and liquid (Radiation substances are excluded in this definition.)" Waste in Japan can be divided into two main categories, common waste and industrial waste. Common waste is some household waste and office waste; industrial waste is usually very large, for example, things like construction waste, electric waste, household appliances and something existed during industrial processes all belong to this category.

Currently, Japan did very well in waste disposal and recycle. Most of the times, recycling plants have exceeded government in recycling rate, and qualifying rate. Under the background of CO_2 reduction, many plants are taking this into consideration when doing recycle. So, coming to the problem of CO_2 reduction rate, near every plant will save a lot of energy, achieving reduction quantity and rate.[3] In Japan, waste disposal and recycle are made according to their categories. Different kinds of waste have a different disposal way for recycle.

Electric waste

As we all know, electric waste are different from other waste in compositions and in contents that restored in them. First, Electric parts are made by Al, Fe, Ti, Zn, Pb and etc, which are hard to degrade in natural environment. On the other hand, these materials will cause serious problems to human health. If left uncontrolled, they will become hazardous waste as well. As a result, all electric waste disposal and recycle plants are trying to refine metals from electric waste, and strive to make them more and more purified. Second, electric parts are usually computer accessories, such as hardware, software, main board or other kinds of data storage parts, so electric waste themselves are not only metals, but also face the problems of information security. Out of safety reasons, all plants should have permits in order to dispose electric waste, and the acquirements of these permits are also selected one in a hundred.

Construction waste

Construction waste is certain kinds of waste, such as large stones, cartons, packaging bags, ropes, plastic substances and something like that. One of apparent characteristic of construction waste is non-flammability. In most plants, after manual sorting, construction waste will be put into shatters, grinding and finally, be made into plaster.

Household appliances waste

Household appliances waste usually contains 4 pieces: refrigerators, TVs, air-conditionings and washing machines. Compared with other kinds of waste, household appliances also have some points which differ from other waste. That lies in component parts. Household appliances usually composed of plastic casing, kinescope, electric lines, metals and glasses as well. As a result, the first step of disposal is to disintegrate them according to categories, after that, different kinds of waste will be disposed separately.

Household waste

Household waste usually means living waste, which is related with everyone's daily life, such as food waste, plastic bags, waste paper, cottons and something like that. According to the law, household waste can be divided into two categories, one is flammable, and the other one is inflammable. Flammable waste will be incinerated, and heat can be used to generate electricity. Inflammable waste can also be shattered and made into other products, so as to realize recycle.

3 COMPARISON AND ANALYSIS BETWEEN CHINA AND JAPAN IN WASTE DISPOSAL AND RECYCLE

China and Japan, two large countries in Asia and the world, have different national conditions, such as different policies, different cultures and history; as a result, they share many in common and have many differences too. Considering comparisons in waste disposal and recycle, there are mainly 4 similarities and differences, and they are listed as follows.

3.1 Law

Similarities

a.Legislation: Both China and Japan are sharing the same legislature. The laws are made by national government and have highest potency comparing with other regulations.

b.Management: Two countries' management is nearly the same, which is "Up-to-bottom". By this way, government saves many time and energy in coping with different benefit groups, which is significantly different from that of western countries.

Differences

a.Contents: (1) Comparing with Japan, China's waste disposal and recycle laws are just in its beginning stage, which are either comprehensive or practical. While on the other hand, Japan's waste disposal and recycle system is mature enough, that one can easily find what they want in the law system. (2) Two countries' waste disposal and recycle law systems have different focuses. In China, the laws are mainly focusing on policies, while in Japan, laws are more related to practices. (3) Considering the objects, differences also exist. Japanese waste disposal laws not only provide legal basis for government, but also regulate corporations and public. While Chinese waste disposal laws mainly concentrate on the former.

b.Maneuverability: Japanese waste disposal and recycle laws are easy for people and corporations to follow, while Chinese laws are difficult to understand, let alone practice.

c.Regulation and punishment: Japanese laws are very restricted, as a result, under this law system, there are very little people crossing the law. However, the punishments in Chinese laws are a little bit weak, so that it seems a little common for people to obey the laws.

3.2 Definitions/ Classifications

Similarities

The same place is that whatever China or Japan, the definitions of waste are in accordance with law. So it is the law that regulates definition as well as classification.

Differences

In China, waste is a certain kind of substance that comes from daily life, industrial production and other ways, and it can be divided into 3 categories, industrial waste, municipal waste and hazardous waste. Right now, large number of municipal waste and small portion of industrial waste is disposed. While in Japan, wastes are mainly two categories, one is industrial waste, the other one is common waste. Industrial waste can be divided into construction waste, electric waste, household appliances waste and food waste in supermarket. Common waste is daily life waste and small number of office waste. Moreover, in Japan, all kinds of waste can be disposed and recycled.

3.3 Economic situations

Similarities

Though China and Japan, one is developing country, the other is developed, but considering GDP issue, they are almost the same. Moreover, two countries are all on the road of rapid development, and more or less, they have the ability to put enough money to handle waste problems.[5]

Differences

a.GDP: Same GDP, but different population triggers the differences in waste disposal and recycle. Japan's per capital GDP is much higher than that of China, and as a result, Japan has more money to handle waste disposal and recycle problems. That's why in China, only household waste can be well treated.

b.Cost: The costs of China and Japan in waste disposal and recycling have large differences. In China, average cost of waste disposal is around 1300 Yen/ton, while in Japan, it is about 7000 Yen/ton, 6 times higher than that of China.

3.4 Public awareness

Similarities

Environmental education seems more and more important in both China and Japan. Nowadays, people are willing to learn about environmental protection methods, and are getting used to environmental protection behaviors.

Differences

Japan's environmental education started much earlier than China, consequently, Japanese nowadays have already formed the good habits of protecting environment, which in China environmental education is just at its infancy stage. For example, in the last food waste disposal supermarket, I saw a lady put all of used plastic packages into supermarket's trash box, and all of the packages have been washed and dried, which is nearly impossible in today's China. However, after several years' environmental education, I'm confident that public awareness toward environmental protection will be raised.

3.5 SWOT analysis between China and Japan

SWOT stands for Strengths, Weaknesses, Opportunities and Threats. This analyzing method is specifically designed for enterprises. It mainly adopted to analyze a company's competing Strengths, Weaknesses, opportunities and threats. And perfectly linked a company's inner and outer resources, and is very useful for a company's future development. As a result, SWOT analysis can perfectly suit for waste disposal and recycle plants[4].

Strengthen

China: (a) Low cost. Compared with Japan, the cost of waste disposal and recycle is much lower and cheaper. This can be explained by cheap manual power, low price of raw materials and products. (b) Large areas. Considering the issue of waste disposal and recycle, large areas means low requirements of treatment technologies and not very strict assortment procedures. (c) Up-down system. China's political system belongs to the "Up-to-Bottom" system, so it's easier for government to make comprehensive management over waste disposal and recycle issues, meanwhile, it's also a way to save time, money and energy.

Japan: (a) Mature law system. Japan has a very comprehensive system of waste disposal and recycling, every process in this system is in accordance with laws, so it is pretty easier for companies and people to follow. (b) CSR. Japanese companies to some extent, has a higher responsibilities, so that government doesn't need to spend time and money persuading corporations to follow recycling laws or regulations. (c) Technology innovation. There's no doubt that Japan's technology is always ranking first three places in the world, especially in electric products and humanize design. The products or production lines maintain both high efficiency and low energy consumption. (d) Public participation. After many years' education and practices, Japanese people nowadays have already formed environmental protection awareness.

Weakness

China: (a) low recycle standard. Considering overall situation in China, nowadays' waste disposal and recycle process is not modern and advanced enough, so the recycle rate is much lower when comparing with Japan's. (b) Recycle products are things like tiles, even can't meet intermediate standards. (c) Smell control problem. (d) Small quantity. Right now, there are very limited numbers of disposal plants using incineration way to handle waste problem.

Japan: (a) Cost. In Japan, the cost for disposing 1 tons household waste is about 7000 yen. And in almost every disposal companies, manual operation cannot be replaced by mechanical operation. Because in every kinds of waste, there is too much other waste, mixed together, as a result, very difficult to pick out, the corporations themselves have no choice but to hire more people. (b) End products. In almost every corporation, the end products are very simple and lacking varieties, such as raw metals, Al, Fe, Zn, Pb, and Cu, much cheaper than processing materials.

Opportunity

China: (a) further treatment over waste disposal and recycle. There's a big market in China waiting to be discovered. This also means we can further contracting the volume and mass of waste products, further reducing threats brought forward, further improving our environment and further enriching our end products. (b) On the basis of previous, our country can develop its trade with other fields or other countries. (c) Prompting technological innovation and scientific researches.

Japan: (a) Cost reduction. Cost is too high in Japan. Companies can do something to cut their cost, as previously mentioned, cost is too high in Japan. (b) Diversity of products. Because at present, the products of recycling are very simple, only some raw materials like Al, Fe, Zn, something like that. Raw materials are usually very cheap, maybe they can be made into some other end products.

Threat

China: (a) Limited land resources. Nowadays in China, due to rare land, the price of purchasing land or house is very high. If the situation continues, it's hard to image or expect that over 10 years, when there's no other land for land filling, what we should do to deal with our waste, and how high it is our housing price will be. (b) Limits in technology. Nearly all kinds of waste disposal and recycle plants are using Japanese or European's technology, so it will constrain our country's own development.

Japan: (a) High cost, low benefit will bring many threats to a company. (b) Too much emphasizing on recycling. As a matter of fact, recycling is not everything; it is only a way to solve waste, at the same time enhancing recycling rate. However, Japanese corporations pay too much attention on waste disposal and recycle, which is of course not the core essence; as far as I am concerned, trying to improve environmental design is a better choice.

4 BETTER SUGGESTIONS TO INTERNATIONAL RESOURCE RECYCLING

4.1 Policymaking system

In light of the fact that China's law system of waste disposal and recycle is not mature and comprehensive, the top priority for Chinese government should be legislation. By setting up various laws and enriching whole law systems, all levels of governments, corporations and individuals can restrict themselves in accordance with laws.

Meanwhile, internationally, all countries should work together to establish new law systems specifically for resources recycling. Modern countries have the rights and responsibilities to provide support to developing countries. By these efforts, global society can strive a balance between international resources recycling and economic development.

4.2 Environmental standard system

Over the international world, there are no other countries can advocate that the criteria system in their own country is complete and perfect, as a result, the first step is completing criteria system so as to maintain the resources recycling within the country safety and in good condition. Meanwhile, global world should work together to set up a whole system of ccriteria to evaluate and set restrictions to regulate their behavior, so as to better promote global resources recycling.

4.3 Industrial structures optimization

There's no doubt that developed countries do better than developing countries in their industrial structures optimization process. Since international resources recycling need input and output chains, global world should pay special attention to provent pollution industry shift, which will definitely do harm to developing countries. In view of present situations, international world should strengthen this industrial chain, protecting the rights of the weak parties.

4.4 Technological innovation and cooperation

Since policies are difficult to establish and be revised, maybe corporations can do something to update their disposal machines and production lines so as to increase profits. And also through cooperation with other countries, the corporations themselves will sure benefit. Meanwhile, global world should encourage the innovation of technology, and work in cooperately to handle and conquer difficulties. While developing countries, should make sure of technological patents, so as to make international technological transfer unimpeded and smoothly.

4.5 Environmental education

It is quite true that public environmental awareness in developed countries have nothing to blame, while, in developing countries, it is in need effort to enlarge and upgrade public awareness toward environment. This kind of education should exist not only in nature environment, but also in daily life as well. For example, from daily garbage classification to resources saving, from protecting water resources to full use of resources. By these approaches, environmental friendly society can be shaped and prolonged.

5 CONCLUSIONS

a) Due to different national conditions, law systems and economic situations between China and Japan, there are separated ways of waste disposal and recycle.

b) Waste disposal and recycle should meet the needs of a country's development. Recycling only for recycle cannot be a good choice.

c) Considering the issue of waste disposal and recycle, technological innovation should always be put into effect.

d) International cooperation will act as stipules in technological innovation.

e) As for international resources recycling, substantial suggestions have been made in order to promote this process.

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Post-Modern Engineering Science: Current Trends and Shortcomings of IT use in Knowledge Generation

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Abstract
Traditional ways of producing knowledge, solving problems, conducting business and making policies are undergoing a drastic change in both theory and practice. Major driving forces providing a multi-dimensional impetus for such a change stem from the post-modernism movement, newly shaped scientific paradigms, rapidly developing scientific instruments and technology, and the concept of sustainability. Despite this development, work on the role and impact of information technology on knowledge generation and concomitants influencing the way research is conducted has been quite neglected. In this paper the potential and shortcomings of current trends in knowledge generation based on data-intensive scientific discovery are analyzed and discussed.

Keywords:
engineering knowledge, know-how, simulation modeling, computational discovery, data mining

1 INTRODUCTION

Current forms of post-modern knowledge production feature a problem-solving methodology, in contrast with modern science, which is influenced mostly by the approaches and methods of empiricism and logical positivism. This problem-solving methodology is much broader and can be placed in an interdisciplinary social and economic context. Here, knowledge is acquired in a more exploratory way in the context of application, providing a strong problem-driven and practice-oriented approach. Various actors and stakeholders from different disciplines and fields of expertise provide a participative mode of knowledge production within a heterogeneous network that extends to various locations beyond the limits of the familiar and traditional institutions of higher education and research. Within this scenario, scientific activity becomes increasingly interrelated with and dependent on data provided by instruments and their proper analysis and interpretation. Here, advanced information technology (IT) in the form of computing machinery, software, and networks represents a key technology, which today is employed in every science and engineering field and discipline.

The remainder of the paper proceeds as follows. In section 2 the nature of engineering science and technological knowledge is briefly discussed. Section 3 provides some background on work in data-driven scientific discovery. In section 4 the trends and shortcomings of current approaches are presented and discussed, and these are summarized in the final section.

2 ENGINEERING SCIENCE AND KNOWLEDGE

2.1 The nature of science

Engineering science, either as an activity to generate engineering/technological knowledge or as a body of knowledge in itself, is different in nature from other sciences, though it also contains some elements to be found in most scientific disciplines. Perhaps its pragmatic orientation is what makes engineering science different from other sciences. Engineering science aims at generating knowledge and technology to modify the real world according to our needs, while other sciences seek knowledge about reality as it was and as it is. Since engineering knowledge is generated with the goal of producing an artifact or service aimed at serving a predetermined purpose, the pre-conditions of the problem-solving process are different from those in other scientific disciplines. In engineering science, problem solving is usually a task-oriented process, which has a defined beginning point and a specific goal. However, in other sciences, whether they be, for example, social science, life science, or natural science, scientific research has no such defined points, telling us exactly where to start and what to investigate. Although the problem-solving aspect in itself is in many cases not characteristically different in engineering science from that in other sciences, the termination criterion surely is. In the case of the former, problem solving ends when an acceptable solution, being verified and tested, is found. However, in the case of the latter, research continues by asking ever deeper-reaching questions, either to unearth further knowledge to increase

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insight and understanding of the subject of investigation or to find an example to falsify a current hypothesis or theory.

2.2 The nature of knowledge

Since both engineering science and engineering practice are strongly bound to technology and applications which need to work with as well as in the complex concrete reality encountered in the real world, the knowledge itself is different from that in other sciences, even though it also comprises concepts that have been derived from other sciences (cf. [1]). Hence, engineering is not just a form of applied natural science, as suggested in [2] and popularized in the 1960s and 1970s in philosophy and science and technology policy making. Due to its pragmatic orientation, knowledge in engineering science is usually more specific, being related to particular situations of application that cannot automatically and easily be transferred to other situations or even generalized. On the other hand, knowledge in other sciences, for example life science or natural science, tends to be universal, i.e. theories and models provide the same contents and outcome, independent of any particular situation or context. Engineering knowledge, sometimes used synonymously with technological knowledge in the literature, represents a body of different kinds of knowledge, with some not to be found in other scientific knowledge. Technical skills and knowledge about how artifacts or processes are to be operated and how they function, in the literature referred to as *know-how* (for original early work see [3,4]), are such examples. Note that this sort of knowledge is inculcated in the sense that one is able to supplement and perfect partial know-how and remedy misunderstandings, a typical exercise in developing competence. Engineers also possess knowledge about norms, i.e. know the character and properties of functions related to artifacts and processes. Normative knowledge, which can handle propositions about, for example, effectiveness and efficiency, is unable to deal with assertions of truth, and thus does not exist in other scientific disciplines. Knowledge represented in graphical forms such as diagrams, sketches and drawings, sometimes referred to as *visual knowledge* (cf. discussions in [5]), also represents a typical part of engineering knowledge. Declarative and procedural knowledge in the form of numerical data, formulae, and other formal or informal notations, in the literature also referred to as *knowing-that* and *propositional knowledge*, can be found across all academic disciplines from engineering and science to humanities and economics. Perhaps it should be noted here that this sort of knowledge is imported in nature, i.e. one knows that or not, in contrast to know-how, where individual subjects of knowledge and skills are usually in certain stages of development. The discussion above has outlined some characteristics of engineering knowledge, though it did not provide any specific details on its contents, which would go beyond the scope of this brief introduction. However, an overview and better understanding on this issue can be obtained by studying the taxonomies and critical comments given in [6,7,8].

3 DATA-INTENSIVE KNOWLEDGE DISCOVERY

Considering science as a problem-solving activity, knowledge can be generated by means of searching a space of possible solutions. Nowadays, vast amounts of data are available from different sources ranging from sensors that provide extensive environmental data throughout the year to immense data collections, sometimes in the range of petabytes, obtained through complex simulations and experiments. When these are combined with an advanced IT infrastructure, in most if not all scientific and engineering disciplines only semi-automatic data analysis and information representation approaches are feasible. Those approaches, which use computational tools, can be divided roughly into two groups, namely digital modeling/simulation and computational scientific discovery, and data intensive approaches referred to as knowledge discovery in databases (KDD).

3.1 Digital modeling and computational discovery

Employing models to either develop or test hypotheses, theories or designs is a common approach used in any science. Models created for this purpose are always an approximation of the real world representing a pre-defined set of properties of an artifact, process or phenomenon. However, models can also serve as a representation of events and things that are contrived. Particularly in engineering science, it is sometimes quite difficult to strike a balance between idealizing and abstracting as used in modeling and the need to produce concrete knowledge to solve a problem related to some application in the real world. Modeling always involves analogies in that a model is analogous to reality in only certain aspects. Different types of analogies relating to properties such as shape, structure and function are employed to create different types of models having a physical, graphical or notational (mathematical/logical) nature. To improve efficiency and reduce the time required to produce a physical or graphical model, especially in engineering science, various sub-disciplines, such as rapid prototyping and computer-aided drawing, evolved along with advances in technology. With advances in both computer technology and software engineering and the increasing need to quickly produce models that could easily be interrogated, analyzed and modified, and could grow in complexity as rapidly as the complexity of problems in post-modern science and engineering was growing, notational models translated into programs and implemented in digital form on computers gained in popularity on a scale unprecedented in history. Since mathematical models quickly tend to become quite complex, analytical solutions presenting precise mathematical proof are of limited use. Hence, approaches to solving the equations used in notational models have to resort to numerical methods, with the understanding that errors and uncertainty are almost always present in such numerically obtained solutions. This situation has led to computer simulation, or what is nowadays also referred to as *simulation modeling* or *modeling and simulation*. An overview of basic principles, individual process steps as related to design, implementation, execution, and verification/analysis of the digital model, including views from current practice, are given in [9,10].

The approach of computational discovery aims at producing knowledge that is in a standard scientific structure and notation such as reaction pathways, structural models and numeric equations [11]. This approach is somewhat complementary to the approach of knowledge discovery in databases, where, depending on the technique employed, either descriptive or predictive models are generated in the form of rule sets, decision trees or neural networks. Although knowledge discovery is not very communicable, computational discovery, on the other hand, seems to be capable of overcoming many hurdles in the communication of knowledge in various scientific and engineering disciplines. Work on computational discovery aims basically to design and develop computer systems that are capable of producing scientific discoveries similar in nature to those made by human scientists. Since science is a remarkably complex intellectual endeavor, with discovery being perhaps the most creative part, efforts to automate it even partially seem audacious and far-fetched at first. However, by approaching this goal through a heuristic search while focusing on small, well-defined tasks, some initial progress could be made, as suggested in early work in the 1960s [12]. Research based on this approach translated in the 1970s and 1980s into computer software [13,14], which was based on data-driven induction of descriptive laws. At that time, employing those first computer programs in experimental work on historical examples provided not only promising results, but the first compelling evidence that computational scientific discovery is possible. Recent examples of progress in this field, including the establishment of models of dynamic systems based on ordinary differential equations, the automated discovery of quantitative laws (expressed in the form of equations) in collections of measured data, and the formulation of equation-based models and laws from observed data, are presented in [15]. Computational scientific knowledge discovery is still in its infancy, with work in progress and successful applications in practice lagging far behind other approaches such as data mining, discussed elsewhere in this paper. Nevertheless, the work and results in this field are a valuable contribution to the ongoing and rapidly growing body of research on computational tools and techniques for post-modern technology- and data-driven knowledge discovery.

3.2 Knowledge discovery in databases

The methods and techniques developed and applied in KDD are aimed at making sense of data sets and, considering the rapidly growing volumes of data being collected and stored digitally, it is preferable to target huge data sets. Classical methods of data analysis in science and engineering are no longer either practical or feasible, since they involve the use of statistics for manual probing of the data by individual domain experts quite familiar with that data. A drastic scale-up of human analysis capabilities by utilizing information technology is what is required to deal with the data overload generated by today's advanced technology. Although the basic methods and techniques developed in KDD are related to research in artificial intelligence, pattern recognition and machine learning and are used for such problems as summarization (high level viewing of a data set), prediction (regression) and classification (discovery) of patterns in data, they are similar in nature to those in statistics. However, techniques such as neural networks and decision trees, used in the inference process, tend to be more robust to noise and uncertainty in data, while at the same time less dependent on analysis skills and the subjectivity of individual domain experts. However, basic issues regarding clean and consistent data, well-defined analysis targets and prevention of data/model overfitting are as important for data mining as they are for classical statistics if one is to generate robust and sound results. Knowledge discovery in databases is an interactive and iterative process involving numerous steps ranging from data cleaning and pre-processing, through data reduction, selection of particular data mining methods, and determination of model and hypothesis employed in the exploratory analysis, to the interpretation of mined patterns and translation into knowledge [16]. Results from the actual data mining step within KDD depend on the method and model selected and can be represented, for example, as decision trees, classification rules or networks. Perhaps the last mentioned are the most difficult to interpret due to their hidden internal nodes and their complex models being captured by link weights. On the other hand, in the case of decision trees, rules can be translated into any natural language, such as English, to explain why a prediction was made for a particular entity. An overview and more details on classic and advanced methods and techniques of KDD can be found in [17]. Early work on KDD evolved with a highly interdisciplinary nature because of the intersecting research fields involved, such as knowledge acquisition from expert systems, pattern recognition, machine learning, database systems, data visualization, and statistics, to name but the most prominent. An overview on research issues and applications in science-related data mining in the 1990s is given in [18]. KDD is comprised of a set of individual processes developed into a methodology aimed at covering the entire process of massive data-based knowledge discovery ranging from how data is stored and accessed to models and algorithms that can be scaled to datasets ranging in size from terabytes to petabytes, thus encompassing methods and techniques reaching beyond the scope of their disciplines of origin. Progress made in KDD, in particular methods and techniques for data mining which have resulted in next-generation data mining systems covering various application fields including natural science, engineering science, social science, finance, and medicine, are discussed in [19].

4 DEVELOPMENT IN THEORY AND PRACTICE

It is the nature of engineering knowledge that it is technology-related, application-oriented and a problem-solving process. Engineering is itself strongly biased towards solutions that are not only feasible in practice, but also effective, and wherever possible efficient as well, in contrast to, for example, natural science, where problem-solving is more problem-centered. Therefore, discussions in the following focus on three particular directions, namely approach-, technology-, and application-related issues.

4.1 Approach-related issues

Some of the shortcomings, which still prevail in data-centric approaches to knowledge discovery can be attributed to the way in which data, with their values and properties, are abstracted and formalized. In our lifeworld (cf. [20]), concepts are formed by the human mind, while reflection upon the environment is subject to experience through the human senses. In science and engineering, concepts can be seen as epistemic capacities, or as cognitive or abstract units of meaning that can be used in the development and testing of hypotheses and theories. In digital models and sets of data stored in information systems, in most cases data entities and their relationships are structured using concepts within a system of categories forming an ontology, which acts as a kind of formal explicit specification of knowledge representation related to a particular domain. As post-modern problem solving demands interdisciplinary and multidisciplinary solutions to problems with ever-increasing complexity, data entities of databases, data repositories, and data warehouses from different domains and disciplines need to be considered and analyzed. However, data modeling and value definition are strongly domain specific, so misunderstandings and misinterpretations arise if systems and experts have to deal with data sets which are not within their domain and expertise respectively. Such problems mainly occur due to misunderstandings regarding entity value semantics and concept/category relationships. For example, in the case of the former, the property of being easily set on fire might be related to the term *flammable* in one domain, while within another domain the term *inflammable* might be used instead. This is a situation which, at the current level of system development, can be remedied only by human intervention. The latter, though discussed in a philosophical rather than technical context, has been referred to as *category mistakes* [3] and is not addressed in practical approaches or in any available software system.

Another source of concept-related misinterpretation of data sets is the changing of data distribution characteristics, i.e. the instability of statistical properties of the target variable within a data set, to obtain a correct predictive model. This phenomenon is inherent in many data streams subject to analysis, though most prominently in those related to biological, socioeconomic, product life cycle, and environmental processes, and is commonly referred to as *concept drift*. Data streams, in contrast to traditional static databases and data warehouses, are comprised of an ordered sequence of entities that arrives in timely order. Due to the increasing interest in and availability of data streams both online and offline, this issue has received considerable attention in the research community in both academia and practice, with many solutions partially overcoming this problem for techniques and algorithms used in knowledge discovery and data mining. An overview and further details on basic and current approaches, such as periodic retraining, also known as model refreshing, weighted ensemble classifiers and cluster models, as well as sliding window based classification, to name but a few, are provided in [21,22]. Current international research in progress addressing approach-related issues regarding time-changing data streams to capture the dynamics of patterns, i.e. how they evolve, grow and decrease, seems to be promising. However, technology-related shortcomings such as parallel computation (in distributed systems) to keep the mining process up with the high-speed characteristics of the data streams, and frequent encounters of local low data storage and transmission capacity in current imbalanced IT infrastructures, still impose considerable limitations on those solutions.

4.2 Technology-related issues

Hardware-related technological shortcomings can be attributed to the increasing imbalance of IT infrastructures regarding the development of the capacity to generate, store and process data compared to the capacity to access and transfer data. Taking a brief look back some three decades from now, hard disk based storage capacity was in the range of 30 megabytes for a regular single device at around a quarter of a million dollars of cost for one gigabyte of storage capacity. Within only three decades, hard disk based storage capacity of single devices has increased in the magnitude of 10^5, while costs have dropped in the magnitude of 10^6. A similar trend has taken place with the development of computational capacity and control processing unit (CPU) technology. Compared to those feats in computation and storage technology, developments in interface standards and technology seem to pale. For example, even after three decades of innovation and development newly introduced standards such as the serial advanced technology attachment (SATA), are only able to support a data rate at 3 gigabits per second. With current trends in data-intensive scientific discovery utilizing data in the terabyte and petabyte range, access and exchange technology poses a severe bottleneck. Until technology in this field can catch up with developments and facilitate adequate data bandwidth, new strategies, such as bringing the processing and analysis to the data, need to be pursued as interim solutions.

One of the soft technology-related shortcomings which is still most prominent can be attributed to the representation of mining models. Since data mining models usually generate results which were previously unknown, it is important that they are represented in a form that facilitates understanding and trust in respect to the domain context, so that this information can in turn be translated by human experts into new domain knowledge. Considerable progress has been made in information visualization technology, providing interactive, multi-dimensional information displays where users not only view results dynamically, but also interact with the visualization in various ways. Thus, analysis and understanding of a wide range of mining models has been achieved. However, currently available KDD systems still do not take full advantage of advanced visualization technology, nor do they provide sufficient interfacing with other computer-aided data representation, analysis and decision tools.

4.3 Application-related issues

Current approaches such as simulation modeling, knowledge discovery and data mining are not only data-intensive, but also data-centric, due to the focus on their structure and values during the knowledge generation process. Accordingly, the quality of data is of utmost importance, though in research practice, when these approaches are applied, the scale and extent of this fact does not always seem to be taken into account fully. Data quality in the literature is usually related to attributes such as consistency, completeness, accuracy and precision, and timeliness [23]. However, aspects of data deficiencies related to their representation and interpretation still do not get the attention they deserve. In particular, data representation deficiency, seen as the difference between how an observer infers a view of a phenomenon from data provided by a system and the view that an observer obtains by directly observing the same phenomenon in our real world, is a problem in the case of technology-driven natural science and engineering science. This situation is in contrast to other disciplines, where, for example, socioeconomic phenomena can be observed almost directly without much necessity for the mediation of technology in the observation itself. Technology-mediated observations of phenomena (cf. [20]), or even technology-generated phenomena, contain considerable amounts of technology-related knowledge on how the observation was performed, i.e. how the data were generated. However, today, in almost all databases, data warehouses, and data streams, this sort of information, which is actually an important element of data quality, perhaps on a higher level than the data quality attributes outlined above, is not available. Of course, for the domain experts and data analysts who also created the data subject to knowledge discovery, a great deal of knowledge is available on how those data were created and which technologies and methods were employed. Hence, interpretation and proper selection of discovery and mining techniques, along with appropriate predictive models, can be employed to translate the endeavor of data-intensive knowledge discovery into a successful scientific activity. The trend to consider what is referred to in the literature as *data provenance* (see also [24]) is surely a step in the right direction, but it is still far from capturing all the information related to this 'how-knowledge' along with the data, and describing the context and conditions relating to how the data were generated, i.e. how the observation was executed, using what technological means and in which way. Perhaps this issue is a problem that should be considered within ontology engineering, a sub-field of knowledge engineering, where development, life cycles, and building the tools of ontologies are at the center of research (cf. [25]). This is in contrast with classical approaches to ontology, originating in metaphysics, which were concerned only with fundamental categories in regard to what exists in our natural world.

Another shortcoming, in particular of data mining models, is the fact that they can reveal connections between data entities and their attributes, but do not necessarily identify a causal relationship. In some applications this may be contributed to by so-called *latent variables*. As opposed to observable variables, latent variables relate to phenomena that are either abstract and not observable (hypothetical) or simply not explicitly present (hidden) in the data model. The latter case represents a typical example of the problem many applications are facing today, namely that the data sets subject to analysis were not designed for the purpose of data-centered knowledge discovery, and thus feature a data structure less appropriate for this type of inquiry.

5 SUMMARY

Current trends have been discussed, together with a selection of problems of an apparently perennial nature regarding major knowledge generation approaches in science and engineering that are moving toward being computational and data based. Due to the nature of engineering knowledge, discussions were sub-divided into approach-, technology- and application-related issues. The more science and engineering are embedded in technological infrastructure, especially that which is IT related, the more that infrastructure is likely to drive them. Indeed, work pursuing scientific and engineering understanding through the use of advanced computing technology, and involving vast amounts of data, is increasing dramatically. In fact, this tremendous impact of IT on theoretical and experimental research has even begun to cause signs interpreted as the rise of a fourth data-driven and data-intensive science paradigm. However, at the current level of development, this data-intensive scientific knowledge discovery should not be mistaken for an attempt to automate creative modeling and the synthesis of new domain knowledge. These highly intellectual capabilities of human experts are still far out of the reach of any computing machinery.

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Creating Sustainable Emotional Value through Personalized Design

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Abstract
In addition to visible sustainability issues like materials and alternative energies, the sustainable emotional value between consumers and products is also important in sustainable design. Products emotional value comes from the meaning products to consumers. Personalized products and personal emotion are closely related, so put forward to explore the personalized product design strategy to improve the consumers' emotional value to products. In this study, through related literature and case analysis, we conclude that sustainable design emphasizes the value creation of the design, which must be durable and amicable to the environment. Personalized commodities also create value, a kind of sustainable emotional value. From the standpoint of sustainable design, the higher the consumers' emotional value to products is, the longer the product's service life is, leading to a stronger intention to recycling and reuse.

Keywords:
Sustainable design, Personalized design, Emotional design

1 INTRODUCTION

In the past, we did mass manufactures, mass consumptions and also excessive wastes. Gradually, environmental protection and environmental sustainability issues had been highly discussed. We started to rethink what we can do to the damaged environment. So are thinking about how to make the earth healthy and sustainable regardless of in sociology, economics, environmental engineering or other fields. So, since the destruction is caused by human, we think it from human, from the point of design, to change consumers' concept to sustainability. By designing, we put sustainability into a force. If the product is perceived to be irreplaceable, other products in the market cannot convey a similar meaning to the owner. Replacing and disposing of such a product is thus perceived as a loss of its special meaning. As a result, the experience of attachment to a product is likely to last over time, resulting in product longevity (Mugge et al. 2005).

1.1 Research Background and Motivation

1.1 Paper title and authors

With each country's policy and consumers' attention to environmental issues, the society who did the mass production and mass consumption causing excess substances past has gradually realized the importance of environmental protection. From the concept of environmental protection, recyclable resources, production process and materials must not harm the earth ecosystem; alternatively, old things can be redesigned and reused through regeneration design; all these is one of the many aspects of sustainable design. So to promote sustainable design is an important trend in design community. In addition to visible sustainability issues like materials, alternative energies, the sustainable emotional value between consumers and products is also important in sustainable design. It is common among people that they will especially love and cherish certain commodities, for which, even if damaged, they would still unwilling to discard but will be willing to do the repair or to redesign for reuse. This is all because the goods have high emotional value to people. By improving consumers' emotional value, the products will emerge some kind of meaning to consumers and thus be more cherished and used and have prolonged life; or an old but meaningful item will be given a brand-new look.

1.2 Research Purpose

Personalized design start from consumers' demand, different from the products mass manufactured. To consumers, personalized design meets their psychological needs of pursuing being distinctive and unique, so as to demonstrate their personal style and taste. It takes "difference design" strategy, personalized products designed through which not only have functions meeting different customers' needs, but also satisfy consumers' wish to create their self images and taste through products. Therefore, if the personalized merchandise appeals consumers to have emotional causes, the emotional value of products will be enhanced.

The purposes of this study: 1. Discussion on personalized design and how to enhance the emotional value of products. 2. The increase of the emotional value will influence consumers' sustainable practices.

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2 RELATED LITERATURE

2.1 The value of personalized design

In the past age of the mass production, products satisfy consumers' pursuit of "excellent quality and reasonable price" by means of low cost and considerable quantities. But in this era of the ever-growing individual consciousness, the pursuit of consumers is out of the ordinary goods. For them, to meet the self realization of personalized products is unique. The mass production of the sense of value is far lower than the customized product. According to theory of hierarchy of needs proposed by Maslow in 1970, human demand level is divided into five levels. Once basic physiological needs are met, people will continue to pursue to a higher-level demand. Similarly, after consumers' basic needs are satisfied by mass production of goods, a higher hierarchy of needs will be pursued and product development and production mode must change according to market demands. From current limited design goods or tailor-made goods emerging in consumptive market, it can also be seen that belongingness needs, esteem needs and self-actualization needs increase as economic ability and social status enhance.

As shown in Figure 1, positioning of personalized design is obvious after comparing Maslow's hierarchy of needs theory and Hancock's hierarchy of ergonomics needs with transformation mode of manufacturing. So, value of personalized product lies in its uniqueness that is different from mass-manufactured goods. After understand consumers' demands through communicating with them, designers can design the goods to meet consumer expectations, such as specific function, modeling, image..... Nowadays, customers not just pursue product function and aesthetic feeling, but the more important is to convey their self image. People utilize various ways such as: clothes, food, cars or entertainment style to create the image of who they are and their unique features. These external materials preferred by consumers can reflect their self image, personality and taste, and personalized merchandise is in response to this trend. Personalized design takes strategy of differentiation design, because when spiritual need rather than mass production is pursued, products should be able to express consumers' unique tastes, preferences and personality in addition to having functionality. Therefore, personalized design has its value and a position in the market.

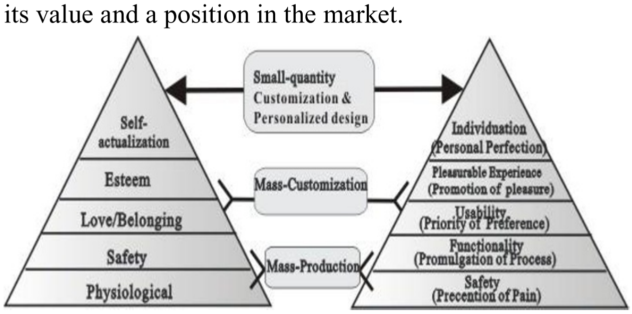

Fig. 1: Production mode

2.2 Emotional Design

Human emotion is the most abundant, including happiness, anger, grief, joy and other mental activities. Emotion has its particularity and presents different personal traits. Integration of emotions into products can improve product difference. As Normand (2005) said, emotional value is a valuable target in terms of product design. Excellence in design is about more than the product itself is. It is about creating positive, rich and meaningful user experiences. Consumers are ever mindful that the products we surround ourselves with and engage with during our daily tasks need to satisfy needs beyond the functional (Deana McDonough a; Howard Denton B; Jonathan Chapman, 2009).

Modern product design is also an activity about emotion activity, and an emotional design process, rather than the development of early simple appearance modeling process. With the wealth of material, and the ever-accelerating pace of life, people's demand on spiritual satisfaction becomes more pressing; people's requirement of product is no longer only on the material surface, but deep emotional appeal is more important. Emotional design language or design elements should make people feel, well, so will stick, and resonance also arises spontaneously.

2.3 Personalized Design, Sustainable Design and Consumption

Sustainable design takes into account environmental, economic and social impacts enacted throughout the product (Bhamra, Lofthouse.2007). So when product development model for groups gradually converts into personalized design mode, the product manufacturing processes have also been changed. Mass-manufactured products are lack of affection, because they are readily available. Therefore, such products have shorter life cycles and are eliminated quickly. The application of sustainable design strategies can greatly reduce lifecycle impact (Lewis et al., 2001). The designer's role is to head to the sustainable design thinking to shape consumer behavior to make it towards the sustainable direction. In addition, in terms of consumer behavior, mass production and mass consumption in past cheap-supply market generates too many disposable products, which bring burden to environment and threats to human safety. So, in policies calling for being environment friendly, the appeal of "sustainable consumption" is also important. User Consumption has been a long-standing concern for sustainability (Ann Thrope, 2010). The concept of sustainable consumption emphasizes that individual, corporate, government, and other units should be responsible to consider the future as a life or the existence way owned by people now; humans and other species should share ecological resources to survive and ensure that people's needs will be met both at present and in the future.

Stewart Walker(2006) said in "Sustainable by Design": product design should not value dazzling appearance and continuous replacement; it is better to focus on product performance that can be used for many years and make consumers have more time to feel the inner spirit of the product. Product personalization is an interesting strategy to stimulate long-lived product attachment and, thereby, contribute to a sustainable society, because consumers may perceive the personalized product as irreplaceable. So, personalized design is to enhance value and significance of product in consumers' minds. When the item is unusable, consumer will wish to recycle and re-create product value. Thus, consumers not only change

3 DISCUSSION OF DESIGN CASES

Taking a look at the concept of the sustainable design, we can find a lot of practical design cases. Some designers collect the recyclable materials, transform them and then sell them, while some other designers are entrusted to design and transform. For example, in the year 2009, an activity named "You bring it, we pimpin it" was held by a group of Dutch designers in Hong Kong. "Pimpin" means "beautification" in Dutch, so a lot of people brought the things that is meaningful to them for transformation. Turning the old objects totally into new ones is not only relevant to the environmental-friendly issue, but also helps those old things find a new place in the hearts of their original owners.

Table 1 :Redesign and Reuse Cases

Objects	Why to redesign ?
	1.The cups that are stored up for long and seldom used. While the owner is unwilling to discard them, so they are transformed into lighting decoration.
	2.「Wool Filler」Wool Filler's favorite sweater is worn but he is reluctant to throw it away, so he has the designer to redesign it.
	3.Empty bottles are usually used as vases. Why not change the stereotype to make it a lamp.
	4.This pair of wooden duck is a wedding souvenir. Because there are a lot of damages, the designer transformed it into a pair of door stops. This transformation not only retains the object, but also makes it more functional. (www.fangstudio.com)
	5.The owner's old pictures and files are already dead with the computer in its hard drive. However, the designer decorated the hard drive with glossy materials and makes it look like a book, which means the reunion of him or her with the memories. (www.fangstudio.com)
	6.The iron chair, even though is old and broken, but being used for years, the owner still cannot bear to discard it. Being transformed, it is more comfortable to sit on with a cushion. The old stuff is given a brand-new look and can be used longer. (www.fangstudio.com)

4 GENERAL DISCUSSION

This study observed and analyzed the current transformation and redesign of the products and found that many people are willing to transform their old products. And this willingness of re-use is caused by the emotional link with the products. So to prolong the life cycle by enhancing the sustainable emotion link from the customer to the products, we recommend these psychological impacting suggestions:

(1) Personalized design strategies

The use of personalized design has a high sentimental value to the consumers. This method, by customizing appropriately seizes the sentiment level of the consumer mentality. When thinking of the personalized design strategies, the customers past experiences can be taken into consideration on the one hand, because one's past memories and experiences are the most distinguishing differences. On the other hand, you can also start from one's five senses, which is disparate from person to person. For example, the familiar colors, sound, smell, texture and so on, can all serve to promote the customers' sentimental value so as to prolong the products' life cycle and further raise up its added value.(Fig.2)

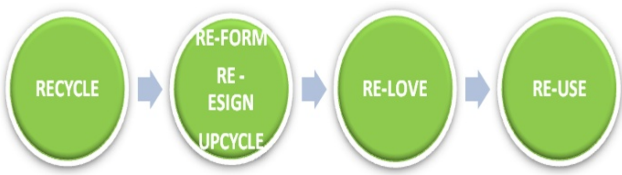

Fig. 2 : The lifecycle of Personalized design products

(2) Customer Co-Design:

Companies become interested in moving from mass-orientation to an individualization of offerings. A promising strategy is to offer consumers a role in the product development process through product personalization (Ruth Mugge, Jan P.L. Schoormans, Hendrik N.J. Schifferstein, 2009).The most intimate objects are the ones that we made by ourselves (Norman, 2005). There are a lot of ways for the consumer involvement in the design: offer of the idea for the design or do it yourself. What we are talking about here is the offer of the concept, the story, and the memory and so on. By communicating with the designer, a personalized product is accomplished. For the consumers, the involvement in the design itself is already a satisfaction of self-fulfillment. As a whole, the consumer participation is needed in the personalized design; the extent of the consumer involvement (like the provision of the information) will affect the degree of the product personalization.

5 CONCLUSIONS AND SUGGESTIONS

Since all designs will have an impact on the environment from the design phase, we should apply recyclable materials and consider how to prolong the products' life cycle in designing to reduce wastage of the resources. Therefore, promoting the sentimental value is one of the sustainable designs. Nowadays, the consumers turn from intelligent consumption to perceptual consumption, their subjectivity become stronger and the demands for the products are varied, differentiated and personalized, so their patterns of consumption are controlled by their emotional feelings. Therefore, from the perspective of the emotional value, the personalized design strives to make meaning of the products to their owners. This strategy is to promote the emotional value of the products, make the consumers love their products and improve the situation of ecological damages caused by the bad habit of wasting. The promotion of the sentimental value arouses the interests of consumers' future "redesign" and "re-use" to achieve the value creation emphasized by the sustainable design. Truly living sustainably and develop sustainably on this beautiful planet. This study suggests that an emotional magnitude of value should be made in the future so as to test the factors that affect the intensity of emotional value. It is already put into use in the personalized design and promotes the sustainability of the products' emotional value.

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A consumption based LCA tool for housing management

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Abstract
The housing sector accounts for roughly 30% of the total annual energy consumption in the developed nations. Notwithstanding, sustainable housing management has not received sufficient attention previously, even though the role of housing managers can be considered significant in reducing the energy consumption of existing residential buildings. This study proposes a concept for a comprehensive and consumption based carbon management tool for professional housing managers. The tool employs a tiered hybrid life cycle assessment approach to evaluate all emissions derived from housing company activities. This paper explores the attitudes and ideas of the housing managers themselves. Based on the interviews, it appears the managers and their clients would benefit from the easy-to-use, quick and non-labor or data intensive tool.

Keywords: housing management, IO-LCA, energy consumption, greenhouse gas (GHG) emissions

1 INTRODUCTION

The built environment accounts for roughly 40% of the total annual energy consumption in the developed nations. Furthermore, the housing sector alone accounts for approximately 30% of the same, and a significant share of global greenhouse gas emissions derive from activities associated with housing [1]. Fortunately, the building sector also has a lot of potential for reducing said emissions. To exploit the potential, much research in the field is needed.

Building characteristics naturally have a significant effect on the energy consumption, and consequently, greenhouse gas emissions of buildings. The amount of greenhouse gases also depends heavily on the energy production mode. However, it is often disregarded that housing managers, through their practices and policies, have direct influence on the environmental performance of buildings, including the energy consumption. A previous study by the authors suggests that in multi-family apartment buildings with a district heating system, individual occupants have limited potential to influence the energy consumption of the dwellings [2]. In fact the housing management company controlling the heating system will inevitably have a higher impact on the overall energy consumption. The role of managers have previously been studied for both commercial buildings, i.e., facility management [3-5] and housing [6-8].

The background to this study is a multiple case study of several different types of housing companies from the Helsinki Metropolitan Area, Finland. The case study utilizes a hybrid LCA method for greenhouse gas emission estimation. The data sets comprise annual economic inputs retrieved from the financial statements of the housing companies as well as metric consumption data reported by housing management. During the course of research, the idea of the possibility to share the calculation tool utilized by the researchers with housing managers, as managers readily hold the data required. The idea emerged, that the input-output based LCA method, which is relatively quick and simple to use, could in the future be easily utilized by housing managers to estimate the carbon efficiency of the housing companies they manage. The purpose of this paper is to investigate the attitudes of the managers towards such a tool. The main motivation is that housing managers could develop the environmental efficiency of their practices and thereby take part in the challenging task of reducing the environmental effects of the built environment.

The remainder of the paper is structured, as follows. The next Section describes the Study design describing both the GHG calculation tool and the case study with interviews. The results of the qualitative study are then presented in two phases in the following Section. The final Section discusses the findings, and draws conclusions regarding the future use of the tool.

2 RESERACH DESIGN

2.1 The employed model

The tool introduced in this study estimates annual carbon dioxide equivalent (hereinafter CO2e or GHG) emissions for housing companies with an application of a tiered hybrid LCA method. The method has been previously employed by Kyrö et al 2011 [2]. The method is based on the Carnegie University’s Economic Input-Output Life Cycle Assessment Model (EIO-LCA) [9]. However, the most significant processes producing carbon emissions are replaced with local process level data.

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In other words, the strengths of the two traditional LCA methods, process LCA and input-output LCA (IO-LCA) are combined. Thus, the truncation error inherent to all process LCAs is somewhat reduced and accuracy compared to direct IO-LCAs slightly increased [10-11].

The main data needed to use the tool comprises annual reports and financial statements of housing companies. Typical housing company related activities are divided into the following nine (9) cost categories:

1) Management and Administration
2) Cleaning and Maintenance
3) Repair
4) Water and Wastewater
5) Heating
6) Communal Electricity
7) Waste Management
8) Insurance
9) Real Estate Tax

In addition to the financial data, annual reports compiled by housing managers provide consumption data for the two categories producing the most GHG emissions, namely, Heating and Communal Electricity. For these two categories, the production phase emissions are replaced with either national or local process data. The calculated national average "g/kWh" emissions for district heating, electricity and oil may be utilized as appropriate. Employment of the method within a case study from the Finnish capital Helsinki is described in detail in Kyrö et al 2011 [2].

2.2 The case study

A multiple case study of housing companies from the Helsinki Metropolitan Area, Finland was the basis for this paper. Several different types of housing companies (condominiums, townhouses) with different demographic structures from the Helsinki Metropolitan area are included in the case study. The case study enables demonstrating both the utilization of a hybrid LCA method for GHG emission estimation, and the possibility to use the tool for carbon management.

In field research and in management studies in particular, understanding activities and phenomena that are less established benefits from the use of qualitative data and research methods [12]. In order to obtain insight on the management policies practices of the housing companies included in the study, interviews of the housing managers were conducted. The interviews also aimed at learning about the manager's general opinions and attitudes towards energy management, and potential interest towards the tool. The interviews were conducted as semi-constructed interviews.

The 25 housing companies were managed by 9 different Finnish housing management companies in 2008, the year of the data. All nine were contacted with requests for interviews. Two of the managers were no longer managing the housing companies in question or had gone out of business. The remaining seven all agreed to be interviewed either in person or via telephone. At the time of writing this paper, five interviews had been conducted in September 2011. The five interviewees manage 12 of the 25 housing companies, i.e. represent 48% of the housing companies included in the sample.

The interviewees were asked about their views on their own potential to manage GHG emissions, as well as what they thought of the possibility to using the described tool. The responses and ideas were transcribed to form an understanding of the overall usability of the tool, as seen by the managers.

3 MANAGEMENT INTERVIEWS

This section presents the findings of the management interviews. Illustrative data, i.e. excerpts from the interviews are used to provide better perceive the managers attitudes. The data are grouped around a few central points which emerged from the interviews.

Overall, the managers had a positive attitude towards the utilization of the tool. The attitude mostly stemmed from the rise of the eco-conscious views in society in general, as clearly stated my one manager:

"I think a lot of people would be interested as these things are becoming more and more popular, especially with the younger, more conscious residents. People would like to know their own carbon footprints."

When asked whether managers would consider using the tool themselves, the most critical factor seemed to be the fear of an increasing work load. The managers maintained that the tool should be made as simple as possible, so that using it would not be time consuming.

"Where would we [managers] find the time? Depends on how quick and simple it would be."

"The tool should be easy and simple to use. It could also encourage managers [to behave more eco-efficiently]."

"…it appears things are going into the direction of housing managers taking care of everything… but I guess that's okay."

With regard to the positive effects of the tool, proper communication of the results was considered essential. Some managers expressed particular concern for the potential misinterpretation of the results.

"The results would need to be communicated well to the residents, so that the numbers are not misunderstood by your average Joe. We would not want anyone to move out,

because they thought the CO2 emissions were too high. You would have to be careful with that."

"…communicating the results properly would be the most important thing."

One manager suspected that, although a good idea, this type of tool would only attract a limited clientele. The manager in question managed properties lower income level areas and did not see the tool as useful to his clients.

"…I think it would really be of interest only to something like 5% of housing companies, the ones with an eco-conscious resident base, or the ones with a long term strategy which includes environmental goals."

Indeed, it has been stated before [8] that environmental goals are not a priority for managers and financial issues are favored over the environmental ones. Discouragingly, similar ideas emerged from the interviews as well:

"Using the tool would be more of a 'nice-to-know' thing… in the end it is the Euro that counts!"

The profitability of using the tool was clearly seen as an issue. The interviewees pondered over the commercial potential and marketability of the tool.

"I'm not sure how we would sell it to the client [housing company]."

"We would need to see a demo version, have someone else use it first in their annual report."

Interestingly, even though all interviewed managers considered the tool a viable idea, no one expressed a desire to be a forerunner in the issue. One interviewee considered the possibility of the government making CO2e emissions calculations mandatory, similar to energy certificates.

4 DISCUSSION AND CONCLUSIONS

The purpose of this study was to explore the possibility to use a tool developed by the authors for carbon management of housing companies. As housing managers readily hold both financial information and metric consumption data of the activities of the housing companies they manage, an input-output based hybrid LCA technique, which is relatively quick and simple to use, could in the future easily be utilized by housing managers. With the tool, housing managers could develop the environmental efficiency of their own practices and thereby take part in the challenging task of reducing the environmental effects of the built environment. Engaging housing managers to this type of proactive involvement would be of essence, as a previous study by the authors suggests [2], that housing management may have a more significant impact on the energy consumption buildings than individual occupants.

The tool is currently in MS Excel format and, although relatively simple to use, a more user-friendly interface would be needed prior to introducing the tool to professional managers. Moreover, housing managers will need help in promoting the tool to their clients, the housing companies. It should be emphasized how the tool will enable comparisons between housing companies from different eras, house types, and technical standards. A further advantage to managers is the possibility of scenario building and benchmarking.

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Energy efficiency in logistics – Potentials and limitations

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Abstract

New modes of production call for new modes of distribution. Just-in-time or just-in-sequence manufacturing for example presuppose more frequent information, freight, transport and vehicle flows. Particularly in connection with transport and logistics negative impact and pollution occur when emissions exceed assimilative capacity. Transport has a number of environmental side effects. These impacts arise through the emission of pollutants, through land-take for new roads for example and as increases in noise levels. Nevertheless, many instruments introduced in the transport system failed to reach their target since gains in global environmental efficiency have not been enough to cope with the consequences of the obvious transport growth. For all that, within the large body of work referring to globalization, internationalization or free trade agreements, transport is not regarded as an important issue, it is rather taken for granted. Classic trade theory for example neglects the role of transport and logistics. In the paper, the scope of interference regarding an enhancement in energy efficiency and carbon dioxide efficiency, which implies an emission reduction, is analyzed. It is tried to get to the bottom of the impact of the configuration of economic activities on traffic flows by an extensive and structured literature review and content analyses in the field of New Economic Geography. The degree, to which logistics principles and requirements are becoming decisive for organizational and location decisions is scrutinized. It is assumed, that political and market-based instruments determine the nature of transport and logistics and therefore hold appropriate potential for alteration in this field. An enumeration of adequate instruments in regard to the demanded energy efficiency in logistics will be given. The aim of this paper is to identify potentials and limitations for an energy efficiency enhancement in logistics and transport by applying principles of the New Economic Geography in a logistics context.

Keywords:

Logistics, Energy efficiency, New Economic Geography

1 INTRODUCTION

The frequently cited globalization comes along with a modification and reconfiguration of freight transportation due to dynamic material, goods and information flows. The impact and emissions respectively caused by transportation are obvious. Taking a closer look at the transport sector within the EU-27 clearly shows that road transport was the most energy consuming mode throughout the last decade. Its share amounts at 81 % of the total in 2008. It is followed by air transport with a share of 14 %. Inland navigation and rail transport consumed around 2 % of the total. Furthermore air transport was the fastest growing sector between 1998 and 2008 with 33 % overall increase for the EU-27. Road transport experienced an increase of 12 %, while energy consumption by rail and inland navigation declined by 3 % and 11 % respectively. [1]

The following picture shows the final energy consumption by the different modes of transport:

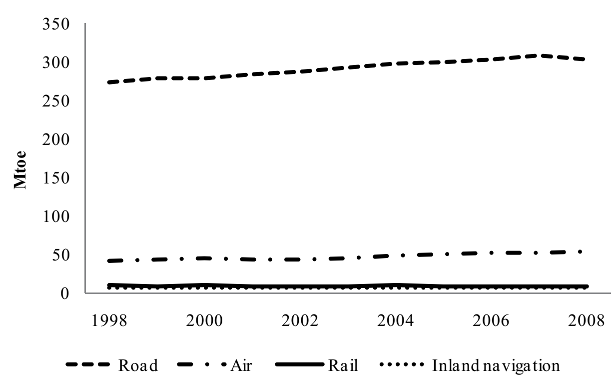

Fig. 1: Final energy consumption by mode of transport

In addition, the European Union certifies the transport sector a potential of 26 % regarding the reduction of energy consumption. The transport sector both depicts a major environmental risk due to its greenhouse gas emissions and a significant factor for the dependency on fossil fuels. [2] A macroeconomic point of view clearly outlines the relation of an economy and the efficiency of

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transport systems. It goes without saying that an appropriate capability of a transport system, depending on various geographical influences and determinants, is an essential prerequisite for an adequate fulfilment of the demand given, the higher division of labour and increased competition respectively in the domestic market as well as in foreign trade. Conversely economic prosperity entails an increase in the need for transport services. [3] New modes of production call for new modes of transport. Just-in-time and just-in-sequence manufacturing for example presuppose an increased exchange of information, freight transport volume and therefore augmented vehicle flows.

Consequently, transport flows are indispensable connected with economic activity levels in the production and household sectors. This linkage offers a first insight into the New Economic Geography (NEG) literature, whose models and findings are at the moment primarily theoretical. Particularly transportation interacts for example with urban development via real income effects, housing demand and mode choice. [4] Anyway its worth having a closer look on the propositions made within this framework concerning the configuration of economic activities and the transport flows resulting from these allocations.

2 THE NEW ECONOMIC GEOGRAPHY

2.1 An overview

New Economic Geography is the second among neoclassical agglomeration theories. It tries to get to the bottom of agglomerations at meso and macro levels. It scrutinizes the formation of agglomerations and the conditions required to keep their setup. As a matter of principle it is assumed, that agglomerations observed do not result from inherent differences of locations but can rather be attributed to so-called circular causality and cumulative processes. [6]

2.2 Key features of the New Economic Geography

Geographical economics takes as its starting point the fact that economic activities are, clearly, not distributed randomly throughout space. Taking a closer look at any map immediately shows that the clustering of people and firms is the rule and not the exception. Geographical models are often hard to analyze analytically, due to the fact that its approaches rely to a large extent on simulations which are supposed to determine the distribution of economic activity across space.

Trade theorists are mostly interested in how market structure, production techniques and consumer behavior interact. Factor and commodity prices resulting from these circumstances are supposed to determine the pattern of international trade flows. Location is, at best, an exogenous factor and is not regarded as significant. On the other hand, regional and urban economics take market structure and prices as given and try to figure out which allocation of space is most efficient. The behavior of consumers and producers, which is of core relevance in trade theory, is less important. [5]

New Economic Geography models describe how spatial distribution of economic activities changes as transportation costs slowly decline. The slow decline aims at mirroring the actual decline in transportation costs observed throughout the last years. With falling transport costs companies are able to increase their exports while being less dependent on immobile factors as sources of profit. [7]

The first key feature in the New Economic Geography models is the so-called home market effect. This effect describes the net effect of market expansion and market crowding. An exogenous change in the location of upstream demands provokes a more than proportional change of downstream supplies in the same direction. Importantly, the intensity of the home market effect is dependent on the level of trade freeness. Since trade freeness weakens the market crowding effect more than the market expansion effect, lowering trade costs intensifies the change of downstream supply which is induced by a shift in upstream demand.

Secondly in NEG models agglomeration forces are referred to as self-enforcing, which is called circular causality. This circularity should point out the feedback relations between economic activities. It is characteristic for NEG models that the strength of the circular causality depends on the level of trade barriers.

The third fact worth mentioning is the fact that the relations between the strength of circular causality and trade freeness show up as so called “hump-shaped agglomeration rents”. Taking a long-run outcome into account where all companies are located in one specific region, agglomeration rents are defined as the loss a company would have to face when relocating to another region. The hump shape shows that the agglomeration rents are a concave function of the trade freeness.

Endogenous asymmetry is also induced by circular causality. The assumption is that two symmetric regions with trade barriers face regional asymmetries when gradual increases in trade freeness take place.

The importance of the extent of trade freeness becomes obvious when talking about agglomerations. Therefore the way in which endogenous asymmetry emerges is extraordinarily discontinuous and is called catastrophic agglomeration. Once a certain point in trade freeness is reached, a small increase causes so called catastrophic agglomeration due to the fact that the only long run outcome is agglomeration.

Additionally local hysteresis is worth mentioning. It arises when the level of trade freeness brings multiple long-run outcomes forward. In an initial situation almost all firms would be in the same region. If in case of a shock a number of firms moved to another region, all firms would suddenly cluster there. A removal of this first shock would not cause a reversal of its effects. This is called hysteresis or path-dependency, which means that transitory shocks have permanent impediments.

The last core element of NEG gets obvious when dispersion and agglomeration effects are both long-run outcomes. To outline this means that the shared belief that firms will cluster in specific regions is self-rewarding and self-fulfilling. [8]

2.3 Krugman's core-periphery model

Paul Krugman launched the New Economic Geography as a subfield of the broader field investigating the location of economic activities. His core-periphery (CP) model forms the basis for the analysis of regional divergence, the formation of regional clusters as well as the impacts of regional policy among others. NEG holds reasons for the existence and persistence of sizable regional disparities at various spatial scales.

The core-periphery-model has two similar regions, two sectors and two factors. One factor is inter-regionally mobile while the other is not and every factor is specific to one sector. The so-called constant elasticity of substitution (CES) differentiated good makes use of the mobile factor and is produced under increasing returns to scale which are internal to the firm. The homogenous goods sector employs the immobile factor under constant returns to scale. Both goods can be traced while the CES differentiated goods trade is impeded by iceberg transport costs and the homogenous goods trade is costless. Therefore two types of equilibria exist: Agglomeration of the CES industry in a single region when transportation costs are low, even dispersion of this industry across the two regions when transportation costs are high. Both equilibria are stable for intermediate transportation costs. [9] It is obvious that this is a very stylized model, which is established in order to enable further research in this field.

2.4 Transport and New Economic Geography

The so-called iceberg transport cost function is distinguishing for New Economic Geography. It was first developed by Paul Samuelson in 1952. Again this contribution is more methodological than practical but facilitates modeling trade costs. It is based on the assumption that two markets exist. A home market *H* and a foreign market *F*. When producing good *x* in the home market *H* with a value of *VXH* and some of the good is consumed by the act of shipment, the value of the good arriving in the foreign market is denoted as $\tau x VxH$, where $1 - \tau x$ is the proportion of the good *x* consumed by the process of transportation from *H* to *F*. For determining the relative prices of the goods in the home market *PXH* and in the foreign market *PXF*, it is crucial to consider that the value of the good in the home market *VXH* is the result of a multiplication of the domestic price per ton of the good *PXH* and the tonnage of good *x* being shipped from the home market *MXH*. In international shipment, although the price per ton of *x* paid by the foreign customer to the domestic producer is *PXH* for each ton purchased at *H*, the overall weight of good *MXF* actually arriving in the foreign market F is only *MXH* tons. To put it differently, the foreign price per ton PXF actually paid by the foreign consumer is displayed as

$PXF = PXH\ (MXH/MXF) = PXH/\tau x.$

Correspondently, the same can be formulated for a foreign-produced good y of the price *PYF* per ton in the foreign market, the home market price of good *y* is denoted as

$PYH = PYF/\tau y$

τy represents the proportion of the good *y* which is not consumed in the process of transportation from *F* to *H*. The iceberg formulation describes transportation costs as stepwise discontinuity between home and foreign prices of any goods. The degree of discontinuity is dependent on the value of τ. [10]

2.5 Iceberg transport costs and New Economic Geography

Krugman spurred on the former works on new international trade and developed and integrated the geographical space in his research work. One of the major achievements was the formulation of iceberg transport cost functions as a continuous distance function. He redefined Samuelson's iceberg function into an explicitly geographical distance-related function. Krugman defines iceberg cost functions as $V_d = V_0 e^{-\tau D}$, where V_0 is the value of the good at the origin location, τ is the iceberg decay parameter, D denotes the haulage distance and V_d is the quantity of the good actually delivered at its destination. Here, τ represents the remaining quantity of the good which tips-off on each kilometer of transportation. In Krugman's elaborations concerning the iceberg model the level of the distance-delivered price convexity increases with the value of the good shipped. Consequently the price of the delivered good rises with distance at a greater rate for goods with higher origin prices than for goods with lower origin prices. [10] Verbal as well as mathematical models make use of abstraction. This means that certain key features of the system of interest are selected and represented in the model, which should display the real world. In NEG reference to so-called "real-world" phenomena is made. Anyway, this abstractions and formalizations are oftentimes subject to debates. Like all economic models, NEG models are surrogates. The focus of theorists is put on the representation, which is the abstract, formalized and simplified landscape in the modeled world. [11] By all means, transportation costs play an important role in NEG models. Notwithstanding, modeling these transport costs is one of its weakest parts and many authors complain about the restrictions that come along with iceberg transport costs assumptions. Furthermore, hardly any progress seems to have taken place in this field throughout the last years. By all means, transport costs are prices which are set in imperfectly competitive markets and which respond to demand and supply shocks. Another important component of the NEG has to deal with the asymmetry of transport and trade costs, since freight imbalances apparently affect transport costs to a large extent. These imbalances evoke strong effects on the spatial structure of the economy. [12]

2.6 Agglomerations and networks

Major transport nodes abet industrial agglomerations. These nodes and transshipment points within transport networks exhibit a favorable location for cost-optimizing or -minimizing companies. Examples therefore are nodes in cities which are located close to road infrastructure such as highways or railroad stations. The co-occurrence of agglomerations and transport nodes stems from the reciprocal reinforcements among them. One of the most important points is the fact that companies want to save transport costs by locating around such nodes. In 2004 an estimation conducted by the researchers Anderson and van Wincoop [13] illustrates that the tax equivalent of trade costs in industrialized countries accounts for 120 %. This number can be split into transport costs (21 %), border related trade barriers (44 %) and local retail as well as distribution costs (55 %). Additionally time related aspects have to be considered concerning transportation. Close contact to suppliers and customers is essential anyway. One more reinforcement aspect is the fact that transport nodes and their efficiency respectively are meliorated by increasing agglomeration tendencies. In this context scale economies assume an important role in this context. The development of large-sized and high-speed carriers, such as container ships or bullet trains, contributed to economies of scale which serve as incentive for collective transportation and consequently bring trunk-routes and hub-and-spoke processes forward. Once again circular causation comes into place. Whenever frequent transport services are available on demand, a large number of shippers will be attracted to this link which again entails the offering of more frequent transport services. This positive feedback again leads to the endogenous formations of trunk links and transport hubs. Whenever scale economies of transportation dominate, certain transport advantages of locations enable the spontaneous emergence of major transport nodes at any place having a large demand such as the existence of industrial agglomeration. Fujita and Mori call this mechanism "economies of transport density" which are primarily present in air, railroad and maritime transportation. [14]

3 INTERCONNECTION BETWEEN NEG AND ENERGY EFFICIENCY

The explanations concerning NEG offered so far are of theoretic nature and call for a transfer to aspects related to real life. Numerous scientists are engaged in abstractions. In this paper and in the project work at the University of Applied Sciences Upper Austria it is tried to figure out, where interconnections between NEG and energy efficiency in logistics can be derived and transferred via specific projects to praxis. Nevertheless, the research work done so far has still to be called work in progress and a lot of theoretical as well as empirical research studies have to be conducted.

Potentials to enhance energy efficiency in freight traffic are numerous. As mentioned in Chapter 1, transport flows are indispensable connected with the economic activities of a country. Therefore mobility and traffic are induced by industrial locations and transport nodes, which are built around these locations respectively. Therefore it is assumed that the competition among industrial locations will increase over time. Nevertheless, whenever companies make decisions concerning the establishment of local operations they do not take the related traffic into account. Conversely, infrastructural measures are oftentimes not oriented towards a strategic, long-term location planning. Consequently, an elaborated strategically oriented and integrated location and land use regulation as well as an adequate transport policy can contribute to a minimization of transportation distances. Again, the previously featured circular causality comes into place at this point. Furthermore, decisions concerning the modal choice can influenced positively and freight as well as individual traffic could be bundled. Altogether it is expected, that these measures contribute to the enhancement of the attractiveness of a location. In the next chapter some practical examples concerning potential contributions in logistics to enhance energy efficiency will be given.

4 ENERGY EFFICIENCY IN LOGISTICS

4.1 Logistics concepts and their impact

Best practices in logistics call for the integration of environmental management with day-to-day operations. [15] Logistics in particular is the process of planning, implementing and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to the point of consumption for the purpose of meeting customer requirements. [16] Logistics and supply chain management focus on the adequate configuration of process chains while at the same time tracking an increase in efficiency as well as effectiveness. Hence, overcoming distances (transport, handling) and time (storage) are the core elements of logistics which necessitate accordant energy consumption. In addition to time and cost aspects, questions concerning energy efficiency come into force. (Freight) Traffic will – besides energy supply, feeding and farming as well as building and living – be one of the most fundamental scopes of action, which have to put the principle of sustainability into practice. [17] Generally, there are two domains of different actors, which can contribute to achieving environmental improvements. One is the macro domain, where actions are taken by the governments and legislative authorities. The other domain is the micro-domain, where companies set priorities in regard to environmentally friendly processes. In the macro domain it has been widely recognized that transport is among the main sources of environmental pollution.

Measures taken in the past are numerous but unsatisfactory due to their inability to keep pace with the growing transport volumes.

4.2 Potentials for a more sustainable transport sector

Improving sustainability within the transport sector requires a comprehensive and integrated transport and environment policy approach which combines legislative and economic instruments in a capacious way across all traffic carriers. A few examples for potential contributions to a more sustainable transport sector will be mentioned at this point: In general logistics can follow three approaches within transport policy in order to minimize negative impact on the environment. The first approach would be a realization of modal shift. Secondly, reducing the demand for transport services and thirdly, reducing the impact of transport processes on the environment. In the micro domain a shift in the processes of enterprises has to take place, more precisely a process restructuring is necessary. [18] A survey conducted at the University of Applied Sciences in Steyr [19] tried to get to the bottom of own-account transport operations in Austrian companies. To specify the question was how many companies operated own-account transports and the reasons therefore. 49 % of the companies surveyed operated own-account transports and the essential reasons given where supposed cost savings as well as quality aspects. The following picture illustrates the capacity utilization of the truck fleets of the particular companies:

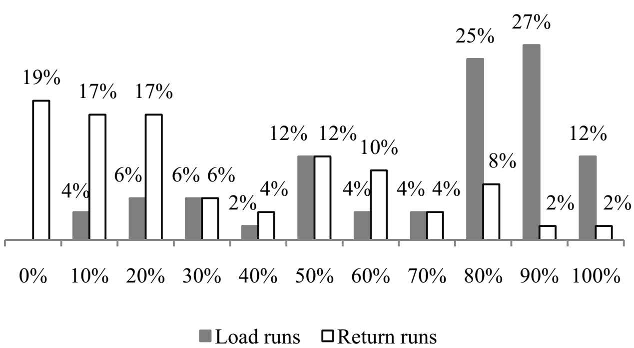

Fig. 1: Utilization of truck fleets

This figure outlines the fact, that companies hold great potential concerning so called freight hold utilization. Especially in the return runs, the figures exhibit a clear tendency towards low utilization. A synergetic increase of freight hold utilization and the avoidance of empty drives respectively contribute exceedingly to a reduction of carbon dioxide emissions. In this context so called logistics pooling systems have to be mentioned. Within such systems truck use (sometimes even warehousing) is planned and optimized company-wide. The physical transport of goods with trucks of the manufacturer or carrier is accomplished in the course of a collectively planned optimization of transport capacities. This can be realized by the minimization of empty drives or rather by the shared utilization of one truck by several manufacturers when supplying a retailer. On the grounds of technical and organizational conditions each carrier processes definable advantages. Road haulage scores with its flexibility, almost infinite interconnectedness and organizational simplicity. Rail transport is especially shows advantages especially on long distances and when carrying bulk load. Transports by plane on the other hand are characterized by speediness over long distances. Concerning the modal shift mentioned before, it has to be said that an intelligent combination of specific carriers according to their advantages to intermodal transport chains has to be realized. Consequently these transport chains can be designed more efficient. At least in Europe certain mental barriers seem to exist and hinder a comprehensive utilization of intermodal transports. Anyway it would lead to a relaxation on the roads in case a successful shift of the main leg from the carrier road to the carrier rail or inland waterway and keep this track as long as possible. The simple principle is, the longer the main leg and the distance travelled, the more environmentally friendly the transport. Another example for potentials in freight traffic is related to a project conducted again at the University of Applied Sciences Upper Austria, which is called "time4trucks". Within this project traffic forecasting data of infrastructure operators are combined with data of shippers in order to unload neuralgic road sections, primarily in urban areas. Hence traffic congestions, time losses, costs and planning uncertainty as well as additional carbon dioxide emissions can be avoided. The consolidation of data allows for influencing traffic conditions. Consequently this leads to improved fuel efficiency and fuel consumption respectively. [20]

5 SUMMARY

It has to be said that in the actual application of NEG models it is important to distinguish two types of impediment to trade in space. In more detail it is about transport costs for goods and communication costs for doing business over space. It is for example suggested to focus on transport costs for goods and communication costs among business units which exert different effects on the spatial organization of economic activities. Comprehensive studies on the nature and modeling of transportation activities have to be a central concern for any further development of the NEG. [14] In practice, potential contributions in logistics to enhance energy efficiency in freight traffic are numerous. In general it can be stated, that ecological strategies contribute to the requirements of customers concerning environmentally friendly and sustainable products. Logistics holds a prominent position in this context, due to the fact that companies can contribute significantly to the reduction of environmental pollution when applying adequate strategies. It is necessary to not only identify different strategic, tactical and operational decisions influencing the environment. Furthermore, it is inevitable to relate them to each other in order to be able to foresee their consequences on the environment. [21] Three main steps have to be considered when designing new logistics structures. First the total costs and the delivery service of the existing structure have to be calculated. In comparison to that, alternative structures and their costs have to be analyzed and calculated respectively. The third point is the calculation of dimensions and size of facilities, which have to be established. [18] Improved planning and organization of logistics processes provoke an increase of the ecological as well as logistical efficiency. The significance of environmental aspects within logistics will continuously rise. A number of reasons, such as rising commodity and energy prizes, increasing integration accompanied by further negative environmental impacts, contribute to this relevance. Additionally it can be expected, that so-called external costs will be increasingly assigned to the respective polluters instead of being borne by the general public.

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Ecolabelling and Design for Environment in Building Transportation Systems

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Abstract

There is a growing need for indicating the environmental performance of products partly due to legislation set by governments and partly to gain an advantage in the markets. For quite some time companies have used life cycle assessment (LCA) to address the environmental issues related to their products. LCA results can be communicated with Environmental Performance Declarations, but these are not as visible as ecolabels or energy performance labels and thus remain generally unknown by the public. The aim of the study is to provide designers useful information about material choices from the environmental point of view by looking at the findings of past LCA studies and seeing how these could be used to rate and indicate the environmental performance. The goal was to provide elevator designers a sketch of a visually easy to understand and a fast to interpret chart to use in material comparison. This chart should indicate a few of the environmental performance indicators that were found necessary by a literature review in the sector of building material performance.

Keywords:

elevator, life cycle assessment (LCA), material rating, environment

1 INTRODUCTION

A growing concern of the environmental issues in all the sectors of industry has set a new challenge to product designers of incorporating environmental issues at a very early stage of the design process. There are several guidelines for ecodesign of which the most relevant for this case study was the ISO 14062 [1]. The ISO 14062 is divided into six stages: planning, conceptual design, detailed design, testing / prototype, production / market launch, and product review. As it has been noted that more than 80% of the environmental impacts are determined at the early stages of product design, the scope of the study performed focuses on the planning and conceptual design stages of the ecodesign standard.

The planning stage of the design for environment process includes such aspects as gathering the information, align with organizational strategy, consider the environmental impacts, and making an environmental analysis of the product. The second stage of the design is the conceptual design, where environmental aspects such as conducting life cycle oriented analyses, formulate measurable targets and meeting environmental requirements are considered. [1] These two stages were the main driving forces in further analysing the material choices in the design stage of a product.

2 APPROACHES AND METHODS

The study uses an example elevator as the case product, but the same kind of study could be conducted on a variety of products. In case of elevators, many manufacturers have presented their environmental product declarations (EPD's), which all indicate that materials are the second largest contributor to the environmental impacts caused by elevators, as presented in an EPD of a KONE example elevator in Figure 1. Often it seems that most effort is concentrated on the use phase and too little effort is put to the material choices. [2, 3]

The literature review looked at different labelling schemes as well as different legal obligations around the world that need to be included when thinking about the design for environment of an elevator. The labelling schemes included in the study covered both green building labelling schemes and product labelling schemes. The reviewed green building labelling schemes included LEED from the United States [4], BREEAM developed in the United Kingdom [5], Green Star currently growing in the Southern Hemisphere originally developed in Australia [6], and CASBEE from Japan [7]. Of these LEED and BREEAM received the most attention as they are used in the largest scale around the world. Product specific labels to indicate the environmental performance of elevators tend to focus on the energy performance of elevators and exclude the material choices made. This is understandable as the energy consuming use phase dominates the life cycle environmental impacts; good example being the example elevator presented in Figure 1. Product specific labels included the energy performance guidelines under development by the International Organization for Standardization [8] and the energy

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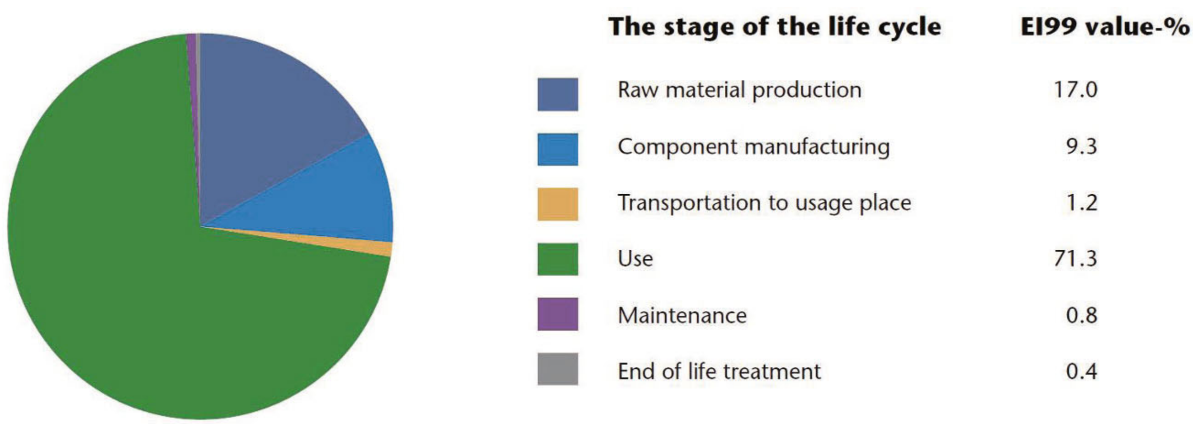

Figure 1 - The shares of different life cycle stages on the environmental impacts of a KONE example elevator

efficiency rating guidelines of Verein Deutscher Ingenieure [9]. As there seems to be no well recognized environmental label to communicate the environmental performance of the material choices in elevator design, the study resulted in presenting the environmental performance of different materials on a 'Material Environmental Radar Chart' as presented in Figure 2. The process of identifying the relevant environmental performance indicators (EPI's) for different materials used in an elevator is a demanding task. This could be performed via a full life cycle assessment, but this is often seen as a daunting task by companies. Thus, finding a simpler way of identifying and visually presenting the relevant EPI's for different materials would be a welcome addition to the choice of tools for designers.

3 TOOLS FOR DESIGNERS

A wide set of tools are available for designers dealing with material choices, but as the environmental issues are often more complex to measure than traditional material properties such as tensile strength or elastic modulus, these tools are often highly indicative and therefore give no exact values. The uncertainty of these tools is possibly the biggest reason for many companies for not having incorporated these tools to their design portfolio in a larger scale. Two tools were tested in this study: the LCA software KCL-ECO developed at VTT Technical Research Centre of Finland and the Cambridge Engineering Selector (CES) with the EcoAudit Tool.

The LCA software KCL-ECO has been developed since 1992 with the version KCL-ECO 4.1 currently in use. KCL-ECO version 5 is currently under development at VTT to integrate knowledge and data from various sources within a company and from external sources. KCL-ECO 5 will have the well-known, highly visual and easy-to-use features from the previous versions with new and improved user interface that helps the user to perform fast, reliable and easily understandable LCA's. KCL-ECO 5 is being built on the Simantics platform to synchronize different software systems such as Balas[1], Apros[2] and CAD.

The EcoAudit Tool is an add-on tool to the CES Selector, which helps the user to address such issues as the carbon footprint, energy usage, waste and emissions produced or the manner of disposal. The EcoAudit takes a two stage approach to ecodesign; the first stage being ecoauditing and the second being optimization of the process to minimize the environmental burden. The latest version of the software is the CES Selector 2012 with an extended ecodesign tool and a wider data selection. The CES tool uses a bill-of-materials fed by the user and associates these materials to a wide database gathered from literature. Nevertheless the amount of processes and materials in the CES Selector is impossible to fully cover, so estimates have been made to present values for materials that have no direct data source. This brings about the error margins of about 20%. [10].

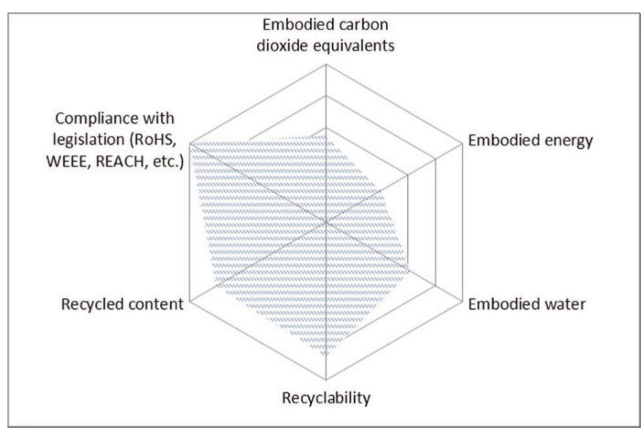

Figure 2 - Material Environmental Radar Chart to be used to present the environmental performance of a material used (example EPI's and figures)

[1] Balas Process Simulation Software, balas.vtt.fi

[2] Apros Process Simulation Software, apros.vtt.fi

4 IDENTIFYING RELEVANT EPI'S

One of the most important aspects for an elevator manufacturer is the green building rating schemes mentioned earlier. It is worth noticing that each of the green building rating schemes has a degree of rationality in it. This rationality presents itself as non-uniform set of categories in which credits can be obtained and as different weighting factors for these categories, e.g. the Green Star puts more weight on water consumption whereas the CASBEE might focus more on structural aspects such as earthquake resistance. This presents a dilemma for multinational companies as focusing on a single green building rating scheme might result in scoring a lower result in other regions of the world. Gathering the most important credits or points from different green building rating schemes might set clear guidelines for EPI's used in rating elevator materials, but often elevators, escalators and moving walks are explicitly excluded from the material categories. Possibly the most important contribution the green building rating schemes have in the scope of this study is the amount of recycled material used. For example CASBEE awards credits for the use of recycled materials as structural framework materials or as non-structural materials. [11]

Two very important EPI's for an elevator manufacturer are embodied carbon dioxide equivalent emissions (CO_2-eq) and embodied energy. These two EPI's are often seen as very comparable, even though this might not be the case. This was noted by Dixit et al. [12] as it was noted that one problem arises from the different system boundaries used in the studies. For an elevator manufacturer the system boundary of interest in material choices is a cradle-to-gate, i.e. from raw material extraction to the gate of the production plant, where as a building constructor might include building demolition as well. The same problem may arise when looking at the CO_2-eq. emissions. A transparent way of reporting these emissions, such as the one presented by the World Resource Institute and the World Business Council for Sustainable Development [13], should be chosen.

A rapidly growing EPI that cannot be omitted is the water consumption. Water footprint methodologies are currently developed by many different parties. The different water footprinting tools and methodologies can roughly be divided into two mainstreams: accountancy schemes (e.g. GRI indicators [14], and Water Footprint Network [15]) and schemes for assessing, certifying and communicating sustainable water use (e.g. Global Water Tool by WBCSD [16] and Water Sustainability Tool by GEMI [17]). No single method is yet widely accepted and as methods are being developed further, the mixing of accountancy and response schemes will further increase. In the sector of water footprinting, the hopes are that the upcoming ISO 14046 will unite and clarify the methodology currently in use and under intense discussion. For this reason this study takes focus only on the water consumption or water withdrawal.

Finally it is seen as a necessity to make a note about the legal obligations of the materials, such as the RoHS Directive, the WEEE Directive and the REACH Regulation. Again the literature review raised the problem faced by a multinational company of having to deal with different criteria in different parts of the world. Nevertheless in this case this problem can be solved by setting the company requirements according to the tightest legislation in the world. This final point in this set of example EPI's can score either zero or one, depending on whether the legal requirements are met or not.

5 RESULTS AND DISCUSSION

At the very early stages of the study, it was the ambition of all persons involved to find an ecolabel for elevators. This, soon after, took the form of making a feasibility study of possible ecolabels for elevators and different materials used in elevators. In the end all parties agreed that at this stage the best and most usable result would be to draft a 'material environmental radar chart' (see Figure 2). This could be used by designers to easily assess the environmental performance of different material options by visually being able to compare associated environmental performance indicators. During the study it was also noted that it would be good to tie elevators to the green building rating schemes also in other areas than energy consumption, as elevators are becoming an increasingly important part of the growing cities.

Further results shall be presented at the 7th International Symposium on Environ-mentally Conscious Design and Inverse Manufacturing (November 30th-December 2nd, 2011), Kyoto City, Japan.

6 ACKNOWLEDGMENTS

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New global warming indicators, CEWN, CETN and s-CETN based on removal rate of GHGs from the atmosphere

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Abstract

A new indicator, the CETN (Carbon Dioxide Equivalent Temperature Change Number), is proposed as an alternative to the GWP (Global Warming Potential). CETN is a metric where the temperature change by the emission of gases is compared at the same degradation rate. There are two types of CETN, CETN and s-CETN, depending on the way of standard setting of degradation rate. They are obtained from simple calculation and the comparative evaluation in equivalent amount becomes available by unifying the removal rate of each gas from the atmosphere. They are realistic and novel global warming indicators as the lifetime of each gas is reflected.

Alongside already reported CEWN, in which RF (radiative forcing) is compared at the same degradation rate, there are three indicators, CEWN, CETN and s-CETN, ready. For these indicators, the removal rate from the atmosphere is set at 75%, at the same time, modifications, such as change of the base year setting of atmospheric carbon dioxide to preindustrial time, inclusion of warming due to degradation products, are made, thereby CEWN_2 (75-pi), CETN_2 (75-pi) and s-CETN_2 (75-pi) are calculated and proposed as actual indicators.

Using these three indicators, LCCP analyses for semiconductor cleaning and blowing agent of polyurethane insulation are carried out, and the results are different from the results with existing GWP.

Keywords:

GWP, CEWN, CETN, s-CETN, global warming indicator

1 INTRODUCTION

The countermeasures against global warming are urgent issues. The quantified emission reduction is assessed by the basket system under the Kyoto Protocol. The idea of the system is that the number which indicates the warming intensity is given to each warming gas and then the total sum of the emission of each warming gas multiplied by its respective number is controlled. Under the Kyoto Protocol, the GWP (Global Warming Potential) is used for the calculation. However, its arbitrary property of being used with a 100-year time horizon and the fact that the relation between the GWP and the climate impact is not clear are acknowledged as problems of the GWP. Under the circumstances, the GTP (Global Temperature Change Potential) which makes clear the relation between the emission of greenhouse gases and global-mean surface temperature has been proposed [1]. However, the GTP_P represents the temperature change due to a pulse emission of a gas after a given period of time has elapsed, thus it does not evaluate the integrated warming. In addition, the fact that the value differs greatly depending on the length of the given period in most cases is also the issue. Meanwhile, the GTP_S is scarcely applicable to the other emission scenarios as it represents the integrated warming based on its own scenario where the emission increases by 1kg every year during the given period. We have developed the CEWN (Carbon Dioxide Equivalent Warming Number) with the view to establish a fair warming indicator and encourage the proper usage of fluorinated gases [2]. The CEWN calculates the warming by the emission of greenhouse gases in the similar way of the GWP, but with the removal rate of each gas from the atmosphere unified. It has provided the fairer comparison values of the warming for various greenhouse gases.

This paper proposes the CETN (Carbon Dioxide Equivalent Temperature Change Number) where the global temperature change, which complies with the GTP, by the emission of greenhouse gases are compared by unifying the removal rate of each gas from the atmosphere. It is thought that the CETN is the comparison values of the greenhouse gases which maintains the fairness of the CEWN and has clearer relation with the climate impact. In addition, as CEWN, CETN guides selection of better technology by being applied to technological assessment.

2 EXPERIMENTAL

2.1 Calculation of CETN

The equation used for the calculation of CETN is as follows:

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Equation 1: CETN calculation

$$CETN(X) = \frac{ACETN(X)_A}{ACETN(X)_C} = \frac{\int_0^{t_{XA}} AGTP(t)_A\, dt'}{\int_0^{t_{XC}} AGTP(t)_C\, dt'}$$

$$= \frac{\frac{A_A \alpha_A}{C}\left\{\tau\left[1-exp\left(-t_{XA}/\tau\right)\right]-\frac{1}{\left(\tau^{-1}-\alpha_A^{-1}\right)}\left[exp\left(-t_{XA}/\alpha_A\right)-exp\left(-t_{XA}/\tau\right)\right]\right\}}{\frac{A_C}{C}\left\{a_0 t_{XC}\tau - a_0\tau^2\left[1-exp\left(-t_{XC}/\tau\right)\right]+\sum_i a_i\alpha_i\left[\tau\left(1-exp\left(-t_{XC}/\tau\right)\right)-\frac{1}{\left(\tau^{-1}-\alpha_i^{-1}\right)}\left[exp\left(-t_{XC}/\alpha_i\right)-exp\left(-t_{XC}/\tau\right)\right]\right]\right\}}$$

When the elapsed years, after 1kg of gas A and 1kg of carbon dioxide are emitted at the beginning until X% of their emission is removed from the atmosphere are denoted by t_{XA} and t_{XC}, respectively, CETN (X) of gas A is given by Equation 1, where C is the heat capacity of the system, A_A and A_C are the radiative forcing due to a 1kg change in gas A and carbon dioxide, respectively, and τ is a time constant for the climate system and equals to λC where λ is a climate sensitivity parameter (here, 0.8 K(W m^{-2})$^{-1}$ is taken). The equation for each AGTP is quoted from Shine 2005 [1].

The coefficients for the above equation, which are the same as IPCC 2007 [3], are as follows:

$$a_0 = 0.217,\ a_1 = 0.259,\quad a_2 = 0.338,\quad a_3 = 0.186,$$
$$\alpha_1 = 172.9\ years,\quad \alpha_2 = 18.51\ years,\quad \alpha_3 = 1.186\ years$$

Both CETN and s-CETN are calculated as the ratio of integrated temperature change of gas A to integrated temperature change of carbon dioxide. In CETN case, temperature changes of gas A and carbon dioxide are both integrated until X% of each emission is removed from the atmosphere, while, in s-CETN case, though carbon dioxide as the denominator is the same as CETN, temperature changes of gas A is integrated until the ratio of integrated temperature change to infinitely integrated temperature change becomes X%.

Some examples of CETN and s-CETN in the case where the removal rate of carbon dioxide from the atmosphere is fixed at 75% are shown in Table 1.

2.2 Base year fixing of atmospheric carbon dioxide at preindustrial time and introduction of carbon dioxide environment number (CO_2 EN)

The base year of atmospheric carbon dioxide is fixed at preindustrial time, that is, year 1750. Based on the formula in IPCC 2001 [4] along with the preindustrial atmospheric carbon dioxide concentration of 278ppm, the radiative forcing per kilogram of CO_2 is calculated and fixed at 2.45×10^{-15} W m^{-2} kg^{-1}. Additionally, the following is defined as the carbon dioxide environment number (CO_2 EN) in year Y.

$$CO_2\, EN_Y = RF_{CO2,\,Y} / RF_{CO2,\,1750}$$
$$\approx C_{CO2,\,1750} / C_{CO2,\,Y}$$

where $RF_{CO2,\,Y}$ is the radiative forcing per kilogram of CO_2 in year Y [W m^{-2} kg^{-1}], $C_{CO2,\,Y}$ is the atmospheric carbon dioxide in year Y [ppm]. The examples of CETN and s-CETN where base year is fixed at preindustrial time are shown in Table 2.

2.3 Inclusion of warming effects due to the degradation to carbon dioxide

The CETN(X) of gas A including the warming effects of carbon dioxide, which is a degradation product of gas A, is calculated and denoted by CETN_2 (X). When every carbon atom included in gas A degraded is assumed to change into carbon dioxide, as the CETN is the value relative to carbon dioxide, the CETN attributable to the degradation product, CO_2, is simply derived from the carbon number of gas A and the ratio of molecular weights of carbon dioxide to that of gas A, and the CETN_2 (X) is given by

$$CETN\_2(X) = CETN(X) + C_A \times \frac{M_C}{M_A} \times \frac{X}{100}$$

where C_A is the carbon number of gas A, and M_C and M_A are molecular weights of carbon dioxide and gas A, respectively.

The examples of CETN and s-CETN in both cases of excluding and including the effects of the degradation products, which are denoted by _1 and _2, respectively, are shown in Table 2. Further, new indicators including the effects of the degradation products for selected gases are compiled in Table 3.

2.4 Inclusion of effects due to degradation to trifluoroacetic acid and its dissolution in water

Some fluorine compounds are known to be degraded to trifluoroacetic acid (TFA) in the atmosphere. Therefore, for gases whose TFA yield rates have been known, inclusion of the warming effects attributable to CO_2 as the degradation product is reduced at that rate. These results are shown in Table 4. In the case of trifluoroethanol, as shorter lifetime considering the wet deposition through uptake by cloudwater and rain has been reported [5], the case of shorter lifetime is also listed.

2.5 Comparison of LCCP analyses by CEWN, CETN, s-CETN and GWP

The LCCP data of semiconductor cleaning gases and blowing agent for polyurethane insulation are as previously reported [6] [7]. The evaluation results using new indicators are shown in Fig. 1 and Fig. 2.

3 RESULTS AND DISCUSSION

CETN is based on the ideas below.

The equation of the temperature change at a given time due to a pulse emission of a greenhouse gas, which Shine proposed [1], is applied with the coefficients quoted from IPCC 2007 [3] and the integrated temperature change over the period leading up to a given time is characterized as the warming amount leading up to that time due to the emission of the gas. This value is different from the warming amount of GTP_P which is the value at a given time, and also, this integration and the integration in the emission scenario of GTP_S differs in meaning.

3.1 CETN

The warming by each greenhouse gas is integrated leading up to the time when the removal rate of each gas reaches to a given rate as is the case in CEWN, and compared each other. This realizes an equivalent quantity evaluation with taking the lifetime into account, which is called CETN.

3.2 s-CETN

The warming by each greenhouse gas is integrated leading up to the time when the ratio of integrated temperature change to infinitely integrated temperature change becomes a given rate, and compared each other so that it may realize another equivalent quantity evaluation with taking the lifetime into account. This is called s-CETN.

3.3 The setting of the removal rate from the atmosphere

The higher setting of removal rate from the atmosphere is more likely to have higher reliability of evaluation as a larger part is evaluated. However, the overhigh setting enhances the uncertainties of evaluation, since long-term evaluation is required. In particular, in the case of carbon dioxide, the change in concentration is complex and the error grows over time. Although it is supposed that carbon dioxide behavior is predictable up to 500 years after, in reality, 100 years of time, which corresponds to 63 % of removal rate, is used in many cases. In addition, if the evaluation term is too short, the difference between the atmospheric models becomes large, then, 75% of removal rate, which corresponds to about 350 years of time in carbon dioxide case, has been employed. Some examples are shown in Table 1.

3.4 The base year fixing of atmospheric carbon dioxide

The concentration of atmospheric carbon dioxide has been increasing year by year. It is known that the radiative forcing (RF) per unit weight has been decreasing with this concentration increment. Despite the persistent decrease in RF, in the case of GWP calculation, carbon dioxide is always used as a reference (= 1), accordingly, the calculated warming due to the other gases becomes large even though it stays unchanged. In addition, the fact that the GWP value of carbon dioxide is always 1 as a reference as well as the increase in GWP value of the other gases is likely to give a false impression that the warming attributable to the other gases has grown. Further, the regular correction is inevitable for GWP values.

Therefore, in the case of CEWN, CETN and s-CETN, the base year of atmospheric carbon dioxide concentration is fixed at preindustrial time, year 1750.

The change in carbon dioxide concentration is decided to

Table 1: CETN and s-CETN for some GHGs in the case where the removal rate of each gas is 75%

Common Name	Chemical Formula	Lifetime [years]	CETN_1(75)	s-CETN_1(75)
Years until CO_2 decreases by the given removal rate			356	356
Carbon dioxide	CO_2	-	1	1
CFC-11	CCl_3F	45	1,430	1,590
HFC-32	CH_2F_2	4.9	62.7	202
HFC-134a	CH_2FCF_3	14	266	427
HFC-245fa	$CHF_2CH_2CF_3$	7.6	133	309
Nitrogen trifluoride	NF_3	740	42,400	42,600
PFC-116	C_2F_6	10000	366,000	366,000

The radiative forcing per kilogram of CO_2 used for the calculation is y2005 value.

Table 2: CEWN, CETN and s-CETN for some gases including the warming effects due to degradation products

Common Name	Lifetime [years]	CEWN_1 (75-pi)	CEWN_2 (75-pi)	CETN_1 (75-pi)	CETN_2 (75-pi)	s-CETN_1 (75-pi)	s-CETN_2 (75-pi)
Carbon dioxide	-	1	1	1	1	1	1
Methane [c]	12	5.42	7.48	3.18	5.24	5.54	8.07
Ethane	0.21	0.31	2.51	0.01	2.20	0.32	3.25
Propane	0.041	0.04	2.29	0.00	2.25	0.04	3.03
Butane	0.018	0.02	2.29	0.00	2.27	0.02	3.05
n-Pentane	0.010	0.01	2.30	0.00	2.29	0.01	3.06
HFC-152a	1.4	26.7	27.7	2.84	3.84	27.3	28.6
HFC-365mfc	8.6	171	172	81.8	82.7	174	176

Table 3: CEWN, CETN, s-CETN and GWP for selected gases

Common Name	Chemical Formula	Lifetime [years]	CEWN_2 (75-pi)	CETN_2 (75-pi)	s-CETN_2 (75-pi)	GWP_{100}
CO_2 EN			1	1	1	0.736
Years until CO_2 decreases by the given removal rate			356	356	356	-
Years until gas X decreases by the given removal rate / Lifetime of gas X			1.39	1.39	gas dependent	-
Carbon dioxide	CO_2	-	1	1	1	1
Methane [a]	CH_4	12	7.48	5.24	8.07	25
Nitrous oxide	N_2O	114	110	108	112	298
Substances controlled by the Montreal Protocol						
CFC-11	CCl_3F	45	1,150	1,050	1,170	4,750
CFC-12	CCl_2F_2	100	3,700	3,640	3,790	10,900
CFC-113	CCl_2FCClF_2	85	1,900	1,850	1,950	6,130
HCFC-22	$CHClF_2$	12	389	229	398	1,810
HCFC-123	$CHCl_2CF_3$	1.3	17.1	2.08	17.6	77
HCFC-124	$CHClFCF_3$	5.8	131	47.9	134	609
HCFC-141b	CH_3CCl_2F	9.3	156	79.1	160	725
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	128	46.9	131	595
Hydrofluorocarbons						
HFC-23	CHF_3	270	10,300	10,300	10,500	14,800
HFC-32	CH_2F_2	4.9	146	46.8	149	675
HFC-125	CHF_2CF_3	29	778	655	796	3,500
HFC-134a	CH_2FCF_3	14	308	197	315	1,430
HFC-152a	CH_3CHF_2	1.4	27.7	3.84	28.6	124
HFC-227ea	CF_3CHFCF_3	34.2	732	641	749	3,220
HFC-245fa	$CHF_2CH_2CF_3$	7.6	223	98.7	228	1030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	172	82.7	176	794
Perfluorinated compounds						
Sulphur hexafluoride	SF_6	3,200	159,000	163,000	163,000	22,800
Nitrogen trifluoride	NF_3	740	30,600	31,200	31,300	17,200
PFC-14	CF_4	50,000	795,000	813,000	813,000	7,390
PFC-116	C_2F_6	10,000	264,000	269,000	270,000	12,200
PFC-218	C_3F_8	2,600	50,300	51,400	51,400	8,830
PFC-318	c-C_4F_8	3,200	71,600	73,200	73,200	10,300
Hydrocarbons [b]						
Ethane	C_2H_6	0.21	2.51	2.20	3.25	1.5
Propane	C_3H_8	0.041	2.29	2.25	3.03	0.19
Butane	C_4H_{10}	0.018	2.29	2.27	3.05	0.09
n-Pentane	C_5H_{12}	0.010	2.30	2.29	3.06	0.04

The radiative forcing per kilogram of CO_2 used for the calculation is y1750 value for CEWN, CETN and s-CETN and y2005 value for GWP.

The coefficients for concentration response function of CO_2 are the same as IPCC 2007.

The lifetimes and GWP values are quoted from IPCC 2007 [3] except for hydrocarbons whose lifetimes are quoted from IPCC/TEAP 2005 [8] and whose GWP values are calculated in the same way of direct GWP in IPCC 2007.

a) The values of CEWN, CETN and s-CETN of methane have been multiplied by 1.4 to account for the indirect forcing following GWP of methane in IPCC 2007 [3].

b) The indirect forcing like effects on tropospheric ozone, CH_4 and CO_2 is not included in any values of hydrocarbons. In IPCC 2007 [3], it is reported that in direct GWP values of Ethane, Propane and Butane are 5.5, 3.3 and 4.0, respectively with uncertainty range of -50% to +100%.

be shown as the carbon dioxide environment number, which is defined as the ratio of RF in a year to RF in year 1750.

3.5 The warming effects due to the degradation product, carbon dioxide

Carbon-containing greenhouse gases are decomposed to produce carbon dioxide in many cases. Assuming that every carbon atom in each gas changes into carbon dioxide, CETN_2 and s-CETN_2, in which the warming effects due to carbon dioxide as a degradation product is added, are also proposed.

The amount of carbon dioxide produced until the given removal rate of 75% and until the ratio of integrated temperature change to infinitely integrated temperature change becomes the given rate of 75%, in the case of CETN and s-CETN, respectively is calculated, and then

Table 4: CETN (75-pi) and s-CETN (75-pi) for gases which produce trifluoroacetic acid (TFA) as degradation products

Common name *Chemical formula*	Lifetime [years]	TFA yield	CEWN_2 (75-pi)	CETN_2 (75-pi)	s-CETN_2 (75-pi)	GWP_{100}
HFC-134a	14	no TFA correction	308	197	315	1,430
CH_2FCF_3		13.0% [10]	308	197	315	
HFC-227ea	34.2	no TFA correction	732	641	749	3,220
CF_3CHFCF_3		100% [10]	732	640	748	
HFO-1234yf	11days [9]	no TFA correction	1.68	0.87	1.98	3.8 [a]
$CF_3CF{=}CH_2$		91% [11]	0.89	0.08	0.93	
Trifluoroethanol	0.5 [4]	no TFA correction	13.2	1.16	13.7	59 [a]
		30% [12]	13.0	0.96	13.5	
CF_3CH_2OH	0.3 [5]	no TFA correction	8.21	0.84	8.60	35 [a]
		30% [12]	8.01	0.64	8.34	

The radiative forcing per kilogram of CO2 used for the calculation is y1750 value for CEWN, CETN and s-CETN and y2005 value for GWP.
The coefficients for concentration response function of CO2 are the same as IPCC 2007.
The lifetimes and GWP values are quoted from IPCC 2007 [3] unless otherwise indicated.
a) Calculated in the same way of direct GWP in IPCC 2007.

the integrated temperature change corresponding to the carbon dioxide produced is added to CETN_1 and s-CETN_1 to calculate CETN_2 and s-CETN_2, respectively. Thus, the given rate of 75% is applied to the additional warming as the degradation product, as well. CETN_2 and s-CETN_2 are simply calculated by adding the carbon dioxide production equivalent to the given rate as they are relative values to carbon dioxide.

3.6 Comparison between CEWN, CETN, s-CETN and GWP

These new indicators and conventional GWP are shown for comparison in Table 3.

As is noted from the table, the values of new indicators are large in the long-lived gases case and small in the short-lived gases case. They are equivalent quantity evaluations and it is thought that they show realistic values with the evaluation fairness ensured.

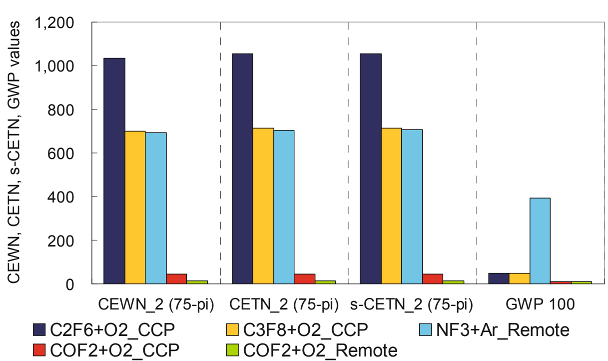

Fig. 1: LCCP analyses of CVD chamber cleaning by new indicators and GWP

Cleaning objects : SiO film
(pre-depo 200nm + depo 600nm (60sec.) on φ8" wafer)
abatement of exhaust gas : on
DEP for abatement --- CF_4 : 0.95, others : 0.99
gas leakage at prod. --- C_2F_6, C_3F_8 : 2.38%, NF_3 : 16.0%

3.7 Correction to hydrosoluble gases

It is known that stable trifluoroacetic acid (TFA) is produced as the degradation products. As TFA is a strong acid with a high affinity for water, it is removed from the atmosphere readily dissolved in the water without being decomposed into carbon dioxide. Trifluoroethanol is hydrosoluble itself and the lifetime becomes short due to

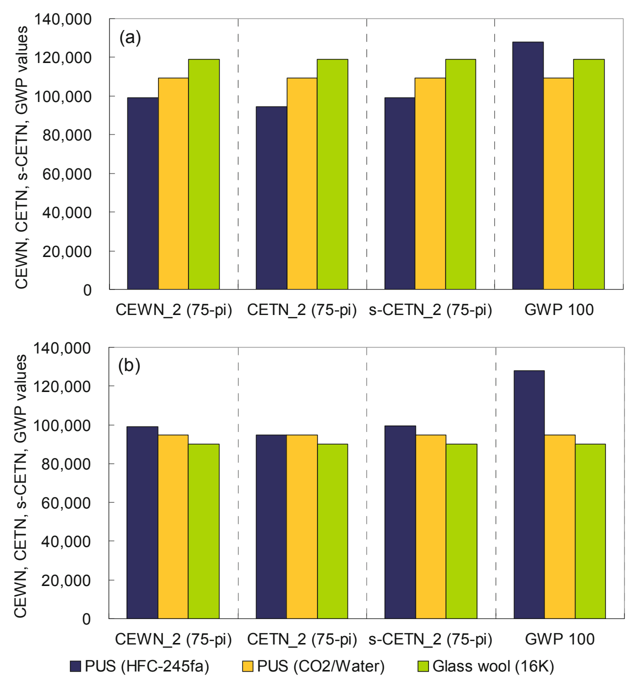

Fig. 2: LCCP analyses of wooden house insulations by new indicators and GWP in the case of (a) equal thickness of insulations and (b) equal heat transfer resistance of wall / ceiling / floor

blowing agent recovery after the 50-year use : no
HDD, CDD data : Japan, national average (2002)

Table 5: Features of CEWN, CETN, s-CETN and GWP

	CEWN, CETN	s-CETN	GWP_{100}
concept	integrated warming values until a given removal rate from the atmosphere is reached	integrated temperature rise until a given ratio to the infinitely-integrated temp. rise is reached	integrated warming values up to 100 years after the emission
evaluation period	lifetime-dependent		100 years
evaluation amount	The residual rate of each gas during a period of evaluation is the same.	The ratio of evaluation to the infinitely-integrated temperature rise is the same.	long-lived gases : partial short-lived gases : total
long-term evaluation	Longer evaluation is possible within the range where the behavior of CO_2 is clear		impossible due to uncertainty over long-term behavior of CO_2
point (years, rates) settings	Higher rates/years are desirable. Progress of CO_2 research can be reflected.		“100 years” is arbitrary
relationship with climate impacts	strong		weak
characteristics of evaluation	Sustainability is evaluable.		one-sided evaluation
warming value of "CO_2 = 1"	fixed (preindustrial value) or settable		changing by time
CO_2 as degradation products	Simple addition is available.		not included

the wet deposition [5]. Trifluoroethanol dissolved in the water becomes TFA without being decomposed into carbon dioxide.

As shown in Table 4, the correction of TFA production and wet deposition is applied to CETN_2, s-CETN_2 as well as CEWN_2 for gases whose TFA yield rates or wet deposition rates have been reported.

3.8 Comparison of LCCP analyses by CEWN, CETN, s-CETN and GWP

The LCCP analyses by CEWN, CETN, s-CETN and GWP on semiconductor cleaning gases and blowing agent for polyurethane insulation are carried out. The results are shown in Fig. 1 and Fig. 2. The results by new indicators are substantially different from the GWP results. In the case of cleaning gas evaluation, long-lived cleaning gases have a huge effect on the environment. In the case of blowing agent evaluation, it is clear that HFCs have a better outcome than non-fluorine series blowing agent.

4 CONCLUSIONS

New global warming indicators, CETN and s-CETN, are presented. The difference between these new indicators as well as previously reported CEWN and existing GWP is summarized in Table 5.

It is expected that these new global warming indicators, as metrics which show new direction of technology development, will make a contribution to future Eco design by changing conventional one-sided evaluation into multi-sided evaluation.

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New Life Cycle Assessment Process for Strategic Reduction of Environmental Burdens

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Abstract

The purpose of this study is to develop a new Life Cycle Assessment (LCA) process that will enable us strategically to reduce environmental burden due to products. This is achieved by combining scientific knowledge on burdens caused environmental problem, the database on burden by material manufacture and product assembly, and sales portfolio of the product.

According to previous popular LCA process, analyzed burden items are assumed as main factor of environmental impact regardless of product category before amount of burden items by the product life cycle are calculated (life cycle inventory analysis). Next, the life cycle inventory analysis and impact assessment are carried out. The impact assessment depends on the initially-assumed burden items. New LCA process does not require the initially-assumed burden items, and enable us to carry out the comprehensive impact assessment.

Keywords:
LCA, new process, comprehensive assessment, strategic environmental improvement

1 INTRODUCTION

Many results of LCA to assess the environmental burdens due to products in life cycle were reported. In these LCA process, analyzed burden items, e.g. CO_2, NO_x are assumed as dominant factors of environmental impact e.g. global warning, photochemical oxidant, before life cycle inventory analysis.

In this study, previous LCA reports on global warming impact assessment were reviewed. Fuluhashi Environmental Institute (2009) carried out LCA on production of cardboard box [1], also Yasuhara Plamics (2009) on production of composite resin[2], and Bluetech (2009) on production of fixation agent for ground improvement[3]. These reports defined three environmental burdens, CO_2, CH_4, N_2O, as global warming gases and carried out life cycle inventory analysis, and environmental impact assessment on global warming with IPCC2001 GWP100. Although there are many kinds of global warming gas, e.g. Dichromethane, Halon,Methyl bromide, Perfuorobutane, Sulphur hexafluoride other than CO_2, CH_4, N_2O, they limited the three items depend on the assumption that the three items emitted by these products were dominant on global warning. The assumption was not validated by them.

Yamato, M (2002) carried out LCA on a Minivan with hybrid engine [4]. In the life cycle inventory analysis, only CO_2 was analyzed. The assumption that CO_2 was dominant global warming gas emitted by the minivan was not validated.

Similarly, Nitta,S., Moriguchi, Y (2010,2011) carried out LCA on passenger car [5] [6] based on the same assumption without validation.

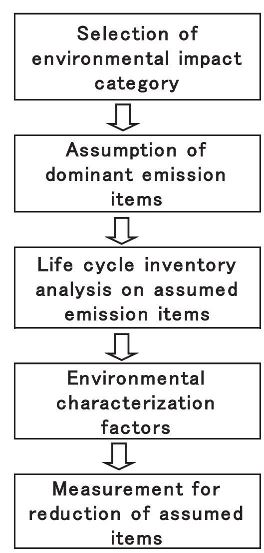

Fig.1 Previous Process of LCA

The previous process of LCA study is shown in Fig.1. In the Previous process of LCA, environmental burden items were assumed as dominant factor of environmental problem regardless the kind of products before lifecycle inventory analysis. The amount of emission of the assumed environmental burden items was calculated. The environmental impact assessment was carried out with the assumed environmental burden items. Whether the assumed environmental burden items was dominant global warming gases was not validated.

A reliability of environmental impact assessment depends on whether early assumption is appropriate or not. The previous process may be necessary to proper man-hours for LCA when the sufficient database on environmental

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burden items emitted by production was not build.

The new process of LCA that does not require the early assumption was developed with recent database for LCA necessary. Amount of emission of all environmental burden items in the database were calculated. And dominant environmental burden items caused the environmental impact are identified. Strategic measurement to minimize the environmental impact is possible by focusing reduction of identified environmental burden items.

2 METHODOLOGY

2.1 New process of LCA

New process of LCA that will enable us to measure the strategic reduction of environmental impact is achieved by combining a scientific knowledge on environmental burden items cased environmental impact, a database on environmental burden items emitted by material production and product production process and a database on sales portfolio of the product. Fig.2 shows the new process of LCA. Each steps of the process are explained as follows.

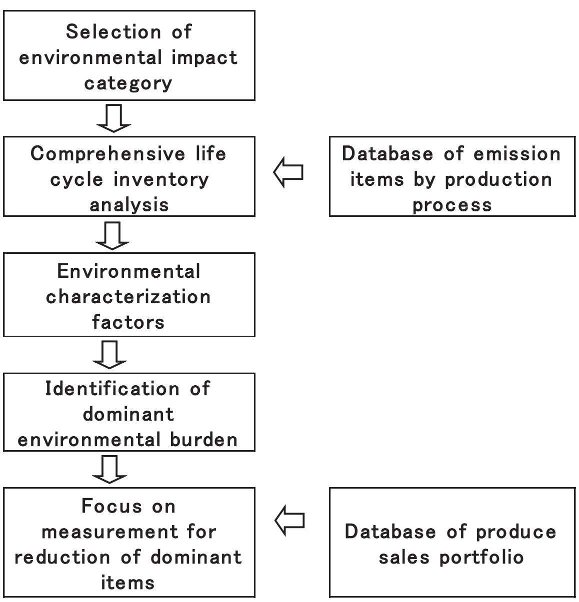

Fig.2 New Process of LCA

Selection of environmental impact category to assess

First, environmental impact category to assess should be selected. There are global warming, acidification, photochemical oxidant, etc. as environmental impact category. In this step, environmental burden items should not be limited to a few items. Global warning impact was selected in this study.

Comprehensive life cycle inventory analysis

Environmental burdens were calculated on each five phases consist of material production, product production, product use and disposal in life cycle. Life cycle inventory analysis on all environmental burden items in the selected environmental impact category was carried out based on the database of emission items by material production and product production process. The amount of all environmental burden items included in the database should be calculated.

Database of emission items by production process

Gabi4 [7] was used as database of emission items by material production process. The database of emission items by parts and product assembly production process was built by a investigation of Mazda factory. The database of sales portfolio was built by Mazda marketing data.

Environmental characterization factors

As for global warming impact in this study, environmental characterization factor is called Global-warming potential (GWP). GWP is a relative measure of how much heat a global warming gas in the atmosphere. It compares the amount of global warming by a certain mass of the gas in question to the amount of global warming by a similar mass of CO2. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of CO2 whose GWP is standardized to 1. The GWP 100 years was popular and used in this study. Specifically, CML2001 by Leiden University[8], e.g. CH_4; 23, N_2O; 296, NMHC; 16, was used as GWP.
CO2 equivalent mass was calculated by Formula (1). A contributing rate of each emission gas was calculated by dividing CO2 equivalent mass of each emission gas by Formula (1)

$$CO2_{equivalent} = \sum_{j=1}^{n} GWP_{a,j} \times m_j \quad (1)$$

where,

$CO2_{equvalent}$:CO2 equivalent mass total
GWP_j: Global warming potential of emission gas j for years.
m_j : Mass of emission gas j (kg)
a: Suffix of the time horizon years over considered
j : Suffix of the kind of emission gas

Identification of dominant environmental burden items

The identification of dominant environmental burden items enable us strategically to minimize the environmental impact.

Mazda announced that all customers who purchase Mazda cars are provided with the joy of driving and excellent environmental and safety performance under slogan of “Sustainable Zoom-Zoom” long-term vision for technology development.

Based on the vision to provide all customers with the joy of driving and excellent environmental and safety performance, LCA of passenger car was carried out for not only special grade installed with improvement device of fuel efficiency but also for sales volume-weighted average LCA of all grade. Taking dominant environmental burden item, the process of LCA is shown in Formula (2).

$$LE_{aveage} = \sum_{i=1}^{m} LEi \times V_i \Big/ \sum_{i=1}^{m} V_i \quad (2)$$

Where,

$LE_{average}$: average envionmental burden of sales portfolio,

LE_i :Life cycle of envionmental burden of *i* car grade,

V_j : Sales volume of *i* car grade

i : Suffix of car grade number 1- m,

Focus on measurement for reduction of dominant items

The process mentioned above enable us to focus on the reduction measurement for the dominant environmental burden items on selected environmental impact category.

2.2 Analyzed Products

The analyzed product was new Mazda Demio shown in Fig.3. The goals of this analysis were to compare environmental performance between new Mazda Demio and its predecessor before miner change, and to identify issues for environmental improvement.

New Mazda Demio was refined on the exterior and inertia appearance, installed the new engine; SKYACTIV-G, i-stop, i-DM and lightweight seats, and improved the air resistance coefficient; Cd. The "i-stop" was designed for

Fig.3 New Mazda Demio

restarting the engine through combustion by injecting the fuel directly into the cylinders while the engine is stopped and igniting it to generate the force necessary to push down the piston by taking advantage of the features of the direct injection system. The i-DM was the Intelligent Drive Master system which would help drivers improve their driving techniques so that the drivers could enjoy driving, offer a comfortable ride to passengers and consequently reduce the fuel consumption. As for safety improvement, New Mazda Demio was installed DSC (Dynamic Stability Control) and 3 point seatbelt of rear center seat. Fuel consumption of New Mazda Demio achieved 30km/l (10-15 driving modes).

2.3 System Boundary s

The system boundary is shown in Fig.4 [5]. The life cycle of car is defined as five phases, material production, car production, use, maintenance and disposal from raw material extraction to disposal.

The durations of car use was set as ten years, and life cycle driving distance was set as 100,000 km by Japanese JC08 driving mode.

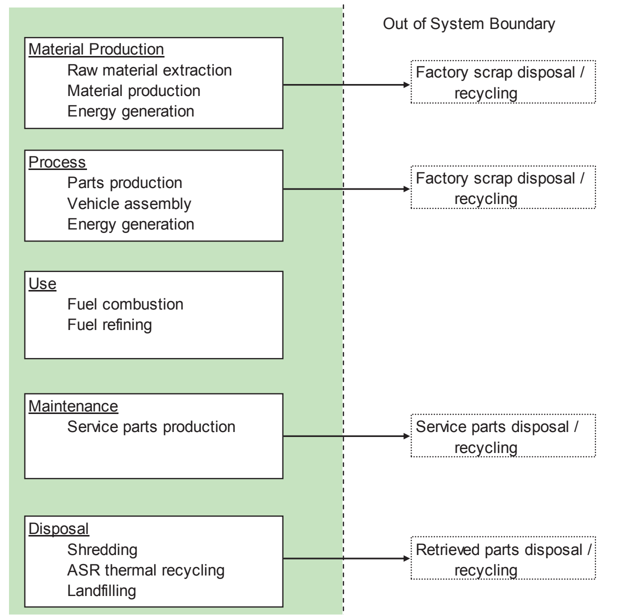

Fig.4 System Boundary[5]

3 RESULTS OF ANALYSIS

3.1 Global warming impact assessment

The masses of global warming gases emitted by the best selling grade of New Mazda Demio in lifecycle were calculated. Fig.5 shows the CO2 equivalent mass component rate of each global warming gases emitted by the New Mazda Deimo in life cycle, CO2:96.897%, CH4; 2.529%, N2O; 0.331%, NMHC; 0.1242% and others: 0.001%. CO2 was identified as the dominant environmental burden item in Fig.5.

The dominant environmental burden items in global warming gases emitted by the car were validated. In term of the results, the dominant environmental burden items were same as previous LCA processes..

3.2 CO2 emission

LCA of New Mazda Demio and its predecessor are carried out according to Formula (2) to reflect diffusion status of each grade into account. Each grade sales volume were indicated as the past record and plan respectively. Fig.6 shows CO_2 emissions by 10000 km driving distance of a unit of Mazda Demio in sales portfolio. In Fig.6, CO_2 emission of the predecessor by 10000 km driving distance indicates 1.0 as a relative scale.

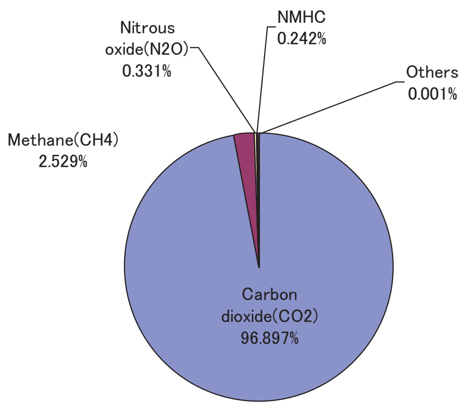

Fig.5 Comparison of global warning potential among greenhouse effect gases due to New Demio life cycle

CO_2 emission of new Mazda Demio decreases by 11% than predecessor. The environmental performance depends on improvement of fuel consumption with new engine SKYACTIV-G, i-stop and air resistance improvement. CO2 emission by production process also decreases by increased production efficiency and energy saving.

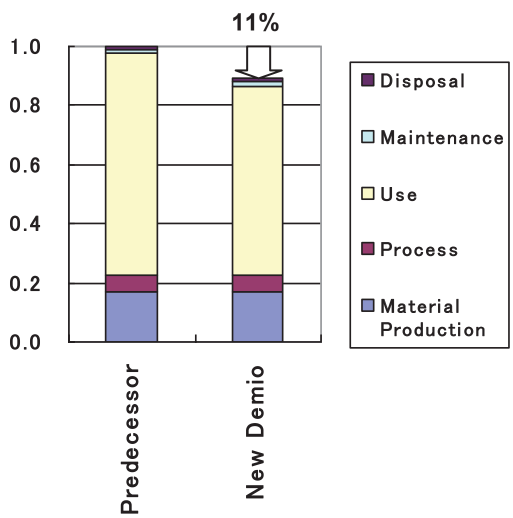

Fig.6 Comparison of CO2 emissions between predecessor and new Demio

4 CONCLUSION

In this study, new process of LCA for strategic reduction of environmental burden was developed, and was validated to be feasibility.

First, amont of all kinds of global warming gases emitted by new Mazda Demio in life cycle were calculated. Second, contribution rario of these gases were calculated with GWP100(CML2001). Third, it was validated that CO2 was the dominant gas on global warming becase of 97% contributing rate. The amont of CO2 emitted by New Mazda Demio in life cycle decreased by 11% than its predecessor.

In term of the results, the dominant environmental burden items were same as previous LCA processes. However, persons in charge of environmental improvement are able to tackle reduction of environmental burden with conviction by the new process of LCA.

Further study is nessesary to expand other environmental impact categories,e.g. acidification, photochemical oxidant, etc. Additionally, new scientific knowledge on burdens are necessary to be reflected in to the databases.

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Integrated LCA for Printing Service in an emerging country

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Abstract

In most of emerging countries in Asia, such as Thailand, Printing Service LCA is not organized, so schematization and localization of practical methodology is transferred thanks to the joint research project by Shimizu Printing Inc. and Chulalongkorn University. Printing Service LCA developed in Japan is focusing not only on $LCCO_2$ but also on Integrated LCA. It has strong possibility to take root even in emerging countries for environment-conscious Printing Services.

Keywords:

LCA, $LCCO_2$, Integrated LCA, Environmental Load Point, Printing Service

1 INTRODUCTION

Quantification of environmental load for Printing Service is well organized in Japan [1], namely Printing Service LCA is precisely schematized in the forms of $LCCO_2e$ [2] and Integrated LCA [3]. But, printing industries in many emerging countries in Asia do not have clues of quantitative assessment method yet and feel rushed to establish calculation method since some of their business model can work out only by exporting related business.

Thailand which is located in the center of Southeast Asia is covered here to validate Printing Service LCA to show possibility of localizing calculation method fitting in Thai printing industry.

In order to promote diffusion of Printing Service LCA, joint research study is conducted with an academic organization. Chulalongkorn University (CU) which is a top national university and the most influential printing related academic institution is selected to be a counterpart.

Carbon centered evaluation method for environmental load might not be perfect even in emerging countries, so Environmental Load Point (ELP) which is Integrated LCA method developed by Nagata Laboratory at Waseda University should be verified its effectiveness in Thailand.

2 ANALYSIS

2.1 ELP quantification method

ELP is based on evaluation of nine different impact categories. Outstanding feature is that order of priority for environmental load is decided by questionnaires from variety kinds of interest groups.

This idea is based on preference order about impact categories which should be determined by people's concern about environmental issues.

Weighting for each impact category is called "category importance"; it is a critical factor when consolidating environmental loads as an integrated indicator. For ELP, questionnaire such as Analytic Hierarchy Process (AHP) is utilized primarily to specify category importance for a specific group. Table 1 indicates an example of AHP explaining how to determine category importance ratio.

Table 1: Category importance determined by AHP

ELP 9-category		B: 1.Energy drain	2.Global warming	3.Ozone depletion	4.Acid precipitate	5.Resource consumption	6.Air pollution	7.Ocean & water pollution	8.Problem of waste disposal	9.Ecosystem effect	Multiplication of 9Cs*1	Category importance*2	Category importance ratio*3
A	1.Energy drain	1.000	3.000	5.000	5.000	1.000	3.000	5.000	1.000	3.000	3,375.00	2.466	0.216
	2.Global warming	0.333	1.000	3.000	3.000	0.333	1.000	0.333	0.200	1.000	0.07	0.740	0.065
	3.Ozone depletion	0.200	0.333	1.000	1.000	0.200	0.333	0.200	0.200	1.000	0.00	0.383	0.034
	4.Acid precipitate	0.200	0.333	1.000	1.000	0.200	0.200	0.200	0.200	0.333	0.00	0.320	0.028
	5.Resource consumption	1.000	3.003	5.000	5.000	1.000	0.333	0.333	0.333	1.000	2.77	1.120	0.098
	6.Air pollution	0.333	1.000	3.003	5.000	3.003	1.000	0.333	0.200	1.000	1.00	1.000	0.088
	7.Ocean & water pollution	0.200	3.003	5.000	5.000	3.003	3.003	1.000	0.333	1.000	45.09	1.527	0.134
	8.Problem of waste disposal	1.000	5.000	5.000	5.000	3.003	5.000	3.003	1.000	3.000	16,908.80	2.950	0.259
	9.Ecosystem effect	0.333	1.000	1.000	3.003	1.000	1.000	1.000	0.333	1.000	0.33	0.885	0.078

Scoring for category importance (key in answers only blue colored cell)	
9.00	A is much more important to the max
7.00	A is much more important
5.00	A is more important
3.00	A is a bit more important
1.00	A is almost same as B
1/3	B is a bit more important
1/5	B is more important
1/7	B is much more important
1/9	B is much more important to the max

Reference: Nagata Laboratory at Waseda University

*1: Multiplication of 9 impact categories

*2: One ninth power of multiplied answer of 9 impact categories

*3: One ninth power of multiplied answer of 9 impact categories is devided by total value of category importance

Proceedings of EcoDesign 2011 International Symposium

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ELP has over 185 of consumption/emission items such as crude oil, coal, iron ore, CO_2, landfill and others categorized in nine impact categories, but items are narrowed down for light version here since inventory data are simplified by the use of CO_2 calculator named "Simple LCA" created by Japan Environment Management Association for Industry and some items are uncollectable ones statistically in Thailand. Weight coefficients for all items in impact categories should be organized by related references; it is summarized in Table 2.

Table 2: Weight coefficients of items in impact categories

Impact category	Item(number of items for full version and light version)	Reference to fix weight coefficient for items in impact category
1 Energy drain	Cruide oil, coal..(5, 5)	Low calorific value/Reserve production ratio (Crude oil=1)*2
2 Global warming	CO2, CH4,CFC..(38, 3)	GWP100*1 (CO2=1)*2
3 Ozone depletion	CFCs..(24, 0)	ODP (CFC-11=1)*2
4 Acid precipitate	NH3, SOx..(7, 2)	AP (SOx=1)*2
5 Resource consumption*3	Iron ore, Boexite..(32, 1)	1/Reserve production ratio (Iron ore=1)*2
6 Air pollution	SOx, NOx..(10, 2)	1/Environmental criteria (SOx=1)*2
7 Ocean & water pollution	BOD, COD..(37)	1/Environmental criteria (BOD=1)*2
8 Problem of waste disposal	Weight calculation (1, 1)	1 (Weight calculation)
9 Ecosystem influence	Hg, Dioxine..(32, 0)	Hydrosphere biological toxic qualification factor(Cr=1)*2

Reference: Nagata Laboratory at Waseda University

*1: GWP values from IPCC AR2
*2: Relativized figure based on an item in bracket
*3: Consumption of crude oil is not included

After category importance and weight coefficient are fixed for impact categories, and then annual load for each item is figured out; it is shown in Table 3.

Table 3: Annual loads for items in impact categories

Impact category	Item	Weighting coefficient C	Consumption or Emission TQ (kg)	Annual load A=C×TQ
Energy drain	oil*1	1.00E+00	4.91E+10	4.91E+10
	coal*1	1.10E-01	3.23E+10	3.55E+09
	natural gas*1	7.70E-01	3.13E+10	2.41E+10
	uranium ore*2	1.48E+01	6.50E+06	9.63E+07
	wood*3	5.00E-02	1.29E+07	6.45E+05
Global warming	CO_2*4	1.00E+00	2.78E+11	2.78E+11
	N_2O*4	3.20E+02	2.80E+07	8.96E+09
	CH_4*4	2.45E+01	6.40E+07	1.57E+09
Ozone depletion	Data is not utilized for ELP calculation of Printing Service			
Acid precipitate	NOx(NO_2)*4	7.00E-01	8.90E+08	6.23E+08
	SOx(SO_2)*4	1.00E+00	4.62E+08	4.62E+08
Resource consumption	Iron ore*2	1.00E+00	1.55E+09	1.55E+09
Air pollution	NOx(NO_2)*4	1.40E+00	8.90E+08	1.25E+09
	SOx(SO_2)*4	1.00E+00	4.62E+08	4.62E+08
Ocean & water pollution	Data is not utilized for ELP calculation for Printing Service			
Waste disposal	Solid Waste*5	1.00E+00	1.53E+10	1.53E+10
Ecosystem influence	Data is not utilized for ELP calculation of Printing Service			

*1: US Energy Information Administration (2009)
*2: Ministry of Natural Resources and Environmnet, Thailand (2002)
*3: Ministry of Agriculture and Cooperatives, Thailand (2006)
*4 :National Statistics Office, Thailand (2007, 2005)
*5: JGSEE King Monkut's University of Technology Thonburi (2008)

Consumption or emission in one year for each item should be investigated from statistics in the specific country since target product is produced domestically here. Annual load is led from multiplication of weight coefficient and consumption or emission, and then summed up for each impact category. Calculation is done as Environmental Load Factor (ELF) for each item, and then is multiplied by inventory data to calculate ELF which is emission factor for ELP. Inventory data for Thailand is not well organized yet, so the one in Japan is utilized instead. Table 4 shows actual calculation of ELF for each item and ELF for each process. Paper is illustrated by an example.

Table 4 ELF for items and specific process (e.g. Paper)

Impact category	Item	Annual load A=C×TQ	ELF C*AHP/Total of A*10^16	1.Paper Inventory data	1.Paper ELF(ELF *Inventory data)
Energy drain	oil	4.91E+10	1.98E+04	2.20E-01	4.35E+03
	coal	3.55E+09	2.18E+03	2.43E-01	5.29E+02
	natural gas	2.41E+10	1.52E+04	2.27E-02	3.46E+02
	uranium ore	9.63E+07	2.93E+05	3.72E-06	1.09E+00
	wood	6.45E+05	9.89E+02		
		7.68E+10			
Global warming	CO2	2.78E+11	5.42E+03	1.42E+00	7.69E+03
	N2O	8.96E+09	1.73E+06	2.45E-05	4.25E+01
	CH4	1.57E+09	1.33E+05	6.70E-05	8.89E+00
		2.88E+11			
Ozone depletion	CFC-11	0.00E+00	0.00E+00		
		0.00E+00			
Acid precipitate	NOx(NO2)	6.23E+08	6.19E+05	1.07E-03	6.63E+02
	SOx(SO2)	4.62E+08	8.85E+05	1.42E-03	1.26E+03
		1.09E+09			
Resource consumption	iron ore	1.55E+09	5.60E+05		
	bauxite	0.00E+00	0.00E+00		
	Cu	0.00E+00	0.00E+00		
		1.55E+09			
Air pollution	NOx(NO2)	1.25E+09	1.07E+06	1.07E-03	1.14E+03
	SOx(SO2)	4.62E+08	7.61E+05	1.42E-03	1.08E+03
	CO	0.00E+00	0.00E+00		
	NMHC	0.00E+00	0.00E+00		
	Particulates	0.00E+00	0.00E+00	3.30E-04	0.00E+00
		1.71E+09			
Ocean & water pollution	BOD	0.00E+00	0.00E+00		
	COD	0.00E+00	0.00E+00		
		0.00E+00			
Waste disposal	Solid Waste	1.53E+10	4.64E+04		
Ecosystem influence	Dioxin	0.00E+00	0.00E+00		
			Total ELF:		1.71E+04

At the end of ELP explanation, practical quantification steps are summarized below.

(1) In order to calculate annual load for each item in each impact category, weight coefficient which is fixed by the reference for item in category (Table 2), is multiplied by annual consumption or emission for item (Table 3) and summed up as annual load for each impact category.

(2) Category importance determined by AHP (Table 1) in each impact category is multiplied by weight coefficient which is fixed by the reference for impact category, and then divided by sum of annual load in impact category for normalization. Total of each item's consolidated coefficient is summarized as ELF for each process; it is basic element, namely emission factor to calculate ELP. (Table 4)

(3) ELP is led by multiplication of ELFs for processes and total inputs or emissions for processes.

Mathematical formulas for three steps are shown below in concert with explanation.

$$A_j = \sum_k (C_{j,k} \times TQ_k) \quad (1)$$

$$ELF_k = \sum_j \left(C_{j,k} \times W_j \big/ A_j \right) \quad (2)$$

$$ELP_i = \sum_k (ELF_k \times Q_{i,k}) \quad (3)$$

ELP_i: Integrated indicator

A_j: Annual load in j impact category

$C_{j,k}$: Weight coefficient for k item in j impact category

TQ_k: Annual consumption or emission for k item

ELF_k: Integrated coefficient for k item

Wj: Weight coefficient (category importance) from questionnaire in j impact category

$Q_{i,k}$: Total consumption or emission for k item in i process

Suffix I: Process or product

Suffix j : Impact category

Suffix k: Item in impact category

ELP evaluates environmental impacts with sufficient balance. It is an Integrated LCA approach illustrating environmental load from wide range of standpoints.

2.2 Survey by AHP for different groups

As mentioned above, ELP is started by AHP to know environment conscious level (category importance) by impact category for specific group.

For this study, people inviting questionnaires in two groups besides CU students and personnel are defined. One is “Printers” (40 interviewees) from Printing Association and the other is “Housewives” (40 interviewees) having strong influence on buying behavior. Both are key groups to know category importance of nine impact categories for further research.

Latest AHP from three groups in Thailand are summarized and compared with the one from “Printers” in Japan. For CU students and personnel, “Resource consumption” is ranked first, “Ecosystem effect” stands second and “Global warming” sits third. Their focus is mainly on scarcity of resources, global warming issue is not paid attention as number one issue.

For Printers and Housewives in Thailand, “Global warming” is ranked first, “Energy drain” stands second and “Air pollution” sits third, two groups shows exact same tendency. Definitive reasons for the results are not known, but it could be considered that Global warming issue also gets a lot of media attentions in Thailand.

For Printers in Japan, they are 30 interviewees from Japan Waterless Printing Association and carbon calculation operators. Namely, they are at the edge of printing industry from the viewpoints of environment conscious, so the result could be the most ideal among imaginable ones. They view “Global warming” as first priority and “Energy drain” as second priority, their way of viewing is all the same as Printers and Housewives in Thailand. Even though their bases of daily activities are different, importance of first and second impact categories they pay attention are all the same. It is shown in Figure 1.

Impact Categories	Printers 40-interviewee JPN	Chula Univ. 100-interviewee THA	Housewives 40-interviewee THA	Printers 30-interviewee THA
1.Energy drain	0.142	0.098	0.142	0.152
2.Global warming	**0.161**	0.134	**0.168**	**0.156**
3.Ozone depletion	0.114	0.129	0.109	0.117
4.Acid precipitate	0.079	0.084	0.083	0.096
5.Resource consumption	0.098	**0.168**	0.089	0.087
6.Air pollution	0.106	0.100	0.112	0.130
7.Ocean & water pollution	0.118	0.082	0.110	0.103
8.Problem of waste disposal	0.059	0.067	0.089	0.071
9.Ecosystem effect	0.122	0.138	0.098	0.088

Reference: Nagata Lab. at Waseda Univ.

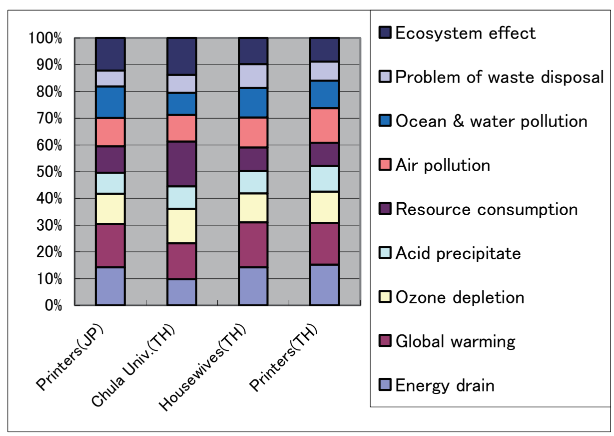


Fig. 1: AHP results in Thailand and Japan

As a result of AHP in Thailand and Japan, it is clear that people who are deeply involved in printing related and buying activities, that is to say that suppliers and consumers are very conscious about “Global warming” and “Energy drain”, but contrastingly do not care almost nothing for “Problem of waste disposal”.

On the other hand, people in academic field are trying to look straight at the current environmental problem. They consider “Resource consumption” as top priority, it means that drawdown of mineral resources in the near future is worried more than a little.

So on that point, in order to speed up people to shift their mood to environment conscious, "Global warming" is definitely critical factor, but people in academic field never be misguided by media and try to keep the ideal balance of environment conscious.

2.3 Case study specification for ELP

Case study here is a textbook for students at Department of Architecture at CU, its specification is summarized in Table 5.

Table 5: Specification of a textbook for case study

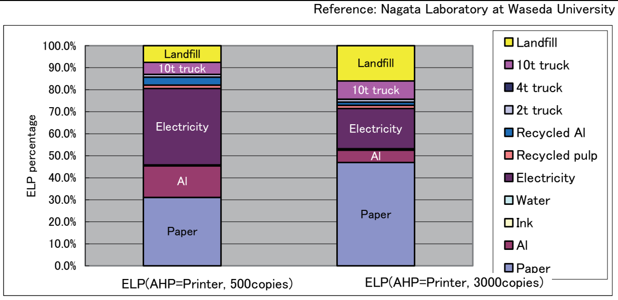
Title:	The beginning of Siam Architecture Arts
Author:	ML Prateep Malakul
Size:	190mm*260mm*6mm
Copies:	500
Pages:	Cover 4P + Text 128P

2.4 ELP results by different production lots

Questionnaires to know category importance of impact categories by AHP are conducted for CU, Housewives and Printers separately in Thailand, but ELP based on one category importance only by Printers but different production lots is verified at first. Figure 2 indicates the difference of ELP by 500 and 3000 copies of a textbook.

Process	Case study-1(500 copies)				Case study-2 (3000 copies)			
	ELF	ELP(AHP=Printer)			ELF	ELP(AHP=Printer)		
		Input	ELP			Input	ELP	
1. Paper	1.71E+04	276.210 kg	4.73E+06	31.1%	1.71E+04	1,058.750 kg	1.81E+07	46.9%
2. Al	2.18E+05	10.000 kg	2.18E+06	14.3%	2.18E+05	10.000 kg	2.18E+06	5.6%
3. Ink(Polyurethane)	5.88E+04	1.033 kg	6.07E+04	0.4%	5.88E+04	4.276 kg	2.51E+05	0.7%
4. Water	9.95E-01	2.580 kg	2.57E+00	0.0%	9.95E-01	10.691 kg	1.06E+01	0.0%
5. Electricity	4.25E+03	1,243.908 kWh	5.29E+06	34.8%	4.25E+03	1,655.352 kWh	7.04E+06	18.2%
6. Recycled pulp	1.57E+03	149.351 kg	2.35E+05	1.5%	1.57E+03	374.659 kg	5.89E+05	1.5%
7. Recycled Al	5.44E+04	10.000 kg	5.44E+05	3.6%	5.44E+04	10.000 kg	5.44E+05	1.4%
8. 2t truck	4.38E+03	41.208 tkm	1.80E+05	1.2%	4.38E+03	114.936 tkm	5.03E+05	1.3%
9. 4t-truck	3.52E+03	2.843 tkm	1.00E+04	0.1%	3.52E+03	2.843 tkm	1.00E+04	0.0%
10. 10t-truck	2.98E+03	278.549 tkm	8.30E+05	5.5%	2.98E+03	1,069.382 tkm	3.19E+06	8.3%
11. Landfill	7.42E+04	15.477 kg*1	1.15E+06	7.6%	7.42E+04	83.459 kg*1	6.20E+06	16.0%
		Total ELP:	1.52E+07				3.86E+07	
		Total ELP/book:	3.04E+04				1.29E+04	

Reference: Nagata Laboratory at Waseda University



*1: Weight of products*Landfill ratio(12.2%)

Fig. 2: ELP of 500/3000 copies

ELP for 3000 copies is 2.5 times as much as the one for 500copies when number of copies for medium-run is six times as many as the one for short-run. ELP per book is cut downed to more than half when production lot is changed from 500 copies to 3000 copies.

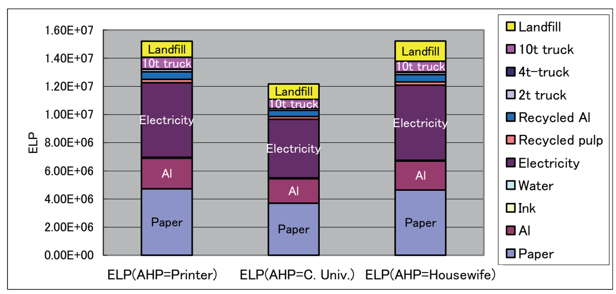
For short-run job, "Electricity" is the highest load because it occupies more than one third of the total. Yet, for medium-run job, "Paper" is the most influential factor since it almost reaches half of the total load. Breakout of environmental load per book depends on lots; it is exactly the same as cost performance.

2.5 ELP result comparison of CU students, Printers and Housewives in Thailand

ELP result is compared among three different groups such as Printers, CU students and Housewives in Thailand to know how category importance determined by AHP influence ELP results. It is summarized in Figure 3.

Process	Input	Printer (THA)		CU (THA)		Housewife (THA)	
		ELF-1	ELP	ELF-2	ELP	ELF-3	ELP
1. Paper	276.210 kg	1.71E+04	4.73E+06	1.34E+04	3.70E+06	1.68E+04	4.64E+06
2. Al	10.000 kg	2.18E+05	2.18E+06	1.74E+05	1.74E+06	2.05E+05	2.05E+06
3. Ink(Polyurethane)	1.033 kg	5.88E+04	6.07E+04	4.38E+04	4.52E+04	5.72E+04	5.91E+04
4. Water	2.580 kg	9.95E-01	2.57E+00	7.93E-01	2.04E+00	1.01E+00	2.59E+00
5. Electricity	1,243.908 kWh	4.25E+03	5.29E+06	3.36E+03	4.18E+06	4.28E+03	5.33E+06
6. Recycled pulp	149.351 kg	1.57E+03	2.35E+05	1.24E+03	1.85E+05	1.58E+03	2.36E+05
7. Recycled Al	10.000 kg	5.44E+04	5.44E+05	4.34E+04	4.34E+05	5.14E+04	5.14E+05
8. 2t truck	41.208 tkm	4.38E+03	1.80E+05	3.39E+03	1.40E+05	4.11E+03	1.69E+05
9. 4t-truck	2.843 tkm	3.52E+03	1.00E+04	2.74E+03	7.80E+03	3.27E+03	9.29E+03
10. 10t-truck	278.549 tkm	2.98E+03	8.30E+05	2.32E+03	6.46E+05	2.76E+03	7.70E+05
11. Landfill	15.477 kg*1	7.42E+04	1.15E+06	7.01E+04	1.08E+06	9.31E+04	1.44E+06
	Total ELP:		1.52E+07		1.22E+07		1.52E+07

Reference: Nagata Laboratory at Waseda University



*1: Weight of products*Landfill ratio(12.2%)

Fig. 3: ELP of Printer/CU/Housewife

ELP for Printer and Housewife is almost the same since the same trend is seen in category importance by AHP for both groups, so compare Printer with CU only here.

ELP for CU is about 20% less than the one for Printer. The reason is that Printer's ELFs which are emission factors for ELP are much higher than CU's ones. Two major influential factors are Paper and Electricity, those ELFs for Printer are around 1.3 times as much as the ones for CU because Printers weights more on Global warming which has almost 50% affect on paper and 60% affect on electricity individually. This is a case study showing different environmental load based on different category importance even though calculating same specification of a printed matter.

Category importance in impact category which is weighted highly for inventory data influences ELF and leads ELP higher even though production lot is the same.

2.6 ELP result comparison of Thai printers and Japanese printers

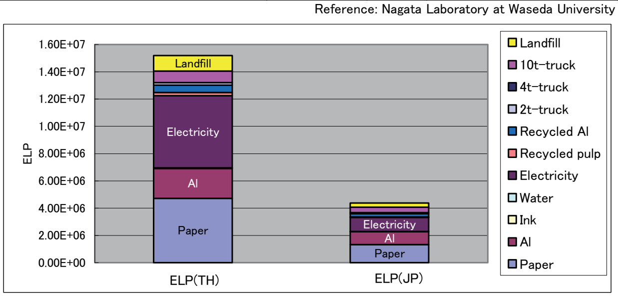
Cross-border comparison of ELP between Thailand and Japan is done based on Printers' category importance in each nation. The result is shown in Figure 4.

ELP in Thailand is almost 3.5 times as much as the one on Japan, namely environmental load in Japan is less than one third. The reason is that the most influential ELF which is Electricity is 5.2 times as much as the one in Japan. Additionally, second highest load which is Paper is 3.6 times as much as the one in Japan. ELFs of two major factors are obviously different on a grand scale.

In addition, Thai ELFs for each item such as oil/coal/natural gas for Energy drain and CO_2/N_2O/CH_4 for Global warming in impact categories are much higher compared with Japanese ELFs for same items after normalization considering item's category importance by AHP and sum of annual load in impact category.

Process	ELF(TH)	ELP (Printers, THA)			ELF(JP)	ELP (Printers, JPN)		
		Input	ELP			Input	ELP	
1. Paper	1.71E+04	276.210 kg	4.72E+06	31.1%	4.75E+03	276.210 kg	1.31E+06	30.0%
2. Al	2.18E+05	10.000 kg	2.18E+06	14.3%	9.62E+04	10.000 kg	9.62E+05	22.0%
3. Ink(Polyurethane)	5.88E+04	1.033 kg	6.07E+04	0.4%	1.49E+04	1.033 kg	1.54E+04	0.4%
4. Water	9.95E−01	2.580 kg	2.57E+00	0.0%	1.93E−01	2.580 kg	4.98E−01	0.0%
5. Electricity	4.25E+03	1,243.908 kWh	5.29E+06	34.8%	8.21E+02	1,243.908 kWh	1.02E+06	23.4%
6. Recycled pulp	1.57E+03	149.351 kg	2.34E+05	1.5%	3.02E+02	149.351 kg	4.51E+04	1.0%
7. Recycled Al	5.44E+04	10.000 kg	5.44E+05	3.6%	2.36E+04	10.000 kg	2.36E+05	5.4%
8. 2t truck	4.38E+03	41.208 tkm	1.80E+05	1.2%	1.86E+03	41.208 tkm	7.66E+04	1.8%
9. 4t−truck	3.52E+03	2.843 tkm	1.00E+04	0.1%	1.68E+03	2.843 tkm	4.78E+03	0.1%
10. 10t−truck	2.98E+03	278.549 tkm	8.30E+05	5.5%	1.42E+03	278.549 tkm	3.96E+05	9.0%
11. Landfill	7.42E+04	15.477 kg*1	1.15E+06	7.6%	1.96E+04	15.477 kg*1	3.03E+05	6.9%
		Total ELP:	1.52E+07				4.37E+06	

Reference: Nagata Laboratory at Waseda University

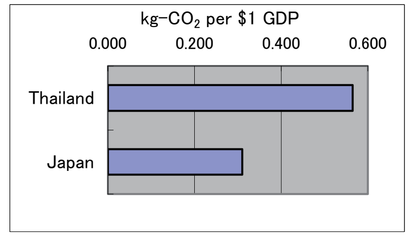


*1: Weight of products*Landfill ratio(12.2%)

Fig. 4: ELP of Printers in Thailand and Japan

This result might be suspicious because the result differs greatly when comparing. Figure 5 could show comprehensive idea and backup the difference of the result in some way since it shows relation nature of environmental factor and economical factor.

Year	2007
Scale	kg−CO_2 per $1 GDP
Thailand	0.565
Japan	0.310
JP/TH	54.9%



Reference: United Nations Statistics Division

Fig. 5: CO_2 emission per GDP 1$ in Thailand and Japan

This data shows that CO_2 emission to generate $1 of GDP, the number in Japan is nearly half of the one in Thailand. It means that efficiency of production and service is down to the half level in Thailand. If focusing only on manufacturing except for service related activities, this difference is easily imagined that CO_2 emission to generate $1 of GDP in Thailand can be much worse than current figure.

3 CONCLUSION

Integrated LCA for Printing Service ranging from primary data collection at production site to secondary data collection by bibliographical survey is established in an emerging country without any serious obstacles. Though there is limited condition such as no statistical data for some items in impact categories, the comparison of environmental load by the scale of ELP can be performed to know the difference between an emerging country and an advanced country. Comparison of the same printed matter based on different category importance in the same nation cannot show any significant meaning, but comparison based on different category importance in different nation can show valuable match-up. This is the way for ELP to be utilized.

Carbon centered evaluation method is viewed with skepticism in advanced countries since many believe that other environmental influences should be considered in some way, it also happens in emerging countries. Surveys for different groups of people mostly show that Global warming is top priority among impact categories, but it does not stick out and other impact category such as energy drain is also considered to be important as well. Therefore, the demand for Integrated LCA such as ELP is expected to be stronger and stronger from now on; the method should be schematized and utilized in other emerging countries in the future even though it has minor limited condition regarding consumptions or emissions of items in impact categories. ELP is the one to be transitioned and localized in different countries in a short span of the time since only questionnaires of category importance and investigation of consumption/emission of item are necessary things to do.

Taking all of these results above into account, ELP for Printing Service can be established even in emerging countries with minimum level of effort.

4 DISCUSSION

Primary data collection is not so difficult since printing related facilities which are utilized all over the world are all the same though mixture of old and new should be considered. But, secondary data collection sometimes meets obstacles because of pending arrangement in national database which is supposed to be organized by government institutions in emerging countries. For the case study here, secondary data of paper occupying majority of the load is not prepared in Thailand for years and is misappropriated to Japanese secondary data. Data for paper is one of the most important one for Integrated LCA, so inventory data for two different kinds of paper which are coated paper and coated cardboard should be well prepared as soon as possible.

Many people especially in academic and industry field in emerging countries feel that Carbon Footprint of Products (CFP) cannot show real environmental load and try to develop comprehensive Integrated LCA approach, but it is not successful yet. When most of people in town cannot understand CFP perfectly, it is presumed that comprehension of Integrated LCA result must be much more obscurity. The time might not be ripe to go on to the next step right now. It is too straightforward for Integrated LCA to utilize for Business to Consumer basis, but it might be much easier for Business to Business basis to start utilizing Integrated LCA as consolidated indicator in the streamline of supply chain.

Finding out the solution for the problem of getting the concept of Integrated LCA across is a great challenge and a near-future agenda.

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Research on Environmental Innovation Strategy that intends High Performance Enterprise in Uncertain Age

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Abstract
The purpose of this content is to clarify the characteristic in the source of the corporate value creation based on empirically analysis of the environmental strategy that intends a high performance in an uncertain age of recent years. Various proofs has already been performed about the Porter hypothesis that the environmental control stimulates the technical improvement and the competitiveness of the company rises inside and outside the country, and financial data of the eco management investigation and the listed company intended for the domestic manufacturing from 2005 to 2010 is used here. The relation between an environmental performance and a financial performance was analyzed by various cuts, and the grasp of a basic theory for modeling and the further validation of the hypothesis by the double check were tried from the trend and the pattern of each enterprise. In a domestic enterprise, it is clear to have to consider the CSR whole that exceeds the environmental range and the viewpoint named ESG as an area expansion and non-financial index to the foreign company when application to the business is considered though a constant tendency was able to confirm the hypothesis. It is thought that the result of the trend analysis clarified here is useful in the meaning of supplementing a part of essential information to make the position of the enterprise in the sustainable society that should be aimed in near future.

Keywords:
evaluation, CSR, ESG, strategy, innovation

1 INTRODUCTION

The company is pressed for various correspondences for continuation while many uncertain factors, such as economy by the global financial crisis or a newly emerging country seen rarely, change of population structure, or a correspondence demand to the social responsibility for which the environmental problem that is progressing steadily although it is not rapid, and a company are asked, occur in recent years. Probably, the action which a sustainable company should take in such a situation must be based on the information gathering more scientific basis, and suitable decision-making. The correspondence although what depends many of former corporate value on an economical result was in the mainstream, non-social acts, such as a scandal, lead to a large drop in share prices also in the viewpoint of compliance, these theme neglect will be impossible. Although financial performance and an environmental performance generally have a relation of a trade-off, It is thought that the Porter hypothesis that environmental regulation stimulates technical innovation and business competitiveness increases is verifiable by clarifying the characteristic of the fountainhead of corporate value creation from analyzing positively the situation of the environmental strategy in which the high performance companies. Although various actual proofs have already been made in and outside about this theme, The financial statistics of the eco management degree investigation for the domestic manufacturing from 2005 to 2010 and a listed company are used here, The relation between an environmental performance and financial performance was analyzed at various cut ends, and re-verification of the hypothesis by the grasp and supplementary examination of basic theory which are turned to modeling from the trend and type of each company was tried. Below, in Section 2, the outline of related precedence research is checked and a hypothesis, the model for verifying it, and data are explained with Section 3. Section 4 shows the contents and the result of empirical analysis, and last Section 5 has stated the implication towards future deployment and practical use in business as a conclusion.

2 THE OUTLINE OF PRECEDENCE RESEARCH

2.1 Relation between regulation, environment policy, and corporate value

The Porter hypothesis is supposed that technical innovation which will bring about expense saving and improved quality if environmental regulation is designed appropriately is stimulated, and business competitiveness increases. Although it receives and the report of the actual proof is carried out one by one from around 1995, The company by Parmar etc. pursues profits to the last at the beginning, and it applies from 1999 in 2002 from a view negative about the synergistic effect by the new technology of an environmental measure, Some reports of

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bringing good influence to financial performance by secondary effects, such as not only the technical innovation by an environmental measure but transparency of decision-making and improvement in reliability, are shown. Moreover, report by the domestic data in 2004 and afterwards the measure for the environment of a company changing from recognition of a cost factor to positioning as one of the most important strategies, and, it seems that the correlation is becoming more clear with progress of time, such as showing the conclusion whether a high environmental performance also come to evaluate the market side simultaneously as a factor which raises a corporate value.

Table 1 : Number of evaluated companies by year

Industory / Year	2005	2006	2007	2008	2009	2010	Total
Food	25	30	31	31	33	36	186
Textile	7	9	9	9	10	12	56
Paper	6	7	7	7	7	9	43
Chemical	52	55	57	59	58	69	350
Drug	12	14	16	16	18	19	95
Oil	4	4	4	4	4	4	24
Rubber	10	9	10	10	10	10	59
Pottery	8	9	10	10	10	11	58
Steel	5	4	6	7	7	8	37
Metal	16	17	17	18	18	22	108
Machinary	30	34	38	41	46	55	244
Electronics	68	74	73	72	78	92	457
Shipbuilding	2	2	2	2	1	3	12
Auto	21	21	23	22	22	29	138
Trucking	2	2	2	2	2	2	12
Precision	11	12	13	15	15	18	84
Others	1	2	2	2	3	3	13
Printting	7	7	8	9	9	11	51
Light Industry	7	9	10	10	11	11	58
Total	294	321	338	346	362	424	2085

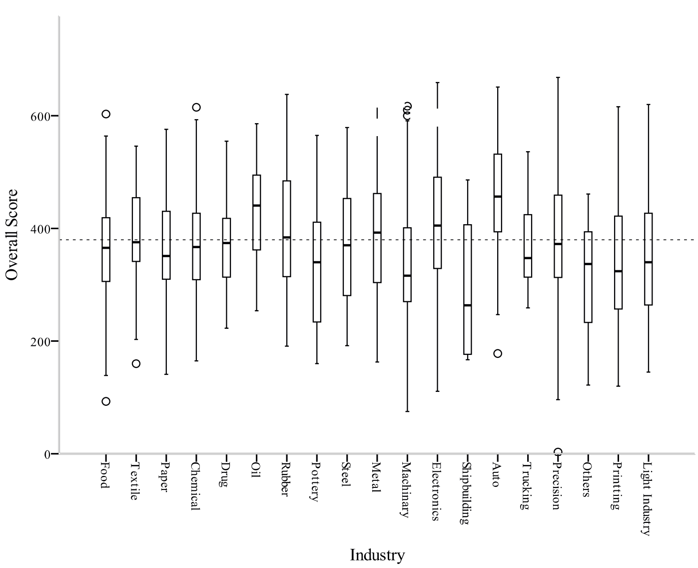

Fig. 1 : Over-all sore by industries (2005-2010)

2.2 Uncertainty of reformist investment

About innovation investment, from the skeptical thing that it may be promoted by the emissions-rights sale profit motive of Alpay in 2001, there is a report of Ambec, Mohr, etc. to which it is supposed that an effect fixed about investment for research and development is seen in 2002 and afterwards. In the situation where environmental regulation is performed by Popp D. in 2005, it is higher profits to perform investment for research and development, and when there is no regulation, in the way which does not perform investment for research and development, the average of profits becomes high. Moreover, if a possibility of gaining such high profits that research and development expenditure being innovatively large scale is high, it will collect, in henceforth the domestic reporting, if the virtuous circle of the environment and economy of what is not necessarily made clear as economic theories, such as evaluation to the inefficiency or environmental conservation activities in a company, is brought about and the possibility of a policy is not denied simply, it is collected.

3 A HYPOTHESIS AND ACTUAL PROOF MODEL

3.1 Verification design outline

Some of the contents already clarified by precedence research, although the concrete verification hypothesis was set up along with five verification themes, the each outline will be explained below. 1 check of relevance of result, 2 classification by synthetic index, 3 classification by degree of similar, 4 check of causal relationship between factors, and 5 predict future from past data as optional.

3.2 About the check of the relevance of a result

The relation between basic environment and financial factor is checked the correlation analysis and discriminant analysis which carried out the focus are given to the holdings company etc. that plan global business and a strategic investment with large size of business and characteristic of a company, for example, an overseas sales ratio, and the following hypotheses are verified. Hypothesis 1: a. Environment and financial factor have

Table 2 : Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Overall	2085	3	668	379.84	109.286
Management	2085	7	100	62.61	18.157
Poution	2085	9	100	68.29	20.825
Recycling	2085	10	100	68.76	17.080
Product	2085	10	100	63.28	19.378
GHG	2085	5	100	57.91	21.703
Sales	1992	1642	26289240	705006.80	1769282.100
ROA	1992	-.55	.14	.0225	.04857
Overseas	1636	0.00	.91	.3914	.21682
RD	1978	0.00	.52	.0371	.03936
Captal	1985	0.00	.78	.0547	.04441
Employee	1990	61	384586	17402.43	38244.244
Sales_Emp	1990	2.00	814.00	46.0714	56.51038
TobinQ	1892	-.91	3.00	-.1671	.46793
Valid N	1575				

positive correlation, b. A size of business and an environmental indicator have positive correlation, and c. A holdings company and global business show higher performance from a strategic intention.

3.3 About the classification by a synthetic index

Principal component analysis extracts the two main ingredients from the synthetic target index this time, and it tries the pattern type according to company. Moreover, a part is verified based on the influence of a related event. Hypothesis 2: The group of the company which raises a corporate value without damaging value by strategic action also in a company with a large size of business and high environment assessment exists.

3.4 About the check of the causal relationship between factors

A financial indicator and an environmental indicator are taken to each dependent variable, the remaining variables are taken to an independent variable, and a multiple regression model is derived by the multiple linear regression analysis by a stepwise procedure.

4 ESTIMATION RESULT IN ACTUAL PROOF

4.1 Data and a sample

Sample data set the listed company which can obtain financial statistics and stock price data as the main objects out of around 400 companies of domestic manufacturing in Japan market which has been the target of the Nikkei eco management degree investigation about six years of 2005 to 2010. Scoring of the result investigated by the contents the evaluation criteria of eco management degree investigation were indicated to be in Table 1 is carried out by environment overall score for each industries. Financial statistics and stock price data collected the corresponding data of the fiscal year from Nikkei NEED-FAME. Moreover, it supplements with attribute dummies, such as a size of business, global business, and a holdings company, in analysis.

4.2 The characteristic of data

The selected company of business environment degree investigation is classified into the industry of 19, and distribution of the comprehensive mean score of each type of industry through 2005 to 2010 shown in Fig. 1. If an overall average is seen, a car, electrical machinery, etc. are positioned by the higher rank. Moreover, the amount of descriptive statistics of the data for analysis is shown in Table 2. As an index of financial performance, it learns from precedence research, and is using the logarithm of the Tobin's Q minus 1 as one of the indices showing the corporate value computed from a stock price. The outline of the business environment of a period by which investigation was conducted is shown inFig. 2. At the financial crisis in 2009, the fall of the corporate value and returns are confirmed in almost the companies.

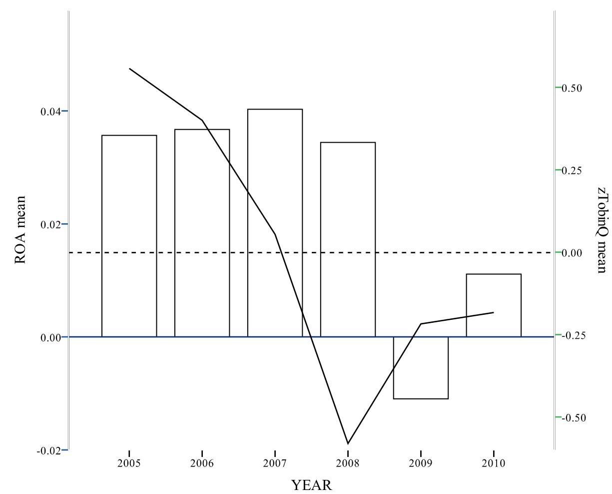

Fig. 2 : Overview of the business environment

4.3 The relation between environment and a financial factor

The investigated correlation between an environmental indicator and each financial statistics described in Table 3. First, although the significant result was not seen for a short period of time for one year in the relation between

Table 3 : Correlations between environment and financial factor

	Overall	Mngmt	Poution	Recyclin	Product	GHG	Sales	ROA	Overseas	RD	Captal	Employe	SalesEm
Management	.804**	1											
Poution	.677**	.620**	1										
Recycling	.781**	.671**	.569**	1									
Product	.753**	.649**	.696**	.638**	1								
GHG	.711**	.729**	.645**	.710**	.656**	1							
Sales	.364**	.399**	.287**	.294**	.308**	.348**	1						
ROA	.163**	.092**	-.060**	.041	-.030	-.021	-.004	1					
Overseas%	.233**	.243**	.243**	.234**	.257**	.226**	.224**	-.017	1				
RD%	.098**	.078**	.132**	.128**	.165**	.105**	.025	-.073**	.151**	1			
Captal%	.074**	.048*	.083**	.055*	.068**	.009	.050*	-.023	.144**	.068**	1		
# of Employee	.413**	.451**	.346**	.342**	.372**	.422**	.844**	-.039	.277**	.080**	.078**	1	
Sales_Emp%	.042	.057*	.013	.017	.012	-.006	.233**	.031	-.149**	-.141**	-.091**	-.045*	1
TobinQ	.140**	.041	-.094**	.101**	.025	-.004	-.053*	.397**	.147**	.258**	.123**	-.043	-.072**

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

ROA and an environmental synthesis rank which shows short-term financial performance, if six years are seen from the mid- and long-term viewpoint, a mutually related tendency will appear. About the item which requires investment, such as countermeasures against pollution and greenhouse gas, especially, negative correlation is shown as what spoils short-term profits. When it sees about the foreign sales ratio and environment assessment, a coefficient is 0.2 set, but positive high correlation is shown relatively and the environmental measure consciousness of global business is imagined. Although ROA which shows profits about a research and development cost versus sales ratio and environment assessment gives impact by negative correlation, it is considered to contribute to improvement in environment assessment, and although it affects profits similarly about a capital investment pair sales ratio, it is raising evaluation of countermeasures against pollution, the measure against a product, and the measure against resource circulation. It is in the tendency which shows a high rank generally in a relation with the consolidated sales and the number of employees showing the scale of a company, it is thought that this comes from the business structure which can be equal to a minimum measure investment. Also it seems that investment contributes to the improvement in the value of a relation with a corporate value, correlation of minus is shown in sales or profits. About environment assessment, variation is seen by items.

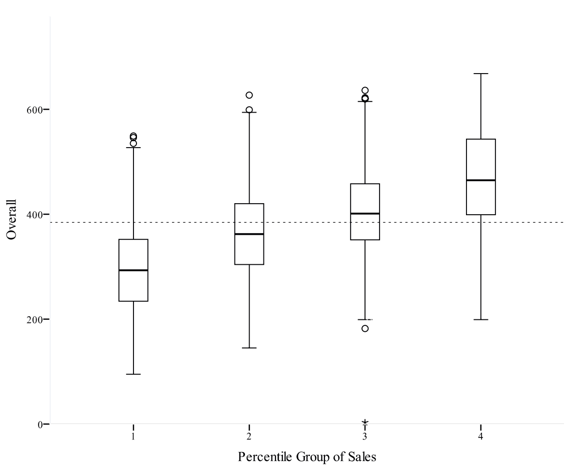

Fig. 3 : The environment-assessment tendency by a size of business

4.4 Trend analysis by a size of business

It divided into four from the higher rank as a size of business from the average of the consolidated sales of a company, and verified the relation with overall environment score. First, the result of having authorized the difference of each index between groups (sales rank) analysis is shown in Fig. 3. Positive correlation is found by a size of business and the environmental indicator from on a graph, and the tendency for the higher rank company to raise environment assessment compared with the market value (equipment and investment for research and development are included) is seen. In another test, the environmental indicator, the big difference was seen especially by the measure against warming and countermeasures against pollution between the groups of a sales scale. This is considered to be a result of being in the environment which is easier to cope with it as a major company compared with small and medium-sized enterprises.

4.5 The characteristic of a holdings company

The result analyzed by the time series about 16 holdings companies among 424 candidate companies shown inTable 4. The environmental comprehensive evaluation of that in which holdings are unexpectedly less than the corporate value from the teble can read the tendency which a holdings company exceeds generally.

Table 4 : Relation between holding companies and environment assessment

		Overall	Management	Poution	Recycling	Product	GHG
Non-HD	Mean	377.89	62.18	67.99	68.46	62.89	57.40
	Minimum	3	7	9	10	10	5
	Maximum	668	100	100	100	100	100
	N	2017	2017	2017	2017	2017	2017
HD	Mean	437.53	75.34	77.28	77.44	74.88	73.12
	Minimum	303	47	19	52	47	27
	Maximum	620	98	100	100	99	95
	N	68	68	68	68	68	68
Total	Mean	379.84	62.61	68.29	68.76	63.28	57.91
	Minimum	3	7	9	10	10	5
	Maximum	668	100	100	100	100	100
	N	2085	2085	2085	2085	2085	2085

4.6 The type of the pattern according to company

The result of having conducted principal component analysis in order to carry out the type of what kind of the tendency and characteristic being according to each company and to extract the factor that it is likely to be the most influential from each index shown in Table 5. The two main ingredients of environmental comprehensive evaluation, a size of business, the 2nd rank, an environmental synthesis rank, an eco management rank, which consist of the 1st consolidated sales, number of employees, etc. were extracted from this result. The result of having mapped these two main ingredients in the graph Fig. 4. The inside where a large number exist in the 2nd quadrant (upper left) if a graph is divided by four quadrants, There is a company county considered to have aimed at the improvement in a corporate value strategically, carrying out an environmental consideration effectively by mega industry like the company of the 1st quadrant (upper right), and although an environmental consideration is carried out by mega industry like the 4th quadrant (lower right), it can read that the company group which has damaged the corporate value also exists. The graph shows which sampled some companies from the food industry and checked the transition by the time series, and it is being checked whether based on the strategy trend of each company, the position is moving at a given fiscal year. The portion which transition based on a strategy can see is considered that the people in general of a certain thing need to conduct detailed analysis by industrial classification from now on since the factor currently influenced by the economic trend is also considered greatly.

Table 5 : Component matrix a

	Component 1	Component 2
Overall	.876	.176
Managemen	.851	.030
GHG	.834	-.025
Recycling	.811	.148
Product	.811	.040
Poution	.755	-.085
Employee	.649	-.340
Sales	.577	-.392
Overseas	.417	.207
TobinQ	.029	.791
ROA	-.016	.575
RD	.194	.394
Sales_Emp	-.006	-.255
Captal	.107	.206

Extraction Method: Principal
a. 2 components extracted.

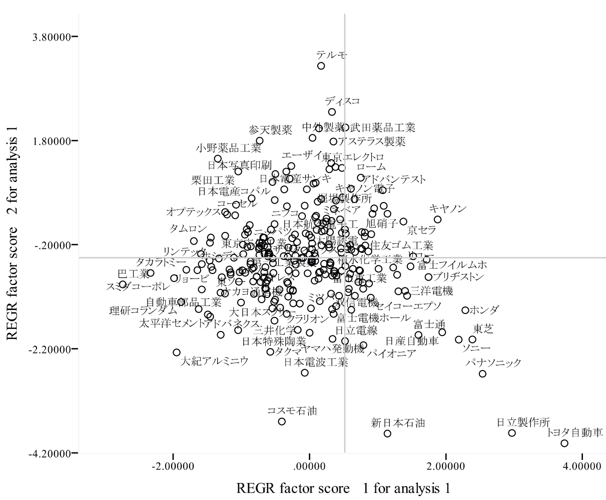

Fig. 4: Environment strategic position

4.7 Determine of a multiple regression model

The result of having taken the Tobin Q minus 1 and the eco management degree evaluation synthesis degree score which show financial performance to each dependent variable, having taken the remaining variables to the independent variable, and having carried out multiple linear regression analysis by a stepwise procedure described in Table 6. Each multiple regression type was drawn from these results as follows.

Financial performance (Tobin Q) =
+ 3.340 ROA
+2.927 R&D investment
+0.347 overseas sales ratio
+0.904 capital investment
-0.006 pollution score
+0.001 overall score
-0.003 environment management score
+0.002 recycling score
-0.437 constant

The correlation coefficient R which is applied although verification by real data was also performed, and expresses a degree is not so high as 0.534, and the coefficient-of-determination adjusted R square showing prediction ratio, it is 0.281 and a still low model, and it is thought that the elaboration according to industrial classification and fiscal year is future still more nearly required.

Table 6 : Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
9	.534[i]	.285	.281	.41464

i. Predictors: (Constant), ROA, RD, Overseas, Poution, Overall,

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
9	(Constant)	-.437	.055		-7.873	.000
	ROA	3.350	.230	.332	14.578	.000
	RD	2.927	.280	.229	10.463	.000
	Overseas	.347	.053	.153	6.549	.000
	Poution	-.006	.001	-.260	-9.018	.000
	Overall	.001	.000	.232	5.107	.000
	Employee	.000	.000	-.093	-3.712	.000
	Captal	.904	.247	.080	3.657	.000
	Managemen	-.003	.001	-.111	-3.008	.003
	Recycling	.002	.001	.077	2.169	.030

a. Dependent Variable: TobinQ

5 CONCLUSION

The motive of this research has begun from an awareness of the importance of not only a company but what kind of stakeholder throat the characteristic like contributes to construction of sustainable society. If it is economical activity, the role which a company plays will be large, and about a global subject, such as what is called an environmental problem, it will become positioning also with an important national policy. Advanced nations specifically create an effective innovation further, and it is thought by these days that a bigger effect is brought about by enabling application to a newly emerging country with great influence. Although ISO26000 was published as a framework of social responsibility as an international system, it is important to establish the foundation of the production of common structure which each stakeholder recognizes each one of responsibility systematically, and can visualize the direction which should be aimed at. The research would be raise accuracy more by using the domain expansion to an overseas firm, corporate social responsibility results of an investigation, the event information on a time series, etc. by using the framework of this analysis as a base.

Although this subject of research is construction of a strategy making support assessment system, it is still required advancing continuously detailed analysis and examines to clarify a necessary minimum and more effective factor efficiently utilizable in business.

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Development of provision of environmental information system on the method of E2-PA: Take an automotive recycle-parts as an example.

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Abstract

Environmental load assessment has been used for a variety of purposes, such as the promotion of environment-conscious products through the environmental disclosure. For example "carbon footprint labeling system" as a model project by The Economy, Trade and Industry Ministry and "Ecoleaf" as an environmental labeling program by The Japan Environmental Management Association for Industry. However, both are limited application to only a small part of many products and services. Making further contribution to the construction of environment-friendliness society, these environmental information systems incorporated into existing distribution systems are required.

In this paper, the development of the possible environmental information system incorporated into existing automobile recycle parts distribution system, called "Green Point System (GPS), is explained. GPS provides the environmental information based on the environmental load reduction effect quantified by E2-PA which we have developed.

Automobile recycle parts used as replacement parts of the accidental damage have some problems, such as "product awareness", "reliability", and are low penetration. Providing the environmental information through the GPS is designed to build recognition and expand with the spread of automobile recycle parts.

Keywords:

LCA, potential assessment, automobile recycle parts, environmental information system

1 INTRODUCTION

The aim of this study is to suggest measures which manufacturers and users have to take for environment-friendliness society through the quantification of design for environment.

In recent years, for building the zero-waste economy/society, the consideration to 3R(Reduce, Reuse, Recycle) at the design phase of various products. At the same time, the method of quantitative assessment of products, services and social systems become important.

Before now, there were cases of quantitative assessment with LCA(Life cycle Assessment) ,however, Existing LCA (Life Cycle Assessment) has been pointed out of "subjective view", "complex and tangled of data collection" and so on.

The Eco-Efficiency Potential Assessment, E2-PA, which solves problems in existing LCA, has been developed [1]. Introducing the concept of the "potential" evaluating maximum environmental load of materials and design factors, one of the features of the E2-PA is to be able to assess the environmental load only by the data on the design phase of products and services.

Environmental load assessment being used for a variety of purposes, such as the promotion of environment-conscious products through the environmental disclosure. As a part of its ways, The Environmental Labeling, as shown in Table1 [2], [3], [4], is used. Especially, the Type Ⅲ has the Environmental Load quantitative data as its central feature. For example, in Japan, there are "carbon footprint labeling system" as a model project by The Economy, Trade and Industry Ministry, and "Ecoleaf" as an environmental labeling program by The Japan Environmental Management Association For Industry. Recently accelerating efforts to provide environmental information. However, both are limited application to only a small part of many, many products and services. Making further contribution to the construction of environment-friendliness society, these environmental information systems incorporated into existing distribution systems are required. In this paper, we mention the development of the possible environmental information system incorporated into existing automobile recycle parts distribution system, that we call "Green Point System (GPS). GPS provides the environmental information based on the environmental load reduction effect quantified by E2-PA.

Automobile recycle-parts used as replacement parts of the accidental damage have some problems, such as "product awareness", "reliability", and "low penetration" [5]. Providing the environmental information through the GPS

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is designed to build recognition and expand with the spread of automobile recycle-parts.

2 DEFINITION OF THE AUTOMOBILE RECYCLE PARTS

In Japan, the automobile recycling law enacted in Jan.1 2005, ELVs (End-of-Life Vehicles) enforced proper treatment for automobile parts as shown on the Fig. 1 [5]. First, Automobile dismantlers retrieve reusable parts from ELVs. Secondly, scrap metal processors pick up recyclable metals and plastics from the rest. Finally, The ASR (automotive shredder residue) has wound up in landfills and recycled.Reusable parts from ELVs retrieved by Automobile dismantlers in this process are called “automobile recycle-parts”, composed of the “reuse-parts” and the “rebuilt-parts” [6].

3 EVALUATION OF CO2 REDUCTION EFFECT IN RECYCLE-PARTS BY E2-PA

3.1 Purpose of evaluation

Now, in Japan, recycle-parts accounts for only 5-6 percents of the aftermarket, on the other hand, 40 percents in USA [5]. So, the recycle-parts market in Japan has some room to grow. In other words, it is required to replace the new parts with recycle-parts in some of aftermarket.

Table 1: Classifications and features of the Environmental Labelings

Number and name of ISO Standards	ISO14024 Type I third-party certificate	ISO14021 Type II Self-declared environmental claims	ISO14025 TypeIII Environmental Load quantitative data
Case	Eco Mark	Recycle Label	ECOLEAF
Operator	Japan Environment Association	Ricoh	Japan Environmental Management Association for Industry
Symbol mark			
Number	120 companies, 8000 products (As of May 2011)	limited to part of products	468products (As of Sept. 6 2011)

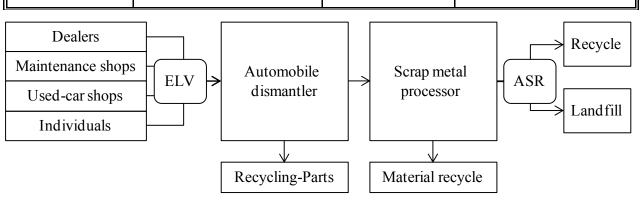

Fig.1 : Process flowchart of ELVs

The reasons why the recycle-parts are not prevalent are because of “quality control and clarification”, “differences between the U.S. and Japanese ways of business practice”, and “lack of awareness of its”. With this background, the aim of our study is to build recognition and expand with the spread of automobile recycle-parts through providing the quantified environmental information.

In this paper, the CO2 reduction effect of recycle-parts are quantified by comparing to new parts.

3.2 Precondition of evaluation

3.2.1 Evaluation scenario of reuse-parts

Fig.2 shows the process of new parts and reuse-parts manufacturing.

The ELVs are trucked to Automobile dismantlers to be dismantled. They retrieve trouble-free parts and market after quality checking. In this reuse part manufacturing process, transportation fuel and energies in dismantling are consumed. Meanwhile, in original system, a new part manufacturing, new resources in new materials and energies in part manufacturing are consumed.

Therefore, the CO2 reduction effect of the reuse part is given by the following equation;

$$R_{X\,reuse} = (E_V + E_M) - (E_T + E_D) \qquad (1)$$

where CO2 reduction effect of a reus-epart X is expressed as R_{Xreuse}; CO2 emissions from producing virgin materials is expressed as E_V; CO2 emissions from parts manufacturing is expressed as E_M; CO2 emissions from transport is expressed as E_T; CO2 emissions from dismantling an ELV is expressed as E_D.

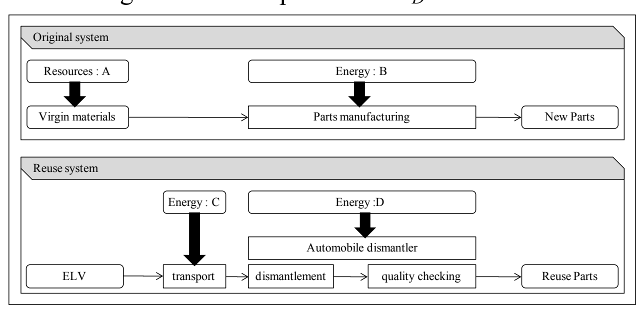

Fig. 2: Process of new and reuse-parts manufacturing

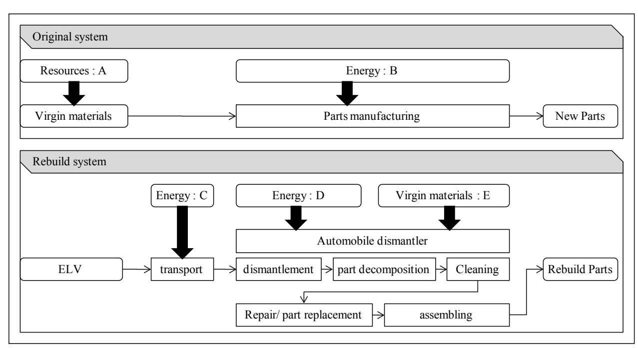

Fig. 3: Process of new and rebuilt-parts manufacturing

3.2.2 Evaluation scenarioof rebuilt-parts

Fig.3 shows the process of new parts and rebuilt-parts manufacturing. The ELVs are trucked to Automobile dismantlers and trouble-free are retrieved. The parts needed locally-repaired are torn down, cleaned, replaced to new parts, and assembled once again. The original sysytem is the same as mentioned.

Therefore, the CO2 reduction effect of the rebuilt-part is given by the following equation;

$$R_{X\,rebuilt} = (E_V + E_M) - (E_T + E_D + E_L) \qquad (2)$$

Where CO2 reduction effect of a part X is expressed as $R_{Xrebuilt}$; CO2 emissions from producing a locally-repaired part is expressed as E_L

3.3 Inventory data

3.3.1 Virgin Materials

To calculate the CO2 emissions from materials which compose parts, data about construction materials of the parts should be revealed.

It is next to impossible to collect these enormous quantities of data from parts manufacturers. So, in this study, we dismantled the ELV, listed in Table.2, to get the data about construction materials of the parts.

The data are classified into 475 parts depend on JAPRA system which automobile recycle-parts distribution system and into 7 kinds of materials, listed in Table.3. Also, the CO2 emission coefficients of them from raw materials taken from the earth to producing virgin materials are listed in Table.3 [7]. Due to limitations of space, the data of construction materials of the parts are omitted.

3.3.2 Parts manufacturing

Energies and resources are needed in the process of parts manufacturing., listed Table 4 [7], [8] .

3.3.3 Transport

The transportation fuel, listed in Table.5 is consumed in the process of transport of ELVs from the auto dealers to automobile dismantlers.

3.3.4 Automobile dismantler (Reuse system)

Meanwhile new materials are not consumed in reuse system, energy, listed in Table.6 [7], to dismantle ELVs is needed.

3.3.5 Automobile dismantler (Rebuild system)

In rebuilt system, new materials are consumed for replacing wear-out parts to new one in addition to dismantling ELVs. In this study, we have explored the ratio of new parts and energies in the rebuilt system by conducting hearings with rebuilt makers, listed in Table.7.

3.4 Result of the CO2 reduction effect

3.4.1 CO2 reduction effect of Reuse-parts

Due to limitations of space, full details of 475 parts cannot be included. So Fig.4 shows the CO2 reduction effect of 10 parts which are widely available in significant quantities. As is evident in the figure, CO2 emissions from reuse system are exceedingly-small compared to from original system. So, using the recycle parts produce over 99% CO2 reduction effects than new parts.

3.4.2 CO2 reduction effect of Rebuilt-parts

Next, Fig.5 shows the reduction effects of rebuilt-parts. They produce 33%-97% (78% on average) CO2 reduction effects than new parts. The reason why there are differences in CO2 reduction effects among each part is because the ratio of new parts in the rebuilt system differs depending on each part.

4 CONSTRUCTION OF ENVIRONMENTAL INFORMATION SYSTEM

As previously mentioned, existing environmental information systems have an issue that they are limited application to only a small part of many, many products and services. The reason for this is that focusing too much on elaborating evaluations that makes it very difficult to collect data necessary. There are about 4000 parts on delivery to the assembly maker and more some tens of thousands of types of vehicles [9]. Therefore, about Automobile recycle parts, it is very difficult to evaluate CO2 reduction effects of each part from the viewpoint of correcting the data. Afterwards, the aim of providing the environmental information should be defined. It helps consumers to select environment-conscious products and as a result, promote moves to develop and sell them. So it is not important to evaluate environmental loads of products too exactly on elaborated data, but to evaluate within the range got across to consumers. Therefore, in this study, we have tried to quantify the CO2 reduction effects of recycle in such a way as to the ratio by weight of a base car.

Table 2: Spec of the Vihecle

Maker	Nissan
Name	Sunny
Type	GF-FNB15
Year	1999
Displacement	1500 cc
Weight	1080 kg

Table 3: CO2 emission coefficient of each materials

Kinds of materials	CO2 emission coefficient kg-CO2/kg
Steel	1.78
Aluminum	6.18
nonferrous metal	4.61
Pla tic/firb	1.29
high molecule	1.45
glass	0.831
Synthetic rubber	4.61

Table 4 : Energies and resources in parts manufacturing

Energy	Electricity	Crude	Natural Gas	Coal	CO2 emission coefficient
Unit	kWh	Kg	Kg	Kg	kg-CO2/kg
Steel	0.753	0.0513	0.0113	0.492	1.48
Aluminum	0.744	0.0534	0.0046	0.792	2.08
Plastic/firb	0.361	0.0484	0.00282	0.492	1.3
Glass	0.354	0.304	0.00424	0.000	1.09
Synthetic rubber	0.649	0.0759	0.0000157	0.0709	0.628
nonferrous metal	0.334	0.0484	0.000989	0.492	1.29
high molecule	0.361	0.0484	0.00282	0.492	1.30

Table 5: Fuel consumption in transport

	Unit	diesel oil
Fuel consumption	L/t	7.84
CO2 emission coefficient	CO2-kg/kg	6.51E-03

Table 6: Energy consumption in dismantlement (Reuse)

	Unit	Electricity
Energy consumption	kWh/t	0.96
CO2 emission coefficient	CO2-kg/kg	9.60E-04

Table 7: Makers and products

Rebuild makers	Products
A	Engine ASSY
B	Turbocharger, Carburetor
C	Starter, Alternator, Compressor, Injection pump
D	Power steering pump, Rack-and-pinion, Drive shaft
E	Transmission, Continuously Variable Transmission

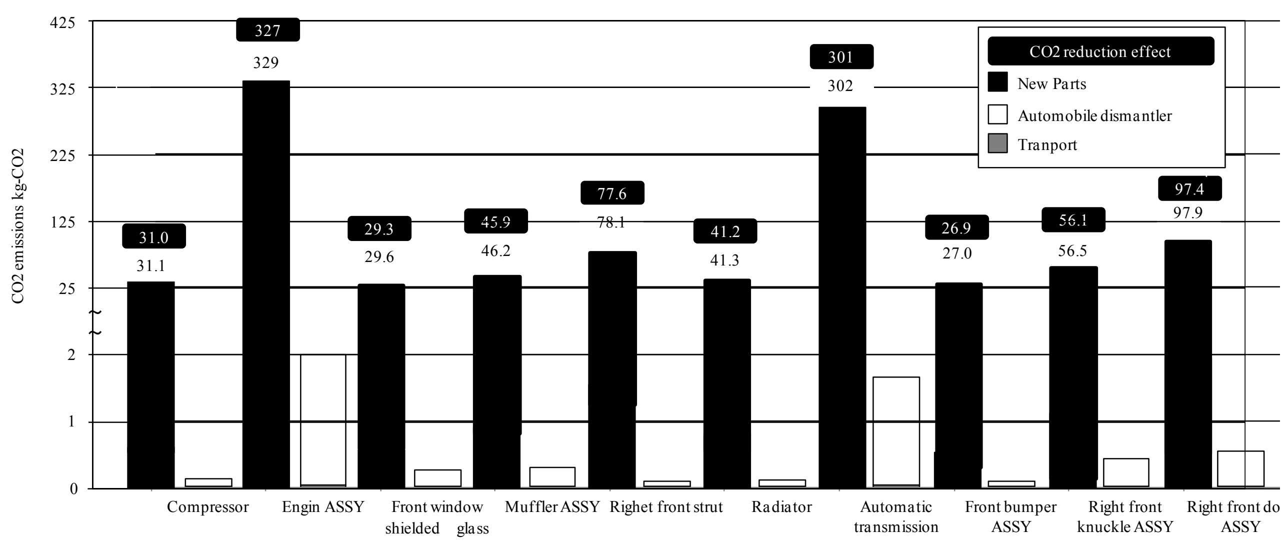

Fig. 4: CO2 reduction effect of Reuse-parts

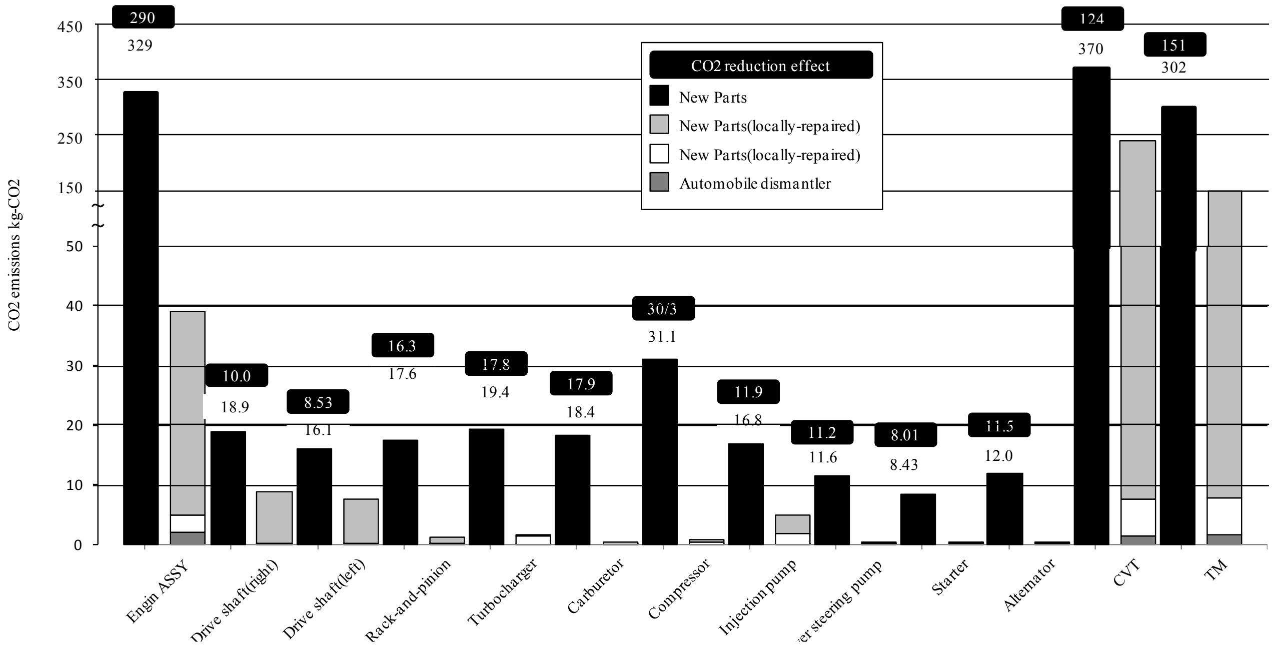

Fig. 5: CO2 reduction effect of Rebuilt-parts

4.1 Concept of the CO2 reduction effects database

There are two ways to evaluate the CO2 reduction effects of recycle parts on the differences in types of vehicles. One is to dismantle and make a survey of each car. The other is to multiply the weight of a car, which is existing data in recycle parts distribution system, by the basic units on a base car. From a viewpoint of integrating the environmental information into existing distribution system, the aim of our study, it is necessary to be ease of maintenance. Therefore, we have made a study on the way of calculating the CO2 reduction effects of various cars by data easy to get. Existing recycle parts distribution systems have data such as “Car Type”, “Year” and “displacement”. So the database to be able to calculate CO2 reduction effects on them is easier to be integrated into existing distribution systems.

4.2 Construction of CO2 reduction effect database

Fig.6 shows the way to assemble a database of CO2 reduction effect.

4.2.1 SUNNY Original Database

As mentioned above, the CO2 reduction effect data of each parts composed of the SUNNYare classified into 475 parts depend on “JAPRA system”, which automobile recycle-parts distribution system.

4.2.2 CO2 reduction effect Unit Database (Based on SUNNY)

The CO2 reduction effect Unit of each parts are given by the following equation;

$$U_X = \frac{E_X}{W_0} \tag{3}$$

4.2.3 Weight of Vehicle Database

Existing recycle parts distribution systems have data such as “Car Type”, “Year” and “Displacement”. So we have estimated the Weight of Vehicles from the displacement.

“Japanese Motor Vehicles Guidebook” [10] has the data of “Car Type”, “Year”, “Displacement” and “Weight of Vehicle”. By the multi-regression analysis, Weight of Vehicle Database has been constructed.

4.2.4 CO2 Reduction effect Database

The CO2 reduction effect of each parts on “Car Type”, “Year”and “Displacement” are given by the following equation;

$$E_{X'} = U_X \times W_X \tag{4}$$

where the CO2 reduction effect of part X on “Car Type”, “Year”and “Displacement” is expressed as $E_{X'}$; the weight of a vihecle is expressed as $W_{X.}$

The database has been applied to the Green Point System (GPS) run by the “Green Point Club” (GPC). GPC promotes the GPS which has been jointly developed by WASEDA University Environmental Reserch Institute and Japan Automobile Parts Recyclers Association and pursues the goal of market extension of recycle parts. Now, 257 automobile recycle suppliers use the GPS. Some use the system for point system between car repair shops.

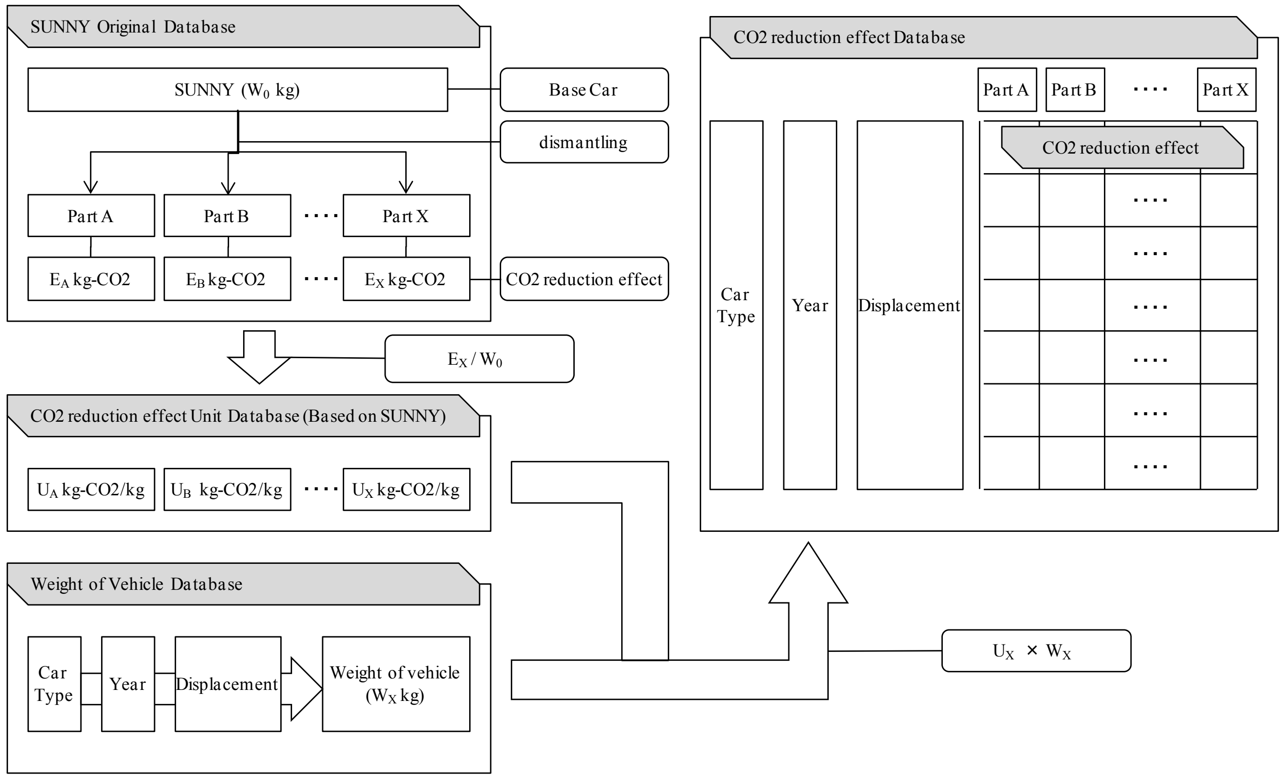

Fig. 6: Structure of CO2 reduction effect database

5 CONCLUSIONS

The present paper has proposed the method of constructing the environmental information system incorporated into existing distribution systems. The results discussed here are as follows.

(1) The important thing for the construction of environmental information system is not to evaluate environmental loads of products too exactly on elaborated data, but to evaluate within the range got across to consumers.

(2) The CO2 reduction effects of recycle-parts are evaluated on the construction materials got through dismantling the ELV.

(3) Constructing the CO2 reduction effects database, the environmental information system, called as “Green Point System”, has been incorporated into existing distribution system.

ACKNOWLEDGMENT

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A study on the development of the evaluation method of supplier's contributions to the Green IT

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Abstract

"Green IT" is expected to become the key to reduce greenhouse gas emissions. Introducing the Green IT can reduce the "total" greenhouse gas emissions. However, attention is required to the fact that the reduction of the "total" greenhouse gas emissions consists of "increase" and "decrease". For example, shifting to use energy-saving home electrical appliances reduces greenhouse gas emissions in consumer category. On the other hand, it increases in industrial category, such as manufacturing energy-saving home electrical appliances. If the way to return the merit of the Green IT, which contributes the reduction of total greenhouse gas emissions, to suppliers is not structured, it is possible to hinder promotion of the Green IT. Therefore, evaluation method of supplier's contribution to Green IT is needed.

In this study defines the Green of IT and Green by IT, which are the composition of Green IT. Green of IT means "improving energy conservation itself" and Green by IT means "reducing greenhouse gas emissions by replacing existing systems with IT". In addition, this study proposes the concept of evaluation method of supplier's contributions to Green IT and evaluated the energy-saving home electrical appliances, as an example for the Green of IT and the paperless stock office, as an example for the Green by IT.

Keywords:

Green IT, inter-industry relations table, supplier's contributions,

1 INTRODUCTION

The aim of this study is to develop the evaluation method through the quantification of environment-friendliness design to be shifted to environment-friendliness society.

Japan is the world's fifth greenhouse gas emission country, and the Kyoto protocol obliges Japan to reduce greenhouse gas emissions by 6% during the first commitment period, taking the 1990 figure as a baseline. The fact, however, greenhouse gas emission is increasing especially in other sectors (the business establishments and the residential sector), as shown in Fig. 1 [1]. Therefore, "Green IT" is expected to become the key to reduce greenhouse gas emission in its categories. Being yet to be clearly defined, "Green IT" includes the concept of "design for environment", such as the reduction of hazardous substances, recyclability and energy-saving. Especially "energy-saving" is now gaining attention as a measure against global warming. It is predicted that introducing the Green IT can reduce the "total" greenhouse gas emissions [2]. However, attention is required to the fact that the reduction of the "total" greenhouse gas emissions consists of "increase" and "decrease". For example, shifting to use energy-saving home electrical appliances, one of the Green IT, reduces greenhouse gas emissions in consumer category. On the other hand, it increases in industrial category, especially in electronic devices sector, such as manufacturing energy-saving home electrical appliances, as shown in Fig. 2 [3]. Until now, manufacturing companies, mainly in industrial category, have made an effort to enhance energy efficiency in manufacturing under the Rationalization in Energy Use Law. And in the near future, it is possible to be introduced the stricter regulations, the cap-and-trade system, than ever before, which means the total volume control of greenhouse gas emissions.

If the way to return the merit of the Green IT, which is expected to contribute the reduction of greenhouse gas emissions totally, to suppliers is not structured, it is possible to hinder promotion of the Green IT. Therefore, evaluation method of supplier's contribution to the Green IT is needed.

In this paper defines Green of IT and Green by IT, which are the composition of Green IT. Green of IT means "improving energy conservation itself" and Green by IT means "reducing greenhouse gas emissions by replacing existing systems with IT".

In addition, this paper proposes the concept of evaluation method of supplier's contributions to Green IT and the energy-saving home electrical appliances, as an example of the Green of IT and the paperless stock office, as an example of the Green by IT have been evaluated.

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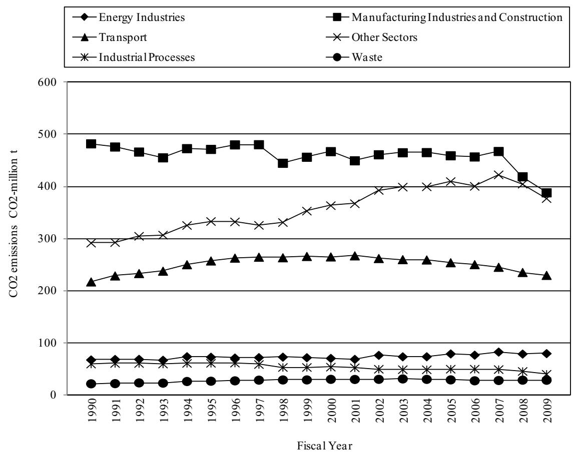


Fig. 1: Changes in sectoral CO2 emissions in Japan

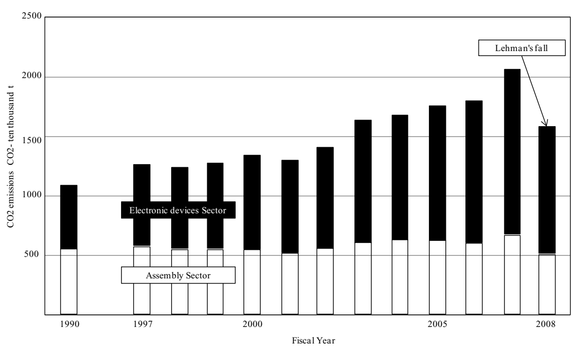


Fig. 2: Changes in sectoral CO2 emissions in the electrical and electronic industry

2 DEFINITION OF THE GREEN IT

In response to a growing worldwide interest in global warming, Therefor, we have defined the effect of Green IT as the CO2 reduction. It is classfied into the Green of IT and Green by IT, being defined as shown in Table 1. The examples of the Green IT are shown in Table 2 [4].

3 TREND OF INCENTIVES

As a measure against global warming, it is important to promote the Green IT. Technological developments leading to save enery and replacing existing products and services with enegy-saving ones are needed, however, there are higher prices and lack of awareness than existing ones. Therefore , providing incentives are needed. Table 3 shows the trend of incentives in Japan [5], [6], [7], [8], [9]. Incentives for suppliers are mainly regulatory ways, such as CO2 reducing obligation, attainment criteria and so on. On the other hand, Incentives for consumers are mainly economic ways, such as the tax reduction, the subvention like the Eco-Point and so on. Therefore, it makes easy for consumers to buy the energy-saving products and services. But the more they are sold, the more CO2 emissions from suppliers are increased. In other words, there is a possibility that the spread of the energy-saving products are hampered because regulatory ways work on suppliers while they manufacture energy-saving products. Therefore, it is needed to clarify whether the supplier's contributions to the CO2 reduction influence the result of economic incentives and construct the way to return the merit of the Green IT to suppliers.

In this study, the evaluation method of supplier's contributions to Green IT is developed.

4 CONCEPT OF CO2 REDUCTION EFFECT AND CONTRIBUTION

We have organized the concept of CO2 reduction effect and contribution to them for evaluating the supplier's contributions to the Green IT.

Table 1: Definition of Green of IT and Green by IT

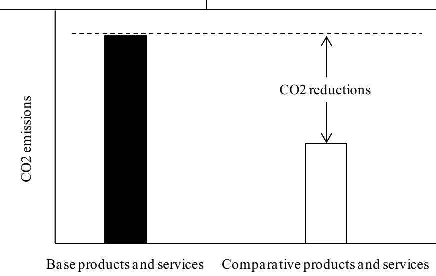
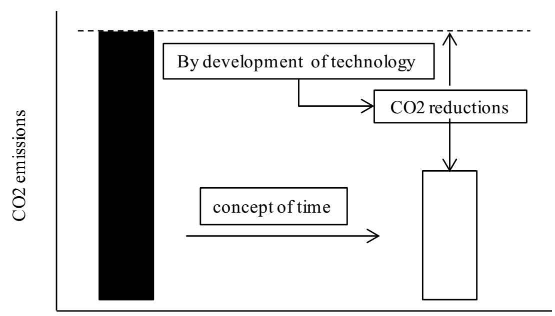
Item	Green of IT	Green by IT
Definition	Energy saving in use of its own products and services	CO2 reduction effect by replacing the existing products and services with new ones.
CO2 reduction effect		

Table 2: Examples of the Green IT

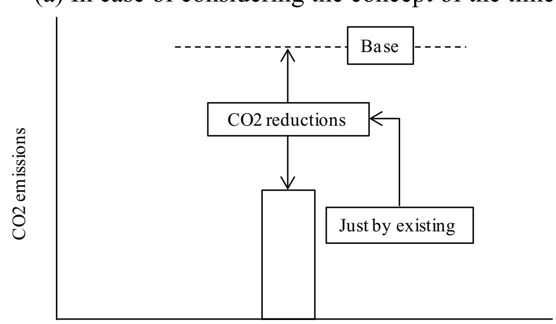
Classification	Case	Notes
Green of IT	Light bulb	Bulb-type fluorescent lights and LED bulbs consume less than the power of incandescent bulbs.
	LCD TV	The brightness control and LED backlight reduce the power consumption.
	Datacenter	Introducing Energy-saving IT devices and air conditionings and devising layout of them reduce the energy consumption of datacenters.
Green by IT	Paperless meeting	CO2emissions from paper manufacturing, printing machines and so on are reduced.
	Music distribution service	CO2 emissions from CD manufacturing, transport to the stores and so on are reduced,
	Telemedicine service	The telemedicine service facilitates sharing of information among doctors and between doctors and patients. CO2 emissions from transport are reduced.

Table 3: Trend of incentives in Japan.

Incentives	Notes
Energy Saving Act against the factories and business establishments.	Obligations as follows are imposed on factories and business establishments more than 1500kL (crude oil equivalent) of annual energy consumption. (1) Selection of the energy manager. (2) Regular report of the status of energy consumption. (3) Submission of the medium and long term plan(limited to more than 3000kL)
Energy Saving Act against the machinery and appliances.	Attainment criteria for energy efficiency are imposed on products of the regulation.
Emissions trading system	The institution for CO2 reduction through the market mechanism. In Japan, JVET-CO2S has been started in 2005.
Act on Promoting Green Purchasing	Act on promoting products which reduce the environmental loads. Public agencies taking the initiative in buying environment-conscious products has been described.
Eco-point system	The Eco-point system was introduced to stimulate the economy and raise public awareness of global warming on May.2009 by The Ministry of Economy, Trade and Industry. The Eco-Points can be exchanged for various products and services.
Green taxation plan	Tax incentives for the spread of vehicles with low-fuel consumption, low-gas emissions which meet certain standards.



(a) In case of considering the concept of the time



(b) In case of not considering the concept of the time

Fig. 3: Concept of the contributions to the Green IT

4.1 Case of considering the concept of the time

On the concept of the time, the effect of CO2 reduction is achieved by (should be rephreased) the developing technologies for energy saving. For example, replacing fluorescent backlight with LED backlight makes the power consumption of the LCD TV lower.

In case of considering the concept of the time, It can be considered that components of the product already exist and contributions to the CO2 reduction effect are provided to the technologies which reduce the energy consumption. Taking a bulb as an example, when the CO2 reduction effect of the bulb-type fluorescent light, compared to the incandescent bulb, has been achieved mainly by the improvement of the fluorescent lamp and electronic ballast, the bayonet cap exists in common. Therefore, the contribution is not provided to it.

4.2 Case of not considering the concept of the time

The effect of CO2 reduction, which is not the concept of the time means that the product which meet a certain energy-saving standard at some point is the energy saving product and the difference between the standard and the energy consumption of the product is considered as the CO2 reduction effect. The leading runner approach is taken as an example of a certain energy-saving standard.

Unlike the CO2 reduction effect on the concept of the time, It can be considered that the product itself which meet a certain energy-saving standard contributes to the CO2 reduction effect. therefore, In case of not considering the concept of the time, contributions to the CO2 reduction effect are proveided to the all components of the product, not only the technologies which reduce the energy consumption.

Taking a bulb as an example, Setting 'The power consumption of bulb must be under 25W' as the standard, the bulb-type fluorescent light is the enegy saving product, but incandescent bulb is not. At this point, the comparison between them have disappeared and it can be considered that the bulb-type fluorescent light itself contributes to the CO2 reduction effect. In this case, all components of the bulb-type fluorescent light, including the commodity parts, such as a bayonet cap, contribute to the CO2 reduction effect.

4.3 Concept of the contributions to the Green IT

Fig. 3 shows the concept of the contributions to the Green IT. In case of considering the concept of the time, as levels of technology improve, CO2 emmisions are decreased. Therefore, it can be considered that technology improvements reduce the CO2 emmisions. On the other hand, in case of not considering the concept of the time, the product itself which meet a certain energy-saving standard generates the CO2 reduction effect.

The former is suitable for continuous product development and the later is suitable for discontinuous.

Taking a energy saving of LCD TV as an example, the existing is modified by LED bucklight. Therefore the concept of the existing product is given and the case of considering the concept of the time is applied to the Green of IT. On the other hand, the paperless services replace the existing paper services, therefore, there are no services for comparison to the existing because the technologies of papereless services are completely different from ones of , paper services. Therefore the case of not considering the concept of the time is applied to the Green by IT.

In this study, it was evaluated that the supplier's contribution to the Green IT, taking a LCD TV as an example of the Green of IT and a paperless stock office service as an example of the Green by IT.

5 DEVELOPMENT OF THE EVALUATION METHOD OF SUPPLIER'S CONTRIBUTIONS TO THE GREEN IT

5.1 Example of evaluation of the Green of IT

Taking the LCD TV as an example, the evaluation method of supplier's contributions to the Green of IT is explained.

The data needed for the evaluation have been got by the hearing investigation to a certain supplier. Products listed in Table 4 were evaluated.

As previously mentioned, the contributions are provided to the the technologies which reduce the energy consumption. The hearing investigation revealed that the breakdown of the energy consumption reduction of the units and parts, listed in Table 5, are known to some extent. Therefore first, the contributions of them were provided according to each energy consumption reduction by the following equation.

$$C_x = \frac{R_x}{R_{LCD}} \tag{1}$$

$$C_{xy} = C_x \times \frac{R_{xy}}{\sum_y R_{xy}} \tag{2}$$

where the contribution of the unit x is expressed as C_x; the energy consumption reduction of the LCD TV is expressed as R_{LCD}; the energy consumption reduction of the unit x expressed as R_x ; the contribution of the part y of the unit x is expressed as C_{xy}; the energy consumption reduction of the part y of unit x is expressed as R_{xy}.

Secondly, contributions of each suppliers are needed to be evaluated for the aim of this evaluation. For evaluating the supplier's contributions, it is needed to reveal the supplier's contributions to each components' contribution. However, it is very difficult to evaluate the their contributions by the data, such as the energy consumption reduction, because various suppliers are engaged in development activities. It is also difficult to get the data, such as R&D investment and development period.

In this evaluation, supplier's contributions to to each components' contribution have been revealed by the panel method. Specifically, 100 points have been provided to them by questionnaires. Therefore supplier's contributions are calculated by the following equation.

$$C_{xyz} = C_{xy} \times \frac{R_{xyz}}{100} \tag{3}$$

$$C_z = \sum_x \left(\sum_y C_{xyz} \right) \tag{4}$$

where the supplier 'z ' contribution to the pats y of the unit x is expressed as C_{xyz}.; energy consumption reduction of the LCD s expressed as C_z;the supplier 'z ' contribution to the part y of the unit x is expressed as R_{xyz}; the supplier 'z ' contribution to the energy consumption reduction of the LCD s expressed as C_z.

Fig. 4 shows the result of supplier's contributions to the energy saving of the LCD TV. As shown in the figure, the contribution of parts manufacturer is the highest and one of assenmly manufacturer is second highest.

The adequacy of the results differing from the persons who answer questionnaires is reviewed.

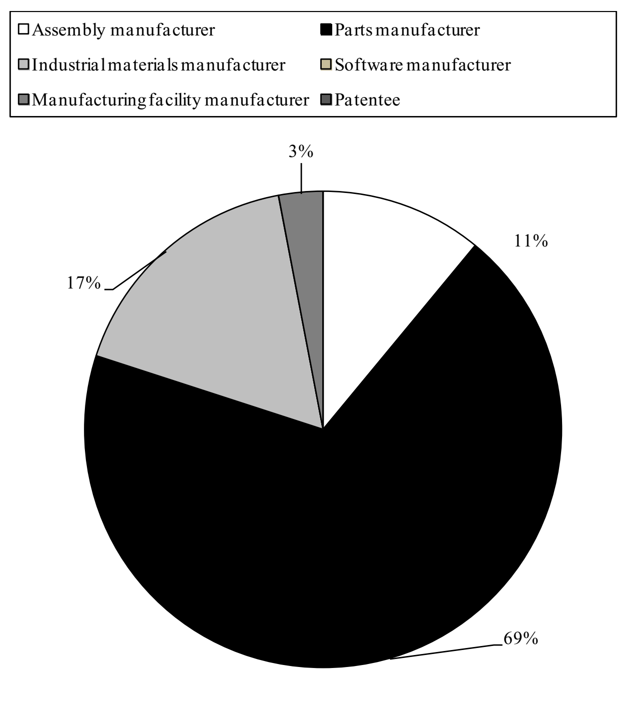


Fig. 4: Result of supplier's contributions to the energy saving of the LCD TV

Table 4 : Spec of evaluated LCD TVs

Item	Unit	Base (old model)	Comparative (new model)
Release year	-	May 2007	May 2009
Screen size	inch	32	32
Electricity consumption reduction	kWh/y	30	

Table 5: breakdown of the energy consumption reduction of the units and parts

Units	Unit	Number	Parts	Unit	Number.
Liquid crystal panel unit	kWh/y	6	Panel module	kWh/y	4
			Drive circuit	kWh/y	2.5
Backlight unit	kWh/y	12.5	Light source	kWh/y	9.5
			Drive circuit	kWh/y	3
			Optical film	kWh/y	1
			Brightness control circuit	kWh/y	1
			light-guiding plate	kWh/y	1
			reflector	kWh/y	1
			Lightproof sheet	kWh/y	1
Power supply unit	kWh/y	4	Main power circuit	kWh/y	3
			Standby power circuit	kWh/y	1
Signal processor unit	kWh/y	12.5	Tuner circuit	kWh/y	1
			Audio circuit	kWh/y	1
			Image processing circuit	kWh/y	6
			Double speed processing circuit	kWh/y	3
			System control circuit	kWh/y	3

5.2 Example of evaluation of the Green by IT

In case of the evaluation of the Green by IT, It is considered that the product itself contributes to the CO2 reduction effect. Therefore, supplier's contribution to the system itsself is needed to be revealed.

The effect of the Green by IT is achived by consumers selections. At this time, they pay forit. Therefore, it can be considered that the price represents the utility of the product or servicce. If each supplier's components of the price could be revealed, the contribution of each suppliers who deliver value to consumers can be evaluated.

However, it is very difficult for suppliers to disclose the components of the price because they are confidential information.

Therefore, in this study, the contributions of each suppliers were evaluated by how the payment prrice of consumers rippled through the suppliers economically by means of the the inter-industry relations table.

The paperless stock office was taken as an example of the Green by IT. This service can reduce the space for paper documents by putting them on a scanner.

In this paper, we evaluated the supplier's contribution to the service introduce into the office of 200 workers. Table 6 shows the expected introductory price .

In this paper, the supplier's contibutions to the paperless stock office have been evaluated at annualized rate.

First, the contributions of the components of the system were provided according to each price by the following equation.

$$C_x = \frac{P_x}{\sum_x P_x} \quad (5)$$

where the contribution of the component x is expressed as C_x.; the price of the conponent x is expressed as P_x.

Secondly, contributions of each suppliers to the contributions of the components were provided by the inter-industry relations table by the following equation.

$$C_{xz} = C_z \times \frac{R_{xz}}{100} \quad (6)$$

$$C_z = \sum_x C_{zz} \quad (7)$$

where the supplier 'z ' contribution to the component x is expressed as C_{xz}: the ratio of the ripple effect through the supplier z of consumer's payment price to the component x is expressed as R_{xz}: the supplier 'z ' contribution to the paperless stock office is expressed as C_z.

At this time, the correspondence relations between the conponents of the system and 190 indutries on the inter-industry relations are shown in Table 7.

Table 6 : Expected introductory price

Component	Price Yen	Useful life Year
Scanner	249000	5
Software	2362500	5
Support	37800	1
Server	460000	5
Personal computer	800000	4

Table 7: the correspondence relations between the conponents of the system and 190 indutries on the inter-industry relations

Component	Corresponding to the inter-industry relations table
Scanner	Office appliances
Software	Electronic computer and ancillary equipments
Support	Electronic computer and ancillary equipments
Server	Information services
Personal computer	Information services

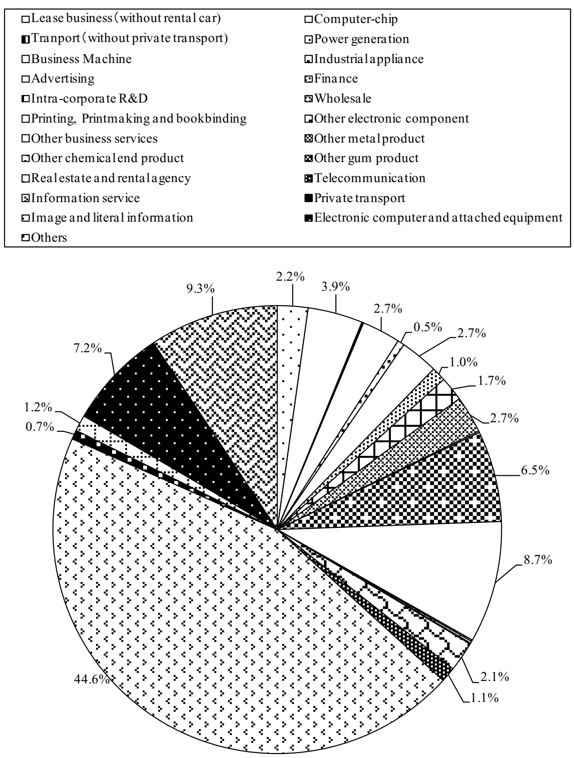


Fig. 5 : Result of the supplier's contribution to the paperless stock office.

Fig. 5 shows the result of the supplier's contribution to the paperless stock office.

As shown in the figure, the contribution of information service industry is the highest and one of other business services which includes worker dispatching service is second highest.

6 CONCLUSIONS

The present paper has proposed the development of the evaluation method of supplier's contributions to the Green IT. The results discussed here are as follows.

(1) The spread of the energy-saving products are hampered beuause regulatory ways work on suppliers while they manufacture energy-saving products. Therefore, it is needed to clarify the supplier's contributions to the CO2 reduction effect in use as the result of economic incentives and construct the way to return the merit of the Green IT to suppliers.

(2) The evaluation method of supplier's contributions to the Green IT differs by introducing the concept of time or not. IT. In case of considering the concept of the time, as levels of technology improve, CO2 emmisions are decreased. Therefore, it can be considered that technology improvements reduce the CO2 emmisions. On the other hand, in case of not considering the concept of the time, the product itself which meet a certain energy-saving standard generates the CO2 reduction effect.

ACKNOWLEDGMENT

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Large scale product carbon footprinting of consumer goods

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Abstract
This paper describes the evolution of a large scale product carbon footprinting programme and lessons learned from its implementation across a wide and varying range of consumer products. The learnings from this process provide valuable insight on key issues arising in different supply chains and product categories. Tesco's carbon labelling programme demonstrates that large scale carbon footprinting is possible, but the supply chain needs support and data need validation to be consistent. The cost of carbon footprint measurement reduces significantly the more it is undertaken – through familiarisation, scale and gathering transferable data. The Tesco case shows us that product carbon footprinting can be achieved to a credible and recognised standard on a large scale. The success of its product carbon footprinting programme was helped by a well considered scoping process and carefully nurtured supplier engagement.

Keywords:
product carbon footprinting, supply chain, consumer goods

1 INTRODUCTION

This paper describes the evolution of a large scale product carbon footprinting programme and lessons learned from its implementation across a wide and varying range of consumer products. The learnings from this process provide valuable insight on key issues arising in different supply chains and product categories.

Over recent years, interest in the greenhouse gas emissions from individual products has gained momentum as consumers, companies and governments alike strive to reduce their impact on the environment. Words such as 'carbon footprint,' and 'food miles', which were once considered environmental 'jargon,' are now commonplace in our everyday language. A better understanding of the greenhouse gas emissions across a product's life cycle helps companies to identify how and where efforts should be focused to minimise them. Publication of product carbon footprint results in the media provides consumers with the information to make their own purchasing decisions. An understanding of impacts incurred during the use phase of products can help consumers to identify ways that they themselves can influence the carbon footprint of a product. The cumulative impact of small changes made from any one of these potential outcomes could be considerable if realised on a large scale.

The emergence of different methods to standardise an approach to product carbon footprinting is an optimistic development to enable wider product carbon footprinting initiatives and to allow for product comparisons. If the ability to compare the greenhouse gas emissions of different products is what is desired, it follows that product carbon footprinting should be undertaken on a large scale. There are challenges to product carbon footprinting on a large scale, including time constraints and barriers to data collection. However, experiences from a large scale product carbon footprinting programme undertaken by Tesco in the UK shows that, for the most part, these can be overcome. The Tesco case highlights the importance of a well planned process and, perhaps more importantly, identifies the significant role that suppliers play in ensuring successful data collection for the product carbon footprint calculations.

The Tesco product carbon footprints were calculated according to the *Publicly Available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* (PAS 2050) [(1)]. However this paper is not intended to promote any particular approach for the assessment of product greenhouse gas emissions.

2 THE TESCO CASE

Early in 2007, Tesco announced an ambition to calculate the total carbon impacts of the products that it sells, including both their direct and indirect emissions. As a part of meeting this objective, the carbon footprints of over 1000 Tesco consumer items across more than 40 different product categories have been calculated, following the PAS 2050 method. The key objectives of the work were to inform consumer communications and to identify hotspots in product supply chains, with a view to a longer term goal of reducing supply chain emissions.

The product carbon footprinting initiative began with a pilot project, which investigated the experiences of suppliers in collating the data needed for the calculations. Suppliers were supported in calculating carbon footprints and their experiences informed recommendations for

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DOI 10.1007/978-94-007-3010-6_59,

future footprinting efforts. Key findings, such as how suppliers responded to the data request, were used to inform the structure of the ongoing carbon footprint work.

The first phase of work was undertaken as part of a product labelling trial and calculated the carbon footprints of thirty products across six product categories. The footprints were calculated to what was then the draft PAS 2050, drawing on ISO standards on life cycle assessment. The thirty product carbon footprints subsequently underwent a verification process by the Carbon Trust, a not for profit company dedicated to supporting companies in reducing their greenhouse gas emissions. As a result of the verification process, twenty products were certified which were labelled and promoted in Tesco stores. The labels were present on product packaging and displayed the greenhouse gas emissions associated with the total life cycle of the product. To date, over 1000 PAS 2050-compliant carbon footprints have been calculated for Tesco own-brand products across a range of categories, from light bulbs to milk and from toilet paper to plastic food containers.

The process for calculating the Tesco product carbon footprints typically followed a standard process, as follows:

- identification of products to be footprinted (on the basis of sales volume, visibility, interest, ease);
- product/supply chain characterisation and mapping;
- data scoping – identification of primary and secondary data needs;
- primary data collection – supplier meetings, issue of questionnaires, data checking;
- secondary data collection – emission factors and supporting activity data;
- development of footprint model (Excel-based); and
- reporting and analysis.

3 KEY TRANSFERABLE FINDINGS

The calculation of over 1000 product carbon footprints across such a diverse range of products was met with a number of challenges and has provided valuable lessons for future work of this type. Lessons learnt from the Tesco case can be transferred to anyone wishing to undertake footprints of multiple products.

3.1 Scoping

When calculating the carbon footprints of multiple products at the same time, scoping is invaluable both in terms of the individual product footprint and the programme as a whole.

How successful the carbon footprint is depends on more than just a number at the end. For a company undertaking the calculations, how efficiently the process is completed and ensuring that the results provide information to meet the requirements of an end goal are key aspects of an outcome that is useful and value for money. Identification of the end goal is one of the first decisions to be made as this will frame the scope of the calculations and the data that are required for them. Whether the goal is for communication of results to an external audience or for internal purposes only, it should be ensured from the start that the calculations are undertaken with sufficient rigour to enable the required level of assurance.

For Tesco, where external communication was a key element of the end goal, it was essential that the product carbon footprints were calculated to a credible and recognised standard. The *Publicly Available Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*, or PAS 2050, was chosen. Further assurance was provided by undergoing the Carbon Trust verification process to attain certified product labels.

Part of the scoping process should be a ‘go’/’no-go’ decision: is it possible to calculate the carbon footprint of the product given timescales and other resource constraints? In order to make this decision and to frame the wider scoping exercise, it is useful to know as much as possible about the whole life cycle of the product, from raw material, through production to use and final disposal at end of life. The life cycle should be mapped out in relation to the specific supply chain for each product, including identifying geographic location and when key materials are sourced from multiple suppliers. Understanding the full supply chain helps to identify what data are needed for carbon footprint calculations and allows for some assessment of the potential for obtaining it. A good understanding of the supply chain will provide an indication of whether primary data collection from suppliers will be possible. It will also help to identify when a certain supplier is present in the supply chain for more than one product and thus when data collection efforts can be combined. This kind of planning streamlines data collection and supplier liaison to result in a better value carbon footprinting process.

For the Tesco carbon footprints, suppliers were approached as early on in the process as possible. This meant that key information, as described above, was obtained to determine whether the footprinting of that product was a practicable option. In some cases, it was found at this stage that the supply chain extended to several small producers in multiple geographic locations, which would significantly increase the time and effort required to obtain a representative dataset for the product carbon footprint calculations. In cases such as this, when the time and effort required to complete the footprint calculations to the required standard would not produce a reflective number of product carbon footprints, the decision was often made to not proceed further. Identifying these cases early on in the process allowed for this time and effort to be focused elsewhere, on a product supply chain that could be expected to provide a more certain outcome. This kind of approach, coupled with the identification of high-volume products, meant that the footprinting programme resulted in enough carbon footprints to enable comparison and for the selection of products that were of interest to the consumer.

3.2 Supplier engagement

The Tesco case generally saw a high level of engagement from suppliers, which facilitated the scoping and data collection exercise and was instrumental to the efficiency of the process. This high level of supplier engagement is possibly a reflection of the close relationship that Tesco has fostered with its first tier suppliers.

Primary data are always preferred for carbon footprint calculations, although not always essential. Suppliers who are engaged in the process are more likely to provide primary data for their operations, to maximise the primary data available for the product carbon footprint. As noted above, where suppliers are found to be present in the supply chains of more than one product, the cross-over should be reflected in the way data collection is handled, as there is likely to be significant cross-over in data needs.

For the Tesco carbon footprints, data were collected via data collection templates, which were tailored as much as possible to the specific supply chain for the product being assessed. Based on detailed discussion with the suppliers, it was possible to structure the templates to suit the exact processes involved and limit confusion on the part of the supplier in terms of what information should be provided and in what format. Again, this upfront investment in time saved significant effort further along in the process, as a clear data collection template minimises the need for follow up questions on the information provided. Data collection is typically the most time consuming part of any product carbon footprint and poses the biggest risk to completion of the calculations. A well-designed template assists suppliers in knowing what is required of them and ultimately saves time down the line.

Increasingly, suppliers in a variety of industries and in different geographies are knowledgeable in carbon footprinting data requirements and have experience in the process. However, it is to be expected that there will be hugely varying levels of knowledge and expertise. For suppliers that have no experience of product carbon footprinting, it is likely that they will need guidance and assistance in understanding the aims of the work and in providing data. This further emphasises the benefit of a complete understanding of the supply chain and early supplier engagement, in order to adequately plan for different levels of assistance to be provided.

The benefit of a large scale programme is that, with each phase of work, there is a good chance that data will be required from the same suppliers, who will already have been engaged in the process and are more likely to be able to provide data with minimal assistance. It is therefore a beneficial investment of time to provide guidance to suppliers on carbon footprinting data collection, where needed, as well as to facilitate a wider understanding of the aims of the programme in general. Indeed, offering to share the product carbon footprint results with suppliers might provide a valuable incentive to encourage cooperation and collaboration.

A further benefit of a large-scale carbon footprint programme is that, with each phase of work, a larger database of information is gathered on a variety of different products and supply chains. More often than not, data collected for a previous phase of work can be useful to estimate the likely impacts of a different product. For example, with data collected for the production of an orange juice product, it might be possible to make some reasonable estimates with regard to certain aspects of the supply chain for apple juice. This bolsters any scoping calculations and provides confidence on where to focus data collection efforts. It also serves to identify the presence of any significant issues.

4 BENEFITS OF A LARGE SCALE PROGRAMME

4.1 Putting product carbon footprint values into context

A large scale product carbon footprinting programme enables more widespread comparison of product greenhouse gas emissions to provide greater context and meaning in terms of an individual product carbon footprint as well as the combined indirect emissions from an entire product range. To the consumer, or to an inexperienced eye, a lone carbon footprint value for a specific product is meaningless, as it cannot be determined whether the number is high or low, good or bad, or how it compares to a similar product. A well thought out large scale programme will identify product categories that are of interest to the audience (eg high retail volume products or product life cycles that have an interesting story) and that can be contextualised by comparing with each other and previously footprinted products.

4.2 Increasing awareness

A large scale carbon footprint programme, that provides footprint values for comparable products, will help to raise awareness of products or processes that result in higher emissions and subsequently identify where efforts should be focused for reduction. Should the product carbon footprint results be communicated to an external audience, consumer awareness will be raised, enabling meaningful comparison of similar products to assist in decision making. Of particular relevance to the consumer are impacts that occur during the use phase. Wider understanding, from large scale exposure of results, of how consumers themselves can influence the carbon footprint of products could have a significant impact in tackling overall emissions.

4.3 Continued supplier engagement

Having engaged suppliers during the product carbon footprint calculation process, this can be continued by sharing and discussing the results of the carbon footprint assessment. The results provide an ideal opportunity to continue working with suppliers in order to initiate efforts for emissions reduction and process improvement. Whilst a product carbon footprint will provide useful information on where the carbon 'hotspots' are in the supply chain, it is a further step to identify realistic and practicable options for reducing emissions. By working with suppliers, an impact that occurs at one stage of the product life cycle (for example disposal of packaging at end of life) can be tackled at another (for example, by working with the supplier of packaging materials). Through continued engagement of the supply chain, the product carbon footprint results can be interrogated to identify opportunities to reduce energy, minimise packaging, use alternative materials and other emissions reduction options. The benefit of a large scale programme is that, as the same supplier is often involved in many different product supply chains, it is possible that working with one supplier will have relevance for several different products.

4.4 Focusing emission reduction efforts

Carbon footprinting on a large scale means that the cumulative impact of a specific product on total company emissions can be identified. By identifying emissions from high consumption products, the actual impact of a product type on a company's emissions or on a country's emissions can be seen. This identifies which products or product categories should be focused on to make an actual difference to total carbon emissions.

The nature of a large scale carbon footprinting programme means that there will be significant cross over between different product categories. This lightens any potential burdens and encourages knowledge sharing where a certain process has significance to a number of different products. An example is chilled transport, which will be used for several different products and often incurs considerable impacts due to refrigerant emissions and increased energy consumption. Focused effort from different areas for a common purpose has the potential to be of greater influence to identify opportunities for carbon reduction or efficiency.

5 NEXT STEPS: FACILITATING LARGE SCALE PRODUCT CARBON FOOTPRINTING

The Tesco case shows us that product carbon footprinting can be achieved to a credible and recognised standard on a large scale. The success of its product carbon footprinting programme was helped by a well considered scoping process and carefully nurtured supplier engagement.

Experiences from the Tesco programme indicate that greater success in data collection is likely with a supply chain that is engaged with the process and that is provided with information to give an understanding not only of the aims of the carbon footprint, but also practical details on process. For suppliers that had prior understanding, the data collection experience was considerably less ominous and was achieved within much shorter timescales. To facilitate large scale product carbon footprinting, encouraging wider understanding of product carbon footprints and the process is a worthwhile investment in order to foster future cooperation in any footprinting initiative.

Data collection is one of the most crucial stages of any product carbon footprint. In order to attain a high level of primary data, which is always preferred for product carbon footprints, it is typically the most resource intensive. Any efforts to streamline this process to make it more efficient would benefit a large scale programme. Further to the points raised above in relation to the benefits of an engaged supply chain, it follows that increased knowledge and experience will enable suppliers to undertake more of the data collection activities unaided.

6 SUMMARY

This paper summarises the evolution of a large scale product carbon footprinting programme and lessons learned from its implementation across a wide and varying range of consumer products.

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The construction of collaboration platform for carbon footprint calculation

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Abstract

Recently, with the technology level is increasing, not only our ecology environment is destroyed, but also the global climate is changed. Many governments are forced to rethink the sustainable issues. Among these issues, the impact of carbon dioxide (CO_2) should be the most serious problem. Therefore, the manufacture industries begin to calculate and disclosure the CO_2 emission and then to reduce it. In the past, the manufacturers need to spend a lot of time and cost to get the product's carbon footprint. In this research, the information communication technologies (ICT) framework is constructed that could collaborate with suppliers to get the life cycle data very easily. The ICT is the new concept to integrate the information and communication technology. Finally, a case study is conducted and analyzed to demonstrate the model...

1 INTRODUCTION

United Nations Environment Programme reported that the significant environmental impacts over the past 20 years include global warming, clean water supply, agricultural land, and biodiversity, while all of which have been confirmed as major menaces to human life. McKinsey (2008) global questionnaire found that senior managers of enterprises generally suggest that there is a need to be responsible for environmental protection and implement in-plant carbon management activities. In other words, current enterprises have to disclose carbon information of various in-plant activities and gradually establish carbon footprint system for products to evaluate the carbon footprint of each product, and further find approaches to reduce carbon emission to achieve the purpose of carbon neutralization. Carbon footprint is defined as the direct (on-site, internal) and indirect (off-site, external, upstream, downstream) CO_2 equivalent, CO_2e, emission of a product or service in its life cycle (Wiedmann and Minx, 2008). Carbon footprint may be viewed as a hybrid, deriving its name from “ecological footprint” and conceptually being a global warming potential indicator (Wackernagel and Rees, 1996). Here, ecological footprint refers to the biologically productive land and sea area required to sustain a given human population expressed as global hectares (Pandey *et al.*, 2011).

Because the competition among “companies” has been transformed to that among “supply chains versus supply chains,” many enterprises also agree that carbon management has become an important issue (Hult *et al.*, 2007) in supply chain management, and thus, requested suppliers to cooperate and assist in investigations. For example, retailer Walmart（2009）provided the criteria for supplier sustainability assessment to request suppliers to disclose carbon information and life cycle information. Rizeta *et al.*（2010）assessed the GHG efficiency of several supply chains of the same product marketed through different types of retail systems in Europe. Lee (2011) integrated the carbon footprint into the automobile supply chain, Hyundai. Fleten *et al.* (2010) analyzed the optimization of carbon storage in supply chains.

The observation of enterprises' past footprint inventory of products showed that, owing to the limited cost and resources, most of these investigation were conducted as special project for target products, were seldom comprehensively conducted, and were not integrated with existing internal management system or information system of enterprises. Due to the lack of system integration, it was time-consuming to conduct these inventory and the data quality could not be ensured for the guidelines, such as PAS2050 specifications (e.g., relevance, completeness, consistency, accuracy, and transparency) (BSI, 2008). In addition, the developmental life cycle of current products are shorter. Therefore, the data obtained from the inventory may only be the carbon footprint of a product or in-plant fragment information, which cannot be reutilized for further data processing, such as the carbon emission reduction of material use/components or manufacture system.

2 LITERATURE REVIEW

Carbon footprint is a measure of a product's impact on the environment, in terms of greenhouse gases (GHGs) emitted along its supply chain (Finkbeiner, 2009; Wiedmann and Minx, 2008). Thus, it is a subset of the data covered by the more comprehensive life cycle stages, which takes into account the consumption of resources and all the impacts associated with a product's full life

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cycle, from raw material, manufacture, transportation through use and maintenance, to final disposal. Busch and Hoffmann (2007) indicated in the study on supply chain that heat (carbon) flux implies a company's carbon emission and carbon constraints in its supply chain, which will affect its financial status. Current enterprises have gradually attached importance to carbon information disclosure of products. If an enterprise only discloses its carbon emission, it is impossible to assess its performance of carbon reduction. The stage of maximum GHG emission cannot be found unless the supply chain carbon inventory of product is obtained. With constant improvements, low-carbon products can also be developed. Many scholars have indicated that in the design of current supply chain, in addition to quality, delivery date, and cost, it is also necessary to take into account carbon emission and include carbon emission into the assessment criteria for suppliers.

Carbon footprint inventory is established based on the methodologies of GHG inventory and life cycle inventory. To conduct consistent carbon footprint inventory, the environmental science and engineering community have developed several systematic methodologies or guidelines for the detailed characterization of the environmental impacts of chemicals, products, and processes.

(1) The Greenhouse Gas Protocol Initiative (GHG Protocol):
(2) ISO started developing an international standard ISO 14067 on Carbon Footprint of Products (Part 1: Quantification, Part 2: Communication) .
(3) The Intergovernmental Panel on Climate Change (IPCC) has developed guidelines for reporting on GHG emissions from a number of industrial processes and activities.
(4) A GHG accounting guidelines. It has published carbon footprints for some food products (ADAS, 2009).
(5) The British Standards Institute developed the PAS 2050 Specification for assessment of the life cycle GHG of goods and services.

Besides the above methodologies and guidelines, there is an established tool, Life Cycle Assessment (LCA), for evaluating environmental outcomes of products or services through their lifecycle. It has broad international acceptance in science as a means to improve environmental performance of products or services (Ortiz et al., 2009). According to ISO 14040, an LCA study essentially consists of four interconnected steps/phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. LCA is an objective process to evaluate the environmental burdens associated with a product or activity by identifying and quantifying energy and materials used and wastes released to the environment; to access the impact of those energy and material used and released to the environment; and to evaluate and implement strategies to affect environmental improvements.

3 METHOD

This study used ICT tool and referred to the existing international references and guidelines and existing methodologies for carbon footprint inventory in an attempt to simplify data collection and inventory procedures, to establish standard procedures, and to establish a tool for calculating carbon footprint of apply chain inventory, as shown in the Figure 1. Figure 1 shows the framework of the carbon footprint disclosure system. This system is based on current carbon footprint inventory technique with the aid of information system. The descriptions are as follows.

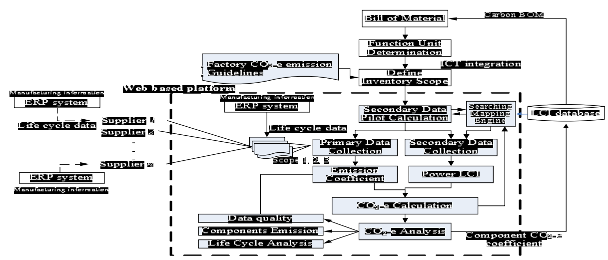

Fig. 1: Framework of the carbon footprint disclosure

3.1 Data form and secondary data collection

During the analysis on carbon footprint, it was necessary to collect all the relevant in-plant information and activity data concerning product manufacture. However, because the inventory data were unavailable, secondary data were used to replace primary one. As for the reason that the data of actual plants could not be collected, the reason was that some techniques did not belong to enterprise, suppliers intended to protect trade secrets, there was a lack of information system in the existing system. The explanations about primary and secondary data are given as follows (Torcellini and Deru, 2004).

- Primary data were those obtained from specific facilities
- Secondary database were those included in the product system life-cycle inventory that have been obtained from published sources.

The quality classification of secondary data varied with the scope of life cycle, and could be divided into: (1) the national emission factor obtained by a certain country using existing data; (2) the emission factor of industrial data obtained by a specific industry using its existing data; the emission factor obtained by a certain enterprise using its internal data.

3.2 Product life cycle primary data collection and input

After function unit was determined, the data of product could be collected according to the stages of life cycle, including stages such as raw material input, product manufacture, transportation, use, and waste. The explanations about them are given as follows:

(1) Raw material input stage: the direct materials are the main raw materials and packaging materials of product. In general, main raw materials are those which will be retained on the product. The data at this stage usually were obtained from supplier inventory form. Therefore, suppliers were requested to directly complete the form according to the materials required by unit product.
(2) Product manufacture stage: the data on energy and resources used in product manufacture stage, auxiliary materials used during processing, such as cutting fluid and cleaning agent, air, water and waste pollutants emitted, and in-plant transportation were respectively collected according to the regulations and criteria of ISO14064 and PAS 2050. In general, these data had to be used to calculate materials used by unit product according to allocation principle.
(3) Transportation and retail stage: the data at this stage were those delivered from manufacturer to retailor and they also included the CO_2e emission of retailers.
(4) Use stage: the data at this stage referred to the air pollution, water pollution, and wastes produced when end-users used the product.
(5) Waste stage: the data at this stage referred to the air pollution, water pollution, and wastes produced by product at waste stage.

3.3 Carbon footprint calculation of full product and carbon BOM establishment

The primary data were combined with the secondary data and were analyzed to calculate the overall carbon emission, namely, the carbon footprint of product. The formula is as follows.

Carbon footprint= $\sum \{all\ CO_2\ emissions\ of\ life\ cycle\ stages\}$

3.4 Analyses and assessments

Relevant analyses and assessments included: (1) data quality; (2) analysis on carbon BOM; (3) assessment on life cycle; (4) other data-related analyses:

(1) Data quality: data quality could be assessed based on the proportions of primary data and secondary data of carbon emission. *DCH* indices could also be used to represent it, including:
- *D*: Direct measure, such as collecting and obtaining data by directly using measuring instrument;
- *C*: Calculation or estimation, such as obtaining data by using electric power receipt to calculation manufacture distribution;
- *H*: Scenario hypothesis: if the scenario of users cannot be actually understood, virtual scenario can be used to calculate carbon emission.

(2) Analysis on carbon BOM: the components of higher carbon emission could be understood based on BOM data, and thus the enterprise could negotiate with suppliers about making improvements. The data on carbon emission of the same components at different plants could also be assessed and analyzed in Carbon BOM to find out the direction for improving production.

4 SYSTEM IMPLEMENTATION

4.1 AS-IS and TO-Be model

(1) AS-IS model

End-user enterprises assisted suppliers in collecting their on-site Material BOM and relevant resource data. The contents of Material BOM should include information such as processing conditions, product materials, assembly proportions, weights, and amount used during manufacture process. Moreover, the data collected were filled in the inventory form one by one, and an e-mail was sent to confirm the accuracy of data with enterprises. After the confirmation of data, data were artificially input into life cycle assessment software, SimaPro v7.2, for assessment of emission. After the analysis, the result of CO_2e emission was artificially backfilled to the inventory tool, and an e-mail was sent as the reply to the enterprise. However, during this series of analysis, it was more difficult for the enterprise to comply with the five principles of PAS2050:

(1) Relevance: the enterprise had to spend more costs to complete the inventory and data collection. The specific project-based management had to consume a large amount of cost and time.
(2) Completeness: the Material BOM of suppliers was a trade secret. Therefore, it was uneasy to obtain it. Suppliers tended to conceal their ingredients. Therefore, carbon emission might be overestimated or underestimated.
(3) Consistency: because the carbon footprint inventory was conducted as a specific project, it was hard to effectively compare the carbon information to that of past years.
(4) Accuracy: because the data were artificially input, there might be artificial mistakes such as double key in or input errors of weight unit, assembly proportions, and amount. Therefore, the accuracy of carbon emission would be significantly reduced.
(5) Transparency: the enterprise failed to immediately and explicitly know the carbon information of various suppliers.

(2) TO-Be model

In this system, the enterprise could integrate the production information (Master Production System, production time, etc.) of in-plant enterprise resource planning (ERP) system with bill of material information (materials, assembly proportions, weights, and amounts), relevant in-plant energy and resource consumption information, or supplier information. Moreover, it could search for relevant materials of LCI (life cycle inventory) database through data inventory form and functions of Searching Engine, Memory Database, and Power LCI Engine. I n this system, memory database was established to record the corresponding materials used by various suppliers, and the purpose was to reduce the time and manpower to re-search the corresponding materials of life cycle assessment software and to maintain the consistency of materials in use. The contents of complete inventory form should include the information such as corresponding product materials, assembly proportions, weights, and amounts of the LCI. The complete form after mapping was input and transformed into the file mode readable by LCI calculation software to calculation CO_2e emission. Moreover, data accuracy was also enhanced and potential artificial input errors were excluded. After the calculation was completed, the CO_2e emission was backfilled into the original inventory form to enable the enterprise to clearly find out the components/parts of higher risk through material flow data and Life Cycle Assessment and to choose suppliers for cooperation from the perspective of environmental improvement. The system is shown in Figure 1. The AS-IS and TO-BE models are also shown in Figure 2.

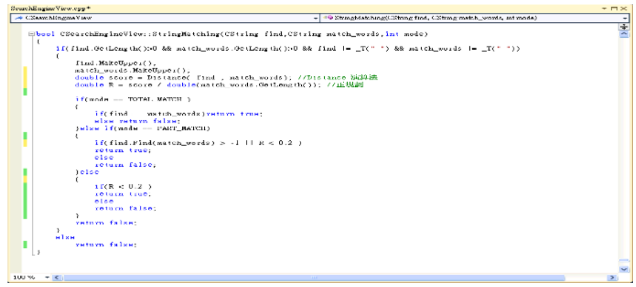

Fig. 3: Searching Engine

4.2 Searching Engine for secondary data

During the citation of secondary data, Simapro, was mainly used. However, it was restricted by regional data. To ensure that appropriate secondary data were cited, some data, including name and coverage of life cycle, might not be directly corresponded. In addition, international database could only be used. Therefore, mapping and searching engine were established to assist the enterprise in establishing its own Carbon BOM to backfill the data it had searched to the database, which reduced the difficulty in searching, ensured the consistency of data, and reduce the amount of data to be inventoried. By using the search engine, the secondary life cycle data could be easily found by using the keywords.

Fig. 2: As-Is and To-Be model for case study system

4.3 POWER LCI Engine

During the inventory, because the names of chemical materials were different, some mistakes were made when citing the secondary data, resulting in the significant difference in data. Therefore, this study used C++ software which could rapidly input the data of life cycle inventory and exchange that with the data of inventory form through the functions of import and export to reduce the occurrence of artificial mistakes. The life cycle data could be exchanged by using this engine very easily. Thus, this engine could reduce the human typos and enhance the data input speed.Each figure and each table must have a caption. Initially capitalize only the first word of each figure caption and table title. Figure captions are to be *below* the figures. Table titles are to be *above* the tables. Captions should be centered. Place the figure or table on the text page as close to the relevant citation as possible, ideally at the top or at the bottom of a column. If a figure or table is too large to fit into one column, it can be centered across both columns at the top

Fig. 5: Carbon footprint of Taiwan EPA

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5 CONCLUSIONS

As the issues concerning GHGs have gradually attracted the attention of enterprises, carbon footprint disclosure has become more and more common. In Recent years, Environmental Protection Agency in Taiwan has aggressively encouraged enterprises to disclose product carbon information, to apply for cable label in Taiwan, and to promote enterprises' disclosure of product carbon emission at each stage of life cycle, in order to propose carbon reduction policies. To date, approximately 80 B to C products have applied for carbon label. For the carbon label in Taiwan, please visit the website: http://cfp.epa.gov.tw/.

Fig. 4: Power LCI Engine

Faced with such a change in industrial demand, although enterprises had developed some techniques and accumulated experiences concerning carbon footprint inventory, these techniques and experiences still fail to meet the need. The main reason is that enterprises hope to use a simple and rapid inventory tool to assist them in finding the direction for carbon reduction. This study used ICT technique, referred to guidelines and methodologies of carbon footprint inventory, and specifically integrated the information required by suppliers to establish carbon footprint inventory system. The development of this system included determining function unit, analyzing product BOM information, inventorying enterprises' primary and secondary data, feeding back product carbon BOM to the designer, and assisting in design and development of system. The results showed that this system could indeed reduce enterprises' investment in manpower and resources of carbon footprint inventory, reduce the time of inventory, and enhance data accuracy. Because previous studies seldom investigated the establishment of product carbon footprint system, the data were provided by ERP and were not obtained from the design stage. Therefore, many aspects of this study can be improved, such as integrating this study with the laws and regulations and guideline principles of carbon footprint inventory, integrating this study with CAD system at R&D stage, performing in-depth analysis on quality of carbon footprint data, and developing energy saving and carbon reduction methods by connecting the data obtained from this system with production system.

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Carbon Footprint Assessment of Water Supply Systems in Taiwan

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Abstract

Recent studies indicate that global warming is worsening, tremendously affecting our environment. Hence, reducing CO2 emissions is one of the most pressing issues in environmental protection. Among the natural resources, water is one of the most vital. Having a clean and secure water supply, as well as a water distribution system, is crucial for modern society. From a life cycle perspective, a complete water supply system is complicated and contains substantial, embedded carbons, which comprise infrastructure, as well as purification facilities and related processes. Assessing the total carbon footprints of a complete water supply system would present numerous benefits. Such evaluation covers the examination of water supply efficiency and identifying opportunities for carbon emission reduction after a thorough inventory. In addition, calculating the carbon footprints of products has become increasingly important for global enterprises. Determining the carbon footprint of unit of water (i.e., in $kgCO_2$ e/m^3) is necessary for the calculation of a product's carbon footprint.

In view of the above-mentioned issues, several countries, including Scotland, the UK, USA, Japan, and Italy, have studied the carbon footprints of water supply systems. In Taiwan, previous studies conducted to determine the carbon footprints of water supply systems were not based on a life cycle perspective. Commissioned by the Water Resources Agency of the Ministry of Economic Affairs, this study calculated the carbon footprints of five water supply systems, each with different characteristics in terms of topography, scale, raw water quality, and purification process. The water supply systems studied included a traditional purification plant, a purification plant with high-turbidity raw water, a multi-process purification plant, an advanced purification plant, and a desalinization plant. The scope of inventory and assessment includes the intake, the purification, and the distribution stages, as well as the infrastructure and the chemicals used that are associated with these stages. Carbon footprints are calculated based on the unit water sold (m^3). The calculation is performed in accordance with the standards set by the Taiwan Carbon Footprint Calculation Guidance for Products and Services. Preliminary results show that the carbon footprints of the traditional purification plant, the purification plant with high-turbidity raw water, the desalination plant, the advanced purification plant, and multi-process purification plant are 0.1768, 0.2646, 9.6249, 0.4969, and 0.1942 kg CO_2e/m^3, respectively.

Keywords: Water supply system, global warming, carbon footprint, life cycle perspective

1 INTRODUCTION

Recent studies indicate that global warming is worsening, greatly affecting our environment. According to the Intergovernmental Committee of Experts on Climate Change (IPCC), average temperature is rising and this would seriously affect our environment [1]. Hence, the reduction of CO_2 emissions is one of the most important issues we need to address to protect our environment. Among our natural resources, water is one of the most vital resources. Water is the new oil and carbon is the currency that drives the water industry to make significant changes by reducing its carbon emissions [2].

In Taiwan, there is abundant rainfall every year, but most of the rainfall is rapidly lost to the ocean because of strips of populous areas, abrupt geographical features of Taiwan's mountains, and heavy downpours. In addition, rainfalls in Taiwan tend to cause zonal or seasonal droughts very easily because of the unequal distribution of rain in certain areas and during certain seasons [3].

In the past few years, political actions and media reports on climate change issues and carbon footprints were brought into the spotlight. On account of its importance, several countries, such as Scotland, the UK, USA, Japan, and Italy, have studied carbon footprints of water supply systems. Taiwan also conducted some studies on the calculation of carbon footprints of water supply systems. However, those studies did not focus on the life cycle perspective. In this study, based on Taiwan Carbon Footprint Calculation Guidance for Products and Services, experience from other countries, extended literature

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review, and expert consultations, the boundary and scope of carbon footprint calculation of water supply systems was decided [4].

Currently, five water purification plants with different characteristics (i.e., traditional treatment, advanced treatment, plant with high turbidity treatment, multi-process treatment, and desalination plant) are being applied to do inventory and to calculate carbon footprints. The results will be used in the future as estimates and reference materials for Taiwan's carbon footprinting of its water supplies.

2 LITERATURE REVIEW

The concept of the carbon footprint came from the ecological footprint assessment created by Wackernagel [5], which considers humanity's energy and resource throughput and converts these data into area units. The ecological footprint and the carrying capacity can then be directly compared because they are measured using the same units. Carbon footprint can be defined as a measure of the exclusive total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product [6]. Thus, reducing energy consumption and carbon emissions entails committed action through sustainable management practices based on a life cycle perspective.

The Life Cycle Assessment (LCA) methodology enables the calculation of environmental burdens in a systematic and scientific way by regarding all inputs and outputs of a system [7]. LCA is mainly used for assessing systems and identifying options for improvement and, in some cases, for developing sustainability indicators [8]. It is a systematic tool used in analyzing and assessing environmental impacts, as well as energy use, over the entire life cycle of a product, which generally includes raw material extraction, manufacture, product use, recycling, and final disposal [9][10] .

Current international guidelines for calculating carbon footprints include ISO 14067, World Resources Institute (WBI), World Business Council for Sustainable Development (WBCSD), PAS2050, and TS Q0010. In 2010, the Environmental Protection Administration (EPA) made an announcement about calculating the carbon footprints of Taiwan in a study entitled, "Taiwan Carbon Footprint Calculation Guidance for Products and Services" (Taiwan's Product Category Rules [PCR]). Taiwan's PCR are founded on CNS 14040 and CNS 14044, which established the LCA methods and the reference PAS 2050 in step with the spirit of carbon footprint assessment [11]. For consistency in calculating a product's life cycle's greenhouse gas emissions, they have detailed specifications on products and services.

The Global Type III Environmental Product Declarations Network (GEDNET), founded in 1999, is an international non-profit association of type III environmental product Declaration organizations and practitioners. "Water Distribution Through Mains, Except Steam and Hot Water PCR Draft" was published by GEDNET. This document provides PCR for the assessment of the environmental performance of UNCPC class 6921 water distribution through mains (except steam and hot water), and the declaration of this performance by an environmental product declaration (EPD). This PCR document was developed by the Emilia-Romagna Development Agency (ERVET) [12]. The water supply boundary is shown in Fig. 1.

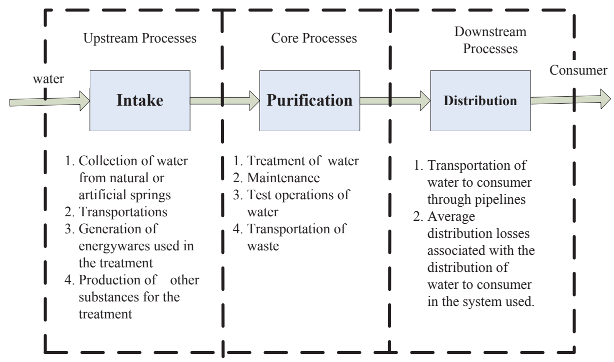

Fig. 1 : Water distribution through mains, except steam and hot water PCR draft

According to the PCR of ERVET, experience from other countries, extended literature review, expert consultations, and Taiwan's PCR in Fig. 2 [13][14][15][16][17][18][19] have decided the boundary and the scope of assessment, including intake, purification, distribution, chemicals, consumables, transportation at each stage, and infrastructures.

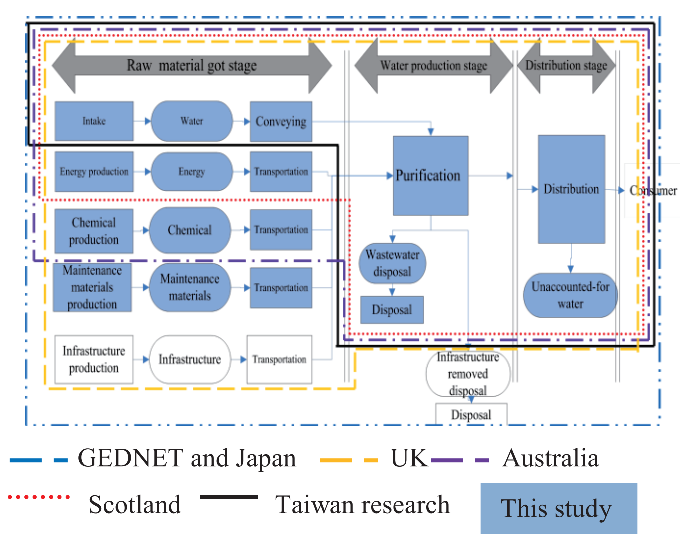

Fig. 2: Water supply system boundary of each country researched

3 RESEARCH METHODOLOGY

The goal of this study is to assess the life cycle greenhouse emissions of five plants in Taiwan through expert consultation. Table 1 shows details about the five plants. This research uses a "cradle to gate" approach, where the functional unit is defined as the global warming potential of 1 cubic meter of water production.

Table 1 The five supply system

	Gongguan Purification Plant	Panhsin Water Treatment Plant	Kinmen Seawater Desalination Plant	ChengChingHu Water Treatment Plant	FongYuan Water Treatment Plant
Operations management	Taipei Water Department, Xindian River System	12th Branch, Taiwan Water Corporation	Kinmen County Waterworks	7th Branch, Taiwan Water Corporation	4th Branch, Taiwan Water Corporation
Headspring	Xindian River	Three-Gorge Dam, Shihmen Reservoir	Sea off Kinmen	Kaoping River	Ta-chia River, Shih-Kang Dam
Intake	Turbidity current	Pumping	Pumping	Pumping	Pumping
Capacity (tons per day)	520,000	680,000	2,000	450,000	600,000
Notes	1.Traditional purification plant 2.Photovoltaic (PV)	1.Traditional purification plant 2.High-turbidity raw water	1.Reverse osmosis system	An advanced purification plant: (1)Pre-ozonation system (2)Crystal softening system (3)Post-ozonatoin system (4)Biologically activated carbon filter pool	1.Traditional purification plant 2.Two purification plants

The system boundary of the LCA method consists mainly of three stages, namely, intake, purification, and distribution stages. This study's results have two parts; one includes infrastructure and another does not include infrastructure. Emissions from the production of capital equipment, including building, pipe infrastructure, and machinery, are in the system boundary of the LCA analysis. Fig. 3 shows the boundary and the inventory of one treatment plant whose inventory time is one year (in 2010).

4 RESULTS AND DISSCUSSION

This study chose the Simapro 7.2.3. Its database is from Eco-invent, and the model used is IPCC 2007 GWP 100a. The electricity coefficient is 0.612 kg CO_2/m^3, which is from the Bureau of Energy, Ministry of Economic Affairs. Fig. 4 and Table 2 show greenhouse gas emissions from different stages, including intake, purification, and distribution stages, for every 1 m^3 of water produced by each treatment plant.

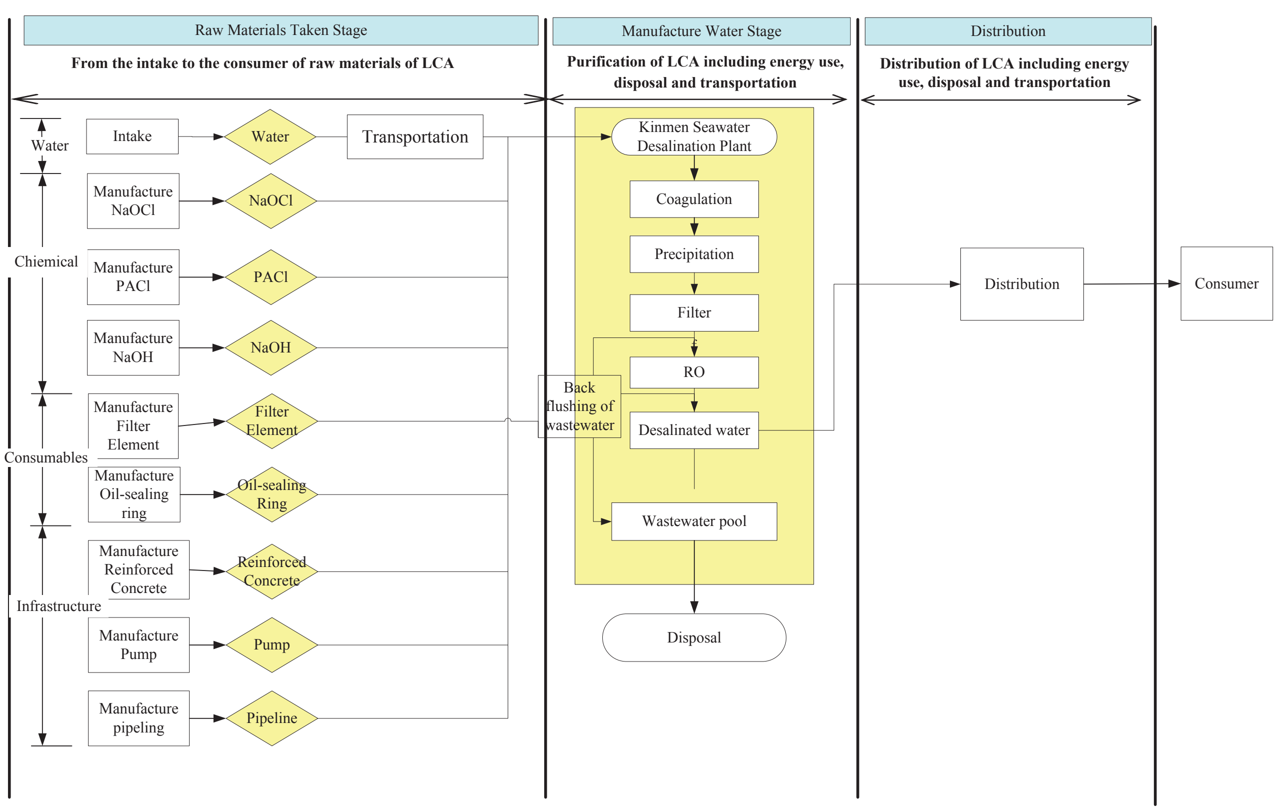

Fig. 3: Boundary and inventory of the Kinmen seawater desalination plant

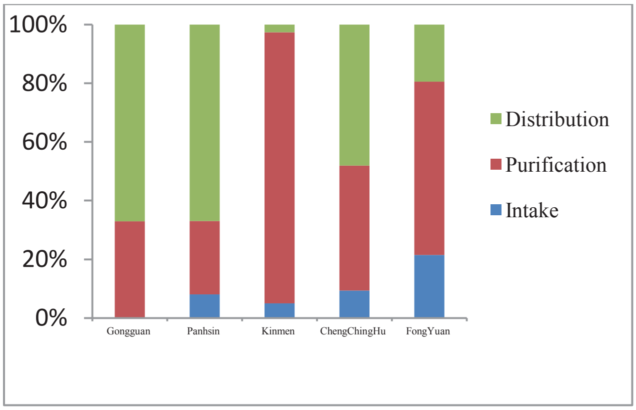

Fig. 4: Greenhouse gas emission percentage of each plant

Table 2: Greenhouse gas emissions of each plant

	Gongguan	Panhsin	Kinmen	ChengChingHu	FongYuan
Intake	0	0.0213	0.4816	0.0464	0.0417
Purification	0.0582	0.066	8.896	0.2117	0.1148
Distribution	0.1186	0.1772	0.2473	0.2387	0.0377
Total	0.1768	0.2646	9.6249	0.4969	0.1942

Unit :kg CO_2 e/m^3

This paper includes the study of boundaries, infrastructures (including construction [steel and concrete]), mechanical and electrical equipment (motors), and pipelines into the calculation scope. The lifetimes of infrastructures are assumed to be 58, 12, and 38 years [20], respectively. To collate data, the calculations of the each plant's carbon emissions are as follows:

(1) Gongguan Purification Plant. The intake stages contain distribution wells. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain two parts, namely, mechanical equipment and cast-iron pipes. The total carbon emission is 0.1833 kg CO_2e/m^3.

(2) Panhsin Water Treatment Plant. The intake stages contain mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, and cast-iron pipes from the 12th branch of the Taiwan Water Corporation. The carbon emission is 0.2689 kg CO_2 e/m^3.

(3) Kinmen Seawater Desalination Plant. The intake stages contain reinforced concrete storing cisterns and mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, High-density polyethylene (HDPE) pipelines, and ductile iron pipelines. The carbon emission is 10.6734 kg CO_2 e/m^3.

(4) ChengChingHu Water Treatment Plant. The intake stages contain mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, and cast-iron pipelines from the 7th branch of the Taiwan Water Corporation. The carbon emission is 0.6032 kg CO_2 e/m^3.

(5) FongYuan Water Treatment Plant. The intake stages contain reinforced concrete storing cisterns. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, ductile iron pipelines, and cast-iron pipes from the 4th branch of the Taiwan Water Corporation. The carbon emission is 0.2832 kg CO_2 e/m^3.

On the overall, carbon emissions in the consumption of electricity are the best emission sources. For example, electrical consumptions at the Gongguan Purification Plant, the Panhsin Water Treatment Plant, and the ChengChingHu Water Treatment Plant are about 67.39%, 67.27%, and 48.19%, respectively. In the purification process, the different processes have different results. For instance, carbon emissions of chemicals in the Gongguan Purification Plant, such as PAC, NaOCl, and NaOH, are about 84%. Carbon emissions of electrical consumptions are about 16.15%. The best carbon emissions are from such chemicals as PAC, NaOH, and liquid chlorine from the Panhsin Water Treatment Plant, which are about 83.75%. Carbon emissions from the reverse osmosis system is the best emission source in the Kinmen Seawater Desalination Plant, whose electrical consumption in the purification stages is about 99.75%. In the ChengChingHu Water Treatment Plant, chemicals, such as NaOH, $Al_2(SO_4)_2$, liquid chlorine, H_2SO_4, and others are the best sources of emission, which are about 67% in the purification stages. Carbon emissions of electrical consumption are about 33%. Finally, in the FongYuan Water Treatment Plant, carbon emissions of chemicals used, such as PACl and liquid chlorine, are about 62.73% in the purification stages. Carbon emissions of electrical consumption are about 36.99%. The solar PV electricity generation systems of Gongguan Purification Plant would reduce about 0.0017kg CO_2 e/m^3 in 2010.

5 CONCLUSION

The equivalent of 0.1768, 0.2646, 9.6249, 0.4969, and 0.1942 kg CO_2e would be emitted from the production of 1 m3 of water from a traditional purification plant, a purification plant with high-turbidity raw water, a desalinization plant, an advanced purification plant, and a multi-process purification plant, respectively. Reverse osmosis contributes significantly higher greenhouse gas emissions than other purification processes during the life cycle of water production. On the overall, the generation of electricity for pumping and for water delivery accounts for a large proportion of greenhouse gas emissions during the life cycle of 1 m^3 of water production.

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Korea*– Japan**
International Cooperation on Type I Eco-Labeling
- Analysis of Its Performance & Future Directions –

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Abstract

Korea Environmental Industry and Technology Institute(KEITI) has established Type1 ecolabelling system based on ISO 14024 and managed it since 1992. KEITI has also cooperated with other organizations abroad which is operating ecolabelling system so that ecolabelling system cannot be the barrier to international trade. KEITI has concluded MRA with Japan Environment Association(JEA) and cooperate actively such as developing common criteria. KEITI will increase common criteria, share recent environmental information and finally make our relationship(KEITI-JEA) last and strong.

Keywords:

Type 1 eco-labelling, International cooperation, Japan Environment Association(JEA), Mutual Recognition Agreement(MRA), Common criteria

1. TYPE I- ECO-LABELING SYSTEM

Environmental labelling are the designs or indications adhered and provided to products and service media with the purpose for delivering economical information for products and services to the consumers. The environmental labelling system solves the economical problems that occur due to consumption of products or services and furthermore, devised to expedite sustainable consumption and production. Moreover, the purpose of environmental labelling is to induce eco-friendly consumption patterns by providing economical information for the overall process of products and services(phases of production, distribution, usage and disposal) for consumers and enabling the producers to develop and manufacture products that correspond to the eco-friendly consumption patterns.

International Organization for Standardization(ISO) has classified environmental labelling into 3 types and has regulated the conditions for each type of the environmental labeling in the 14020 series. Among the conditions, Type I Eco-Labeling signifies the method where a 3rd person validates the eco-friendly products by sorting products with smaller environmental influence when compared to other products of same usage over the product's lifecycle including manufacture, distribution, usage and disposal.

Since its initial enforcement in Germany during 1979, the Eco-labeling system has been successfully enforced in 48 different regions including the European Union, Northern Europe, Canada, the U.S. and Japan. The nation of Korea introduced Eco-Labeling system by establishing the "Laws on Development and Support for Eco-Labeling" in 1994 and the national contest for environmental cover designs in 1990. From then on, the grounds related to the system operations for "Laws on Development and Support for Eco-Labeling" were found in 1994 to establish the Eco-Labeling Association(present, Korea Environmental Industry & Technology Institute, KEITI) to revitalize Eco-labeling system.

The Eco-Labeling system of Korea is generally operated through the following phases.

A. Select subject product group as the category for subject of certification

B. Determine criteria for evaluating the eco-friendliness for selected product group

C. Verify the appropriate certification standards for subject product group when a corporation is to request certification and approve certification for product appropriate to certification standards according to result of deliberation

D. Surveillance check for the certified product to inspect whether the product is consistently satisfying certification standards during the certified period

All nations or organizations that enforce the Type I Eco-Labeling program operate with the similar forms of the system as stated above.

* Korea Eco-labeling organized by KEITI (Korea Environmental Industry & Technology Institute)

**Japanese Eco Mark organized by JEA (Japan Environment Association)

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2. INTERNATIONAL STANDARDIZATION AND MUTUAL RECOGNITION ARRANGEMENT OF ECO-LABELING SYSTEM

The international society's debates on the Eco-Labeling system are accomplished largely by the international organizations including the World Trade Organization(WTO), the International Standardization Organization(ISO) and the Eco-Labeling Operational Institution Conference Group including the Global Eco-Labeling Network(GEN). Major issues include the international standardization for Eco-Labeling system to harmonize with free trade principles for removing irrational trade barrier effects for export products of each nation while expediting developments and supply of eco-friendly products.

WTO supports conclusion of the Mutual Recognition Agreement(MRA) amongst nations so that the conformity evaluation system for the purpose of environment, safety, health, consumer and protection does not act as Technical Barriers to Trade(TBT). Moreover, the Global Eco-Labeling Network(GEN) is actively encouraging the Mutual Recognition Agreement(MRA) to progress the international standardization of Eco-Labeling system.

The Mutual Recognition Agreement(MRA) is the agreement concluded to recognize the "Conformity Assessment" by the agreed nations for regulated products determined by each nation for safety, health, environment, consumer protection. Here, the Conformity Assessment" implies the test, evaluation and judgment of whether the product, process or service satisfies the standards, average or technical regulations. Moreover, "recognition" is recognizing that the results from the opposite side's conformity assessment and the person involved are equivalent.

The process and method of mutual agreement for Eco-Labeling have the need for the following approach. As the 1st phase, 'Mutual Recognition for True Nature of Both Nations' speaks of the mutual recognition that recognizes the opposite nation's eco-friendly products by verifying the true nature of the Eco-Labeling system between the nations and concluding the memorandum of agreement. KEITI has concluded the 1st phase MRA with Nordic Swan, the Eco-Labeling organization of 5 Nordic nations. As the 2nd phase, 'Mutual Agreement of Environmental Examination Methods for Products and Examination Organizations' standardizes the recognition process and evaluation methods for examinations in the nation's Eco-Labeling institutions to assign the official evaluating organization in each nation to mutually recognize the test results. KEITI has concluded the 2nd phase MRA with Taiwan, Thailand, Australia, China and New Zealand.

The 3rd phase 'Mutual Recognition by Common Recognition Standards' is the method of unifying the Eco-Labeling certification standards of a nation to recognize that the certified product has the same eco-friendly excellence as the products certified in the agreed nations. At the present time, the common standard agreement taking place between Korea and Japan can be considered as a good example of this phase. Lastly, the 4th phase 'Unification of Eco-Labeling System amongst Nations' is the method of unifying the different systems of each nation to operate by unifying the operational institution, certification process and test evaluation in one organization. This corresponds to the European Flower system enforced among the member nations of EU or the Nordic Swan that is enforced among the Northern European nations.

3. Korea-Japan Mutual Recognition Agreement

KEITI and Japan Environmental Association(JEA) have recognized the system of both nations in 2003 and concluded MRA that recognizes the official test evaluation results. Since then, the two have consistently progressed the cooperation business for developments of common standards on personal computers(2007) and the multifunctional devices(2010). Since the conclusion of MRA in 2003, when a Korean corporation desires to apply for Japan's Eco-Mark, the preparations of verification report and test evaluations are deputized by KEITI and when a Japanese corporation desires to acquire the Korea's Eco-Mark, the reports and test results from the JEA side are recognized.

The common standard developments between Korea and Japan began as the needs to standardize the 3 nations Eco-Labeling certification standards were brought up at the '5th Korea-China-Japan Environmental Industry Round Table(RTM)' in 2005. At the 3rd working-level meeting in 2007, personal computers were selected as the subject product for development of common standards and in the same year, the Partial MRA was concluded by RTM for the operation of common standard for 'personal computers.' When recognized from the certification organization of one's own nation that the corporation applying for the opposite nation's Eco-Labeling is satisfying the common standards through the same MRA, the opposite nation must also recognize this corporation and the corporation that received their nation's certification for product was enabled to use the opposite nation's Eco-Label just after receiving the verification for the non-common standards of the opposite nation. Based on the conclusion of the Mutual Recognition Agreement, the discussions for common criteria amongst the 3 nations was more actively progressed and at the 5th working-level meeting in 2008, the common certification criteria for personal computers were finally determined.

At the 8th Korea-China-Japan Round-table Meeting(RTM) in 2008, the 'multifunctional devices were selected as the next item for development of common standards and through discussion, the common/uncommon standards amongst Korea, China and Japan were finally completed in December of 2009. Due to the position differences on China's side, the common standard development agreement was not ultimately concluded among the 3 nations and in 2010, only Korea and Japan concluded the agreement. Through the working-level meeting held in Korea, the detailed processes that were left out in the agreement while progressing with mutual recognition and the agreement for operational regulations were additionally completed to enable a more articulate progression of tasks. KEITI and JEA agreed on all items with the exclusion of forced standard and independent operational standards within one's own nation for the multifunctional devices(8 items including quality and consumer information).

The working-level meeting held in 2010 involved not only KEITI and JEA but also the attendance of various persons concerned including the president of Korea's Business Machine Association and the secretary-general of Japan's Business Machine Industry Association(JBMIA). They visited the major test institutions of Korea to observe the testing process for 'noise' and 'discharge of harmful material including VOCs' to serve as a great opportunity to widely notify the high reliability and clear task executions of Korea.

4. Effects of Korea-Japan's Mutual Recognition Agreement

The mutual recognition of the Eco-Labeling system has the advantage of reducing projected costs related to certification since the test, analysis and evaluations can be received within the corporation's own nation when desiring to acquire the Eco-Label of an opposite nation. Moreover, there is the effect that the time consumed for testing is reduced since the tests are progressed in domestic institutions. This system also reduces costs for acquiring foreign Eco-Labels to induce corporations with high dependence on exportations to acquire the Eco-Label as measures to secure the foreign markets and this will soon become the opportunity to revitalize the corporate participation in the Eco-Labelling system.

5. Future Plans

The 3 nations of Korea, China and Japan are annually holding the RTM and working-level meetings to place efforts for increasing items of development for common standards and strengthen cooperation. Henceforth, the agreement for mutual recognition process amongst 3 nations will be derived. Moreover, there are plans to review the development items for new certifications standards and drafts of common standards for the DVD players.

The Korea-Japan Eco-Labelling cooperation is being evaluated as a model example of cooperation in that it has concluded the cooperation in detail such as preparing detailed processes of mutual recognition and operational regulations and that is under direct operation of the agreement. It is suggested to KEITI and JEA that the detailed certification standard data system for each Eco-Label product is constructed. Through this, Korea and Japan will be able to further understand each other's certification standards and also provide help in developing the common criteria. KEITI also desires to share the information on recent trends of foreign regions with JEA. For example, Korea will be able to inform JEA about their experiences on recognition of the GENICES(Global Ecolabelling Network's Internationally Coordinated Ecolabelling System). KEITI will spare no efforts in cooperating with JEA to make the Korea-Japan common criteria as Asia's Eco-Labelling standards.

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Current status of Japanese pilot project of Carbon Footprint of Products

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Abstract

The Japanese national pilot project of Carbon Footprint of Products (CFP) have mainly two purposes. One is to provide GHG communication information to consumer. The other one is to find processes with great GHG emissions by CFP assessment for companies and further reduce GHG emissions by identifying points of GHG emissions reduction. JEMAI has involved as the secretariat of CFP project. In this paper, I introduce the history, the basic structure, current situation and experiments of Japanese pilot project of CFP.

Keywords:

LCA, Carbon footprint, Product category rules

1 INTRODUCTION

In fiscal year of 2008, 30 companies joined preliminary pilot project of CFP to individually provide case studies of their own products' CFP without basic guideline document and Product Category Rules (PCR). From which key issues have been extracted and a guideline document of CFP was generated [1].

In fiscal year of 2009, the Japanese government has launched pilot project of CFP. The first step for each business field was PCR establishment, and 45 PCR and corresponding 99 products were certified by the committee of pilot project [1].

In fiscal year of 2010, the guideline document and PCRs were updated by these two years' experience and public comment. Some experiments such as reduction quantification, system certification scheme, verification by verification bodies, rules for diversification of labeling, validation method of service category and broadly-applicable PCR were launched under the project. Through the experiments, additional rules were established. And generic database for CFP quantification is opened to public [1].

In fiscal year of 2011, some of experiments, CFP verification and PCR certification have been continued.

2 BASIC STRUCTURE

2.1 Basic rules

The basic concept of the project is based on ISO14040-44 and ISO14025. From which the two main guideline documents are established. One is "Basic Guideline of the Carbon Footprint of Products". It provides basic frameworks for CFP quantification, communication and other schemes regarding the project. Another is "Guide of establishing product category rules". It provides principles, criteria and process for establishing PCR in accordance with the guideline.

Through the project experiments, additional rules were established such as "Application rules for reduction quantification (provisional)", "Application rules for referencing a existing PCR & CFP " and "Application guideline for PCR & CFP of services"[1].

For the program operation, three operational guidance are established such as "Rules concerning the registration of draft PCR development plan and approval of PCR", "Rules concerning the verification of CFP calculation results and labeling method" and "Specifications of CFP label and displaying other information "[1].

2.2 PCR

PCR defines the criteria for CFP quantification and labeling method for a certain product category. PCR makes clear to consumers and businesses, how the declaration quantified.

Companies (or industrial circles) develop PCR. To begin the development of PCR, companies shall register the PCR developing plan; let the interested parties be involved in the discussion.

Range of the PCR is difficult to arrange. Typically, companies would want to develop a PCR only for their product which they want to evaluate. Then, the range of PCR tend to become narrow. The narrow range PCR is easier to develop. However, for whole CFP program, a number of PCR is needed. With a wide range PCR, more companies can participate in the CFP program. However, it is difficult to develop PCR, because of many participants' consensus. And also it is difficult to clarify

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the requirements.

PCR certification procedure contains 5days public comments, review by an independent reviewer(s) and then examination by PCR review panel for certification.

2.3 CFP quantification and verification

The companies quantify their products' CFP pursuant to the certified PCR and receive CFP verification. CFP verification is conducted by a third-party verifier(s), and then PCR verification panel examines. CFP verification checks evidences and validity of adopting the quantification methods. If the result is considered appropriate, companies can market their product with the CFP label.

Quantification and verification of CFP strongly require LCA expertise to the companies and verifiers. However, each companies and each verifier have difference of LCA expertise competence. It is very hard to participate CFP program for the beginner companies and verifiers. PCR, other basic rules, past case studies, common examples, common CFP application format and guidelines for verifier are useful to participate CFP program. In many cases, the most important key to improve thier LCA expertise is experience. So far, the appropriate training with actual case study was effective to improve LCA expertise.

2.4 Establishment of generic database

To support CFP quantification, generic database for basic materials is opened to public. On the database, more than 1000 GHG emission factors are listed. The coverage is agriculture, forestry, fishery, mining, food, chemical, oil industry, ceramics, machinery, utility supply, transportation etc. [1] .

The Secretariat and the industrial associations developed each GHG emission factor data to pursuant to GHG emission factor data criteria. Then the data was reviewed by the data validation panel.

3 EXPERIMENTS

3.1 Reduction Quantification

Application rules for reduction quantification has been established, as requested from participants. Basic concepts are based on ISO14044 and ISO14025.

Requirements are [1],

-The same PCR shall be used for calculations.

-Product from other company shall not be compared.

-The function shall be the same or similar. (less - functional product, which is old, can be compared)

-Data shall be collected in the same manner.

- Comparison shall be done between verified results, and Information on comparison shall be disclosed.

3.2 Experiments on system certification

To make verification cost down, some experiments on verification scheme has held.

System certification is management system certification including CFP quantification, internal independent verification and declaration. In fiscal year of 2010, system requirements for CFP quantification was developed. And also formats for system certification were developed. In fiscal year of 2011, some companies have been trying to establish the system under support of the Project.

3.3 Experiments on verification by verification bodies

In the project, the individual LCA/CFP experts who assigned by the CFP program examine verification of the CFP application from companies. By this experiment, the feasibility of product-by-product verification by verification bodies has been studied.

3.4 Other Experiments

Some other experiments are carried out under the project.

Examples are [1],

-PCR certification method and CFP validation method in service category

-broadly-applicable PCR

4 CURRENT SITUATION AND PROJECT SCHEDULE

On September 2011, 65 PCR were certified and 345 CFP labeled products were verified. Some of CFP labeled products will be exhibited at Eco-Products Exhibition in December 2011. Then, the acceptance of CFP application will be suspended.

To prepare privatization of CFP program, the essential result of the three-year pilot project will be reported till March 2012.

Since fiscal year of 2012, private organization is going to operate the CFP program. The program also is based on ISO 14067 in future.

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Design for Sustainable Behaviour Research Challenges

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Abstract
This paper reviews the current state of Design for Sustainable Behaviour, and concludes that so far, the body of literature mostly presents, explains and structures possible design strategies, proposes design solutions based on these strategies, and presents case studies that evaluate the acceptance and effectiveness of such designs. In order to advance the field, three main research challenges have been identified. These are establishing a common terminology, more formalized research protocols for user centred research to better inform design solutions, and selecting target behaviours

Keywords:
Design for sustainable behaviour, user centred design, case study research, research design

1 INTRODUCTION

Partly because of growing attention for sustainability in design, design researchers increasingly acknowledge their role that through design they can have a profound influence in altering users' behaviour into more sustainable behaviour and consumption patterns [1]. As a result, fuelled by dedicated conference sessions, international workshops and other ways of scholarly cooperation, in recent years a 'design for sustainable behaviour' research community has developed. In the earlier phases of ecodesign research, attention for the use phase has mainly focused on using technology to increasing resource (mostly energy) use efficiency. Now it is understood that by understanding user behaviour, and using that in design solutions including shapes, colours, affordances, 'nudges', up to 30% energy consumption reduction may be achieved [2]. Research into Design for sustainable behaviour strategies aims at exploring design strategies for reducing behaviour-related environmental impacts of product and systems, although they have also been proposed for more general applications to persuade users into more socially desirable behavioural patterns [3].

This 'design for sustainable behaviour' community embraces insights from a various relevant scientific fields, such as social psychology, persuasive technology, sustainable consumption, industrial ecology, stakeholder analysis and interaction design. Also within these fields, interest in looking at design as a possible source for solutions is growing, creating a mutual cross-fertilisation of ideas and concepts.

On-going research focuses on exploring relevant concepts and disciplines to provide an understanding of relevant user, product and system aspects that need to be studied and incorporated into design strategies for sustainable behaviour – ultimately to facilitate the successful application thereof. Attempts to conceptualize, frame and structure research constructs, influencing factors, and strategies are abundant, but results thereof are not established yet as a common language that facilitates research progress. In recent years also several case studies have been published focusing on the collection of relevant data for designing solutions that inform, persuade or force sustainable behaviour. Still, this process of selecting, generating and exchanging case study data is observed to be rather unorganized and ad-hoc.

These observations are by no means meant as critique, and are largely unavoidable consequences of an immature research area trying to mature. Therefore it is essential to periodically reflect on how this 'subfield' of sustainable design could or should evolve in the next years; do we continue to randomly select interesting case studies because of a certain perceived improvement potential in changing environmentally-relevant behaviour, or can this process be better structured and motivated? Do we continue to do case studies on a standalone basis, or do we find ways to integrate case study results to facilitate cross-case study analyses? This paper aims to sketch and motivate the need for the selection, collection and exchange of case study results, and to discuss formats for doing so, implicitly advocating the need for a common understanding, and use, of relevant terminology.

2 AN INVENTORY OF RESEARCH CHALLENGES

One of the commonly agreed upon research challenge in design for sustainable behaviour research is to overcome the lack of understanding of when to apply what type of behaviour-changing strategies. It is understood that

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particular ways of influencing are more appropriate than others in particular situations [1,4], and that a thorough understanding of human–product interaction would be required to select the right strategy to induce the desired sustainable behaviour [5].

Ideally industrial designers should be equipped with a decision-making tool, enabling evaluation of alternatives in order to choose the [design for sustainable behaviour] strategies best suited for each project [6]. Also, more research into how users might experience persuasive technologies has been advocated, as well as addressing ethical issues related to removing freedom from users by using such technology [1,7].

In 2009, based on a survey among scholars active in design for sustainable behaviour research, Pettersen and Boks presented a reflection on the main priorities, challenges and opportunities for future development of the field [6]. The study demonstrated a strong connection between research into design-led influence on behaviour and fields linked to interaction design and consumption studies, where deep knowledge about human behaviour and how to influence was considered fundamental, along with issues regarding the development of design interventions. The survey participants saw the development of the field as following a certain path; it was, suggested that first, through theoretically and design oriented research, research should focus on how to understand, assess and analyse influences on and consequences of interaction and how to design influential interventions. A next step would be to study how to fit it all into a company context. Still, with integration into industrial product development rated as the most important research topic, but simultaneously questions concerning stakeholder, managerial and organisational issues seemingly put on hold, some concern was expressed about the risks of creating an island and walking into the same trap of 'classic ecodesign': lack of momentum after decades of tool development.

The above considerations leave us with both a notion of actual progress, and further needed progress in this field. However, taking this starting point of identifying research challenges in existing literature shows that scholars are so far mainly concerned with a content perspective, without addressing the more pragmatically oriented questions posed in the introduction of this paper. The next sections continue therefore with exploring these questions one step further, and are concerned with three main perspectives: 1) developing a common terminology, 2) developing research protocols and frameworks that allow for cross-case analysis, and 3) selecting target behaviour.

2.1 Developing common terminology

One of the key understandings needed to develop and successfully apply design for sustainable behaviour strategies has been found to be a certain categorization of mechanisms that can be used to influence user behaviour. This is widely acknowledged in the design for sustainable behaviour research community. Earlier research focuses on creating prompts [8] or scripts [9,10] to induce environmentally preferred behaviour, and such mechanisms are often used as starting point for developing such a framework. One of the first categorisations was made by Lilley et al. [11], defining three types of product-led interventions: (i) Scripts and behavioural steering – based on definitions by Jelsma and Knot [10]; (ii) Eco-feedback – products informing users of the impact of their behaviour, hoping to induce attempts by users to minimise that impact; (iii) 'Intelligent' products and systems – products circumventing the user's decision making process by ceding the decision making to the product. Wever et al. [5] used a similar categorization using eco-feedback, scripting and forced-functionality as mechanisms to trigger the desired behaviour. Also similarly, Elias et al. distinguished Consumer education, Feedback and User Centred Eco-Design, the latter being defined as "creating products where the most intuitive and comfortable way of using and interacting with a product or system is also the most environmentally friendly" [12]. Bhamra et al. [13] elaborated the distribution by Lilley et al. further by splitting it up into seven parts. Figure 1 is an attempt to an overview of the distributions as proposed by various authors, based on the description of how the strategies will affect the behaviour of the user. On the left side of the figure the use of a spectrum is suggested reflecting a continuous distribution of control where the user has complete control on one end and has no control on the other. Tromp et al. distinguish four types of influence that designers can exert (coerce, persuade, seduce or decide), and add another dimension, namely salience; a design can exert influence that can vary from an implicit to a more explicit manner (salience). In an article yet to be published, Zachrisson [14] explores this additional dimension further by introducing obtrusiveness, using Jelsma's 'force' property of the script, described as "restricting the opportunities for undesired use, or strengthening the stimuli for desired use" [15], thus creating an 'obtrusiveness-control landscape.

Clearly, developing a joint terminology is still an on-going process, and the near future may see additional dimensions to be proposed for characterizing design for sustainable behaviour strategies.

2.2 Choice of methods - towards cross-case analysis

Social psychology literature has a tradition for carrying out experiments using a wide range of methods, with the aim of identifying and understanding behavioural patterns. As this very understanding is often the main goal in this field, there is no tradition in this field to take findings further towards designing solutions that alter behavioural patterns. In design literature most available studies focus on explaining mechanisms that may affect user behaviour, and on translating these mechanisms to suggest design strategies that may convert user behaviour towards more sustainable or socially acceptable patterns.

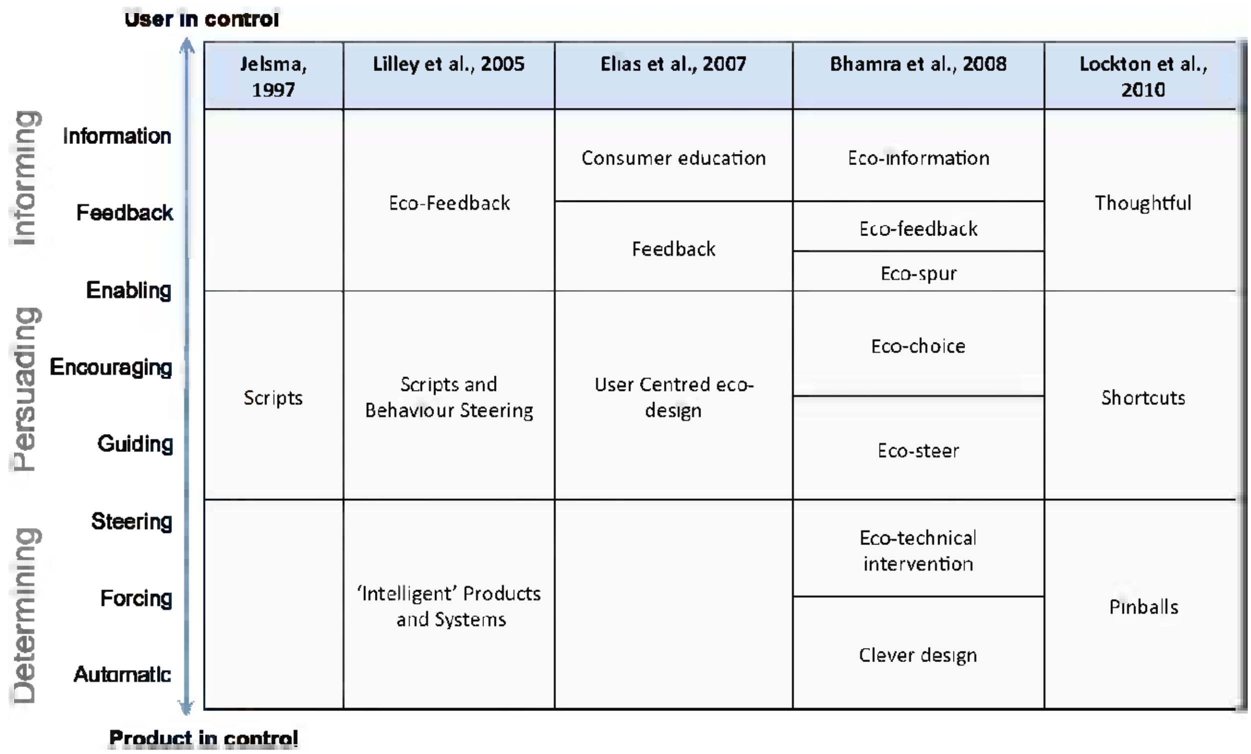

Figure 1: Comparison of design strategies for sustainable behaviour

Such case studies often include the testing of a priori designed solution concepts, and refrain from a substantial collection of user data before such solution concepts are generated. Only a minority of publications seem to rely on a priori data collection on aspects of user behaviour, or report in any detail on research protocols used to collect user data. Among these, Elias [16] reports on using video observation studies to collect raw data which was converted into times and frequencies of particular behavioural patterns related to the opening of refrigerator doors, thus identifying a top 5 of highest energy impact behaviours. A case study on investigating littering behaviour in public spaces largely depended on direct observation and counting littered products in various spaces [17. Lilley gathered behavioural data of mobile phone users based on live data collected on the use of the phone using 'context-aware' technologies such as Bluetooth, GPS and motion sensors [18]. Laitala et al. collected quantitative information on consumers' experiences and opinions concerning clothing consumption habits, including buying, maintenance and discarding behaviour, together with qualitative data from user interviews, wardrobe observation, and laboratory tests to study a range of relevant aspects [19,20]. Papantoniou et al. report on participatory approach followed applying conventional ethnographic methods such as interviews, observations, probes and focus groups in order to gain insights on what people "say, think, do and know" about energy consumption in their day-today practices [21]. An on-going study on oral healthcare practices applies several user-centred-design research methods including interview, overt observation, covert observation (video recording), cultural probing, survey, generative sessions and a blog analysis to collect a rich base of information concerning how oral health care is conducted in order to identify various factors that affected this behaviour. Structuring and analysis of this data is used as input for generating design solutions with the intention to create more sustainable oral healthcare practices, such as reducing water consumption [22].

Even though case studies based on empirical data are limited, the above examples suggest a considerable variety in research protocols used, both in terms of aim of the study, in terms of which variables data was collected on, and in terms of conclusions drawn.

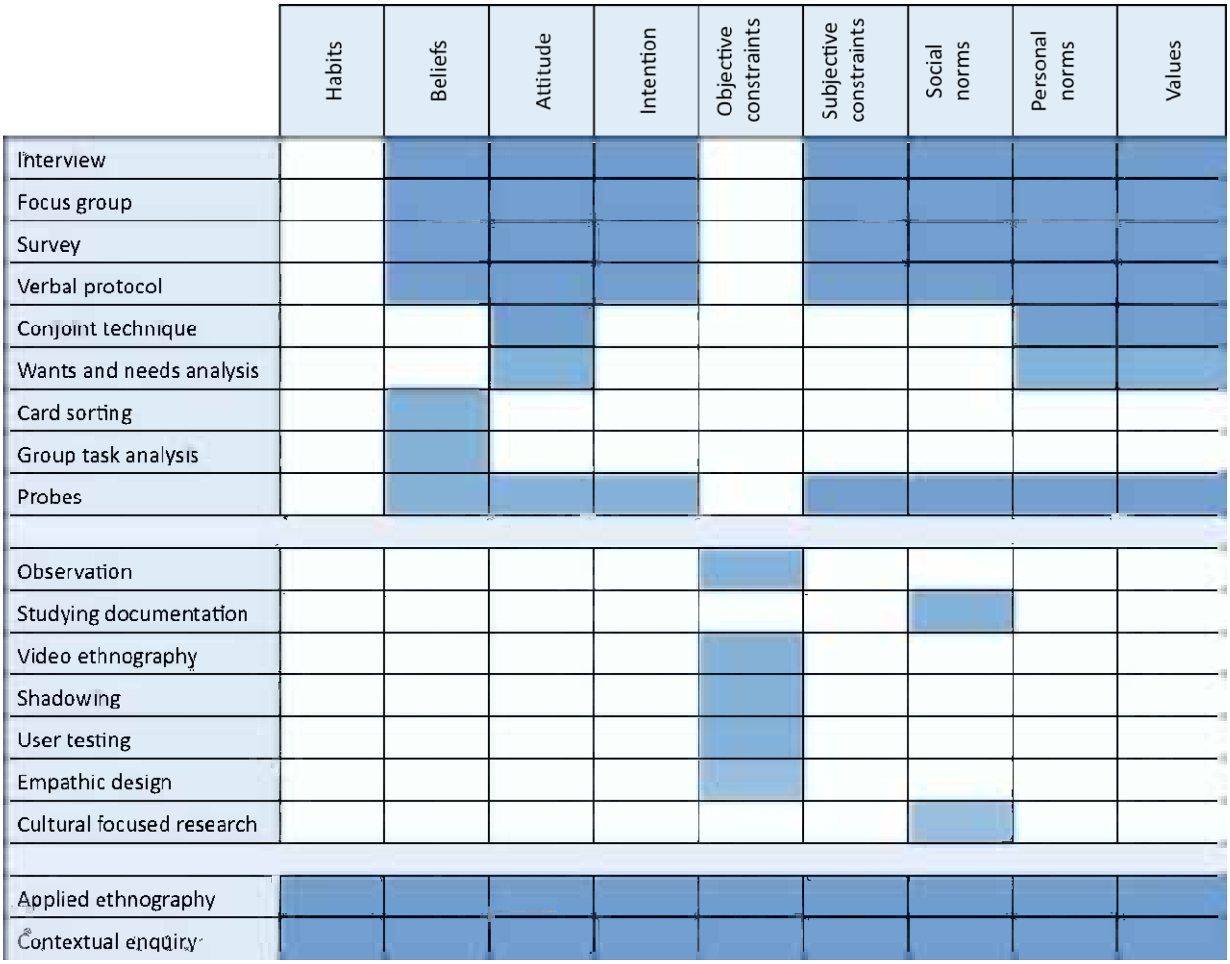

Figure 2: Matching behavioural aspects and suitable user data collection methods

Taking this one step further, Figure 2 presents a matching of various aspects of behaviour that may be relevant to study, with data collection methods that may be most appropriate for that purpose [23]. This table may be relevant future reference for choosing appropriate data collection methods in research protocals for future design for sustainable behaviour case studies.

In time, a better understanding of which data collection methods to use to research which aspects of relevant behaviour may also lead to more standardised research protocols. This in turn would in theory allow for creating databases in which empirical data from different but compatible case studies could be collected. Data collection on individual product-related practices, but in a compatible format, may thus facilitate future meta-analysis of consumer practices, studying broader routines or parts of life styles. For example, integration of separate case studies on the use of kitchen appliances would allow addressing behaviour-related aspects of kitchen-routines in a synergetic way, just as separate case studies on different interfaces for heat, ventilation and air conditioning in different areas of buildings would provide a more complete understanding of how dwellers could be stimulated into more sustainable behavioural patterns for operating these interfaces [24]. At the same time, this may leverage the academic standing of design for sustainable behaviour research, and fuel the integration of design research with and socio- psychological research.

2.3 Selecting target behaviour

So, even if we would have a framework available for systematically collecting relevant data from cases, which cases should we select? Why did Elias select the opening of refrigerator doors as a target behaviour for one of the first main case studies based on empirical data? Would the large project on design for reduction of littering in public space have been carried out if it were not for an NGO contacting the Design for Sustainability Research Group at Delft University of Technology, as they did? Would on-going case studies in woodstove use and littering behaviour in cinemas have been selected if external partners would not have approached the design for sustainable behaviour research group at NTNU as they did?

One logical starting point for selecting appropriate behaviour could be the size of the potential reduction in environmental impact through altering user behaviour. Theoretically, selecting relevant case studies would not be a problem, if all user behaviour that impacts sustainability through the use of products and systems would be systematically listed, if extensive life cycle assessment studies would be done to classify these behaviours according to their impact; the ones that would come out ranking highest could then be identified as target behaviours. This is however a highly impractical and time consuming activity. Moreover, additional relevant considerations would be missing, such as related to the magnitude of the behavioural component, and the improvement potential from a designerly perspective. Designing solutions at both ends of the spectrum depicted in the left side of Figure 1 (providing information leaving the user in full control, or making certain behaviour impossible, leaving the product in control) may require less designerly competence and creativity than creating solutions on the middle end of the spectrum, where users are to be enabled, encouraged or even seduced towards desired behaviour. In additional, the complexity of the situational context may be a relevant aspect to consider in selecting target behaviours.

Within the sketched literature field, this issue has so far remained unaddressed, but as early in the mid-nineties, methods have been proposed to identify target behaviours most suitable for policy measures aiming for reduction of environmental impact [25]. Relevant considerations may include the 1) potential for impact on the environmental problem, 2) the existence of approximations to the ideal behaviour, 3) compatibility with cultural norms or current practices, 4) costs, and 5) complexity. Scoring on these parameters would help understand which behaviours have the most potential for impact on the specific environmental problem and which are feasible. It is also argued that using a scoring system based on these considerations would facilitate a participatory, detailed analysis of the environmental issue and the ideal behaviours, which permits all of the principal concerns from the variety of disciplines and perspectives to be discussed systematically.

Although providing a starting point for solving the question how to select target behaviours to be changed by design for sustainable behaviour strategies, the approach may be less relevant in this very context. Firstly, applying these considerations appear close to the theoretically flawless but highly impractical approach sketched above: doing a detailed analysis and then targeting the one with the highest potential; which is not what we are after. Secondly, the approach appears to target those behaviours that are easiest to change, which might neither be the ones with the highest improvement potential, nor the ones with the most interesting design challenge; as such, the proposed method is highly compromising.

Then, should we instead depend on gut feeling? Interestingly, in 2005 Gardner and Stern [26] presented a short list of target behaviours, for which action would be most effective based on the estimated percentage of total US individual/household energy consumption that can be saved by 27 actions. These actions were selected based on an informal survey of books and articles that offer individual advice to citizens, mostly in the form of unranked list of actions, on how to reduce their energy consumption. This list appears very attractive, though not very detailed for design case studies purposes, and suggests that a heuristic method for selecting target behaviour can provide meaningful results. From a design for sustainable behaviour perspective, some interesting aspects can be derived. First of all, this list by and large suggests that energy consumption can be reduced most significantly by changing citizens' behaviour in a way that is either related to 1) purchasing behaviour of major items that are bought only few times in someone's life, such as a house, car, or major appliances, and 2) installing of and choosing initial settings on systems such as heat, ventilation and air conditioning, that citizens only do few times or year, or perhaps only at the moment of purchase. Changing behaviour related to product use that is more frequent has, according to list, less of an impact on total energy consumption. Moreover, several of the items in the list are of a yes/no nature such as shifting to energy saving lamps or low-resistance tires yes or no, or participating in a carpool yes or no. The list essentially includes only three items that have an everyday behavioural component: driving behaviour, daily setting of a thermostat, and clothes washing. From a design for sustainable behaviour perspective again, these might be the most interesting to focus on, in the context of the desire to focus on the middle end of the aforementioned spectrum. And indeed, these items have been received scholarly attention, though so far limited in the context of design for sustainable behaviour.

It should be noted that Gardner and Stern's list focuses on energy consuming behaviour and does not feature any actions that are based on consumption of other resources, such as water or firing wood, which do have environmental implications as well, and do also provide interesting designerly challenges.

3 CONCLUSION

Design for Sustainable Behaviour is an emerging research area, which is gradually gaining momentum and a critical mass of scholars focusing on this topic. So far, the body of literature mostly presents and structures possible design strategies and to what designs the application thereof may result in, and presents standalone case studies that evaluate the acceptance and effectiveness of such designs. In order to advance the field, three main research challenges have been identified; establishing a common terminology, the use of user research to better inform design solutions allowing cross-case analysis, and selecting target behaviours with high potential for both environmental improvement potential and contributions from design thinking. .

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Case-based Design Aid for Sustainable Behavior and Lifestyle

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Abstract
This study proposes two approaches to facilitate design for sustainable behavior and lifestyle based on a case library containing existing product designs that lead to behavior change. For each case, expected behavior change, design patterns and technologies used are analyzed and recorded in the cases library. In the first approach, relationship between target behavior, design pattern and technology used is constructed based on the cases. With tables presenting the relationship, designers can find suggestions of design patterns and technologies for a given target sustainable behavior. In the second approach, sustainable Kansei descriptors are chosen to describe customer feelings for each case so that relationship between Kansei description and design patterns and technologies used can be established. After sampling measures of multiple Kansei description via a questionnaire survey, statistical correlations between Kansei description and design patterns and technologies used are obtained. Designers can find useful design patterns and technologies for intended feelings with Kansei descriptors.

Keywords:
Case based reasoning, design with intent, Kansei, sustainable behavior.

1. INTRODUCTION

In the past decades, design for lower environmental impact in manufacturing stage has caught more attention than in use stage. Recently, focus may have turn to environmental impact occurring in use stage. Bhamra et al [1] stated that a great potential of lowering environmental impact exists in household energy use. Herring and Roy [2] suggested that a "rebound effect" appeared when energy saving produced by energy efficient products is taken back in the form of higher consumption. Many consumers, knowing that products (e.g. light bulbs) now costs less, are less concerned about turning them off, or even leave them on all night. Thus these behaviors 'take back' some of the energy savings by the green products. Because of these phenomenon, design for sustainable behavior (DfSB) was discussed most anxiously recently. Eco-design has to not only adopt green materials or energy efficient technology but also change consumer's behavior in the use stage. Consumers' decision and behavior should be incorporated in design stage so that eco-design could lead consumer to a sustainable way of living.

There are many literatures working on design that can lead to behavior change, although they could be presented in different terms. For instance, Lilley [3], Elias et al [4], Lockton et al [5], Wever et al [6] and Pettersen and Boks [7] worked on "design intervention" emphasizing that designers should take responsibility of user behavior. If applied to DfSB, design and technology should persuade or guide users to sustainable way of using products. Design intervention was categorized into three types: educational intervention, technological intervention and product-led intervention. In product-led intervention, designers can adopt concepts of behavior steering, eco-feedback and intelligent product or systems to guide consumers. Jelsma [8] worked more on the design philosophy "behavior steering". Wever et al [6] suggested to involve users in the design stage and used the term "user-centered design" where designers should collect information, identify needs of users and invite users to involve, evaluate and test the product design. Lockton et al have had a series of studies and developed methodology called "design with intent" (DWI) ([5][9][10][11]). They presented three ways to influence user behavior: enabling, motivating, and constraining behavior. Wever et al [6] integrated the concepts mentioned above and suggested more work could be done in "design for sustainable behavior" area. To summarize, there are several ways to influence user behavior including

(a) Eco-feedback

(b) Educational intervention

(c) Scripting, enabling behavior

(d) Forced functionality, intelligence system

Locton et al presented useful DWI method with 11 target behaviors and more than 101 design patterns and 8 lenses that can be adopted to achieve target behaviors. They [9] mentioned that DWI method can also be used in design for sustainable behavior. In this study, target behavior and design pattern are included as major elements of domain model of case based reasoning.

On the other hand, technology should also be developed for changing people behavior instead of simply

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fulfilling their needs (Verbeek et al [12]). Fogg [13] started research on "persuasive technology" that focuses on how technology could persuade or influence people. Jager et al [14] used persuasive technology to raise awareness of energy consumption of household devices. Midden et al [15] suggested using persuasive technology to encourage sustainable behavior. Midden et al [16] summarized four ways in which human and technology interact with respect to sustainability. The four roles technology can play are (1) as intermediary, (2) as amplifier, (3) as determinant, and (4) as promoter of environmentally significant behavior.

This study aims at helping designers find useful design patterns and technologies for DfSB. Existing cases of DfSB were collected to form a case library so that experience can be extracted. Concepts of case based reasoning (CBR) such as setting domain model, retrieve, and reuse of cases are adopted to facilitate DfSB.

2. DESIGN FOR SUSTAINABLE BEHAVIOR WITH CBR

This section discusses how to extract information of past cases and find useful suggestions for designers. In light of the above literatures, design patterns and technology used are found essential for leading to behavior change. For example, DWI provides 11 target behaviors and 101 related design patterns. Using the idea of DWI, existing cases are analyzed and coded with a domain model that consists of target behavior and design patterns.

In addition to design patterns and target behavior, authors suggest that domain model should include: (1) technology used in DfSB products and (2) emotional or Kansei descriptors that are used to describe the feelings and affective influence of users (see Figure 1). The second idea is from Kansei engineering approach that builds relationship between design parameters and Kansei descriptors so that design parameters can be properly controlled to have a design reaching users' emotional expectation (Nagamachi [17]).

Target behaviors and users' feelings represented by Kansei descriptors could be seen as expected results of DfSB while design patterns and technologies are means to behavior change. Hence, a domain model is proposed to describe past cases containing:

(1) target behavior that are adopted from DWI method,
(2) design patterns that are adopted for DWI method,
(3) Kansei descriptors to describe the feelings of users for each case product, and
(4) technologies used in the cases.

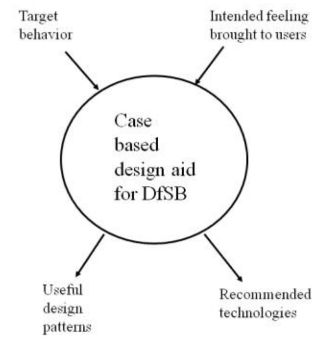

Fig. 1: Scheme of case based design aid for DfSB

With the domain model, cases of products with DfSB were written into a case library. To demonstrate the approach, fifty household products with DfSB were collected, analyzed and coded based on the domain model. The cases are collected from websites of large companies (like Philips), platforms of green products, and descriptions of intelligent house, and meet three conditions: (1) leading to sustainable behavior, (2) household use excluding personal mobile devices, and (3) applying information and communication technologies (ICT). Since there are only fifty cases, limited number of design patterns and target behaviors out of DWI are found. Table 1 shows six target behaviors while Table 2 contains fifty design patterns. Numbers of target behavior and design patterns should increase as the number of collected cases increases.

Table 3 shows examples of 20 Kansei descriptors that are collected from literature describing sustainable lifestyle. Table 4 shows some examples of 23 ICTs found in the cases. Two approaches that start from target behavior and intended feelings to facilitate DfSB using the case library are presented in the following two sections.

Table 1: Target behaviors for DfSB for household ICT products

User-system interaction	
S1	User follows a process or path, doing things in a sequence chosen by the designer
S2	User follows a process or path that's optimized for those particular circumstances
S3	Decision among alternatives: a user's choice is guided
S4	Only certain users/groups of users can use something
S7	Users only get functionality when environmental criteria are satisfied
User-user interaction	
U2	Users (and groups of users) do interact with, and affect each other while using a system

Table 2: Examples of the fifty design patterns adopted from DWI

index	Design patterns
A3	Conveyor belts
A4	Feature deletion
A6	Material properties
A8	Pave the cowpaths
…	…
I8	Summary feedback
I9	Tailoring
I10	Tunneling & wizards

Table 3: Examples of Kansei descriptors

Sustainable Kansei descriptors
energy-saving
environmental-friendly
good looking
plain
simple
safe
…
harmonious
tranquil/peaceful

Table 4: Examples of ICT used in DfSB

index	Technology application
a	display
b	lighting/ to guide by lighting
c	camera/ monitor
d	audio
e	voice record
f	alarm clock/stopwatch/timer
…	…
u	automation
v	remote control
w	sensor that detects circumstance

3. DfSB STARTING WITH TARGET BEHAVIOR

After the case library of products with DfSB is built, cases with intended target behaviors could be retrieved. To use this approach, premise is that designers know what behavior DfSB intends to lead to. Once designer has an idea of intended behavior, cases with the specified target behavior could be retrieved and therefore design patterns and technologies adopted in the cases can be found. Since multiple cases that have the same target behavior may be retrieved, number of times that design patterns and technologies appear is used to reflect strength of suggestion. Design patterns and technologies with more times of appearance are considered highly related to the target behavior.

Table 5 shows design patterns recommended for various target behaviors where design patterns on the left are highly recommended because they appear more times than others in the retrieved cases. Indices representing design patterns are shown in last section. In other words, the number of appearance of the design patterns in retrieved cases decreases from left to right. Similarly, Table 6 shows technologies recommended for various target behaviors where technologies on the left are strongly recommended.

Designs could refer to these recommended design patterns and technologies for conceptual design of DfSB. Combination of multiple design patterns and technologies could be acquired from these tables. Since these recommendations are based on past cases, users may be more convinced as the number of cases increases.

Table 5: Recommended design patterns for various target behaviors

Target behavior	(Strongly Recomm) (weakly Recomm)
S1	A12, I6, M7, P8, …..C10, M14, S3
S2	I6, I9, A12, E3,…. P10, M11, M14, S2, S5
S3	I6, I8, I9, A3, ….., C6, C10, M1, S6
S4	A3, M14
S7	A12, I6, L1, …., P14, C6, C10
U2	I6, I8, A12, L1,….. M3, M11, S2, S3

Table 6: Recommended technologies for various target behaviors

Target behavior	(Strongly Recomm) (weakly Recomm)
S1	a, b, o, p, f, j, ……., s, w, g, k, v
S2	o, a, o, j, u, b, ……. k, c, e, l
S3	a, o, b, h, j, p, c….., m, q, w
S4	a, c, g
S7	U, v, t, b, f, j
U2	a, o, d, b, ………... l, r, u, v

4. DfSB STARTING WITH INTENDED FEELINGS OF USERS

Designers conducting DfSB may start with intended feelings that a new design would bring to users. Kansei (emotional) descriptors were selected to describe feelings of potential users with respect to each case. In a questionnaire survey, consent/dissent of using Kansei descriptors to describe feeling for each case is collected from each respondent. More than 30 respondents were asked whether they would use each of the twenty Kansei descriptors for each case. For each case, we can collect 20 normalized scores (ranging from 0 to 1.0) with respect to 20 Kansei descriptors. If the score is 1.0, it means that all respondents used the descriptor to describe the case.

With the survey results, correlation coefficients between scores of Kansei descriptors and appearances of design patterns and technologies are hence calculated. Tables 7 shows design patterns with positive correlation with Kansei descriptors. Table 8 shows technologies with positive correlation with Kansei descriptors. To achieve intended Kansei descriptors in DfSB, design patterns and technologies with highly positive correlations are recommended. Contrarily, those negatively correlated design patterns and technologies are not recommended. Designers could certainly start with multiple Kansei descriptors and thus find more suggestions using the information in Tables 7 and 8.

Table 7: Examples of design patterns with positive correlation with Kansei descriptors

Kansei descriptors	Design patterns Highly positive corr	Design patterns Positive corr
Energy saving	I8, A11, I6, P2, P14	A9
Env. protection	A11, P2, I6, P14	A9, I8
Good looking	I6, I8, P2, P14	C6, A11, L1, L7, L10, P12, S2, S5, S6
Plain	A11, I6, I8, P2, P14	A 9
Natural	M7	A4, A9, A11, E7, E9, P9, P10, I5
Safe	M11, M14	A8, I2, C9, P13
…	….	…

Table 8: Examples of technologies with positive correlation with Kansei descriptors

		Technologies (Highly positive corr)	Technologies (Positive Corr)
Kansei descriptors	Energy saving	b j o	f
	Env protection	b j o	f
	Good looking	b j	o
	plain	b j o	f
	……	…..	….
	relaxing	s	
	leisure	a	p
	friendly		e
	warm	r u	
	simple	f l	j o

5. CONCLUSIONS

Two approaches to facilitate DfSB are proposed with concept of case based reasoning. Cases of existing DfSB are collected and expressed with a domain model that includes target behavior, Kansei descriptor, design pattern and technology used. In the first approach, relationship between target behavior and design patterns and technologies used is established via statistical analysis based on the fifty cases. Designers can start with target sustainable behavior and find suggestion of design patterns and technologies using the tables provided.

In the second approach, Kansei descriptors for sustainable lifestyle are chosen to describe customer feelings for each case so that relationships between Kansei sustainable description and design patterns and technologies used are established. For each case, measures of multiple Kansei description from customer opinion are collected via a questionnaire survey. Designers can start with intended Kansei descriptors and find useful design patterns and technologies based on the correlation analysis.

Both approaches would provide recommended design patterns and technologies that could be basis for conceptual design of DfSB. Two approaches could be adopted simultaneously, starting with both target behaviors and Kansei descriptors and obtaining multiple suggestions of design patterns and technologies using the tables resulted from statistical analysis.

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Packaging: Sustaining cultures and meeting new imperatives

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Abstract

Managing the 'waste' generated through what is seen as excess packaging is not a simple technological problem. The social and cultural aspects of using packaging and wrapping must be considered in any strategies that aim to reduce our consumption of packaging materials.

Keywords:

3Rs, packaging, wrapping, social dimensions, culture

1 INTRODUCTION [1][1]

Packaging, the wrapping of goods and materials, indeed "wrapping" in even its widest sense, is integral to human exchange and interaction. There are of course direct functional reasons for both personal and commercial packaging: physical protection, including barrier protection; containment or agglomeration, with the potential for portion control; security; information transmission, including marketing or advertising, and, of course, for general convenience, to name but a few.

Most or all of these criteria are considered when packages, and their contained products, are designed. Concerns about the environmental and ecological impacts of packaging have now, finally, been added to the list of criteria that must be considered when packages are created. Great strides have been made: the adoption of "cradle to cradle" thinking in developing sustainable products; new materials, e.g. truly biodegradable plastics made of starches, cellulose, and polylactic acid, etc., and the implementation of strategies like the "3 Rs" (Reduce, Reuse, Recycle) in waste management hierarchies.

The latter strategy is significant in light of the social aspects of ecological design. Without minimizing its importance, it is, I think, important to understand that a strategy that asks people to reduce, reuse, and recycle may be at odds with cultural uses of packaging, e.g. a package as package may have an emotional, or communicative, or symbolic import that is integral to a social group; hence, the pragmatic exhortation to change a social norm, even if recognized as a common good, is likely to encounter difficulties.

An important challenge for ecodesign is the reconciliation of social customs with ecological concerns. Given the importance and long traditions associated with packaging and wrapping in Japanese culture, along with the technological, design, and aesthetic sophistication of their manufacture, use, and appreciation, it seems to me only natural that a close study of past, present, and potential future developments in various cultures can result in a significant contribution to resolving at least some of the ecological challenges that we face today. Japan, with its long history of traditional packaging practices, continues to revive and develop strategies that satisfy both ecological responsibility and the cultural importance of packaging. This paper is a sketch of an ongoing body of research, focused on paper packaging and wrapping, that will result in tangible and practical design solutions to a dilemma faced by all of us.

2 BACKGROUND

Japanese wrapping and packaging using both paper and other traditional materials occupy a distinguished position in the world, and their presentation, dissemination and popularization have had profound influences on packaging design. Various Japanese design associations publish annual collections of commercial packaging designs, however, the explicit cultural importance of packaging in Japan was perhaps first introduced to a wider Western audience with the translation of Oka Hideyuki's *How to wrap five eggs* (1967)—a work produced in affiliation with a traveling exhibition that was staged over 100 hundred times—, continued in a subsequent volume, *How to wrap five more eggs*, in 1972, reprised in some measure in a series of Canadian exhibitions in 1988: 'The Art of Japanese Packages' [2]. In these texts and exhibitions the aesthetic elements, and their inextricable relationships with other cultural values inherent and underlying the designs are explicitly and implicitly emphasized. A hands-on approach was published Ekiguchi Kunio with his *Gift-Wrapping: Creative Ideas from Japan* in 1985 [3]. This book introduced Western readers to the ineffable

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haptic and temporal qualities that inhere in making and opening gifts and packages. Ekiguchi explains carefully the important spiritual and cultural role of packaging in Japanese day-to-day living. Together, the publications make clear and the exhibitions make manifest the close connections between aesthetics and their relation to cultural and spiritual expression. Joy Hendry too has noted the elegiac tone in Oka's writing, particularly in the 1988 'The Art of Packages' catalogue [4]. He mourns the loss of the spirit of 'care' in the wake of industrialization while Ekiguchi celebrated the continuing importance of careful wrapping in present-day Japan. Both sentiments were discernable in the exhibition, 'Tsutsumu: Traditional Japanese Packaging' staged at the Meguro Museum of Art, Tokyo this past winter. The exhibition re-presented many of the types of packages highlighted by Oka almost fifty years ago, including Oka's eponymous 'five eggs'.

It is also noteworthy that in the printed interviews with designers in other published collections of Japanese package designs—e.g. *Wood package : Keiko Hirohashi, Toshio Sugimura, U.G. Sato, Kozo Okada, Ryo Arai, Akiko Arai, Shigeru Akizuki* (1987), *Package Design in Japan* (1989) [5]—that the creators of the packages invariably mention the cultural implications of packaging, e.g. animistic ideas about packaging protecting the 'being' of the contents, the importance of care for both the contents and the recipient, and the nature of the communication conveyed by the package and the circumstances of exchange. These dimensions are bound up with the aesthetic elements, indeed, as Saito Yuriko [6] has elaborated in numerous publications, the one is almost synonymous with the others.

Anthropological studies of gift-giving, and by extension packaging, in English, have also kept pace. For instance, Befu Harumi published "Gift-Giving in Modernizing Japan" in 1968 [7], almost at the same time as Oka's work was being translated. It is, however, Joy Hendry's 1993 book, *Wrapping Culture: Politeness, Presentation and Power in Japan and other Societies*, has had the longest-lasting effect [8]. Indeed, Hendry's use of 'wrapping culture' as a descriptor, in her careful study not only of gift wrapping and packaging, but also of social 'wrapping', was and has become an accepted metaphor under which to discuss Japanese culture, e.g. Eyal Ben-Ari's et al 1990 *Unwrapping Japan: society and culture in anthropological perspective* [9], or, from a design perspective, Ekuan Kenji's 1998 *The aesthetics of the Japanese lunchbox* [10]. Ekuan draws metaphoric parallels between Japanese lunch boxes—wrapping, containment, beauty, and its 'spiritual precision'—and approaches to product design in Japan. Two recent, important additions to the literature on packaging and its social implications are Katherine Rupp's 2003 *Gift-giving in Japan: cash, connections, cosmologies* [11] and Inge Daniel's 2010 *The Japanese House: Material Culture in the Modern Home* [12]. Both Daniels and Rupp engaged in an exhaustive fieldwork in which they examined and recorded the social ramifications and uses of gifts and their wrappings in daily Japanese domestic life.

3 3Rs

Against the background of these investigations, it is illuminating to revisit the seeming pragmatic strategies to manage our strained resources in efforts to address our ecological dilemmas. For instance, a wonderful case in point: Reduce, Reuse, Recycle, or the 3Rs— a striking, poetic, self-reflexive illustration of its own message—succinctly outline one of the strategies for promoting environmental responsibility and ecological balance in a world of limited resources. This collective strategy enjoys widespread, in fact global, acceptance and increasing implementation. A global 3R initiative for waste management was first proposed at a G8 summit in 2004; this was formalized in a meeting of G8 environment ministers in the 3R Kobe Action Plan in 2008. (Earlier warnings of a need to address the issues have of course been issued over the last 40 years, e.g. the Club of Rome's 1972 *Limits to Growth Report* [13] and the Brundtland Commission's 1987 *Our Common Future* [14], to name only two.)

Under the banner of each of the 3Rs, multiple efforts are under way, but even straightforward proposals to use less stuff are (much) debated and even potentially contentious. One simple proposal is to reduce paper weights and alter standard sizes—Japanese businesses use a lighter weight than both America and Europe for their day-to-day uses, although Japan adheres to ISO paper standards—; another, of course, is to ask people to refrain from printing digital texts. It is noteworthy that this latter advice has in the main gone unheeded. The vaunted "paperless" office has not materialized, in fact, paper use has increased exponentially with the introduction of computers and inkjet printers. I surmise that the reason for this is our need for a material or substantial "proof" of our records and actions: the haptic experience of texts is somehow comforting. Michael Braungart, the co-author of *Cradle to Cradle: remaking the way we make things* (2002) with William McDonough [15] , has argued for what he has termed "rematerialization" by which he means making things properly first and foremost, not smaller or fewer of them; the quantitative for him should be a secondary concern. He is speaking about more technologically complex manufactured components, not simple wrappings and packaging, nevertheless, his arguments are indicative of the issues. He sees efforts at dematerialization as part of a destructive, linear, production system that aims to simply amend an existing system without making necessary fundamental changes [16]. His observations offer a glimpse of how vexed the issues can quickly become.

Reuse also seems self-explanatory. Things are reused, e.g. shipping containers, cartons, and so on are either reutilized for their original purpose, or repurposed in some way. In North America at least, shoeboxes, at one time, enjoyed an almost iconic significance as a repository for personal photos and correspondence. Braungart has also proposed a "technical circulatory system"—an additional closed, parallel system within the 'natural' ecosystem—in which components are part of an "intelligent materials pool"; they are reused in the next generation of goods, rather than being "downcycled" and used for something else [17]. This proposal is in essence the creation of an exclusive system that is completely self-referential. It would seem, at first glance, that the social and cultural import of such systems are not a consideration, except in the widest sense.

Among the three Rs, recycling seems to have enjoyed particular popular attention and appeal, perhaps because, once systems are in place, everyone can easily participate in recycling programs, and in fact, not insignificantly, it takes minimal effort for a concomitant, substantial emotional reward. In an odd way, the act of recycling on a domestic level—the separating of 'waste' into coloured boxes and bins, or into transparent plastic bags, for display on the street before collection—is a repurposing of the discarded materials for communicating ecological and social concern.

Like other countries, Japan has instituted legislation to promote recycling: the law for the promotion of sorted collection and recycling of containers and packaging (1997); the home appliance recycling law (1998); construction material recycling law (2000); law for the promotion of effective utilization of resources (2000), to name only some. Japan also put forward another domestic plan to meet the challenges: Japan's New Action Plan towards a Global Zero Waste Society, in 2008.

Indeed, on the whole, Japan's efforts are remarkable. The Japanese Paper Recycling Promotion Centre reports that in 2008 Japan recovered about 22. 75 million tons of paper of which 3.5 million tons were exported and 0.o6 imported, leaving about 19 million tons of which 99% were used to re-make paper [18].

The reuse of paper—cellulose—fibers is unfortunately limited. The recovery and use of fibers from already-made paper presents technical challenges in their recovery and reconstitution, and their suitability for continuous reuse is limited. New fibers must be added to make new paper. Similarly, cellulose from material other than trees: straws, hemp, etc. is also challenging. One difficulty, for instance, is the amount of silica in the material that must be removed with new processes that risk causing further harm to the envirionment. Japanese paper (*washi*), made from non-hardwood pulp, the sole paper source in Japan before the Meiji era, and uniquely strong and appropriate for a host of uses, has now become a fine craft enterprise, rather than a commercial source of paper.

3 SOCIAL IMPLICATIONS

What is worth noting, at the risk of belabouring a point, is that all of these efforts to manage paper use are in essence technological fixes that seem not to pay any attention to the cultural and societal dimensions of the problem of over-use of a limited resource, and it is these that I think important to at least outline briefly. Japan's traditional paper packaging culture offers a particularly illustrative case study.

To state the obvious, packaging is the lynchpin of any functioning economic or supply system. It is absolutely necessary, in some form, for almost any kind of trade. In fact, some goods or products could not be distributed without some sort of packaging. Two examples, both ubiquitous, at least in North America, are portion-controlled, take-away coffees in paper or styrofoam plastic cups and drinking water in plastic bottles. Japan is unique in the world for its sophisticated network of vending machines that provide drinks of all kinds, both hot and cold, in metal cans, plastic– and glass bottles. It is safe to claim that almost all exchange goods are in some way, or at some time packaged, and almost one-half of all packaging is made out of paper.

In economic contexts, packaging has a number of clearly defined purposes. First and foremost, packaging is designed to protect something from its environment: from temperature, from humidity, from mechanical shock, and so on. Packaging must also be designed to be secure, i.e. to tamper proof, or, failing that, to make any interference immediately noticeable in some way. Visible evidence of a package's protective powers may be of great symbolic importance., e.g. visible protection of the physical 'object' and its spiritual qualities.

Packaging is also meant to conceal, or to partially obscure. Saito, in her essays, writes of miegakure (now you see it, now you don't) and the aesthetics of the attraction of the concealed. In the same context, Saito also elaborates the importance of the temporal aesthetic inherent in the acts of wrapping and unwrapping. One of the small pleasures for visitors to Japan to discover is the ease with which one can open packages once one has found the (hidden) key: the little notch from which to start a tear, the small tab or the discreet string to pull, or the initial fold that when undone opens all the others. The starting point of the process also literally gives pause, elicits pleasure, and preserves the wrapping. The rich tradition of white paper packets and envelopes closed with elaborate knots, themselves indicative of a sentiment or meaning is a uniquely Japanese development. Some knots are not meant to be untied; they signify permanence. This is diametrically opposed to the Western practices of impatient, destructive unpacking.

One of the other practical demands on packaging is its use to containand and to agglomerate: liquids have been mentioned already, but powders, granules, and similar materials are usually gathered in one package. This allows not only for portion control and convenience in distribution, but also, importantly, the ability to give shape while protecting otherwise amorphous goods: *onigiri* and *inari sushi* come to mind. This kind of packaging raises another interesting dimension to the relationship between the contents and their wrapping. In the case of both, one can eat the wrapping, raising the question where does one begin and the other end. As well, the two together elaborate the gustatory aesthetic involved in the consumption of the two. A Western equivalent can be seen in wafers used as substrates for baked goods, in fact, a German-language variant is known as *Esspapier*: eating paper.

Small packaged goods are themselves often collected in a secondary package, which in turn may be arranged within a still larger tertiary package (and so on). This adds convenience—there have been efforts to revive the use of furoshiki in day-to-day use as a replacement for plastic bags. Collections of smaller packages in a larger one allow for specific arrangements within the package, again to reflect cultural symbols and identifiers, e.g. the number of items in a package may be relate to numerology, lingusitic homonyms, and the like. The ensuing layers of wrappings or packaging also may also have social import: The layers of wrapping may be associated with layers of meaning and hierarchies of importance.

Imparting meaning, or in a more prosaic sense, communicating is another key function of wrapping. W are all intimately aware of the function and power of branding. In some instances the package—the brand—is more important than its contents. As noted earlier the kinds of knots used to tie packing string (*mizuhiki*), the colour of the string, their orientation all convey a message and its sentiment. The number of layers also convey emotional messages: the message is directed at the recipient through the packaging, and to its contents. An example of pragmatic communication can be seen on seasonal gifts—*chūgen-seibo*—sent to people at the appropriate times of the year and on which the outer wrapping bears important information: the name of the store, the location of the store, and the costs involved: All of these data are important in determining degrees of obligation for reciprocity. Once this layer is removed, the next layer of wrapping carries additional meanings that reflect other aesthetic concerns. Again, the aesthetic is not to be separated from the meanings.

4 SUMMARY

These very few illustrations—formal constraints prohibit greater elaboration—of the profound importance of packaging as a means of cultural exchange and communication illuminate, I hope, in some measure the care that must be taken and the sensitivity we must exercise as we address our ecological concerns. Failure to do so will make our collective task that much more difficult: *Mottainai*.

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An easy-to-use methodological proposal for considering ubiquitous controllers in energy use optimization

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Abstract

The aim of this paper is to highlight possibilities for designers to change their products towards showing a better energy performance during their usage. To this end, the paper offers them a simplistic methodology, which supports the consideration of the most important aspects of energy saving. This methodological support is needed since not only electronic household products, but also consumer behaviors have become more complex over the years. In this research we are focusing on saving by adding extra smart energy saving functions. Product equipped with some level of intelligence are able to perceive their environment, can be aware of the presence of people and other agents, and can respond smartly to the needs of these agents. The proposed methodology has been developed to support designers in using these ubiquitous controllers to optimize energy consumption. Because it seems to be not obvious to find the energy saving controller or combination with the highest gains. The ubiquitous energy controllers are nonetheless additions to the original product and the trade-off between the extra gains and the costs of adding a control function must be made.

Keywords:

Ubiquitous controllers, smart energy saving, design for energy efficiency, trade-off calculation

1 INTRODUCTION

The principal question of our research is why designers do not develop electronic household appliances that provide optimal energy performance?

Energy consumption and their environmental problems are becoming a heavy concern all around the world. Several studies pointed at the fact that many household appliances have a strong environmental impact due to their high energy consumption and especially because of the amount of energy that is wasted during this consumption. Contrary to the efforts, the progress to reduce this amount of waste is not optimal. Still plenty of electronic household appliances are inefficient in terms of energy consumption.

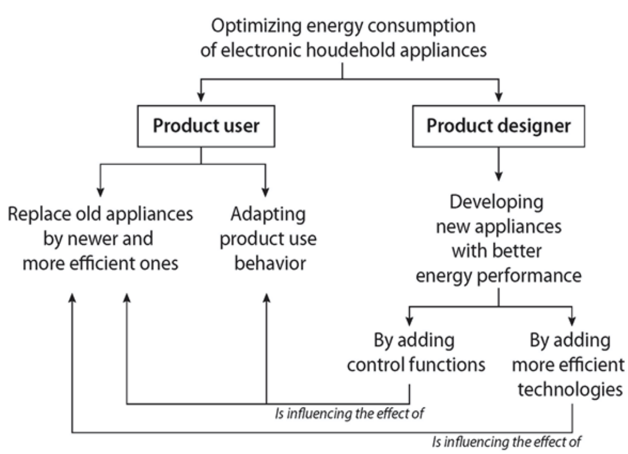

Fig. 1: optimizing the energy consumption of electronic household appliances

The ways of energy saving which could be found in literature (through the product designer and through the product user) are visualized in Figure 1, and are useful to argue why it is important to develop energy intensive products, that designers must do this, and consequently how they must do this. This paper we will investigate what the related difficulties are in the design process and how to apply control functions in the design of electronic household appliances with the purpose to save energy.

In Figure 2 we present a graphical representation of a model to reason about all aspects that are related to this energy efficiency problem with the focus to develop a methodology to support designers in using ubiquitous controllers to optimize energy consumption. Some of the research areas had to be further decomposed due to the different relevant issues and their complexity.

The research started in the domain of the energy efficiency problem. In Section 2, we are considering the energy efficiency problems that are appearing in the design process. Next, in Section 3, the saving possibilities that can be used by designers were examined. And lastly, in Section 4, we are focusing on the trade-off calculations that must be done to achieve an energy efficient product. In addition to this research, in Section 5, the research is discussed and some concluding remarks were made.

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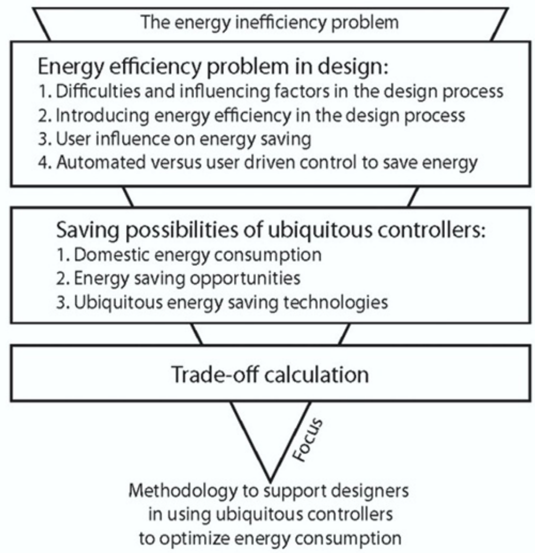

Fig. 2: reasoning model

2 ENERGY EFFICIENCY RELATED PROBLEM IN THE DESIGN PROCESS

2.1 Difficulties and influencing factors in design activities

In order to reduce consumption and impact, product designers have to use environmental friendly technologies and must fulfill environmental specifications and legislative norms. Nevertheless, these activities are not yet *embedded in designers' daily activities*. This is because achieving optimal energy performance with electronic household products needs a wide ranging search for optimal solutions, as well as a complicated multi-criteria optimization process and decision-making, The process of designing for optimal energy performance features complexity that is caused by the fact that designers should consider not only the operational functions and the actual energy consumption related to them, but also the type of usage of the products, the user behavior, and a lot of other intangibles[1]. In addition, it is rather resource and time consuming to take all influencing parameters into account simultaneously.

Designers are no technology engineers nor can they educate people in how they have to behave with electronic products [2]. On the one hand, a designer is generally not supposed to get engaged with designing more efficient technologies, but to make the most out of possible technology combinations or adaptations by including them during design. This obviously implies that they should be aware of what technologies exist, what functionality they are able to realize, and what are the best ways of their application. On the other hand, as Crosby and Taylor did, we should make a distinction between consumer 'information' (e.g. specific information attached to a given product) and consumer 'education' (e.g. more generic data or training as how to judge the performance of a product form its stated characteristics) [3], since designers can only inform users of their energy consumption through the design of the appliances but cannot educate them.

2.2 Introducing energy efficiency in the design process

Towards involving energy efficiency in the design process, two major considerations have been proposed. Firstly, we have to be aware of the fact that energy efficiency should be seen as *just one of the requirements* to which the future product should come across. A general household product has multiple requirements that must be fulfilled. Thus designers must pay attention to all of them. In contrast, this research is only considering the effectuation of the requirement of having an optimal energy performance during the product use.

Secondly, considering this accomplishment we also have to realize in which *stage in the design process* the execution of energy efficient actions should be accomplished. We considered some common used models to structure the new product development process, to think through the most important phases for designing energy efficient products. [4-6]. As already mentioned above, crucial to energy efficient design is the phase in which the product specifications and requirements should be defined. Often this is step two in the design process, following the ideation step and prior to the concept development. During the definition of the product requirements, it is important to adjust the requirement of energy efficiency, in order to be able to spent time designing the product having an optimal energy performance. The actual design action appears during the concept development phases of the product. In this phase designers have to implement all requirements into their product.

2.3 User behavior influence on energy saving

While reading literature we noticed that much effort is put into the motivation and education of users to change their behavior concerning energy savings, in contrary to this effort, we also notice that not all household appliances are designed to support users in this environmental behavior. Products often suffer from some sort of secret energy consumers, such as a clock or a light, and they cannot be turned off completely. So even if consumers want to reduce their energy consumption, it is not easy to do so.

Obviously, this also means that designers can support users in receiving optimal energy consumption. A typical consumer is influenced by a variety of factors, including where and how the specific information is provided, and the exact format in which it is presented. Mansouri argued that the general conclusions are that end-users tend to apply energy-thrift actions if (1) they understand the benefits, (2) they are motivated, and (3) appropriate information–feedback techniques are applied [7, 8]. To reduce household consumption designers need methods of encouraging the adoption and use of energy efficient technologies. In these methods, socially and culturally sensitive research should be combined with technically proved technologies [3].

2.4 Automated vs. user driven control to save energy

Often in literature [9-12] there is also discussion on the level of automation. Energy consumption can be reduced by people‘s decisions or by machine’s decision, and the whole range between.

If the responsibility is given to the user, designers must engage users in the design of control systems that they like in order to allow them to create the comfort conditions they want and which will support them, through using auxiliary technology, to reduce their energy consumption. In contrast, if users do not have any intention to reduce their energy consumption, automatically adapting the energy consumption is also a possibility. One of the challenges of designing for sustainable behavior is that users’ actions can be difficult to predict as they are driven by a complex array of internal and external influences. To minimize unpredictability and ensure compliance with energy saving goals it is possible to design highly autonomous systems which minimize or eliminate the need for human intervention completely or use constraints to prescribe actions [9].

However, by taking the decision making capability away from the user to prevent ‘unsustainable’ actions, we separate cause and effect. Some authors fear that without feedback on cause and effect users may be less likely to learn from, and adapt, their behavior accordingly. In addition, some authors say that users may perceive automation as a lack of choice and this may reduce acceptance [9, 13-15]. We can conclude that there are different views on it, but also that further research is needed to determine where automation of actions is acceptable and where choice is preferred.

3 ENERGY SAVING POSSIBILITIES OF SMART, UBIQUITOUS CONTROLLERS

3.1 Domestic energy consumption

The electricity consumption of the total amount of appliances in a household is determined by two main factors: the type and number of electrical appliances in the property; and the use of these appliances by the members of the household. The family members influence the electricity use of a dwelling both by their purchase of electrical appliances and through their use of these appliances [1, 16, 17]. Considering the duration of use of these products, we see that time actually means three different things: (i) duration of usage, (ii) frequency of usage, and (iii) product lifetime [15]. Longer use duration, larger use frequency, and longer lifetime mean larger total energy consumption.

Another difference between household appliances is the power consumption level [18]. We can differentiate low-powered and high-powered products. Typical examples of low-powered products are mobile phones, shavers, toothbrushes, clocks etc. Typical examples of high-powered products are heating systems, air conditioners, washing machines, etc. considering this difference, we conclude that if a product implements a critical energy conversion process (e.g., converts electric energy to thermal energy) and consumes a large amount of energy, we can expect a relatively higher saving by reducing the energy saving opportunities in comparison to low-powered products [19]. This assumption is also underpinned by the fact that, typically, these products also feature high stand-by power consumption [1]. Besides, most low-powered products are battery-powered today. As the energy provided by batteries is limited, the energy performance of this kind of products are usually optimized [20], and various technologies are used to improve the energy performance [21].

3.2 Energy saving principles

Based on the energy-related characteristics (usage and power characteristics) of electronic household appliances we can distinguish three general energy saving opportunities: (i) the useless operation time, (ii) the useless operation, and (iii) the overload of power. Useless operation time can be found in products that are in active power but that are not used for a certain period of time e.g. light that is left on in the toilet when there is nobody there, a television that is playing in the living room when the family is eating in the kitchen. Useless operation is when a product does something that is not needed by the user. Often this occurs as heating or lighting e.g. the light of a power button shining red when the appliance is switched off, the heat production of products components such as in a notebook. Overload of power can be located when a product is ‘working harder’ then needed. For instance a vacuum cleaner that sucks harder than necessary to suck the substance.

After locating the energy saving opportunities, it is also important to know how to reduce them. In contrast to designers, engineers can develop new less energy intensive product technologies, and powering and materialization solutions to eliminate this useless energy consumption [22]. Designers on the other hand should be aware of these advanced solutions and use and combine them in an efficient way to make consumer products. If we suppose that they are using the most efficient technologies, designers can only save additional energy by adding auxiliary functions to control the products energy consumption and reducing the saving possibilities. Control can be achieved, as discussed above by human control or automatically and can vary from low intelligent functions, such as switches and buttons towards more complicated and context aware controllers.

3.3 Ubiquitous energy saving technologies

The term ‘context-aware ubiquitous technologies’ describes a class of (still emerging) technologies that are everywhere and anywhere present to seamlessly assists us in our daily tasks, i.e. many functions are intelligently automated, and can significantly contribute to the quality and sustainability of life [23]. The idea of using ubiquitous technologies as enablers of smart energy saving functions has emerged during the last decade.

Products equipped with some level of intelligence are able to perceive their environment, can be aware of the presence of people and other agents, and can respond smartly to the needs of these agents [24]. Ubiquitous controllers can contribute to optimization of energy consumption based on this kind of extra context information. [25]. Information displays, computing, sensing and communication will be embedded in everyday objects and within the environment's infrastructure [23]. For example, motion sensors can be used to increase energy efficiency: (1) for indoor and outdoor lights (the lights turn off once they stop sensing motion), (2) motion sensor alarm: when it is triggered by activity, it activates a camera, (3) use motion sensors to start music when you enter a room and stop it if you leave, and so on [26].

4 TRADE-OFF CALCULATION

The main problem with smart control devices is that they are added extras. Though ubiquitous devices are becoming smaller in size, cheaper to manufacture, more powerful and multi-functional, application of complex control subsystems typically goes together with non-ignorable additional costs. energy saving must be calculated. In certain situations, the extra costs of applying ubiquitous controllers to improve the energy performance of electric household appliances can be higher than the actually attainable savings. Obviously, the ubiquitous controller must not consume more electricity than it allows users to save. Accurately there is a balance between how much energy additional controllers can save and how much it will cost energy wise. In other words, a trade-off must be reached between the gains of the smart energy saving controllers on one side and the extra costs of these controllers on the other side.

In addition to the tangibles, which can be expressed in terms of financial means, we consider the user acceptance as an intangible, which is critical from the aspect of the appreciation of the product. In this calculation, we assume the users to be rational and so neglect the quantification of the intangibles and consider only the product cost or, from the perspective of the user, the selling price of a new product, and the energy cost as determining parameters.

To estimate the trade-off, we should compare the total costs characterizing a product which is not equipped with a ubiquitous controller with the cost and appreciation of the product equipped with ubiquitous controller. From now on, we refer to the product not equipped with ubiquitous energy saving controller as original product, and to the one equipped with this as extended product. It should be assumed that the information about the possible energy waste and energy saving possibilities are known before the trade-off estimation. The financial trade-off for an extended product can be expressed mathematically as an optimum finding problem:

$$TO = \max(G_1, G_2, \dots, G_n) \qquad (1)$$

Where:

TO is the trade-off result that takes the value of the maximum of financial gains which is determined by comparing the particular gains obtained for each considered extended product variant.

G_i is the financial gain (or saving) that can be achieved in the case of a particular product-controller combination (i) in comparison with the original product. The gain can be calculated as:

$$\mathrm{G} = \mathrm{TPC_O}\text{-}\mathrm{TPC_N} = (\mathrm{PP_O} + \mathrm{EC_O})\text{-}(\mathrm{PP_N} + \mathrm{EC_N}) \qquad (2)$$

Where:

G is the achievable financial gain (or saving) in the case of a new product equipped with ubiquitous energy saving controller in comparison with the initial product

TPC_O is the total product cost of the original product

TPC_N is the total product cost of the new extended product

PP_O is the product (sale) price of the original product

PP_N is the product (sale) price of the extended product

EC_O is the energy cost of the original product

EC_N is the energy cost of the extended product

To calculate the gains, we also need information about the sale prices of product variants (product costs). There have been many papers published both on quantitative estimation and on numerical calculation of sale price. Typical quantitative cost estimation methods assume that detailed design of a product has been completed [27]. Cost estimation tools to support early design are scarce and rough. However, various methods, such as case-based reasoning, decision support mechanisms, and analogical reasoning techniques have been successfully applied in a quasi-numeric or qualitative estimation of product price [28]. Typically, these techniques make use of past data to predict the costs of a new product without requiring precise information on the product itself. Literature shows that calculation of product cost is a complicated summation with multiple unknown variables. What it means is that we can consider and use the selling price of the product as a substitute of the actual product cost. It is a frequently applied simplification [29] and this has in fact been considered in above Equation (2). In the case of an extended product, the total cost of the original product needs to be appended by the cost incurred by the applied ubiquitous energy controllers. The additional product cost components include the market price of the controller, the additional embedding cost, and the implementation cost.

Literature was investigated to see what software tools are available for energy cost calculation. What we found is that the currently available tools typically require very detailed information about the embodiment (manifestation) of the product. On the other hand, the need for supporting energy consumption and estimating the various costs in the early phase of product development has also emerged. In fact, some first steps have been made in this direction [30]. A proper energy saving calculation should consider the hours of being in operation and in standby mode [1]. In order to make reliable estimations, we need detailed use scenarios and user behavioral patterns [31]. The most obvious measure is cost and this explains why everything is expressed in terms of money in our calculation scheme. In practice it means that the calculated energy consumption is converted to money by considering the energy prices. The energy consumption of the original product can be calculated as:

$$E_O = (OH_A \times NP_A) + (OH_L \times NP_L) + (OH_Z \times NP_Z) \times 365 \qquad (3)$$

Where:

E_O is the energy consumption of the original product (expressed in kWh/year)

OH is the number of operation hours in a day for the original product

NP is the nominal power required for the operation of the initial product (expressed in kW)

A is the index of the active power mode

L is the index of the low power mode (stand-by)

Z is the index of the off or zero power mode

Furthermore,

$$\sum OH_i = 24h \qquad (4)$$

For the original product, the energy consumption cost can be calculated as:

$$EC_O = E_O \times \sum(TU_p \times EP_p) \qquad (5)$$

Where:

EC_O is the energy consumption cost of the original product

TU is the time in use (expressed in years)

EP is the energy price per kWh consumption

P is the time period in which the EP is unchanged

E_O is the aggregated energy consumption of the original product,

It can be assumed that equations for energy cost and energy consumption calculations remain the same for the original and the extended product only in incidental cases. Therefore, the above Equations (3) till (5) must be adapted to and specialized in terms of the descriptive variables and their relationships.

Obviously, when the physical manifestation of a new product remarkably differs from the original product the variables, and consequently the respective equation will be partially or completely different. These changes may require a comprehensive redefinition of the workflow of computation and the descriptive equations [32].

5 DISCUSSION AND CONCLUDING REMARKS

The objective of this paper was, firstly to highlight possibilities for designers to change their products towards showing a better energy performance during their usage, and secondly, to develop a new methodology to supports the consideration of the most important aspects of adding auxiliary ubiquitous controllers for energy use optimization. This support is needed since the complexity of electronic household products has increased and consequently consumer behavior has also become more complex over the years. Some authors even argued that reductions up to 10-20 % of the products annual energy consumption can be achieved.

5.1 Advancements and limitations of the research

The scientific novelty of the research can be found in the commonsensical approach towards the development of the methodology in which we strive after converting theoretical behavior into a practical means of assistance. Also did we considered the problem from the side of the designer and was the focus of energy optimization entirely limited to the use phase of the appliances. The research was narrowed to the category of electronic household appliances to make the whole manageable. We have to indicate that in addition to the possible implications of the methodology, the methodology is still basic and does not take following aspects into consideration: (1) consumer acceptance, intangible influencing factors and therefore irrational consumer decisions, and (2) the flexibility or irrevocability of the controllers.

5.2 Interpretation of the result

The intention of our work is to convert the existing theoretical knowledge into a computer oriented practical means. Parallel with the methodological investigations, we are studying the requested functionality and possible implementations of the computer tool that can assist designers in selecting and designing smart energy saving controllers. Our interpretation is that more support is needed to assist designers in making a decision on smart energy saving. The methodology remains too complex and extensive to let designers work with it. Moreover, designers are already overloaded with all kinds of methods to optimize the design process. To get a new methodology or tool launched and accepted it must fulfill a number of extra requirements.

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Materials and Design: Investigating the Durability of Cork Products – a Longitudinal Study with Users

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Abstract

This paper investigates the life-span of cork products, and how the knowledge from use enables to learn about the material. This is accomplished through a longitudinal approach with users; several cork products are being used, and interviews are performed. In general, users are satisfied with the products, and the specific appreciation of aspects such as performance, quality and aesthetics is also good or very good. Main differences observed are dirt and other visual changes, and at this moment (three months) the life-span of the cork products is good, and the use of the material can be considered appropriate.

Keywords: Sustainable consumption and production; life-span and use(r); cork products and materials

1 INTRODUCTION

1.1 Cork – origin, materials and applications

Cork is a renewable resource, the outer bark of the cork oak tree, and can be removed periodically from the tree stem without endangering vitality. The cork oak forests occur in the Mediterranean region and provide multiple important functions, such as preventing soil erosion and the protection of biodiversity [1] [2]; therefore the production and use of cork contributes significantly to the sustainability of these ecosystems and regions.

Cork is namely a light material, rather impermeable, resistant to wear, and has high friction. Wine cork stoppers are the main cork application, and others include construction materials, floating devices, and for aeronautics [3] [4]. More recently its use has also been increasingly explored in the field of design [4] [5]. Currently there are already several cork materials, such as: white agglomerates, black agglomerates, rubber-cork, cork gel, CPC - cork polymer composites, cork wool, cork paper, cork textile/ skin [3] [4] [5] [6] [7].

1.2 Product life-span and materials use

The durability of products is generally acknowledged as a requisite for sustainability [8], and lifetime extension is in general environmentally desirable, except for energy consuming products [9]. Succinctly, it enables to reduce resource use and the subsequent outflows to the environment. From a resource perspective, this is particularly important in the case of cork since the production is limited – slow growth in a specific region. The relevance of addressing product longevity has been more recently presented by Cooper [10], as well as a clarification of related designations: while *life-span* (or lifetime, longevity) are acknowledged as broader concepts, by including multiple influencing factors, *durability* refers mainly to product intrinsic characteristics. In this paper, durability is referred to in the title since most of the issues arising so far are product intrinsic aspects, and also due to the material focus; although, it should be noted that the general scope of the research is broader – at life-span.

Materials are a specific product feature influencing the life-span of products; how they age is directly related with the materials they are made of. Even though some properties in databases provide an indication on how materials withstand use, such as hardness, there is generally no specific information on the issue available to the designer. Following, two examples of research in the field are succinctly introduced.

Within *Eternally Yours* [11], one of the projects addressed plastic materials; a *Proud Plastics Survey* was performed to collect information about plastic products, originating in a *Plastic Experience Guide* and production experiments to enrich the aesthetic quality of plastics. And Fisher [12] investigated how plastic materials age with use and gather dirt in ways perceptible by users; this may elicit strong feelings and promote the disposal of products.

1.3 Research aim and questions

From the above, this work aims to investigate the life-span of cork products, and how the knowledge from use enables to learn about the material, through the following Research Questions:

RQ1 – How is the life-span of cork products?

RQ2 – What can be learnt about the material?

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2 METHODOLOGICAL ASPECTS

2.1 Study setup

Several cork products are being used: at specific moments, interviews are performed with the users, and photographs are taken to register changes in time. Here, results from the three months moment are presented.

Planning: currently, the planning of the moments to collect information is (in months): [0m], 3m, 8m, 16m, 24m, 36m.

Products: 18 cork products for household (bath, kitchen) and personal use (leather market, stationary) were selected and acquired, and different cork materials were contemplated. Some scale was also introduced: with few exceptions, a minimum of three units of each product is being used.

Participants: there are 31 participants, and approximately half are related with research on cork or wood; the study is being performed in Portugal.

Interview: the interview is semi-structured, including open and closed questions coherently organized. This was considered appropriate for the explorative scope of the research.

2.2 Contents of the interview

A – Use of the product (general characterization)

The 1st group of questions aimed to characterize the use conditions: confirm if the product is being used (use of the product); how the product is used (context of use); and, how often it is used (intensity of use).

B – Product appreciation (general)

In the second part the aim was to accomplish a general appreciation of the products, and users were inquired namely about likeness (if they like using the product), and satisfaction (if they are satisfied and would recommend the product).

C – Product evaluation (specific keywords) – five aspects

To accomplish a more specific appreciation and evaluation of the products, five aspects were selected for exploration and assessment in the study. These are: performance (e.g. functionality), quality (technical or broader concept), durability, aesthetic appreciation, and attachment.

At this moment only qualitative appreciations were requested; these were transported to quantitative [1-5] and objective [Y/N] scales to enable comparisons. The correspondences are presented in the table below.

Table 1: Scales for qualitative appreciations

Performance, quality and durability	Excellent; entirely	5			Aesthetic appreciation and attachment
	Very good; good	4		Yes	
	Sufficient; moderately positive	3		Yes but	
	Insufficient; moderately negative	2		No	
	Bad; very negative	1			

D – Comparison/ others (several)

The last group of questions addressed some other aspects: comparison with new – observed differences in time; required maintenance/ cleaning; and, possibility to offer as a gift (answered in B).

2.3 Products – a selection

Table 2: Products being studied – a selection

Household	Personal use
	
(a) PC – Soap dish [White agg. (small)]	(c) PN – Wallet men [Skin/ Textile (dark)]
	
(b) PD – Coaster bk [Black agglomerate]	(d) PR – Pencil case sm [Cork-wood mix]

3 RESULTS

3.1 Use of the product (general characterization)(A)

Use of the product

In general the products were effectively being used, and therefore the implementation of the study was successful. Although, a few exceptions occurred, and which have slightly affected the sample size: PD – Coaster bk, PJ – Keychain, PO – Notebook.

Context of use

With regard to the context of use of the products, in a general way it was possible to characterize them; users have described it appropriately, and at least with the information that seems necessary so far. This is relevant to characterize the circumstances of use, and interpret aspects that may arise; exemplifying, while two soap dishes are used in the sink, for washing the hands, another is used for the bath.

Intensity of use

Similarly, the intensity of use is also relevant 'background' information to characterize the use of the products; it describes how often a product is used, and should be balanced with time. Accuracy is difficult to obtain in this issue, and it also depends on the kind of product. Exemplifying also with the soap dish, use intensity is different if used frequently by four people, two or one, and some users also wash their hands more often than others.

3.2 Product appreciation (general) (B)

In general the appreciation of the products is good. With regard to likeness, with few exceptions responses were favorable [Yes], participants like using the products; there were only three negative situations and five [Yes but]. Users were also in generally satisfied with the products, and willing to recommend them; there were also three negative cases, and four positive but with observations [yes but].

When asked if the product would be suitable to offer as a gift, there were five negative situations and four doubtful ones. Additionally, and since several users have multiple products, some were not mentioned; in general these were household products, and the least mentioned ones were basic or plain (coaster wt, pan base, and place mat wt – all made of white agglomerate).

Table 3 - Exceptions to the general positive appreciation

	Yes but	No
Like Use	Soap dish Fruit bowl Place mat bk Notebook Pencil case sm	Place mat bk Keychain notebook
Satisfaction/ Recommend	Bath mat dry Soap dish Fruit bowl Pencil case sm	Place mat bk Notebook (2)
Gift	Soap dish Fruit bowl; Pen Pencil case sm	Place mat bk (2) Keychain Notebook (2)

3.3 Product evaluation – specific five aspects (C)

Following, participants were asked to more specifically evaluate the products according to five aspects: performance, quality, durability, aesthetic appreciation, and attachment. Following responses are presented, and from the individual charts, a general comparison one was made to visualize aggregated results.

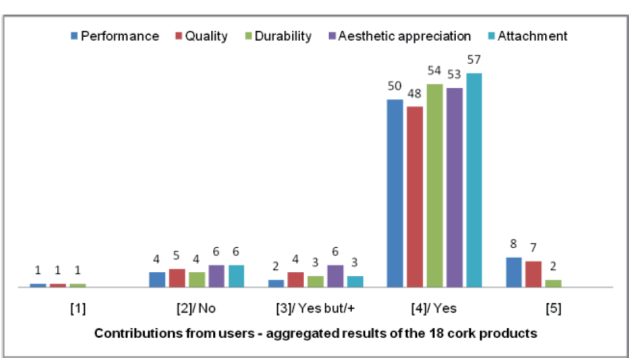


Figure 1: General comparison of the five aspects

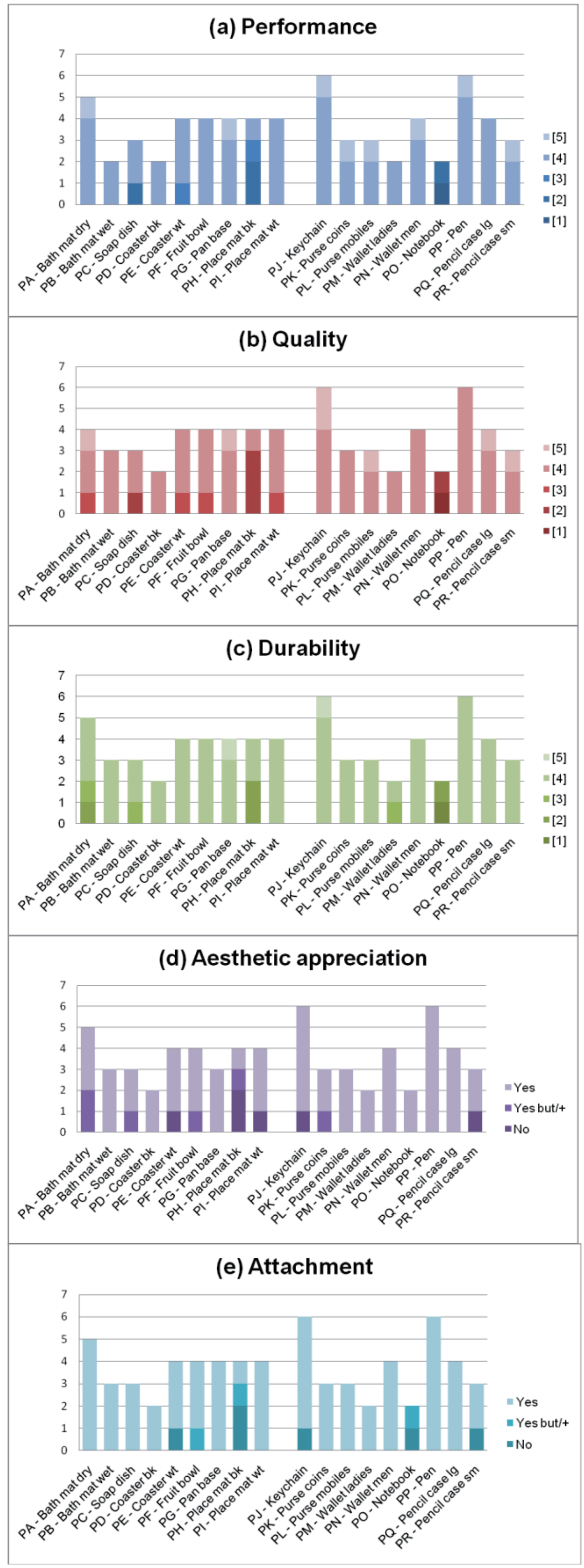


Figure 2: Product evaluation of the five aspects

As can be observed, in general, the evaluation of the five aspects is good or very good [4/ Yes] for most product-user situations. By observing the comparison chart, it can be noticed that the results are relatively similar: in one hand it is still early (3m) and therefore a good appreciation is natural; on the other hand, even though these are all different aspects, they appear correlated – one issue that occurs has sometimes repercussions in some of the five aspects, even if not up to a negative assessment. Following, the few cases for which negative evaluations occurred are succinctly described.

PA – Bath mat dry: in this case there was one negative product-user evaluation in a household with higher use intensity; there is slight damage in a corner/ edges and which is perceived as happening too soon; dirt was also noticed.

PC – Soap dish: in this case, with one of the users with higher use intensity, there is already some slight surface material deterioration, and a usability issue was noticed – the soap gets too attached to the soap dish, which is lifted together.

PH – Place mat bk: with this product several issues were pointed out by different users: fragility – in a household the products got broken and were returned (end of life-span); smell – this dark cork material has a peculiar smell; the fact of being dark for the function of eating; and, little bits of the material get loose.

PO – Notebook: in this a binding problem was found by both users, and sheets get loose easily (products returned).

PE – Coaster wt and PI – Place mat wt: in each case, one user indicated to have no aesthetic appreciation (or indifference) for the products; the fact that these are relatively simple and common cork products and material (white agglomerate) may justify that.

PJ – Keychain and PR – Pencil case sm: in these cases also one user in each declared to have no aesthetic appreciation of these products and materials, and the reasons provided were personal taste.

3.4 Comparison/ others (several) (D)

Differences in time

With regard to changes identified in the products, succinctly and from an aggregated perspective, in 41% of the product-user situations no differences were identified. The chart in Figure 3 presents the three main categories of differences observed.

The main single aspect arising is related with dirt (general or stains), and this accounts for 45% of the situations. Another significant category (22%) includes some visual changes – getting darker, color change, ageing of material, or evidence that it has been used (excluding dirt). Other aspects are grouped in a larger category (33%) and among examples are damage or slight changes in shape.

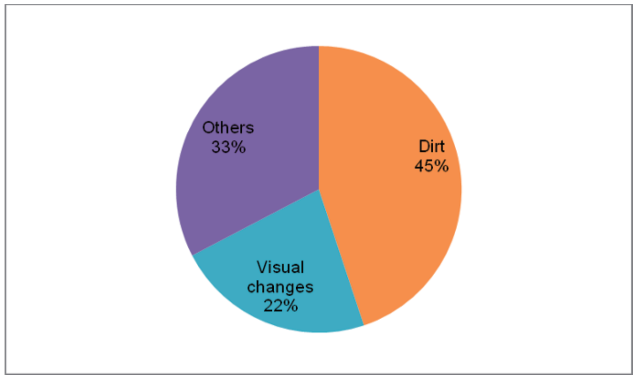


Figure 3: Main differences observed – aggregated results

From a product perspective (Fig.4), it can be noticed that the opinions and experiences of different users are relatively diverse; this may result from distinctive use intensities.

Only three products have entirely no differences observed (coaster bk; coaster wt; and pan base), and the pen is an example in which mainly that is observed, although 2 users mentioned it seems to have become slightly darker; in the bath mat wet, 2 users mentioned that the colour became lighter (lost ink). Mixed examples are e.g. the fruit bowl and the keychain: while some users acknowledge dirt, others have noticed it got darker, and others observed no differences. In other situations some kind of aspect was found by one user, such as in the bath mat dry: dirt by 4 of the users, evidence of use by one, and damaged corner by another. With regard to the two main products with problems, the notebook and place mat bk, besides the specific issues (binding and fragility, mainly), their visual appearance was in most cases similar.

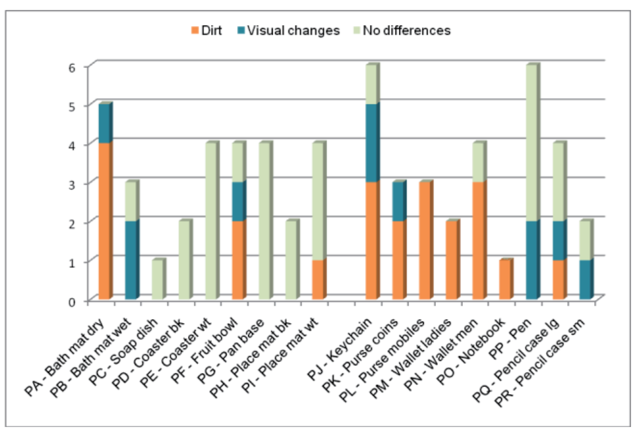


Figure 4: Main differences observed – per product distribution

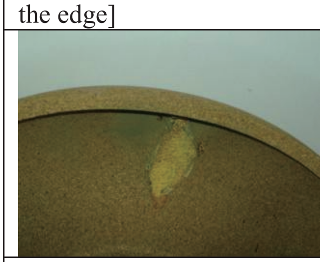
For 11 of the 18 cork products a few other aspects occurred, and are succinctly presented in Table 4.

Table 4: Differences observed – Other aspects (33%)

Product	Other aspect
Bath mat dry	damaged corner (1)
Soap dish	Soap in surface and slight deterioration; slight soap residue in surface, but not well washed. (2)
Fruit bowl	Rot orange peel merged with cork itself; fruit that rots a bit makes cork darker. (1)
Place mat bk	corners are broken (2); deformation with pan (heat); residues and smell intensity decreased. (4)
Keychain	small scratches in metal (1)
Purse coins	Very slightly breaking, crack, rip or tear; Softer: more malleable and smooth. (2)
Purse mobiles	Shape: more flat or flexible; less perfect. (1)
Wallet men	Softer: in body of wallet, but corners still stiff; shape: curved to one side – use in trousers back pocket. (1)
Notebook	binding problem (2)
Pencil case lg	pen marks (1)
Pencil case sm	has extended - is larger (more pens) (1)

Additionally, it should be noticed that the dirt observed is not necessarily a negative issue. Differences acknowledged have a visual emphasis but a few exceptions were observed: residues and smell in the place mat bk, and a more malleable and smoother material in the purse coins. Bellow a few images of used products situations are presented.

Table 5: Images of used products

Household	Personal use
	
(a) PA2 – Bath mat dry [dirt and slight damage on the edge]	(c) PJ6 – Keychain [ageing, darkening (not dirt)]
	
(b) PF2 – Fruit bowl [residues of orange peel]	(d) PK1 – Purse coins [Dirt or ageing]

Maintenance

For personal use products no maintenance was necessary, including cleaning, and only one user mentioned to 'shake off' dust or dirt in a purse mobiles. Although, three users of different cork skin products mentioned the need to clean, or that it would look better if so. One of the products was cleaned by the researcher and user, with a wet cloth; it was simple and the result was good.

In contrast, for the household products, some kind of cleaning operation was reported by about half of the users. For most of these products cleaning was performed with a wet cloth, and was generally considered normal or simple. A few exceptions were also observed: fruit bowl – product was cleaned by researcher with user – better overall aspect but main spot remained, where the orange peel merged with the cork material; perhaps it could be removed entirely, but with even more effort – moderate to difficult effort. Place mat bk – cloth got dirty with residues. Place mat wt – still dirty, grease (but no soap used).

4 DISCUSSION

Concerning the general methodological approach, and considering that similar studies were not available, it is interesting to point out the successful implementation of the study, and that the results are appropriate for the two scopes of the study – life-span and material.

With regard to the characterization of the use of the products, context and intensity of use are difficult issues to measure in a precise way, and there are other differences in how people use the products. These are not simple aspects but so far the objectives were well accomplished.

The evaluation of the five aspects is good, but it should be noticed that this is still an early moment; later results will provide more relevant contributions. Additionally, situations with sufficient evaluation ([3]) can be regarded as opportunities for improvement, and negative assessments ([2], [1]) should be regarded as problems.

And about differences in time, even though some can already be observed in several products, most are slight or moderate, and do not constitute a problem.

5 CONCLUSIONS

With regard to the characterization of use, the products are being used indeed, and it was possible to successfully characterize the context and intensity of use.

Concerning the general appreciation of the products, with few exceptions, responses were positive; participants like using, are satisfied, and consider most products appropriate to offer as a gift.

About the specific appreciation of the products with the five aspects – performance, quality, durability, aesthetic appreciation, and attachment – the evaluation of most products was good or very good [4/Yes]. Additionally, responses for these five aspects are not precisely the same, but there are only slight differences.

With regard to the differences observed in the products, these were mainly dirt related or visual changes. Other aspects were also noticed but are mostly product specific or not mentioned often. And about maintenance, no specific operations were required besides cleaning.

RQ – How is the life-span of cork products?

For the moment, the life-span of the cork products is good. There is a general positive appreciation, and the evaluation of the five key product aspects is also generally good or very good [4/ Yes]. Several issues were already identified as differences in time, but few were explicitly acknowledged as problems by the users.

With regard to the products for which the life-span ended, only a few were returned due to specific problems: the notebook, in which a binding problem was identified by two users, and both units were returned; and the place mat bk, in which some fragility was noticed in one of the households – the products got broken and were returned.

RQ – What can be learnt about the material?

Considering the general positive appreciation, and good or very good evaluation of the products, for the moment, the use of the material in these applications can be considered appropriate.

Most issues that can be learnt directly about the material arise mainly from differences in time. The two large categories identified are dirt and visual changes, observed in several products. As such, the material may be considered somehow delicate or susceptible to visual changes.

From this, as a suggestion with regard to material developments, future research in surface finishing's and engineering seems relevant.

ACKNOWLEDGMENTS

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Product Subjective Sustainability: Analysis of the Japanese Users' *Kansei* Evolutions over their Short/Long-lived Products' Lifetimes

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Abstract
Focusing on the subjective side of product sustainability and considering the lack of a wide expression to encompass product subjective issues that contribute to products' longevity with regard to sustainability values, the present work proposes the concept of Product Subjective Sustainability (PSjS) to particularly indicate 'the emotional, affective and/or aesthetical capability of a product to satisfyingly and pleasantly last during its expected long/short lifetime'. Aiming to expand this concept experientially by using the *Kansei* Engineering approach, this paper presents the process and results of an analytical study on the evolution of Japanese users' *Kansei* toward their short/long-lived product during its entire lifetime. The specified short and long lived product types for this analytical study are, respectively, mobile phone, private passenger car and Japanese handicraft or traditional furniture. As the main outcome of this analysis, the *Kansei* structures and the trends of PSjS are drawn and compared between these products.

Keywords:
product longevity, psychological lifetime, mobile phone, passenger car, handicraft

1 INTRODUCTION

Although the importance of subjective aspects of sustainability has been reinforced within some scientific debates [1-5], most studies about sustainability have focused on its objective aspects (such as recycle-ability, renewability, eco-material, green energy and so on), whereas its subjective side have not been observed adequately [6-7]. The key challenge of "subjective environmental aspects of products and processes" has been discussed in design research since the last years of the 20th century [8]. Nevertheless, the importance given to the subjective issues of sustainability within design research is increasing theoretically and empirically [9]. Practically, the focus of design research concerning such issues is on 'lifetime optimization of products' [10]. Nes and Cramer proposed five design strategies for product longevity among which 'product attachment' seems to be the most directly related to the product's psychological or subjective lifetime [11].

As emotional bonding may increase a product's lifetime [12], extending the psychological lifespan of durables and increasing the degree of consumer-product attachment could be instrumental in reducing both the demand for scarce resources and the rate of solid waste disposal and may contribute to a more sustainable society [13-16]. The strategy of enhancing product attachment, however, brings many challenges and is the most uncertain as to whether it actually enhances longevity [10]. A product, even a very personal one like a mobile phone, could be emotionally pleasurable, aesthetically appealing and/or functionally comfortable during its expected short/long lifespan while there might be a very weak user-product attachment. Therefore, the durability of users' satisfaction and emotional pleasure regarding a product and its appeal do not necessarily eventuate to attachment. According to the findings of our previous researches, there are at least two other effective trends than just product attachment that could be used for extending the psychological lifetime of such short-lived product as mobile phone [17-18]. In fact, user-product attachment is one of the important subjective issues about a product, which include the user's total attitude, feeling, affection, emotion and/or appreciation. Such subjective issues could be professionally called *Kansei* [9, 19-20] rather than any other term like emotion.

As user-product attachment seems to be not the only means for extending or optimizing the psychological or subjective lifetime of products, there is room for an open concept or wide expression (such as product subjective sustainability) to comprehensively encompass product subjective issues that contribute to products' pleasurable longevity when considering product sustainability.

The term 'subjective sustainability' has been used as a versatile and wide concept in the literatures of various fields such as social sciences [21] public policy [22], forest management [23], urban design [6-7, 24-25] and package design [26]. Nonetheless, the definite territory of

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'subjective sustainability' has not been identified clearly or explained well within the literature.

In this research, we have named "a product's capability of being pleasing, appealing and satisfyingly enduring during its expected long/short lifetime" particularly as 'Product Subjective Sustainability' (PSjS). The word 'sustainability' in this concept is not only meant to imply a fair durability but the imperative application of such durability in terms of product sustainability. Nevertheless, PSjS could be expanded to generally embrace all subjective issues of how a product reflects or affects sustainability values [27]. This concept was first proposed at IASDR 2009 [17] and then expanded at EcoDesign 2009 [18] by the authors.

2 APPROACH

Focusing on the particular concept of PSjS, we have used the evolution of users' *Kansei* toward their short/long-lived products over the entire lifetime of products as a framework to clarify the concept. To cover all subjective issues together, the analysis of such an evolution is based on the *Kansei* Engineering approach [19-20]. The entire lifetime of the product from the user's perspective is here divided into three main lifecycle stages: Purchase (P); Keep or Use (KU); and end, throw away or Replace (R). This framework is to approach PSjS experientially and expand it analytically.

Considering the following points, mobile phone, private passenger car and Japanese handicraft or traditional furniture are designated, respectively, as the short and long-lived product cases for this analytical study. The subjective issues of mobile phone are more considerable than other kinds of products due to the users' very close/personal relationship with it despite it being a short-lived product [28-29]. A user's emotional attachment to a mobile phone – rather than other kinds of products – has been reflected in numerous scholarly works [30-33]. There is also a considerable level of attachment between a user and his/her own car [15]. Private passenger car is an approximately long-lived product in Japan [34]. As a private passenger car registers its owner's individual character and social class, a user may have a personal relation with his/her car. But the traditional furniture or handicraft is definitely long-lived product, which are very valuable and respectable for the owners of such objects considering their rich cultural aspects. Nevertheless, these three kinds of products completely vary when considering their function, technology, mobility, status, background and scale beside the user. Within our previous research, the patterns of three groups of Japanese users' *Kansei* evolution over the lifecycle stages of their mobile phone, car and handicraft/furniture were extracted separately and compared between these products [35]. But, here, to comparatively show the trends of PSjS between the short/long-lived products, the responds of these three groups of subjects are analyzed all together.

3 METHOD

To gather the data required for this study, three groups of Japanese subjects (as user/owner of mobile phone, passenger car and handicraft) are investigated through the definite and descriptive questionnaires. The subjects are questioned about their feelings, emotions, images and/or attitudes – namely, their *Kansei* – regarding their products (mobile phones, cars or handicrafts) in each of the three lifecycle stages (P, KU and R) separately in three different questions.

The first group of subjects, as the users of mobile phone, ranged from 15 to 24 years old, were 31% female and 69% male and consisted of 32 students at Chiba University and 17 high school students living in Chiba. The second group of subjects, as the owners of private car, ranged from 49 to 74 years old, were 29% female and 71% male and consisted 18 students' parents or professors of Chiba University. And the third group of subjects, as the owners of handicraft, ranged from 38 to 74 years old, were 33% female and 67% male and consisted of 15 students' parents or professors of Chiba University.

The descriptive words that the subjects used to describe their *Kansei* about their products in the lifecycle stages are summarized into *Kansei* items through the KJ Method [36-37]. The *Kansei* items based on the subjects' responses are processed by using Quantification Theory Type III (QT3) [38] to show their distribution in X, Y and Z dimensions and, accordingly, their major trends. This number of axes for the spatial data derived from QT3 has been decided on the basis of the resulting Eigen values which were more than 0.500. The distribution of the subjects' *Kansei* statuses in the three lifecycle stages of their products would be another output of this QT3 process. To show the trends of the subjects' *Kansei* evolutions over their short/long-lived products' lifetime, the Centers of Gravity of the spatial data relevant to the subjects' *Kansei* statuses in the three lifecycle stages of their products are used as the indictors. Finally, the resulting trends are compared between the short and long lived products.

4 RESULTS

4.1 *Kansei* items distribution

In total, respectively, 626 Japanese *Kansei* keywords (including 278 for the P stage, 212 for the KU stage and 136 for the R stage), 430 Japanese *Kansei* keywords (including 135 for the P stage, 163 for the KU stage and 132 for the R stage) and 269 Japanese *Kansei* keywords (including 119 for the P stage, 90 for the KU stage and 60 for the R stage) were derived from the subjects' responses regarding their *Kansei* about their mobile phones, cars and handicrafts/furnitures in the different lifecycle stages of these products. All of these keywords were summarized into 73 *Kansei* items or descriptive keywords through the KJ method. The subjects' responses about their *Kansei* regarding all three lifecycle stages of their products were adapted to these 73 *Kansei* items and processed by using QT3. The overall output distributions of the *Kansei* items are shown as X-Y and X-Z graphs in Figure 1. Considering the context and distribution of the *Kansei* items in the graphs, the three axes of X, Y and Z are, respectively, named '*Passive Affection – Active Emotion*', '*Pain – Pleasance*' and '*Subjectivity/Attitude – Objectivity/Value*'. The *Kansei* items, their resulting dimensions and frequencies in each lifecycle stage and product type are presented in Table1.

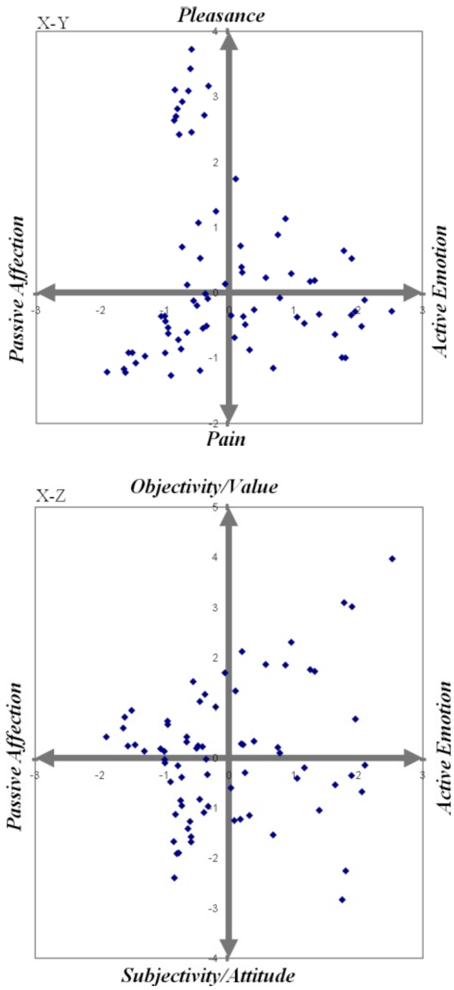

Fig. 1: Distribution graphs of the resulting *Kansei* items

4.2 *Kansei* evolutions over the products lifetime

In addition to the *Kansei* items' dimensions, the other result of this analysis is the spatial data representing the subjects' *Kansei* statuses during P, KU and R lifecycle stages of their products. As the spatial data relevant to the resulting *Kansei* items and the one representing the subjects' *Kansei* statuses are the "sample score" and "category score" derived from of QT3 analysis on the same input data, the same names could be given to the axis directions of their distributions graphs.

Table 2: The *Kansei* items and their dimensions and frequencies in each lifecycle stage and product type

	QT3 Output			*Freq. in Stages*			*Frequency in:*			Total
Kansei Items	**X**	**Y**	**Z**	**P**	**KU**	**R**	*Phone*	*Car*	*Craft*	*Freq.*
Accustomed	0.03	-0.35	-0.60	1	15	0	9	5	2	16
Achievement	0.10	1.74	1.33	17	5	0	9	6	7	22
Anger	0.68	-1.15	-1.54	1	1	2	2	2	0	4
Anxiety	0.79	-0.08	0.09	17	5	4	12	8	6	26
Apology/Shy	-1.50	-0.92	0.94	1	3	4	0	5	3	8
Appeal	-0.80	2.81	-1.91	1	3	0	0	0	4	4
Appreciate	-1.31	-0.97	0.13	0	15	24	15	19	5	39
Attachment	-0.99	-0.44	-0.10	2	22	15	19	9	11	39
Beautifier	-0.84	3.10	-2.40	5	1	0	0	0	6	6
Boasting	2.52	-0.28	3.97	3	0	0	3	0	0	3
Boring	0.25	-0.49	-0.30	4	4	1	6	3	0	9
Cherished	-1.00	-0.36	0.13	4	14	13	19	0	12	31
Comfortable	0.19	0.39	0.28	27	25	4	27	17	12	56
Communicating	-0.95	-0.54	0.73	2	4	1	0	7	0	7
Complain	1.80	-1.00	-2.26	7	7	2	16	0	0	16
Complication	1.64	-0.64	-0.54	18	6	4	28	0	0	28
Curiosity	0.57	0.23	1.86	7	0	1	4	4	0	8
Desire	1.96	-0.29	0.77	7	5	0	12	0	0	12
Discovery	1.90	0.52	3.01	4	0	0	4	0	0	4
Efficient	-0.73	0.70	-0.39	12	15	8	0	21	14	35
Excited	0.96	0.29	2.30	10	1	0	6	5	0	11
Familiarity	-0.65	-0.61	0.32	2	11	5	9	9	0	18
Fastidious	0.22	-0.36	0.26	2	1	0	0	3	0	3
Flaw/Defect	0.32	-0.88	-1.15	1	10	7	9	9	0	18
Fragile	1.05	-0.37	-0.41	2	2	0	4	0	0	4
Freshness	0.87	1.13	1.85	19	0	0	10	5	4	19
Functional	1.17	-0.47	-0.20	37	19	15	60	11	0	71
Good-look	0.76	0.89	0.21	15	6	1	13	0	9	22
GUI	1.89	-0.34	-0.36	6	4	0	10	0	0	10
Happy	-0.21	1.24	1.01	16	2	2	0	14	6	20
Harmonic	-0.32	3.16	-0.97	5	2	0	0	0	7	7
High Quality	-0.85	2.64	-1.67	4	6	0	0	0	10	10
Important	-0.35	-0.51	-0.03	10	8	14	21	11	0	32
Increasing Value	-0.58	3.72	-1.68	0	2	0	0	0	2	2
Indebted	-1.61	-1.22	0.81	0	1	4	0	5	0	5
Individuality	0.39	-0.26	0.33	2	4	2	4	4	0	8
Interested	-0.48	1.07	0.24	12	5	4	0	12	9	21
Longevity	-0.33	-0.09	-0.34	11	27	23	35	14	12	61
Lost/Missed	-0.90	-1.27	-0.48	0	2	5	4	3	0	7
Material	-0.59	2.45	-1.58	4	2	0	0	0	6	6
Memories	-1.06	-0.36	0.18	3	8	11	0	15	7	22
No-accustomed	0.20	0.31	2.12	4	0	0	0	4	0	4
No-boring	-0.65	0.12	0.42	1	8	1	0	7	3	10
Nostalgic	-1.63	-1.17	0.59	0	5	21	11	7	8	26
Novelty	1.40	-0.33	-1.05	12	10	3	18	7	0	25
Old	0.08	-0.69	-1.25	2	12	6	11	6	3	20
Painful/Tragic	-1.90	-1.21	0.42	0	0	6	0	2	4	6
Partner	-0.99	-0.92	-0.04	1	10	9	11	9	0	20
Pet	-0.95	-0.63	0.66	1	3	2	0	6	0	6
Pity	-1.45	-1.08	0.26	0	2	3	3	2	0	5
Pleasure	1.26	0.17	1.76	33	4	2	32	7	0	39
Proportions	-0.39	2.71	-1.09	8	3	0	0	0	11	11
Puzzled	2.06	-0.52	-0.68	8	2	0	10	0	0	10
Realistic/logic	-0.50	-0.20	0.19	6	7	5	0	15	3	18
Reasonable	0.18	0.71	-1.23	9	7	2	8	0	10	18
Regretful	-1.56	-0.92	0.24	0	1	15	0	7	9	16
Relax	-0.63	3.09	-1.42	3	1	0	0	0	4	4
Repair	-0.79	-0.72	-0.16	0	3	3	0	6	0	6
Satisfied	-0.45	0.53	1.12	8	5	5	0	13	5	18
Secure/Reliable	-0.83	2.70	-1.13	3	4	0	0	0	7	7
Sober	-0.60	3.43	-1.27	5	2	0	0	0	7	7
Social/Solidarity	-0.37	-0.02	1.27	2	2	0	0	4	0	4
Strange/Odd	-0.06	0.13	1.69	2	1	0	0	3	0	3
Strong-feel	-0.55	-0.12	1.52	3	3	1	0	7	0	7
Superfluous	2.10	-0.11	-0.15	2	1	0	3	0	0	3
Surprise	1.78	0.64	3.10	3	1	0	4	0	0	4
Tattered/scratched	-0.75	-0.86	-0.85	0	2	4	4	2	0	6
Temporary	1.75	-0.99	-2.83	2	9	3	14	0	0	14
Toy	1.33	0.19	1.72	1	1	0	2	0	0	2
Traditional	-0.73	2.92	-0.96	3	0	0	0	0	3	3
Trouble/Difficulty	-0.41	-0.55	0.22	3	4	2	0	9	0	9
Warmth	-0.78	2.42	-1.90	1	0	0	0	0	1	1
Wasteful	-0.45	-1.19	-0.83	0	4	18	15	7	0	22

Here, the averages of the X, Y and Z dimensions relevant to the subjects' *Kansei* statuses in the three lifecycle stages of their products are considered their Centers of Gravity. The graphs shown in Fig. 2 are built on the basis of the resulting Centers of Gravity to indicate the trends of subjects' *Kansei* evolutions over the lifecycle stages of their products.

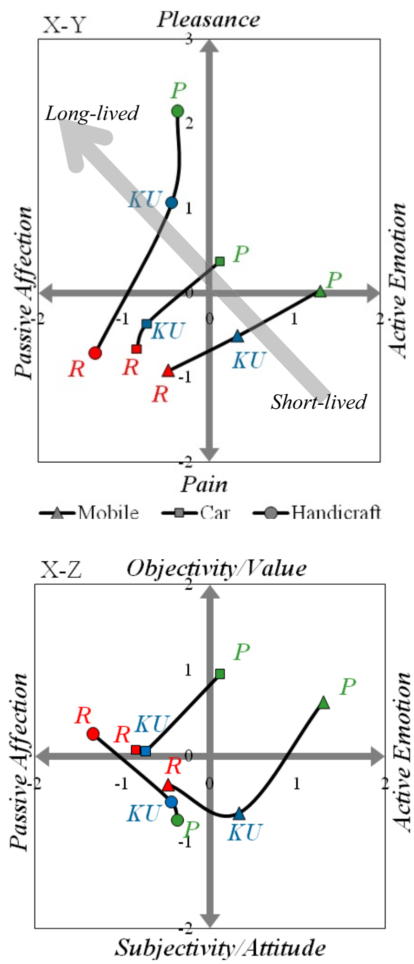

Fig. 2: Trends of *Kansei* evolutions over the lifecycle stages of mobile phone, car and handicraft

5 DISCUSSION

5.1 Trends of *Kansei* evolutions

Comparing the trends of subjects' *Kansei* evolutions between mobile phone, car and handicraft/furniture beside the axes directions of the graphs (Fig. 2), the subjects' *Kansei* statuses in stage R tend to the *Passive Affection* and *Pain* directions regardless to the product type. Regarding all product types, the subjects' *Kansei* statuses roughly evolve from *Active Emotion* and *Pleasance* in stage P to *Passive Affection* and *Pain* in stage R. The subjects' *Kansei* status regarding such short-lived product as mobile phone in stage P tends to *Active Emotion* and borderline of *Pain–Pleasance* directions, while such a status regarding the long-lived products is gradually tending to *Passive Affection* and *Pleasance* directions. Accordingly, the gray arrow highlighted in X-Y graph in Fig. 2 is considered product lifetime scale to indicate the total tendency of users' *Kansei* evolutions in short and long lived products. The subjects' *Kansei* statuses in KU and R stages of their car are so close, probably due to the users' reasons and intentional circumstances of replacing private cars, unlike the other products.

Looking at X-Z graph, the subjects' *Kansei* statuses regarding such definitely long-lived product as handicraft/furniture evolve from *Subjectivity/Attitude* to *Objectivity/Value*, while such trend is reverse in private car. Regarding mobile phone, the subjects' *Kansei* evolution from P to KU stages follows the same trend as car, while such evolution from KU to R stages is reversely following the same trend as handicraft/furniture. The reasons of such dual trend might be the similarities of purchase circumstances between mobile phone and car and replace circumstances between mobile phone and handicraft/furniture. The subjects' *Kansei* statuses in P and KU stages of their handicraft/furniture are so close; probably, because a user's attitude toward such a cultural/traditional object might have no drastic change in these two lifecycle stages.

5.2 *Kansei* structure

The structure of the *Kansei* items from product lifetime and lifecycle viewpoints is visualized into a diagram shown in Figure 3. Overall, considering the *Kansei* items' frequencies in the product types and lifecycle scales, (shown in Table 1) they could be laid in five different levels indicating the state of their generality/particularity. Some of the most frequent *Kansei* items belonging to each level are shown as instance in the diagram.

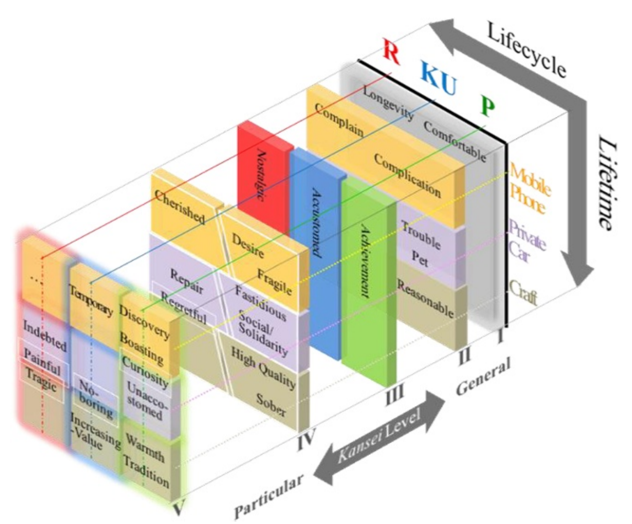

Fig. 3: The levels and structure of the *Kansei* items

The most general *Kansei* items such as Comfortable and Longevity, which a user may have about a product regardless to its lifetime and lifecycle, are placed in the level I. The other *Kansei* items, which are general in the lifecycle stages of more than one product type, could be also laid in this level. The *Kansei* items of level II (such as Trouble and Pet) are specified for a product type (like car) but common in all its lifecycle stages. But the *Kansei* items of level III (such as Achievement or Accustomed) are specified just for a lifecycle stage (such as P or KU) regardless to the product type. Level IV involves those *Kansei* items (such as High Quality and Sober) that a user may have regarding a product (like his/her handicraft) during two close stages of its lifecycle (like P and KU). However, some of the *Kansei* items laid in level IV might be the same for two product types. The *Kansei* items of level V (such as boasting and Discovery) are the feelings that a user may particularly have about a product (like mobile phone) during one of its lifecycle stages (like P).

6 CONCLUSION

The results of this study show that the subjects have had different *Kansei* statuses during the lifecycle stages of their short/long-lived products. Consequently, PSjS is indeed the issue of a user's overall pleasure, satisfaction and/or attachment regarding his/her product by which he/she may experience various/alterable emotions, feelings or moods that evolve from being mostly good, pleasant or dynamically positive to affectively becoming mature throughout the product's expected lifespan. Depending on the product type and its replacement circumstances, such a *Kansei* may evolve from *Subjectivity/Attitude* to *Objectivity/Value* or vice versa.

The *Kansei* structure (Fig. 3) that we arranged could be an initial instrument of guideline for product lifetime management from *Kansei* viewpoint. As those *Kansei* items that are placed in levels IV and V belong to the particular products studied within this research, they could be applied specifically for such products or a similar one to each of them from both lifetime and status points of view. But for a new product in general, the *Kansei* items of level III could be applied. In order to expand such a guideline and its applicability for promoting PSjS, our future research will focus on the design factors associating with each level of the *Kansei* items.

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Using a guide to select design strategies for behaviour change; Theory vs. Practice

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Abstract

In recent years there has been an increased focus on researching the potential environmental benefit from altering the way users interact with products. A number of strategies for how products may be designed to affect the behaviour of the user have been identified. However, there is a need for a guide that may help designers make informed decisions about which strategies to apply.

An ongoing research project at the Norwegian University of Science and Technology is aiming at creating such a guide. The initial phase of the project focused on identifying insight from social psychology regarding the factors that may affect the behaviour of a person. This is used as a framework for suggesting when different behaviour changing design strategies may be most promising. The preliminary result was a set of guidelines, proposing how information about the user or the context may give an indication of which design strategies to apply. This paper is based on the experience of working with the guidelines in a practical design project. The aim of the project was to reduce the environmental impact of behaviour related to oral healthcare, in collaboration with Philips.

Keywords:

Sustainable behaviour, Design guide, Case study

1 INTRODUCTION

In recent years there has been an increasing attention for the environmental consequences of consumption and the need to reduce these [1, 2]. Literature suggests consensus about the large potential for achieving environmental benefits from altering users' behaviour through the way they interact with products [3-7]. Brezet and van Hemel [8] even state that if a product consumes energy, it is the use phase of the product that has usually the largest environmental impact. Within the product design domain, strategies for affecting user behaviour and limiting the environmental impact have been proposed. One example of this is the "Design with Intent" card deck, where 101 behaviour changing design patterns have been collected and printed on cards in order to make them suitable for idea generation [9]. This research has shown the potential and identified design strategies, but there has been limited discussion in literature about when and in which context the different strategies are most likely to be effective. "Ideally industrial designers should be equipped with a decision-making tool, enabling evaluation of alternatives in order to choose the strategies best suited for each project [10].

At the Department of Product Design at the Norwegian University of Science and Technology (NTNU), ongoing research aims at providing designers with a means of making informed decisions about which design principles to apply, to achieve less environmental impact from the usage of products. In an earlier phase of this project, preliminary guidelines for selecting principles have been proposed [11-14]. These guidelines propose a way of translating information about the user and the context to recommendations of design principles. However, these preliminary guidelines have been derived from literature and theory, and have not yet extensively been tested in practical design projects. The project described in this paper, is the first case study where the guidelines have been applied in an actual design project. The focus was on the evaluation of the format of the guidelines and how they fit in with a designer's way of working, and not on evaluating the recommendations from the guidelines. The structure of the paper is as follows: first the preliminary guidelines are presented. Secondly, the case study is briefly described and the challenges regarding the use of the guidelines are pointed out. Finally these challenges are discussed and possible solutions to them are presented.

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2 PRESENTATION OF THE PRELIMINARY GUIDELINES

In 2010 a set of preliminary guidelines for selecting "design for sustainable behaviour" strategies was proposed [11]. The basis for the guidelines is a combination of insight about human behaviour, mainly from the social psychology literature, and insights on how the design of products may affect the behaviour of the user, mainly from literature focusing on design for sustainable behaviour. The starting point is an understanding of the different factors that may affect the behaviour of the user. This can be seen as a central topic in psychology and has been widely described in the literature [4]. The Comprehensive Action Determination Model (CADM) by Klöckner and Blöbaum [15] was selected as a promising entry point to this vast bulk of knowledge (Figure 1). This model describes how human behaviour is affected by a combination of factors categorized as habitual, intentional and situational influences, and in addition indirectly affected by normative processes. Each of these can be divided into a number of sub processes.

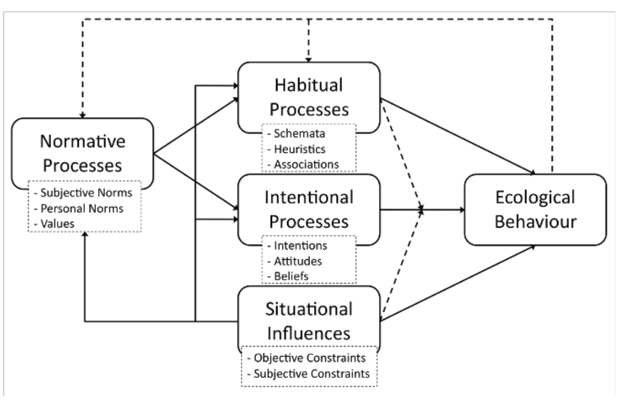

Fig. 1: The Comprehensive Action Determination Model

The theoretical basis for the guidelines is built up by analysing how factors identified by the CADM might be connected to different principles for behaviour change through design. A few common properties of the different design principles were used to enable a comparison between them. The most important of these properties, and also the one most commonly described in literature [16-18], is the distribution of control between the user and the product (Figure 2). At one end of this spectrum there are principles leaving the user in complete control. The user decides if and how the behaviour should be changed. At the other end, the user has no control, and the product forces the user to behave a certain way or causes the behaviour automatically. Between these two extremes, there are many variations of enabling, encouraging, guiding, seducing and steering towards the desired behaviour.

Fig. 2: Distribution of control

Based on the particular factors affecting a user's behaviour, recommendation may be given to how much control this user should have, to achieve a particular behaviour change. Similar recommendations can be given for other properties of the design principles. These recommendations can be combined in a set of preliminary guidelines encompassing the majority of the factors identified by the CADM (Figure 3). The guidelines consist of a number of statements regarding the effects different properties of design strategies can have on the behavioural factors. These statements are accompanied by graphs illustrating the relation between properties of the design principles and the behavioural factors.

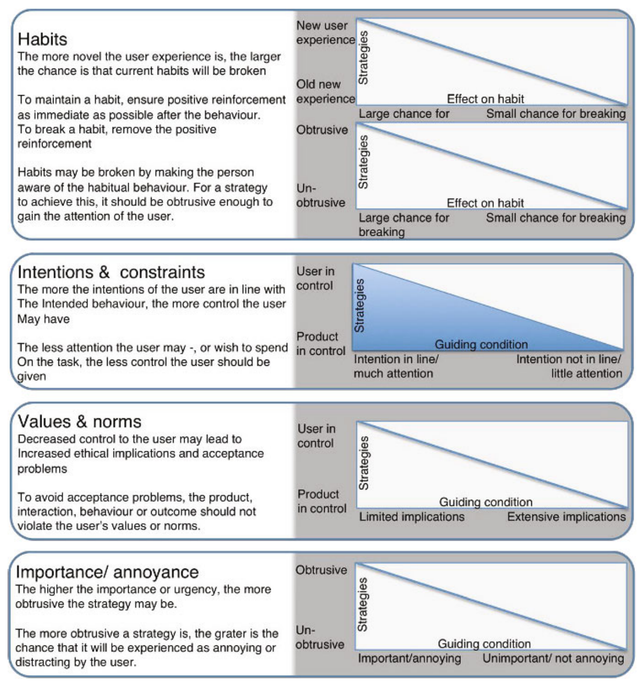

Figure 3. Summary of the preliminary guidelines.

The statements and illustrations are results of a combination of psychological theories and logic deduction. As an example we may consider the first statement of the 'Intentions & constraints'. The statement says that 'the more the intentions of the user are in line with the intended behaviour, the more control the user may have'. This is based on the ABC theory [19] and the following logic deduction: For a user to be willing to make the effort to change his behaviour based on information or feedback, which is the 'user in control' end of the control spectrum, the user should have some motivation to do so. If we move down towards the middle of the control spectrum, we find that the intended behaviour is the easiest or it is more difficult not to behave that way. We can then expect that not only users who find it easy to do what they wish may behave the desired way, but also those how have no strong opinion about the matter. Why should they make the extra effort of behaving differently, if they have no motivation to do so? However, users who have an opposing intention to the desired behaviour, may make that effort, and thus can we not expect to see any behaviour change among this group. If we consider the end of the spectrum where the user has no control, all users are being forced to behave the desired way, and we can expect the desired behaviour change for all users. However, as stated in some of the other guidelines, there may be other complications related to leaving the user completely without control.

3 THE CASE STUDY

As the guidelines so far had a purely theoretical basis, a project was initiated to test their practical application, in order to validate whether they actually are capable of pointing out promising design principles and to make sure the way the guide is presented accommodates the needs and desires of the designer. The focus of this paper is on the latter; i.e. to investigate the user friendliness of the guidelines. This order is useful, as improving the format of the guidelines will not only improve the usability of the guide, but will also enable easier and more extensive application in future design projects, when the quality of the recommendations will be tested. However, as this paper only describes a single case study, the results should rather be considered as input to the development process than as final results.

The project described in this paper is a master thesis project at NTNU, in collaboration with Philips Research in Eindhoven, The Netherlands. The topic of the project was sustainable behaviour in the context of oral health care.

In this project the oral health care practices of a target group of Norwegian or Dutch citizens within the age of 25-35 and 50-65 was investigated by using a combination of several user-centred-design research methods: interview, overt observation, covert observation (video recording), cultural probing, survey, generative sessions and a blog analysis. This resulted in a rich base of information concerning how the oral health care was conducted and the various factors that affected this behaviour. Structuring and analysis of the data could then be used as the input for the guidelines and should enable the identification of the type of design principles that would be most likely to have the intended effect. The scope of the project made it suitable to evaluate the structure of the guide, as it included an extensive user research and aimed to translate this into behaviour changing design solutions.

The exercise of structuring the data and applying the guidelines identified a number of problematic aspects of the guidelines. These are summarized in the following list of challenges, which will be more extensively discussed in section 4. However, it should also be noted that the guidelines did provide valuable support during the project and did show a potential encouraging future improvements.

3.1. The process.

Early in the project, it became apparent that it was unclear where in the process of designing for behaviour change, the guidelines were supposed to be applied. This became particularly clear when preparations were made for a creative workshop to generate ideas for design solutions. Either, the guide could be used to limit the selection of possible design strategies before generating ideas, or it could be used to evaluate the ideas and identify their potential after they had been generated. The advantage of limiting the solution space before generating ideas could be to have a more focused idea generation process and avoid a lot of time and energy being spent on ideas that easily could have been dismissed beforehand. On the other hand, such a narrowing of the solution space could exclude the potential of promising concepts being inspired by ideas that originally were unsuitable. In this project, the guide was primarily used to evaluate the ideas after the workshop. However, the overview of the different factors that may affect behaviour was used as a checklist during the user studies and preparation of the workshop, to make sure that all the factors had been investigated. This may perhaps also be a third way of using the guide, which might prove to be valuable also in future versions. To ease the use of the guide, there is a need to explain where it is intended to be used in a design process. Possibly, suggestions should also be made for tools or methods focusing on other parts of the process, which the guidelines may be combined with.

3.2. The factors.

The behavioural factors identified by social psychology, as for instance presented in the CADM, can be difficult to grasp for designers within the limited time they normally have at their disposal. One of the primary reasons for this is probably the level of detail and distinction between different concepts that are unfamiliar for designers. For instance, it cannot be expected that designers are familiar with the difference between the different forms of habits: schemata, heuristics and associations. Such distinctions may be unnecessarily complicated, as the guide also does not distinguish between the different types. Rather than trying to distinguish between attitude, beliefs and intentions, it might be sufficient to figure out the intentional factors, or “what the user wants”. After all, the factors are connected in a hierarchical structure where intentions are affected by attitudes, which again are affected by beliefs [20]. It might, however, be useful to distinguish between these three when analyzing how a particular intention may be changed. The understanding of the hierarchical relation can help understand that addressing the underlying attitude may change an intention, and similarly between attitudes and belief. A simple explanation of these relations should be included in the guide.

In addition to experiencing difficulties with structuring the information according to all the individual factors identified by the CADM, the format of the recommendations given by the guide was experienced as unclear and a bit hard to grasp. In particular the illustrations were not clear and should be presented in a simpler manner.

3.3 Conflicting factors.

As the guidelines identify promising design strategies according to specific information about the user or the context, the recommendations will vary depending on the target group and which factors one identifies as the steering once. There may be variation in which part of the behaviour it is relevant to address and which factors affect the behaviour the most. The designer will have to select the most important once and use these as the input to the guide.

Also, in some cases the suggestions by the guidelines may be in conflict. This can be illustrated by a case from the project. A group of users was characterized by their value of having to control the world around them. According to the guide, this indicates that the designer should strive to find solutions where the user is in control. However, within this group a number of users believed that they should rinse their mouth thoroughly with water after brushing their teeth, to improve the oral healthcare. This is a misconception, as it actually is desirable to leave the remains of the toothpaste in the mouth to gain maximum benefit from the fluoride. As the user therefore wants to do the opposite of the desirable behaviour, the guide suggests design principles where the user does not have much control. The two suggestions from the guide are in conflict as the designer is recommended to make sure the user is in control, and take away the control of the user.

4 DISCUSSION

As the designer experiences these problems as obstacles for applying the guidelines it is essential to solve them. Not only to enable future testing of the validity of the guidelines, but also to accommodate for the use of the guidelines in real projects. In the following section, each of the problems identified in the project will be addressed and possible solutions will be suggested.

4.1 The process.

To ensure that it is clear which part of the process of designing a behaviour change the guidelines are meant to address, an overview over a design process with the relevant areas highlighted could be accompanying the guidelines. Two versions of such overviews have been presented [12, 14]. However, one primarily focuses on the logic behind the guidelines itself and the other only looks at how the guidelines may be integrated with one other framework. A more holistic overview including a greater part of the design process and suggestions to supporting frameworks would be valuable. Figure 4 presents a suggestion to a process of designing a behaviour change.

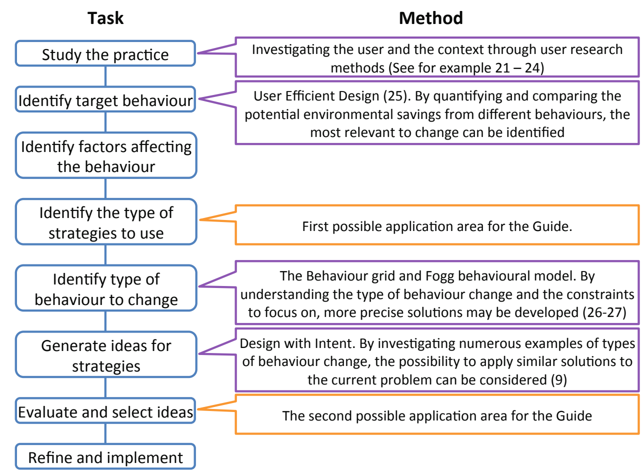

Figure 4. A sketch of a design process with suggested additional methods [9, 21-27]

4.2 The factors.

Both the amount and names of the factors in the preliminary guidelines are imported from the CADM model. These are selected to describe the reasons for behaviour in the best possible way, and not to accommodate a design project with strict time limitations. The number of factors and naming was know as a potential problem, but was not addressed particularly in the preliminary guidelines, as this had to be documented first. In addition, if the number of factors is reduced, there is a risk that valuable nuances between the factors are being lost. One way of coping with this might be to maintain the distinctions of the CADM, but only consider the factor categories instead of the individual factors. After all, as described in the CADM the factors in each category are closely related. This has to a certain degree already been done, as can be seen in figure 3, where for instance there is no distinction between the three different types of habits. However, as no distinction between the three is made in the recommendations found in literature regarding how to address habits, a distinction in the guide will not enable any additional recommendations. Thus may such a distinction only increase the complexity without providing any benefits, and should rather be left out of the guide. And after all, product design has a long tradition of simplifying methods from other disciplines to accommodate the needs of the industry. It is more important to get quick answers rather than precise ones [22]. This will have to be considered further when reviewing the results of future case studies.

As for the naming issue, this can be the subject of improvements through all the iterations of the development process. It is crucial that the designer feels comfortable with the terminology, at the same time as it is important to maintain the distinctions and the precision of the original terms. This might be achieved by using more everyday language and possibly substitute single words with short, descriptive sentences. An alternative presentation of the guide could be as following, with added explanation of the terms, simplified illustrations and reformulation of the recommendations:

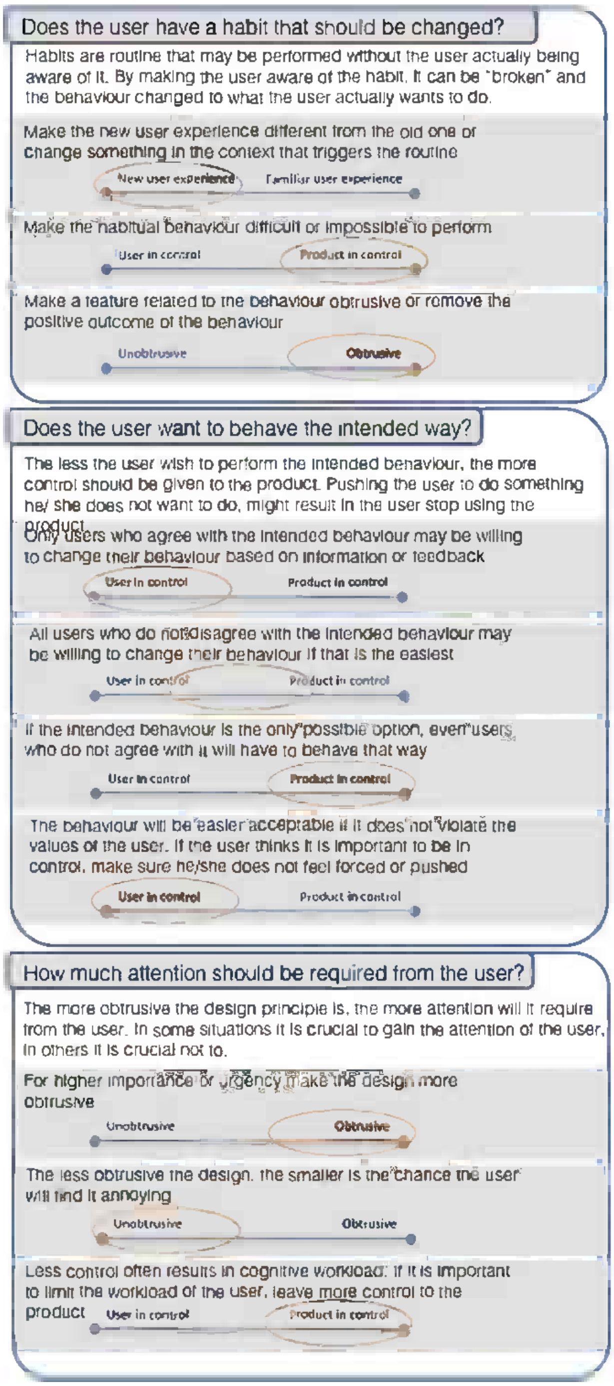

Figure 5. An alternative way to present the guidelines

4.3 Conflicting factors.

Based on this one case study, it is impossible to predict how great a problem conflicting factors may be. If future case studies uncover that this is a frequently occurring problem, it might require radical changes to deal with it. Perhaps is it necessary to develop some system to navigate between the conflicting factors, or change the entire structure of the guide. However, before any such measure can be motivated or informed, substantially more experience is required.

For the specific problem described in the example from the project, there is a difference in the types of factors that causes the problem. The wish to control the world around oneself is a value or norm, whereas the wish to rinse the mouth to improve the oral health care is based on the belief that this is the right thing to do. As norms and values are stable over time [28], it may be difficult to change the wish to control the world. However, the belief that one should rinse the mouth thoroughly may be possible to change, and may be both desirable and ethically responsible, as it is a misconception. This could be addressed by providing evidence that the belief is erroneous. This will not only remove the conflicting factor, but also make the user more willing to change their behaviour.

5. CONCLUSIONS

The project described in this paper, was primarily used to improve the usability of the guide. If it is easier to apply the guide in design projects, there may be fewer barriers to gaining more experience from other case studies. Thus will it be both easier to test the validity of the recommendations, and the testing will be more reliable, as there is a smaller chance of interference from usability issues. The guide, and the improvements suggested in this paper, should also be presented in a format that is easy to work with and provide an overview. Considering the amount of information and diversity of topics, a small booklet might be a suitable format. This could include both the guide, explanation to the process, instructions of how to use the guide, examples of design principles and introductions to other methods the guide could be combined with.

The development of the Design Behaviour Guide will need to go through several iterations to improve the quality of the recommendations and user friendliness of the guide. This paper describes the experiences from one case study, based on a single master project. The identified problems and the suggested solutions should thus be considered as input and a single iteration, and not as final by any means.

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System Design of Maintenance Service for Distributed Production Facilities

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Abstract

Maintenance is fundamental service for the manufacturing industry to increase the performance of production facilities from both economic and environmental perspectives. This paper proposes a simulation-based method that supports maintenance service design of distributed production facilities from a system-level perspective. The simulation result shows relations between the productivity of distributed facilities and total maintenance service cost considering system constraints such as the availability of maintenance engineers. The paper shows how the simulation model is developed on a Service CAD integrated with a life cycle simulator.

Keywords:

maintenance, system design, simulation

1 INTRODUCTION

Manufacturing is one of the most energy and resource intensive processes in the global economy. Sustainable manufacturing is a crucial concept for the decrease of environmental impacts created in life cycles of products [1]. Various systematic methods for sustainable manufacturing have been proposed, which include reconfiguration of manufacturing systems [2] and design of closed-loop flows of products and reusable modules [3].

For the manufacturing industry, systematic design and management of innovative service offerings in product use stage (e.g., pay-per-function and product sharing) have gained attentions [4]. Among these service offerings, especially for production facilities such as machine tools and industrial robots, maintenance service plays a crucial role in the decrease of cost and energy usage in the life cycles as well as the increase of quality of products [5].

Recent studies analyzing maintenance service from a life cycle perspective focused on single production facility (e.g., [5]). These studies considered systemic aspects in the analysis such as trade-off relations between the cost of maintenance service and that of other activities in life cycles of products (e.g., operation). However, product and process models used for the analysis could not sufficiently deal with constraints on maintenance service for multiple facilities such as the availability of maintenance engineers and spare parts. Such constraints often appear when the number of production facilities is large relative to that of the service resource owned by service providers. This is why maintenance service design considering such constraints seems to be useful for small-middle enterprises (SMEs) of machine tools and industrial robots with limited resources, which are installed on distributed production plants of diverse manufacturers.

Traditionally, supply chain logistics including system-level constraints have been modeled and studied with such techniques as mathematical programming (e.g., [6]) and material flow analysis (e.g., [7]) for the analysis and optimization of resource flows. However, these techniques could not deal with complex behavior of production facilities in the use stage.

Life cycle simulation (LCS) is a technique to simulate the behavior of a large number of products in a market [3]. LCS can deal with a variety of product-related service (e.g., maintenance and upgrade) offered by manufacturers and service providers. System-level constraints can be included in LCS in order to apply LCS to the design of maintenance service from a system-level perspective.

This paper analyzes maintenance service system design for distributed production facilities. The analysis is conducted with a modeling tool for LCS called Service CAD integrated with life cycle simulation (ISCL) [8]. ISCL is equipped with a service modeling technique to build discrete event simulation of the life cycle of production facilities. The simulation model includes a system-level constraint representing the number of maintenance engineers. With a case study, the paper analyzes how the constraint and related parameters of maintenance service influence the productivity of production facilities, while simulating the occurrence of physical deterioration of distributed production facilities and the shortage of maintenance engineers.

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The rest of the paper is organized as follows. Section 2 clarifies the concept of maintenance system design discussed in the paper. Section 3 proposes a maintenance system model based on the concept and describes the procedure to build the model on ISCL. Section 4 presents a simulation model developed for a case study and its results. Section 5 summarizes the study and draw conclusions.

2 MAINTENANCE SERVICE SYSTEM DESIGN

In order to clarify the maintenance service system discussed in the paper, it assumes an enterprise that offers maintenance service for a large number of distributed production facilities. The main constituents of the model of a maintenance service system are system performance indicators, deterioration behavior of production facilities, maintenance options, and maintenance resource as constraints on the system.

System performance indicators

System performance indicators are necessity to evaluate the performance of a maintenance service system offered by the enterprise from a system-level perspective. This means that system-level performance should be dependent on the performance of individual production facilities. The average of productivity, energy usage, and life cycle costs of all production facilities are examples of system performance indicators.

Deterioration behavior of production facilities

Accidents such as breakdowns and failures of production facilities are causes of system performance deterioration. These accidents happen to individual facilities at different timing in their lifetime. The influence of these accidents on the performance of facilities can be defined by the magnitude of performance deterioration due to the occurrence of accidents. Given these accidents as stochastic events, the occurrence of accidents can be defined with probabilistic variables. The accidents introduced here is similar to risk of an event defined in terms of its probability and effect.

Maintenance options

This study focuses on the fundamental aspect of maintenance service that it improves the performance of facilities. Maintenance service can be classified into two types regarding execution conditions. First, preventive maintenance is performed following given schedules. Second, corrective maintenance is performed when the performance of facilities is deteriorated.

Resource constraints

The enterprise may not be able to distribute maintenance resources such as skilled maintenance engineers to each production facility. The number of these engineers is regarded as capacity of the enterprise. This is why a maintenance service system has to be designed considering such resource constraints.

3 MODELING AND IMPLEMENTATION

3.1 Modeling procedure

This section explains the model of a maintenance service system based on the concept introduced in Section 2. The model is implemented on ISCL and simulated with LCS.

Product facility model

A production facility is regarded as a discrete system, whose behavior is characterized with performance deterioration due to usage and performance recovery as a result of maintenance service. In this study, it is assumed that the performance is measured with respect to several major failure modes, and the modes are defined before this modeling procedure. The state of a production facility k is defined by a set of performances with respect to failure modes.

$$s_k(t) = (p_1(t), \dots, p_i(t), \dots, p_M(t)) \tag{1}$$

Where, p_i is the performance measured in terms of failure mode i, and M is the number of given failure modes.

Performance deterioration model

Performance deterioration is dynamic behavior occurred to individual production facilities with respect to failure modes. Events causing performance deterioration such as failures and accidents are defined by the probability of occurrence r_i and its effect d_i with respect to a failure mode i. The effect indicates the magnitude of performance deterioration.

$$p_i(t+1) = p_i(t) - d_i \; [if\; r < r_i] \tag{2}$$

Where, r is a random variable between 0 and 1.

Maintenance service model

Maintenance service is defined by the condition and consequence of the occurrence. The condition is defined by the performance of production facilities with respect to failure modes (for corrective maintenance) and/or given maintenance schedule (for preventive maintenance). The consequence of maintenance service is described by the recovery of performance m_i and the increase of maintenance service cost, which depends on the total number of maintenance service n_i. Equations 3 and 4 formalize the consequences of an occasion of maintenance service with respect to failure mode i.

$$p_i(t+1) = p_i(t) + m_i \tag{3}$$

$$n_i(t+1) = n_i(t) + 1 \tag{4}$$

Performance model

In this paper, productivity of a set of production facilities at a system level $P_{SYS}(t)$ and the total maintenance service cost $C_{SYS}(t)$ are regarded as the performance indicators of a maintenance service system.

First, $P_{SYS}(t)$ is defined by the average productivity of individual facilities $P(t)$. The relation is formulated in Equation 5.

$$P_{SYS}(t) = \sum_{k=1}^{N} P_k(t)/N \tag{5}$$

Where, N is the number of production facilities.

The productivity of a production facility $P(t)$ is defined by the product of $p_i(t)$, i.e., the performance of the facility with respect to failure mode i.

$$P(t) = \prod_{i=1}^{M} p_i(t) \quad (6)$$

This formulation assumes that failure modes are independent one another. The system-level productivity at specific period T is defined by the time average of $P_{SYS}(t)$.

$$P_{SYS,T} = \sum_{t=1}^{T} P_{SYS}(t)/T \quad (7)$$

Second, the maintenance service cost $C_{SYS}(t)$ is the sum of maintenance service cost for each facility $C(t)$.

$$C_{SYS}(t) = \sum_{k=1}^{N} C_k(t) \quad (8)$$

Maintenance service cost for a production facility is the inner product of unit maintenance service cost c_i and the number of occurrences of unit maintenance service n_i with respect to failure mode i. In case of preventive maintenance, the product of the cost of a visit to facilities and c_p the number of visits n_p is added to the maintenance service cost.

$$C(t) = \sum_{i}^{M} (c_i \cdot n_i(t)) + c_p \cdot n_p(t) \quad (9)$$

This formulation asusmes that unit maintenance service cost is a constant, but that the number of the occurrences of maintenance service is a dynamic variable. The total maintenance cost accumulated during specific period T is defined in Equation 10.

$$C_{SYS,T} = \sum_{T} C_{SYS}(t) \quad (10)$$

A resource constraint

As a system-level constraint in the propose model, the number of maintenance engineers R is introduced. The constraint is described with the following inequality relation.

$$\sum_i e_i(t) x_i(t) \leq R \quad (11)$$

Where e_i is the required number of engineers for maintenance service for failure mode i, and x_i is the number of facilities, to which the maintenance service is offered. Due to the constraint, the priority of maintenance service types should be defined. For instance, maintenance engineers are first delivered to facilities suffered from severe accidents then delivered to those suffered from light accidents.

3.2 Implementation on ISCL

Fig. 1 shows the implementation of the model on ISCL, which is used in the cased study described in Section 4. The model consists of Entities, Attributes of entities, Activities, and Scenes.

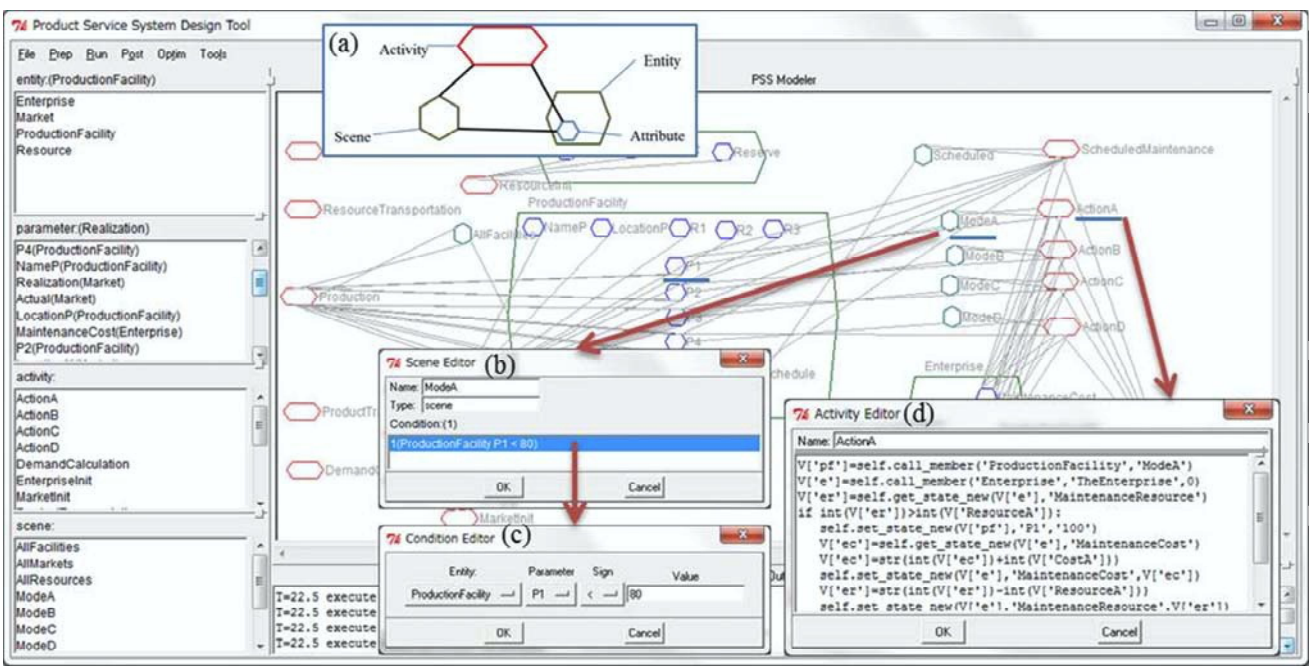

Fig. 1: Implementation of a maintenance service system model on ISCL

Entities are physical elements in the model. This study focuses on two entities in Fig. 1, *Production facility* and *Enterprise*. In the simulation, instances of these entities are created. In the case study, 500 *Production facility* instances and an *Enterprise* instance are created.

Attributes of *Production facility* define the state with respect to failure modes (i.e., *P1* in Fig. 1) and other parameters assigned to each failure mode (e.g., condition of the occurrence and effect). Individual *Production facility* instances have their own state.

Activity represents all kinds of processes in the life cycle of *Production facility* (ex. manufacture, use, maintenance, other services etc.). As a result of executing these processes, *Production facility* instances are created (removed) and the state of individual instances is updated. Each activity is described by its condition and consequence. Quantitative and probabilistic information is supplied to the definition of consequence. The condition is defined with Scene explained below.

Scene is defined by the partial state of *Production Facility* as execution condition of Activities. For instance, there is a link *ActionA(Activity) – ModeA(Scene) – P1(Attribute)* in Fig. 1. *ModeA* is defined by an inequality relation about *P1* (i.e., *P1*<80) and it is connected with *ActionA* (see Fig. 1 (b) and (c)). This is interpreted as "Maintenance service A is offered for all production facilities, whose performance *P1* is lower than 80".

Fig. 2 shows relations between model elements on ISCL. Table 1 details these relations. Relations 1 and 2 correspond to the definition of Scene, Relation 3 to the condition of Activity, and Relations 4-8 to the consequence of Activity. Visible relations on ISCL are generated based on the model description defined either with dialogs (e.g., Fig. 1 (b) and (c)) or programs on text boxes (e.g., Fig. 1 (d)). Parameters and performance indicators are defined with a separate window shown in Fig. 3. With ISCL, the users of the simulation model do not need to look at the detail of the simulation model developed by the modeling experts.

Table 1: Meaning of relations defined on ISCL

	Relation	Connected when
1	Scene-Entity	Scene includes all instances of Entity
2	Scene-Attribute	The value of Attribute is included in the definition of Scene
3	Activity-Scene (1)	Scene is regarded as the execution condition of Activity
4	Activity-Entity (1)	Activity creates instances of Entity
5	Activity-Entity (2)	Activity deletes instances of Entity
6	Activity-Scene (2)	Activity refers to an instance of Entity specified by Scene
7	Activity-Attribute (2)	Activity gets the value of Attribute
8	Activity-Attribute (3)	Activity sets (changes) the value of Attribute

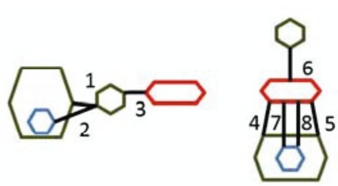

Fig. 2: Relations between models elmeents on ISCL

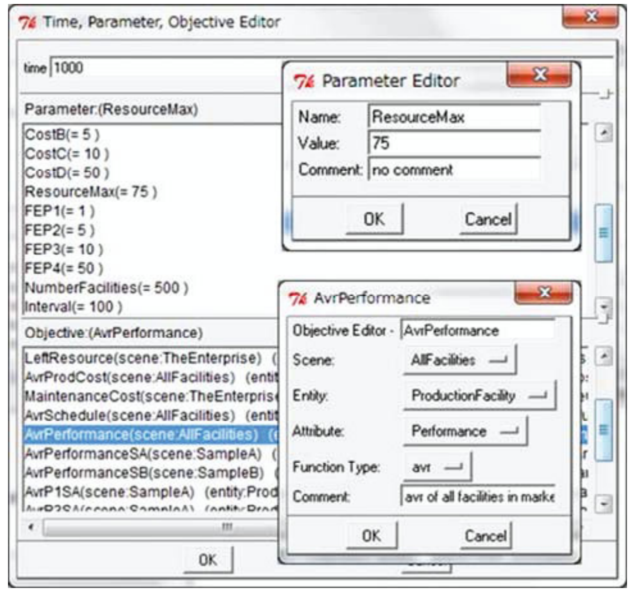

Fig. 3: Windows to define parameters and performances

4 A CASE STUDY

4.1 Simulation settings and assumptions

This study assumes production facilities with four independent failure modes (i.e., *M*=4) and four types of accidents I-IV. Table 2 shows the parameter values of individual accidents explained in Section 3. It is assumed that the cost of visiting production facilities for preventive maintenance is 1 regardless of the state of facilities.

The attributes of production facilities representing the performance with respect to the failure modes are named *P1-P4* in Fig. 1, which corresponds to accidents I-IV. The initial value of these performance is 100. The value may decrease at the occations of accidents at production (i.e. use of production facilities) and recovers at maintenance service, each of which is named *Action A-D* (for corrective mainteannce) and *Scueduled Maintanance*. The activation conditions of maintenance service is defined in Table 3 and the interval of preventive maintenance as one of the simulation parmeters in Table 4.

Table 4 shows 10 scenarios simulated in the case study. These scenarios are defined by three critaria, (A) whether corrective mainteanance is offered or not, (B) whether preventive mainteanance is offered or not and the interval of priventive maintenance (if it is offered), and (C) the number of maintenance engineers as a system-level constraint. The selected values of the interval (100 and 200) were calculated based on the average decrease of perforamnce 0.05 (the product of r_i and d_i) and the difference bbetween the initial value (i.e., 100) and thersholdes defining the conditions of maintenance service in Table 3 (i.e., 80 and 90). The number of facilities is 500. The number of simulation steps, which characterizes the specific interval of the study *T*, is 1000.

Table 2: Parameters of accidents and recovery

i	r_i	d_i	e_i	c_i
I (very light)	1/20	1	1	1
II (light)	1/100	5	5	5
III (modest)	1/200	10	10	10
IV (severe)	1/1000	50	50	50

Table 3: Activation conditions of maintenance service

Description	Condition
Corrective maintenance	$p_i(t) \leq 80$
Preventive maintenance	$p_i(t) \leq 90$

Table 4: Simulated scenarios

Index	A	B	C	Index	A	B	C
1	Yes	No	100	6	Yes	100	75
2	Yes	No	75	7	No	200	100
3	Yes	200	100	8	No	200	75
4	Yes	200	75	9	No	100	100
5	Yes	100	100	10	No	100	75

4.2 Simulation validation

The simulation model has been tested for model validation. The test model excluded preventive maintenance, and the threshold of corrective maintenance was set to 100. This means maintenance service is immediately offered at the occurrences of accidents regardless of the failure modes. Under the situation, the expected value of maintenance cost of a production facility was 0.2 (0.05 for each failure mode calculated by the product of $\boldsymbol{r_i}$ and $\boldsymbol{c_i}$ in Table 2). Since the total number of production facilities is 500, the total maintenance cost per time step is 100. Fig. 4 shows the progress of total maintenance cost (Y-axis) with respect to simulation step (X-axis) as a simulation result of the test model. The simulation result showed the validity of the developed model.

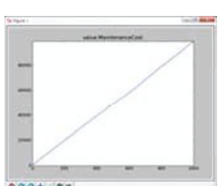

Fig. 4: Validation of the simulation model

4.3 Simulated behavior

Fig. 5 and Fig. 6 show the performance (Y-axis) with respect to simulation step (X-axis) under the scenario 3. They show deterioration and recovery of the performance of a production facility (individual) with respect to failure modes I and III, and that of the average of 500 production facilities, respectively. They show the timing of periodical maintenance (P) and corrective maintenance (C). In Fig. 5, two occasions of preventive maintenance were found. In Fig. 6, several occasions of both corrective maintenance and periodical maintenance were found. The average behavior of 500 production facilities seemed to converge with simulation progress.

Fig. 7 shows the number of maintenance engineers (Y-axis) after allocating them to production facilities at every simulation step (X-axis). The number was always bigger than 0 during the simulation. This is why the number was sufficient to offer maintenance service under the scenario.

Fig. 8 shows the productivity of a specific facility and that of the average of 500 facilities with respect to simulation step (X-axis). Fig. 8 shows performance deterioration at all failure modes I-IV.

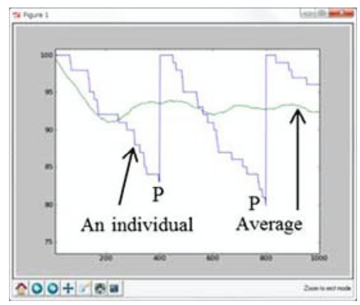

Fig. 5: Performance of a production facility and the average of 500 facilities (failure mode I)

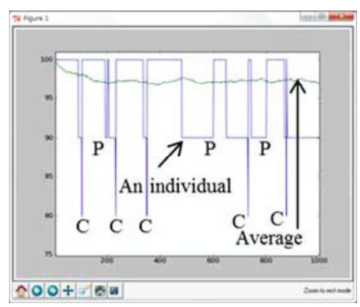

Fig. 6: Performance of a production facility and the average of 500 facilities (failure mode III)

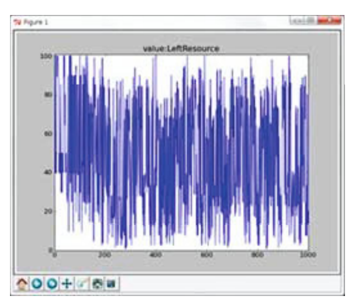

Fig. 7: The number of maintenance engineers left

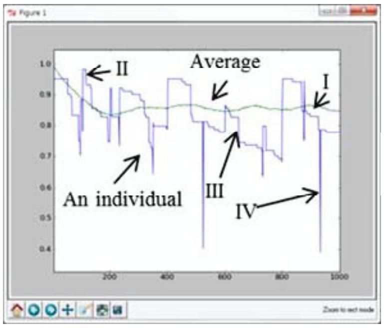

Fig. 8: Productivity change with simulation progress

4.4 Simulation results

Table 5 shows the simulation results of 10 scenarios in Table 4. In Fig. 9, C_{SYS}, (i.e., the average of the cumulative maintenance service cost) and P_{SYS} (i.e., the time average of the average performance of production facilities) are plotted on X-axis and Y-axis, respectively.

In general, the maintenance service cost increases as the productivity increases. The productivity is higher and less sensitive to the number of maintenance engineers when corrective maintenance is included (comparing pairs 1-2, 3-4, 5-6 with pairs 7-8 and 9-10). The shorter interval of maintenance service leads to higher productivity, when predictive maintenance is included (comparing pairs 5-6 and 9-10 with pairs 3-4 and 7-8). However, a ratio of the productivity over the maintenance service cost is higher with longer maintenance service interval.

Table 5: Simulated results

Index	$C_{SYS,T}$	$P_{SYS,T}$	Index	$C_{SYS,T}$	$P_{SYS,T}$
1	5.32	86.1	6	5.63	87.9
2	5.25	85.2	7	4.34	78.5
3	5.14	86.1	8	3.96	75.2
4	5.11	85.3	9	5.64	84.8
5	5.92	88.9	10	5.10	80.1

$C_{SYS,T}$:Maintenance service cost [10^4],

$P_{SYS,T}$: Productivity [%],

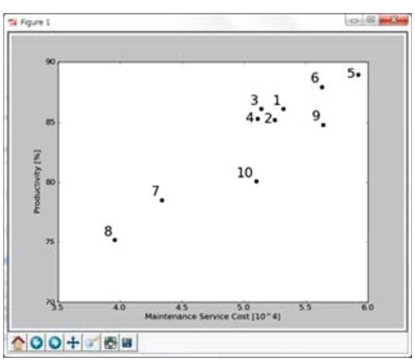

Fig. 9: Maintenance service cost vs. productivity

5 SUMMARY AND CONCLUSIONS

This paper has proposed a simulation-based method that supports maintenance service design of distributed production facilities. The simulation result has shown relations between the productivity of distributed facilities and total maintenance service costs, while considering physical deterioration of facilities and availability of maintenance engineers. With the method, providers of maintenance service can qualitatively assess and design a maintenance service system with higher productivity with lower maintenance service cost. It has shown the procedure to build the simulation model on ISCL and shown how a service modeling technique is used with a specific simulation-based method for the service design in life cycles of products such as LCS. Simulation-based design of a maintenance service system like one presented in this paper is crucial for the early assessment of product-related service from a system-level perspective.

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Ecodesign through Environmental Risk Management: A Focus on Critical Materials

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Abstract

This paper presents an approach to Ecodesign based on the management of environmental business risks, which are defined as 'stakeholder responses to environmental impacts with the potential to cause harm to business objectives'. Case studies are used to demonstrate the approach, with a particular focus on the management of critical materials. The paper concludes that by using risk, environmental considerations can be integrated into design decisions at Rolls-Royce, although the method contains significant uncertainties. In particular, the paper highlights the complexity of both assessing the supply risk of a material and how this could translate into an impact on the business. The paper also discusses how the risk model could be expanded to address other environmental business hazards.

Keywords:

critical materials, risk, environmental risk, life cycle management

1 INTRODUCTION

Rolls-Royce provides power systems and services for use in the air, on land and at sea, focusing on four main markets: civil aerospace, defence aerospace, energy and marine. Predominantly, although not exclusively, Rolls-Royce's products are based on the gas turbine engine.

The nature of Rolls-Royce's products present several unique barriers to the implementation of ecodesign approaches:

1. Environmental impacts from the 'in-use' phase dominate over the product life cycle. Understandably this is the focus for addressing environmental impacts, although this also means that environmental impacts from other phases of the life cycle can be overlooked.
2. Rolls-Royce's products are designed to have an operational life of up to 50 years. Environmental problems can change significantly in this time and it is difficult to foresee what the next problem might be.
3. Rolls-Royce's products are technically mature. There is very little design freedom to make non-use phase environmental improvements.
4. Due to the safety critical nature of Rolls-Royce's products, the company uses rigorous design systems to verify product designs against well defined requirements. At the present time, non-use phase environmental impacts are not comparable within the traditional design space, which means they are largely ignored.

Risk management is used within the Rolls-Royce design system to identify hazards that can impact on design and other business objectives. By translating environmental impacts into an assessment of business risk, barriers to ecodesign can be overcome and non use-phase environmental impacts considered within the design process. This paper presents two case studies that test an approach to ecodesign based on the management of environmental risks. The case studies focus on the use of critical materials, which is linked to the abiotic resource depletion environmental impact category.

As risk is a broad term, the paper first defines what is meant by 'environmental business risk'. Materials criticality is then introduced as a significant risk, using an approach developed by the European Commission to highlight materials that are of concern. Based on knowledge of where these materials are used in Rolls-Royce's products, case study risk assessments are then presented, which show how the risks posed by materials criticality can be incorporated into standard design decisions. The paper discusses the practicalities of the risk based approach, in light of significant uncertainties that will be inherent in any system that seeks to look into the future. The paper also discusses how the risk model could be expanded to address other environmental business hazards.

2 ENVIRONMENTAL RISK MANAGEMENT

Environmental risk management adopts a business risk perspective, concerned with identifying hazards that can impact on business objectives [1]. It is based on the

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observation of a cause-effect cycle between the environmental impacts of a business' operations and products and stakeholder responses to these impacts (whether they are actual, potential or perceived) which seek to reduce them and can impact on business objectives [2]. The stakeholder responses to environmental impacts, with the potential to cause harm to business objectives, are defined as 'environmental business hazards'. The environmental business risk is a product of the likelihood of a hazard occurring and the impact it would have on business objectives if it did. There are many sources of environmental business hazard, regulation being a primary example.

Business risk is assessed against objectives, which are generally based upon the provision of products and services and the revenue this provides. It follows that, to assess the risk posed by environmental business hazards, it is necessary to understand how hazards impact on the ability of the business to make and sell products. Risk can be assessed by connecting some feature of the hazard with a feature of the product. Appropriate mitigating actions can then be implemented.

3 CRITICAL MATERIALS: A SIGNIFICANT ENVIRONMENTAL BUSINESS HAZARD

A significant environmental business hazard that has been the subject of recent attention is 'critical materials'. The phenomenon is concerned with constraints being placed on the accessibility of material commodities as a result of geological, political and economic factors. Whilst it is not purely an environmental problem, the depletion of abiotic resources is a common impact category within life cycle impact assessment [3], and it falls within the definition of an environmental business hazard.

There are two *"dimensions"* of materials criticality [4]:

1. Supply risk: identifying and applying factors that can be used to assess the risks to the supply of a material.
2. Economic importance: an assessment of how important the use of a material is in meeting economic goals, which can be also be assessed at a business level e.g. restrictions in the availability of materials can also restrict the ability of a business to make a product.

A material is referred to as critical when it has a high supply risk and is of high economic importance.

The two dimensions of materials criticality need to be applied to understand the business risks posed. These can be achieved through the:

1. Identification and application of a method for assessing supply risk, which identifies materials of concern.
2. Connecting these materials with uses in products to evaluate the risk posed to business objectives.

3.1 Assessing supply risk

Several different methods have been developed to assess supply risk [5] [6] [7]. Due to the use of a transparent methodology with available data, this paper focuses on an approach developed by the European Commission (EC) [7]. The EC method applies four metrics to assess supply risk:

1. Monopoly supply: materials that come from few sources are assumed to be higher risk.
2. Governance indicators: materials that are sourced from politically unstable regions are assumed to be higher risk. Governance indicators are merged with the monopoly supply index to highlight where a material's supply is dominated by unstable producing countries.
3. Recycling rate: based on the assumption that the availability of recycled sources lowers risk.
4. Substitutability: materials that are substitutable are likely to be more flexible to changes in demand, reducing risk.

Monopoly supply is measured using the Herfindahl-Hirschmann Index (HHI), which is the sum of the squares of the supply percentages (S) of producing countries (c) for a given material (i), as shown in Eqn. 1:

$$HHI_c = \sum_c S_{ic}^2 \qquad \text{(Eqn. 1)}$$

The equation produces a figure between 0 and 10000, a higher number signifying higher risk.

World Governance Indicators (WGI) produced by the World Bank were merged with the HHI to highlight where supply was dominated by an unstable producing region. The WGI scored countries according to 6 categories (including political stability, control of corruption and rule of law), producing a result between 0 and 10. These scores were merged with the HHI as shown in Eqn. 2:

$$HHI_{WGI} = \sum_c S_{ic}^2\, WGI_c \qquad \text{(Eqn. 2)}$$

The result produces a score of 0 to 100000, which was scaled to a value of between 0 and 10.

The recycling rate used for a material i (ρ_i) applied the ratio of current demand met by old scrap. Data on recycling rate is given in the EC report [7].

Substitutability (σ_i) for a material i was measured using an index developed through expert judgements (Table 1).

Table 1: Substitutability indices [7]

Score	Substitutability
0	Easily and completely substitutable at no additional cost.
0.3	Substitutable at low cost.
0.7	Substitutable at high cost and/or loss of performance/
1.0	Not substitutable.

All of the metrics were merged into the final equation for supply risk, calculated by material (i):

$$SR_i = \sigma_i (1 - \rho_i) HHI_{WGI} \qquad \text{(Eqn. 3)}$$

The term (1- ρ_i) is used as a higher recycling rate will reduce supply risk. The result of the supply risk calculation will produce a score of between 0 and 10 by material, with a score of 10 representing the highest possible risk.

SR scores were calculated for 41 materials, 14 being highlighted as potentially critical (Table 2). Both of the highest scores were attributed to materials that have relatively few sources (monopoly supply).

Table 2: The EC 14 (SR scores in bold) [7]

Rare Earth Elements (REE) **[4.9]**	Indium **[2.0]**
Platinum Group Metals (PGM) **[3.6]**	Tungsten **[1.8]**
Niobium **[2.8]**	Fluorspar **[1.6]**
Germanium **[2.7]**	Beryllium **[1.4]**
Antimony **[2.6]**	Graphite **[1.3]**
Magnesium **[2.6]**	Tantalum **[1.1]**
Gallium **[2.5]**	Cobalt **[1.1]**

The 14 critical materials highlighted from the EC report and the method for assessing SR solve the first problem of identifying materials that are of concern. To understand the risk, it needs to be identified where these are used in products.

3.2 Identifying uses of critical materials

Product data is required to understand the uses of critical materials. Basic data on product content is provided by a standard engineering Bill of Materials (BoM). A BoM is unlikely to be sufficient to identify product features related to all environmental business hazards. Hazards can relate to any impact over the product life cycle, requiring a life cycle view. However, a BoM is sufficient for identifying uses of critical materials as an initial approach.

There are two perspectives on the problem of identifying critical materials in products. One approach could be to use a list of critical materials (for example the EC 14) and compare these with all product BOMs to identify any matches i.e. where a BoM lists a material of concern. This is necessary to identify all uses of critical materials within existing products, and is called the existing product perspective.

The opposite approach would be to start with a BoM and compare it with a list of critical materials to determine if any are used in the product. This is called the design perspective, where only those critical materials in the product being designed are of interest. The next sections focus on assessing the business risks posed by the use of critical materials approaching the problem from both the existing product and design perspectives.

4 CASE STUDY 1: ASSESSING RISKS TO EXISTING PRODUCTS

The following steps summarise the process for assessing the risks posed by critical materials to an existing product:

1. Identify at risk elements (the EC 14).
2. Identify if those elements are present in a product (required in order to understand the risk).
3. Complete a product based risk assessment by combining the measure of supply risk for the materials in question with the potential impact on business objectives from using the high risk material. To be relevant to existing design processes, the risk assessment has to be completed using the appropriate risk management criteria within Rolls-Royce.

PGMs were identified as having a high supply risk from the EC report. One particularly rare PGM is used as an alloying element within turbine blades on one of Rolls-Royce's large civil aero-engines. Using an alloy with this PGM maintains high creep strength within blades that operate at very high temperatures and pressures [8].

When designing a component, several business objectives are set against which risk can be assessed. One of the main objectives is a target unit cost for the parts and engine. Risks to unit cost of using the PGM in turbine blades can therefore be assessed. Rolls-Royce applies 5x5 risk matrices combining measures of likelihood and impact to assess risk. The unit cost risk matrix relevant to the product being analysed is shown in Fig. 1.

Likelihood	V. Low (< 3)	Low (3 to 5)	Med (5 to 25)	High (25 to 50)	V. High (>50)
V. High	9	14	19	24	29
High	7	12	17	22	27
Med	5	10	15	20	25
Low	3	8	13	18	23
V. Low	1	6	11	16	21

Impact (unit cost £K)

Fig. 1: Risk criteria case study 1

Likelihood

Assessing risk using the matrix in Fig. 1 requires the likelihood assessment method from the EC report to be translated into the scoring scheme applied, using a scale of v. low to v. high. Based on the actual SR scores given in Table 2, Table 3 outlines how the SR translates into an assessment of likelihood consistent with the risk matrix.

Table 3: Translating SR scores into the risk matrix scale

Likelihood (L)	SR score
Very high	SR ≥ 4
High	3 ≤ SR < 4
Medium	2 ≤ SR ≤ 3
Low	1 ≤ SR < 2
Very low	SR < 1

PGMs having a SR score of 3.6 translates into a high likelihood from Table 3.

Impact

To assess the impact, a breakdown of unit cost is required to understand how much of the total cost of turbine blades the materials account for. Illustrative cost data is presented in Table 4.

Table 4: Illustrative unit cost breakdown

Element	Cost (£s)
Casting	600
Material	60
Coating	250
Machining	150
	1060

An estimate of the potential cost increase of the material cost fraction is required, which is a function of:

1. How much the cost of the PGM could increase.
2. The PGM fraction of the whole material cost.

It is impossible to predict what the future cost of a material might be with any degree of certainty. To give an indication of the potential cost increase, the price volatility of the material is used. From company data the historical price volatility of the PGM in question is approximately 20 (calculated by dividing the maximum market price by the minimum taken over a 10 year period). For illustration, the PGM fraction of the cost of the material is estimated to be 1/3. Thus the impact can be calculated by multiplying 1/3 of the material price by 20, shown in Table 5.

Table 5: Impact on unit cost

Element	Cost (£s)	New cost (£s)	
Casting	600	600	
Material	60	**460**	
Coating	250	250	
Machining	150	150	
	1060	**1460**	
			Engine unit cost change
	Change	400	**45600**

As over 100 turbine blades are used in the engine, the total impact on unit cost of approximately £45000, which represents a high impact on the scale shown in Fig. 1.

Risk assessment

Combining the high likelihood from Table 3 with the impact calculated above produces the risk assessment result in Fig. 2.

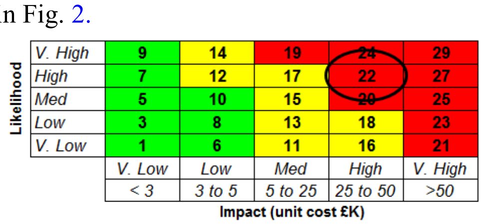

Fig. 2: Risk assessment result

Being the top right of the risk matrix this risk is deemed unacceptable and will require mitigating actions.

Mitigating actions

One mitigating action would be to take the PGM out of the blade. However, this will have an impact on specific fuel consumption (sfc), which is another design objective. Risk criteria for assessing risks against sfc is shown in Fig. 3.

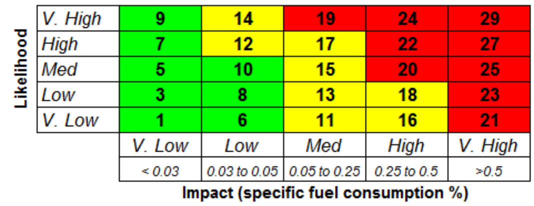

Fig. 3: Risk criteria for sfc

The impact on sfc of taking the PGM out of the blade is estimated to be between 0.1-0.2%, from internal engineering data. An sfc reduction of this magnitude translates into a medium impact using the x-axis scale in Fig. 3.

As the impact on sfc will only occur if an alloy not containing the PGM is used, which is dependent on the likelihood of the PGM becoming unavailable, the likelihood result from the unit cost assessment is used. Combining this with the sfc impact produces the risk assessment result shown in Fig. 4.

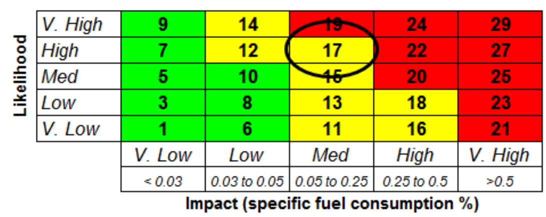

Fig. 4: Risk assessment result for sfc

As the risk to unit cost is higher than for sfc, on balance it is likely that the PGM would be removed and a different alloy used.

5 CASE STUDY 2: ASSESSING RISKS TO NEW DESIGNS

The following steps summarise the process for assessing the risks posed by the use of critical materials to new designs:

1. Select a BoM for a new design.
2. Identify critical materials used within the a BoM for a new design, by comparing it with the EC 14.
3. Complete product based risk assessment, using risk criteria relevant to the product in question, by multiplying the likelihood (supply risk) by the impact on business objectives.

A BoM for the outer liner of an annular combustor used on a small military turbofan engine is used for this case study, which is being re-designed to meet new customer requirements. Two uses of at risk elements were found in the new design:

1. Cobalt within the combustor alloy.
2. Yttrium (a REE), used within the thermal barrier coating applied to the combustor.

As with the previous example, the case study will focus on the impact on unit cost objectives. The risk criteria taken from the relevant business risk management plan is shown in Fig. 5.

Likelihood					
V. High	9	14	19	24	29
High	7	12	17	22	27
Med	5	10	15	20	25
Low	3	8	13	18	23
V. Low	1	6	11	16	21
	V. Low	Low	Med	High	V. High
	< 0.6	0.6 to 1	1 to 5	5 to 10	>10

Impact (unit cost £K)

Fig. 5: Risk assessment criteria

Likelihood

From Table 2, the SR scores for cobalt and yttrium are 1.1 and 4.9 respectively. These scores translate into a low likelihood for cobalt and very high likelihood for yttrium using Table 3.

Impact

The unit cost breakdown for the component is required to assess the impact on unit cost objectives. Illustrative cost data is given in Table 6.

Table 6: Illustrative unit cost breakdown

Element	Cost (£s)
Casting ops	2500.00
Material	500.00
Machining	1250.00
Coating	250.00
Remaining ops	1500.00
	6000.00

As with the previous case, to understand the impact on unit cost, an estimate of the potential cost increase of the material cost fraction is required, which is a function of:

1. How much the cost of the cobalt and yttrium could increase.
2. The cobalt and yttrium fraction of the overall material and coating costs.

From company data, the historical price volatility of cobalt is 6 (max. price/min. price over 10 years) and for yttrium is 7. For illustration, cobalt is estimated to represent 20% of the total material cost and yttrium 3% of the coating cost. The impact is calculated by multiplying 20% of the materials cost by 6 (volatility of cobalt) and 3% of the coating cost by 7 (volatility for yttrium). The overall impact on cost is shown in Table 7.

Table 7: Unit cost impact

Element	Cost (£s)	New cost (£s)	
Casting ops	2500.00	2500.00	
Material	500.00	**1100.00**	
Machining	1250.00	1250.00	
Coating	250.00	**302.50**	
Remaining ops	1500.00	1500.00	
	6000.00	**6652.50**	
			Engine unit cost change
	Change	652.50	**652.50**

The impact on unit cost of £600 for cobalt represents a low impact on the scale shown in Fig. 5. Impact on unit cost of £52.50 for yttrium is very low using the same scale.

Risk assessment

Combining the low likelihood and impact for cobalt produces a low risk (Fig. 6). Combining the very high likelihood with a very low impact for yttrium also produces a low risk (Fig. 6). Aggregating the scores of impact and likelihood for both cobalt and yttrium gives a total materials criticality risk towards the centre of the risk matrix in Fig. 6. A risk of this magnitude is unlikely to be of concern, not requiring mitigating actions. Being towards the centre of the risk matrix it may require monitoring to ensure the risk does not become unacceptable.

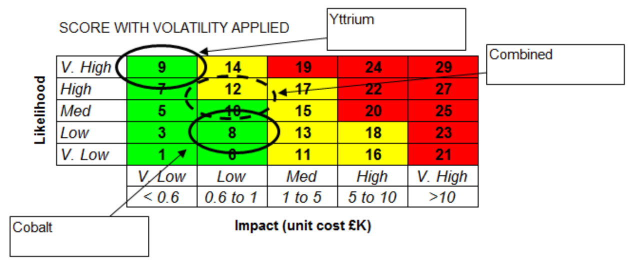

Fig. 6: Risk assessment result

6 DISCUSSION

The two case studies show how the risk based approach can be used to consider a complex environmental issue in a format that is consistent with standard engineering design decisions at Rolls-Royce. However, the approach is challenging for a number of reasons, discussed below.

There are significant uncertainties within all parts of the assessment. Firstly, assessing supply risk is not a simple task. The EC method was applied as it provided a transparent methodology and developing a bespoke approach was outside of the scope of this work. However, in reality there are many metrics that can be included within the assessment which were overlooked, for example risks related to materials produced as co-products or future changes in material demand. Adding both of these might have identified some of the 14 materials as being not critical, or highlighted at risk materials which have been overlooked. The method could be improved by selecting metrics that are relevant to the context (Rolls-Royce), or even better using a dynamic modeling approach instead of relying on proxy metrics as representations of dynamic material supply systems [9].

Another area of uncertainty is in the product cost data used within the assessment. In a company with an extended supply chain, quite often a lot of the costs related to raw material inputs are not readily available. For the purposes of this paper illustrative costs were used. Although in practice cost data is difficult to get hold of. Costs can be estimated by comparing raw cost data from the purchasing function with cost breakdowns for parts. Engineering judgement can then be used to estimate what fraction of the cost of, for example a forging on a BoM, might be related to raw material inputs. Greater accuracy, and thus confidence in the results, could be obtained if the BoM (or other system) clearly outlined what costs elements were related to raw materials.

The most obvious area of uncertainty is predicting how a risk to supply may translate into an impact on cost. It is impossible to try and predict material prices. To obtain defendable estimates historical price volatility was used, although this must go with the caveat that relying on historical trends is a very poor means of estimating what might happen in the future [10]. For example, the price volatility for cobalt and yttrium were quite similar. Although the current price trend for cobalt is stable, while the shape of the yttrium curve is exponential. If this trend continued using past data is a very poor estimate of the future impact. This problem is not likely to be resolved; there are always going to be uncertainties in predicting the future.

A final source of uncertainty is in the business objectives themselves. Risk can only be assessed against objectives. If the business alters the criteria used for the risk assessment (the scales of impact, likelihood and acceptability of risks) the risks presented here could be more or less acceptable. Assessing risk is inherently subjective.

Acknowledging these uncertainties, the paper has shown how the risk based approach is useful. One classic problem in ecodesign is determining how to trade-off between environmental impacts. Using the framework of business objectives, the first case study successfully demonstrated how this can be achieved.

7 EXPANDING THE RISK BASED APPROACH

A final consideration is how the risk approach could be expanded to include other environmental business hazards. Building from the two perspectives described in Section 3.2, this could be achieved by defining more features of environmental hazards (for example the use of hazardous substances). This would also require more detailed product data containing features of products that could be connected to these hazards, with a life cycle view (for example, a life cycle inventory). Ways of measuring the likelihood of different hazards will also be required.

8 CONCLUSIONS

This paper has presented an approach to ecodesign based on environmental risk management, in conclusion:

- The risk based approach successfully demonstrates how a complex environmental problem could be considered with standard engineering decisions. It has also shown that by using business objectives, environmental impacts can be traded off with each other.
- However, whilst the method was successful, there were significant uncertainties. In particular assessing supply risk and how this translates into an impact on material price.
- The risk based approach could be expanded to include other environmental business hazards. This requires more detailed product data.

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Building Sustainable Product Service Systems between SMEs

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Abstract

Product Service Systems (PSS) can help small and medium enterprises (SME) to become environmentally and socially responsible. However, there few examples of PSS developed by SMEs and even less sustainable PSS. Design and Information and Communication Technologies (ICT) are the main areas in the development of PSS and their integration can be used to encourage the adoption of sustainable PSS in SMEs and make them more suitable for these small businesses. Additionally, considering the development of sustainable PSS not only on an individual basis but also on an industry-wide basis can be one way of involving SME in larger systems. A case study with 16 SME is presented exploring this approach.

Keywords: Product service systems, design, sustainability, ICT, SME

1 INTRODUCTION

Industrial development during the last fifty years has been growing at an accelerate rate without considering all possible environmental and social impacts produced [1]. In consequence the planet has shown strong signals of deterioration in environmental terms and large inequalities in social aspects have emerged [2]. Facing this reality during the last thirty years different calls have been made asking for profound changes and searching for a new business paradigm [3] [4].

In that search, concepts with potential to contribute to achieving sustainable businesses such as cleaner production, recycling, ecodesign and product service systems (PSS) have been deployed [5], [6]. In the case of PSS and despite its potential contribution to develop sustainable businesses there are not many successful examples implemented by small and medium enterprises (SMEs), they have been limited mainly to medium and large firms. It is then interesting to explore this lack of examples in SMEs especially if it is considered that nearly 80% of the world's firms are SMEs [7]. Some of the reasons given in the literature that could explain this difficulty to develop a PSS in SMEs have to do with the internal and external barriers to develop a PSS in any firm such as costs, organizational resistance and regulatory context [8] [9] but also with particular problems of this type of firm.

However it is the hypothesis of this research that it is possible to consider developing sustainable PSS in SMEs based on the integration of design and ICT as the main areas in the development of a PSS. It is also considered the development of sustainable PSS between different stakeholders and not only on an individual basis. ICTs could play an important role in this kind of large PSS articulating the relationships between SMEs, suppliers, clients and other stakeholders. In this paper first the concept of sustainable PSS is presented, then the potential contributions of ICTs to develop sustainable PSS, and then the analysis of thirty-six commercial PSS is deployed as basis of four types of PSS characterized by the relationships between ICT and design. Finally, an overview of a case study with sixteen Colombian Manufacturing SMEs from the leather industry is presented and three alternatives to develop a sustainable PSS proposed.

2 BACKGROUND

2.1 Sustainable PSS

PSS are defined as "a system of products, services, supporting networks and infrastructure that are designed to be: competitive, satisfy the customers' needs and have lower environmental impact than traditional business models" [10]. These kinds of systems can also help companies to become more socially responsible [11]. In this case where there are environmental and social benefits PSS are considered as sustainable PSS. However, PSS are not necessarily sustainable, they have to be designed and implemented to achieve environmental and social benefits [9]. Examples of PSS already in the market are Auto-Share from Car Sharing Network Inc., Xerox Document Services by Xerox and Reuse System Housing by Sekisui Chemical between others. Some of the benefits mentioned in the literature coming from a PSS are increment of customers' loyalty, better strategic position for companies, reduction of materials and energy used implementing innovative usages, and encouragement to create collaborative networks [9], [10], [12-14].

Despite the benefits PSS is not a concept massively developed in the market and less so in SMEs [15]. General barriers such as lack of infrastructure, lack of mentorship,

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poor communication channels between stakeholders, and difficulties to access financial capital are part of the reason why innovative solutions such as PSS could be too demanding for SME [16]. Additionally, lack of knowledge of environmental legislation, lack of awareness of their impacts and general difficulty to embed the concept of sustainability make even more unlikely the development of sustainable PSS in SME [11] [17].

2.2 ICT potential contributions to sustainable PSS

The rapid evolution of ICT during the last decades has opened opportunities to contribute to sustainable development [18]. Between these opportunities there are for example the development of smart green products, virtualization, better communications between stakeholders, e-commerce and servitization [19]. The development of these opportunities can facilitate and improve environmental and social industrial performance.

In relation to SMEs, ICTs can also act as generators of change in the way these firms design and develop their products [20]. The adoption and use of technologies change how firms design their products and services and those changes could result in a greater disposition to innovate and a more flexible and inclusive design process. Finally, previous studies have suggested a possible contribution of ICT to make PSS more practical and operable [21] or to develop indicators of performance for these systems [22]. However little has been done in a structured way about the potential contribution of ICT to PSS and less to sustainable PSS. Also little is known about the relationship between ICT and design.

In this sense new approaches to address the challenges to develop sustainable PSS in SMEs are needed. Using insights from the literature and from a scoping study developed at the beginning of this research a reference model was built to direct the research. In this model design and ICT are considered as the main areas in the development of sustainable PSS. The integration of these areas can give the structure needed to make more operable the concept of sustainable PSS in small businesses. The opportunities mentioned earlier where ICT can contribute to develop sustainable business could be oriented to develop sustainable PSS and in the same way concepts already developed around design for sustainability can be used as a basis to ensure sustainable results. Considering that the possible relationships between design and ICT in a PSS are not defined yet in the literature, the first stage addressed in this research to formalize the integration of these two areas was to explore these relationships in different PSS.

3 DESIGN AND ICT IN PSS

3.1 Analyzing PSS on the market

In parallel to a case study with a group of Colombian Manufacturing SMEs a set of 36 examples of PSS were analyzed. The objective of this analysis was to establish possible relationships between design orientation and use of ICT in these PSS. To select the PSS previous literature, research projects and technical reports were reviewed. The PSS selected in this revision fulfilled two conditions: first they were examples developed by companies and second they claimed to have some environmental or social benefits or both. The assessment of the PSS to determine how well the benefits claimed were achieved was not part of this analysis. The analysis instead was oriented to review each PSS trying to understand how design and ICT were related to each other.

The selection of PSS did not try to have a statistical representation, however the intention was to select a variety of examples coming from different sectors. Along with the information reviewed in each PSS a general description of the offer, the country or countries where the PSS was offered, the orientation of the PSS to customers, to businesses or both and finally the industrial sector was included. In the end the analysis of the PSS was reduced to four types of PSS according to the relationship between design and use of ICT. This typology is described in the next section.

3.2 Four types of PSS

The four types of PSS defined by the relationship between design and use of ICT were:

1. Design based
2. ICT based
3. Design and ICT as supporters
4. Design and ICT integrated

Design based, PSS where products and services are designed specifically to fulfill the purpose of the PSS. ICT play mainly a commercial role establishing relationships with customers and as means to deliver the offer. Products and services in this kind of PSS could demand the use of innovative materials or especial production processes.

ICT based, ICTs are the element that articulates the PSS and enables its existence. Products and services are not necessarily designed for the PSS, it means it is possible to find the same products and services which are not part of a PSS. Some technologies could be embedded in the products of the PSS but demanding just slight modifications in the product design in comparison to a standard product.

Design and ICT as supporters, in these PSS design and ICT are part of the PSS but not directly attached to the main value delivered by the offer that is usually convenience. Products and services are not designed particularly for the PSS and ICT are used with commercial purposes.

Design and ICT integrated, the relationship between design and ICT is stronger and more balanced than in the other cases. Products and services are designed specifically for the PSS and ICT enables the delivery of the value of the offer and the interaction with the customers. ICT play a very important role connecting consumers with the products and the services of the PSS.

The importance of identifying these relationships and to characterize a PSS with them is to understand how the actual design process and use of ICT in a company can be oriented in one direction or another towards a PSS. Depending on the initial conditions of a company one type of PSS is more deployable than others. It means for example that a company with highly differentiated products could be more suitable to consider a design based PSS rather than an ICT based one. The four types of PSS according to the relationships explained are presented in Fig. 1.

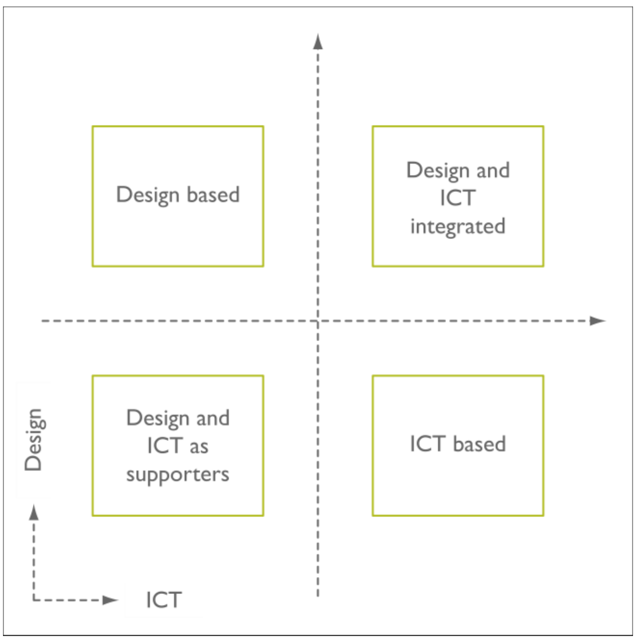

Fig. 1: Types of PSS defined by the relationship between design and ICT

Understanding a PSS in terms of the relationships between design and ICT can also be useful when PSS are thought of on an industrial basis rather than on an individual basis. If the PSS is developed by the articulation of different actors in an industry the integration between design and ICT can be established by competences developed by different stakeholders and they do not need to be present in just one.

In the next section an overview of a case study with 16 Colombian Manufacturing SMEs belonging to the same industry is presented. In this case study possibilities to develop sustainable PSS supported by design and ICT between different stakeholders are explored. In this sense the four types of PSS characterized in this section are used as part of a framework to define opportunities according to the findings in the case study.

4 CASE STUDY

4.1 Overview

16 Colombian Manufacturing SME belonging to the Leather Industry mainly shoemakers were approached to develop a case study. The data was collected through semi-structured interviews with the owners of the SME. Additionally documents from the companies and previous studies about the industry were included and analyzed. All the SMEs involved in the case study were previously participants of an ICT implementation project supported by the Colombian Ministry of ICT.

The research question behind the case study was to find out how design and ICT could be integrated to contribute to develop sustainable PSS in SMEs. In this sense the interviews were especially focused on exploring the design process and how the use of ICT have changed that process. In the next two sections the characterization of the actors in the industry and current practices and dynamic around design and use of ICT in relation to the actors identified are presented.

4.2 Identification of actors in the industry

Part of the analysis done during the case study was related to identifying the actors involved in the industry and to defining their roles. The objective to do this identification was first to understand better the dynamics of the industry and second to recognize gaps that could suggest opportunities to develop sustainable PSS in an individual or in an industrial basis. The actors identified were:

SMEs, small factories dedicated mainly to produce shoes and some leather accessories, usually with 20 to 30 full time employees. Their production is mainly for national market. Their clients are from small shops to large distributors and shop chains. They do not have direct sales to final customers and in some times of the year with high production levels they have to outsource parts of the production process to small satellites composed by three to four people working from home. Their financial capital is very limited, their main resource is their production capacity. The use of ICTs is limited to commercial purposes and in general is limited to very basic technologies such as email and web search. They do part of the design process internally and other part is subcontracted externally to model makers.

Model Makers, they are professionals usually with some training in design or with large experience in the industry. Their job is to translate photos and basic drawings of concepts (shoes) to soft models in cardboard. Their job is mainly manual and assisted by traditional techniques such as the use of the pantograph. Their work with the factories is based in long-term relationships.

Associations, they are industrial bodies dedicated to support the SME's operation. That support is manifested mainly in the organization of commercial fairs during the year. It is during these commercial fairs that the SME show their products to potential clients. Additionally Associations also prepare courses and seminars on topics such as commercialization, production techniques, and money management between others. These Associations also offer assistance on themes related to fashion and new commercial trends but this service is not clear and widely accessible according to the SME. All these services are offered to the SMEs on a membership basis.

Suppliers, there are mainly two large group of suppliers in this industry one are direct producers of the materials and the other are distributors and resellers. It is more usual that SME are approached by suppliers of the second group for materials like glues, soles and synthetics. In the case of leathers the suppliers are in general the tanneries directly. Suppliers play an important role in the diffusion of new production techniques, machinery and materials. They also push new concepts such as the use of ecological glues that was in force during the case study development.

Clients, they are small shops, large distributors and chain shops. They are the ones to define the guidelines for the factories' production including trends, materials and styles. With a large offer of shoes coming from the SME they are a powerful actor in the industry able to define commercial conditions including price.

Satellites, they are small and informal workshops based in the workers home. They are usually composed of three to five people who meet to undertake specific production tasks that don't require a factory. These satellites work on a temporal basis during the year.

After the actors in the industry were identified and described, a map was produced to show the main connections between these actors, (see Fig. 2). This map was used later during the case study in the analysis of the opportunities to develop sustainable PSS.

4.3 Design and ICT functions of the actors

Design in the SME was usually defined not as separate function; it was described as part of the production process. Even if some activities related to the design of the shoes are done internally in the SME the recognized designers in the industry are the model makers. In this sense the design process is divided into internal and external activities. The internal activities are carried out by the owner who decides the initial concept, materials, colours and combinations for final models while the model maker does the external tasks. Despite the fact that design is considered important for the SME they do not create value through design. In general when they decided to develop a new concept they start with products already on the market produced by other companies in other countries, then design is used to make slight modifications to models being more followers than leaders in the industry.

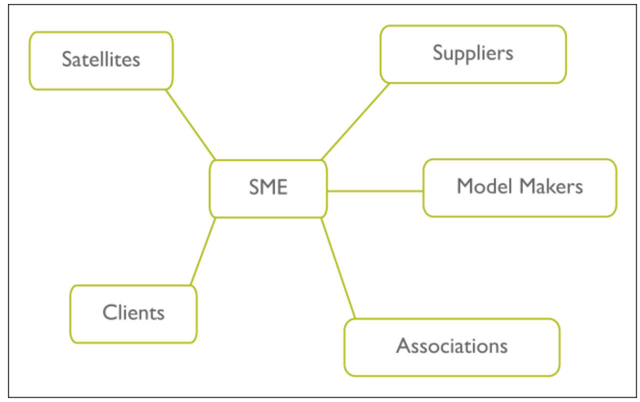

Fig. 2: Actors identified in the case study

The relationship between design and the clients is almost strictly related to the final assessment of the models during the commercial fairs. Clients in general do not intervene in the design process until that point when they can reject the models or accept them with or without some final changes. These design changes in the final samples are just small modifications. According to the SMEs one of the reasons why clients do not intervene in the design process is because the offer of samples at the commercial fairs in much larger than the demand. It means that for clients it is easy to choose the models without being involved in a collaboration process of design with the factories. Finally Associations give some advice on themes such as trends and fashion; however they were only mentioned by two of the SMEs interviewed. In a review of the Associations websites programs of support on themes such as design and commercialization were found but these programs are not widely accessible for all the SMEs in the industry even when all the SMEs involved in the case study were members of at least one of these industrial bodies.

In terms of ICT, there is a general lack of knowledge about the possible technologies that can be used in the design process. Owners in the internal design activities and model makers in the external ones do not use ICT to support the design process. In general design is manual and there is some resistance to consider replacing the manual process for activities that involve the use of ICT. This resistance is not because SMEs do not like the idea of using technologies it is more because they consider the use of ICT difficult and not suitable for the kind of task that they need to do to design a shoe. Currently the main use of ICT in the design process occurs at the beginning of the process when the Internet is used to search for models from other countries and markets. The main output of this search are photos and drawing used later by the model maker. In this sense the current use of ICTs in the design process is limited and not the most appropriate to develop competences such as innovation.

4.4 Development of sustainable PSS between SMEs and other stakeholders

Taking into account the general analysis of the industry, the findings about design and ICT in the SMEs involved in the case study and the characterization of the actors presented, it was concluded that the idea of developing sustainable PSS was more suitable in this case on an industry-wide basis. It means that according to the general definition of a sustainable PSS and the types of PSS defined by the relationships between design and ICT, the SME involved in the case study did not have the conditions to develop a sustainable PSS. Even, if the competences required to build a sustainable PSS could be developed in these SMEs, the analysis of the case study showed that the opportunities to develop the concept was in considering the integration of different stakeholders in the industry and not on an individual company basis.

The opportunities identified were mainly related to current practices in the industry that could be improved by the concept of sustainable PSS. During the case study it was found that different activities give value to the final offer but because the industry is strongly product oriented these activities are not valued and opportunities to improve the operations of each SME and the industry on a sustainable basis are missed. Using the map of relationships between the actors of the industry three subsystems were identified (see Fig. 3). Each subsystem represents one opportunity to develop a sustainable PSS integrating two or more actors and transforming some of the activities currently done by these actors. These sustainable PSS are supported by design and ICT and explained in part in relation to the types of PSS presented in section 3.2.

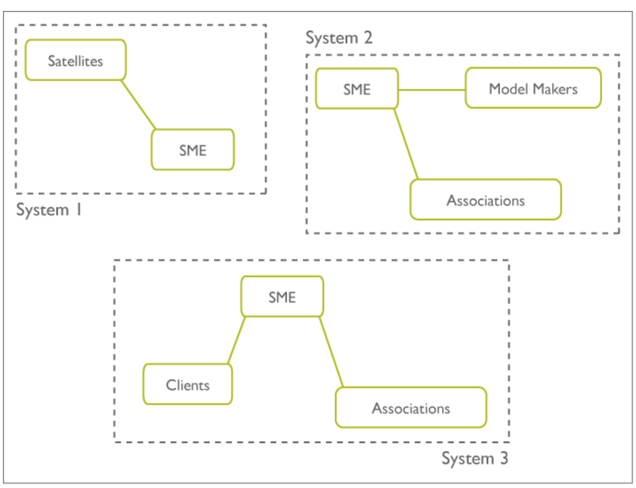

Fig. 3: Possible systems between actors

System 1, the first possible option to develop a sustainable PSS is related to the relationship between SME and production satellites. In this case the production capacity of the satellites is the main service associated to the system. If the production tasks are coordinated through the system that is supported by ICT there could be benefits associated to better production planning, traceability of materials, management of design and production standards, coordination between satellites and reliable deliveries. In a seasonal industry such as the leather industry with low and high periods of production a system that helps to coordinate factories and satellites could contribute to solve current problems such as lack of personnel in some periods of the year, work force instability, unfair wedges, delays and reprocesses. These improvements in terms of design could represent better use of resources, the possibility to sustain satellites work through out the year working for different factories in a better schedule

System 2, in this case the opportunity could be oriented to develop a sustainable PSS with *design and ICT integrated* according to the types of PSS presented in section 3.2. Currently design is a competence divided between SME and model makers. Associations give some advice but it is not widely exposed. Changing current manual practices of design into a design process supported by ICT could improve the interaction between SMEs and Model makers allowing also the participation of the association. A collaborative design platform between these actors could enrich the process of design reducing times to market and number of iterations between SME and model makers changing the current manual interchange of photos into a systematic process of collaboration from concept to detail design leaving register of the whole process. If SMEs and model makers design in a virtual platform the dynamic of the process could change from producing physical samples to producing virtual collections. These kind of collections could reduce significantly the use of resources used currently especially for the commercial fairs in terms of materials, energy and time. Additionally a system with these characteristics could improve themes such as traceability of design models, development of new trends and possibility to support large productions between SME to satisfy international markets where design standards have to be fulfilled by different factories. In terms of the associations this system could be used to improve and make more accessible their services.

System 3, based on a similar platform to the one presented previously as system 2, could be developed as a sustainable PSS between SMEs, clients and Associations. This third system could be an *ICT based* type. Basically the interaction between SMEs, clients and associations could be improved supported their communication process by ICT. This improvement could be reflected in a new assessment process based on virtual collections and the possibility for clients to suggest and see in real time modifications to the final samples during the commercial fairs. Additionally this system could also affect current problems such as commercial safety, payments and lack of cooperation between SME and between SMEs and associations. In terms of benefits the assessment of the samples could be more efficient, communication between stakeholders more fluent, it includes the interchange of information about design, orders, sales, payments, claims, suggestions and new events between others. Under this scheme of cooperation new services can be developed between SME and clients such as models repositories, e-commerce, visit arrangements and the main collaborative design.

These opportunities identified as subsystems in the industry are a preliminary result of the analysis of the case study. The final objective is to transform the logic used in this case to propose the three sustainable PSS into a final framework that can give structure to the idea to develop sustainable PSS in SME.

5 CONCLUSIONS

Design and ICT are the main areas in the development of sustainable PSS and the identification of the possible relationships between them in current PSS is a first step to formalize the integration of these areas. Considering the develoment of sustainable PSS between different stakeholders enlarges the amount of possibilities and can make operable the concept of PSS for SMEs. The three PSS proposed in this paper were the result of the thematic analysis of the interviews and document analysis collected during the case study, this procedure has to be refined and transformed into a generic framework that can be used in a systematic approach with similar industries. That final framework is the next stage of development of the research.

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Integrated Product Service Engineering - Factors influencing environmental performance

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Abstract

This paper aims to lead theoretical discussion regarding which IPSE (Integrated Product Service System) factors are expected to increase environmental performance of a life cycle compared to a traditional product sales business. Existing theories such as theory of product development, transaction cost theory and theory for risk management are used and the paper theoretically analyzes and identifies the following crucial characteristics; complexity of the product, uncertainty of offering, control of product operation, asymmetric information and scale of economy.

Keywords: PSS, environmental performance, information asymmetry, economies of scale, risk

1 INTRODUCTION

In society today there is increased awareness about environmental problems and this in combination with concern about future shortages of natural resources has resulted in increased pressure to find innovative strategies that can tackle these problems. During the last two decades, industry and academia have proposed and tried to implement several strategies and solutions. In much of the manufacturing industry today, numerous companies' business offerings are a combination of physical products and services. From academia, these include Functional Economy [1] and the Integrated Product Service Engineering (IPSE) concept, also often called Product/Service Systems (PSS) (e.g.[2]). PSS is defined, for instance, as "a marketable set of products and services capable of jointly fulfilling a user's needs" [3]. The proposal of a "life cycle-oriented design" [4] highlights an important step for the "product and technical service design processes" integration. Additionally, some specific engineering procedures and computer tools have been developed and validated with industrial cases (e.g.[5]).

However, the research in this area is still in its infancy and a number of questions remain unanswered. Specifically, a general weakness in existing literature is that even though a large number of authors have stressed PSS' environmental and economic potential (e.g.[6]), very few studies have proved PSS' potential for changing environmental performance. There are two main questions to consider. One is under which conditions PSS is a suitable offering and in general, PSS approaches seem to work well for e.g. products with high costs to operate or maintain, complex products and long life products [2]. Theoretical investigation has also begun: For instance, property rights have gained attention as a key for PSS to be meaningful [7]. Yet, all these literature are insufficient, especially from scientific viewpoints. The other main question is which PSS factors influence the environmental performance in comparison with traditional product-sales type business. Very few e.g. [8] have attempted to analyze the relation between PSS types and their influence on environmental impact.

2 REDEFINING IPSE

Our research group at Linköping University and KTH (The Royal Institute of Technology) in Sweden has developed what is termed Integrated Product Service Engineering (IPSE) [9]. IPSE looks at combinations of products and services and is a type of engineering, which is different from PSS per se. In addition, it attempts holistic optimization from the environmental and economic perspectives throughout the life cycle. IPSE also consists not only of design as the most influential activity, but possibly other engineering activities such as maintenance, upgrade, remanufacturing, etc. Therefore, IPSE has to deal with the time dimension of the life cycle. Figure 1 depicts different interesting processes for IPSE, obviously showing various disciplines and different aspects to be addressed. An IPSO (Integrated Product Service Offering) is an offering that consists of a combination of products and services that, based on a life cycle perspective, have been integrated to fit targeted customer needs. This often creates close contact between the supplier and customer. Further, IPSO means that products and services have been developed in parallel and are mutually adapted to operate well together in contrast to traditional product sale.In many cases, the service provider retains responsibility for the physical products in the IPSO during the use phase, e.g. the customer only uses the machines and pays for the manufactured volumes; then, when the customer does not need them anymore, the supplier takes back the machines. Such cases increase the provider's interest to ensure that the customer uses machines installed as long as possible and

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that any disturbances, such as the need for repairs, are reduced. This could lead to a product lifetime extension.

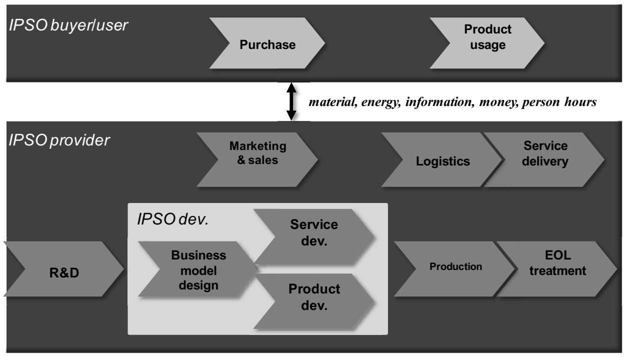
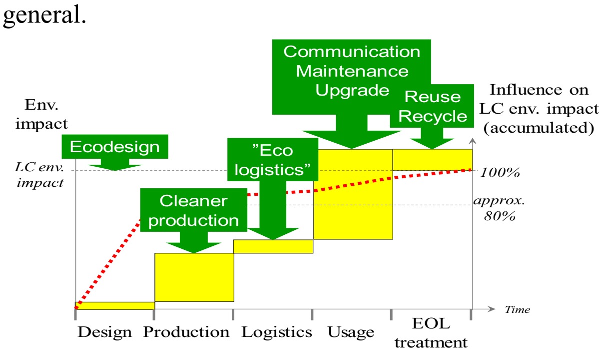


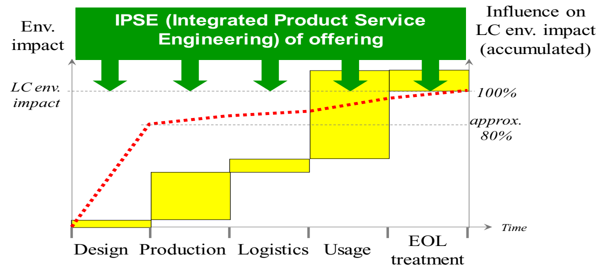
Fig. 1 : Processes of IPSE's interest [10]

Based on [11], IPSE is explained in comparison to Ecodesign (environmentally conscious design) due to some commonality with Figure 2 (a) and (b), where different types of engineering activities are put on the identical graph. The graph depicts the environmental impact of a certain type of product with high impact from its usage phase, which holds true in many cases. The horizontal axis represents the time dimension on the life cycle. Bars represent the environmental impact from each phase such as production and usage (scaled with the left vertical axis). A dotted line represents the accumulated influence of the activity at each phase of the life cycle's environmental impact. It is shown that the design phase has by far the highest ratio, which is generally known. As seen by the dotted line, Ecodesign is obviously crucial, since it is the design activity with the dominant influence. However Ecodesign is not sufficient since it leaves out control after the design phase. This is why IPSE is more effective, including the possible employment of other engineering activities such as maintenance.

In this paper the following characteristics are to be paid particular attention. The first is its length of the usephase which be long, e.g. more than 20years. Therefore IPSE has to address much of this time dimension with design and especially effective design since the earlier a certain action is taken the more effective its outcome is in general.



(a) Various Eco-activities



(b) IPSE

Fig. 2 : Comparison of IPSE and other activities

Note: The environmental impact (shown by bars) is a rough estimation of active products. EOL and LC stand for end-of-life and life cycle, respectively.

Then, what is design? A seminal work by [12] states "design is an engineering activity that … provides the prerequisites for the physical realization of solution ideas" (originally in [13]). This mainly concerns processing information about needs and wants from stakeholders and through the product life cycle, as well as about function and structure of the product. Effective processing of information plays a central role in IPSE – this is the second characteristic.

Then, design of what? This is the next relevant question as discussed in [14], which points out an artefact, i.e. an object to be designed, is today "integrated and systemic product-services linked in a high-level user experience". Also acknowledging co-creation of value by a provider and a customer/user is a strong idea behind the servicizing (see e.g. [15]), a provider cannot get rid of influence from its customer/user to create the intended value. Thus, a provider can design something contributing to its value, but cannot design the value itself. This means that control of risks of the value creation process is crucial. Thus, this risk is the third characteristics.

In sum, IPSE can be defined as an engineering activity controlling risks of value creation through dealing with information originating from a wide window on the time dimension.

3 PRODUCT DEVELOPMENT

According to ENDREA [16], product development is defined as: "all activities in a company aiming at bringing a new product to the market. It normally involves design, marketing and manufacturing functions in the company". The current business model for many products the focus is normally on cutting down the cost for manufacturing and delivering and little focus is placed on later phases of the product's life cycle. At the same time, life cycle cost studies and life cycle assessments have shown that for many products, it is during the use-phase where the major costs and environmental impact for the product occur. Figure 2 shows, in a basic way the environmental impact accumulation over the product's life cycle.

When developing IPSO, the basic principal is to consider all life cycle phases in order to optimize the offering from a life cycle perspective. The idea is to get the lowest total cost for the offering possible, not only to get the lowest cost for product. Costs are often associated with the use of materials and energy, which in turn provides a negative environmental impact, implying that more cost-optimized products usually have less environmental impact. Figure 2 also illustrates the different phase's impact on the total environmental impact and how important the design phase is, especially the early part of it where the product specification is defined.

At the same time, the initial product specification sets up boundaries for potential actions in the later phases which is often referred to as the "design paradox". The paradox, Fig 3., is that when the general design information is needed, it is not accessible, and when it is accessible, the information is usually not needed. Costs for later changes increase rapidly, since earlier work must be redone [17]. Figures 2 and 3 illustrate the importance of the design phase as well as getting in relevant requirements as early as possible in the development process. It also shows the problem with traditional product development where often little care is taken in product development (and in its specification) for future services, maintenance, and end-of-life-treatment. Traditionally, the initial focus is on developing the physical product and subsequently a possible service (intangible product) is developed, but this is hindered by the limitations set up from the physical product. When developing IPSO, the development is accomplished in an integrated and parallel approach.

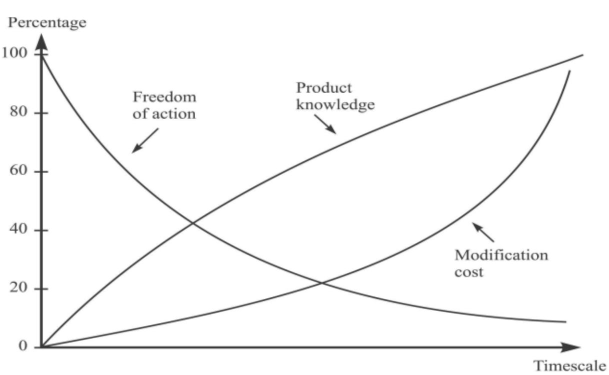


Fig. 3. The relation between "Freedom of action", "Product knowledge" and "Modification cost" is shown [18].

The rate of market and technological changes has accelerated in the past decade implying that companies must be pro-active and rapidly respond to fluctuations in demand [19]. A way to handle these challenges is to do more of the product development in a more parallel and concurrent way in order to e.g. shorten the calendar time (from start to stop) and increase the collaboration over competence disciplines. One concept in line with this is Integrated Product Development (IPD), whose basic idea is to increase the efficiency in product development by more parallel activities and a higher degree of co-operation between functions, levels and individuals in an enterprise [20].

However, if a business model is changed from selling products to providing a function via IPSO, this also changes the conditions for development. When selling products, there is a need to constantly sell new ones or new models in order to survive. This implies that a company should want to split technical improvements between several versions in order to be able to sell more products over time. However, if a company sells IPSO, this is changed since the company wants the customer to use it for as long a time as it is economically interesting. The company will implement the best technique at once instead of taking it in steps leaving more time for developing more optimized offerings - offerings that are more cost-efficient and effective, and therefore in general give a lower negative environmental impact. Nevertheless, it will still be relevant for shortening the calendar time (from start to stop).

4 INFORMATION ASYMMETRIC BETWEEN A PROVIDER AND A USER

In general, environmental impact of a product life cycle is determined by product characteristics themselves and processes on the product. The former includes the type and amount of materials in a product, while the latter includes how to treat the product at EOL (end of life). Thus, the environmental impact of a product can be decreased by changing either its characteristics or its processes. However, one has to own and apply appropriate information to do so. There are different types of such information about a product itself or processes along the life cycle phases such as design, manufacturing, usage, and EOL. In addition, the information may not be documented in such a way that it is easily transferrable to another actor.

Who owns the information on how to improve the environmental aspect of the product and processes at different stages of the life cycle? Information asymmetry exists in many cases between the OEM, who in many cases designs a product, and the user. For instance how to attain the best energy performance for the product in practice may be more hidden to a user than to a designer – the user simply does not know how to operate the given product for the best performance, or the provider has more knowledge of the best available technologies at the moment. There can be various reasons for this, such as a lack of user education in spite of the existence of the necessary information, or the strategy of a user as a company not to get the competence.

Note that information asymmetry in the "market for lemons" addressed by [21] is not the main issue of this paper. In that case, the information possessed by a provider is about a product at a point of sale and is unchanged after the sale of the product, as it is based on a product-sales type business and the provider has no access to the product afterwards. This is shown with gray lines in Figure 5: the information of a user about the product increases along time and can surpass that of a provider. Note that variation of speed of the increase along time is not considered in this graph. In IPSE, on the other hand, a provider can obtain more information with access to the product during usage, and could maintain superiority regarding product information over the user. This is drawn as Cases 1 and 2 in Figure 5, to refer to the same and a higher speed as compared to the user, respectively. In Case 3, due to the lower speed than the user, the provider is surpassed by the user.

Information asymmetry can be a weapon for a provider to obtain payment in IPSE and makes IPSE meaningful as a business. For example, in the case where an OEM owns more information about usage or EOL of a product, there is potential for the OEM to provide IPSO so that the environmental impact is less than would be for product sales. It is also often reasonable for an OEM to be able to provide maintenance or upgrade service of its product. From the viewpoint of environmental performance, on the other hand, information asymmetry is a hindrance to improvement, since it is costly to transfer information to an actor who needs it.

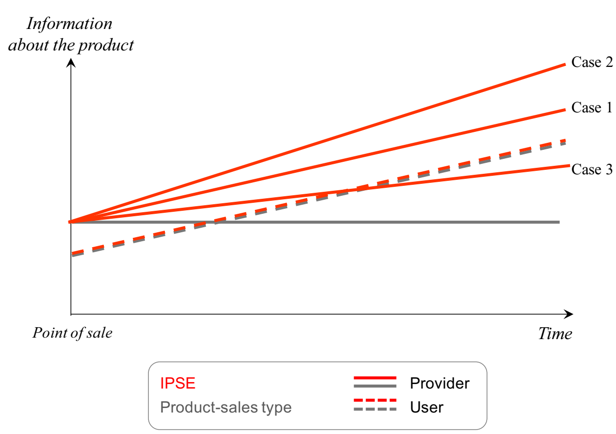


Fig. 4. Transitions of amount of information about a product after sales

5 ECONOMIES OF SCALE

Economies of scale are the result of an increased number of units produced or distributed, making it possible for the unit price to decrease [22]. An IPSE provider has the possibility to attain economies of scale through several different aspects. To provide IPSE is, in some cases, equal to being responsible for all the life cycle costs of the offering, which provide incentives to optimize the total cost as well as to realize economic development, and potentially environmental development [2, 9]. The provider would be able to gain economies of scale for both the products and the services. Leverage in production and administration could be created by offering the same services to different customers [23]. Another way of decreasing costs and achieving economies of scale could be realized when answering customers' demands by constantly configuring the same technology and skills in different ways [24]. For a certain industry the market capacity is limited, which means that a single company may not reach its scale of economy since its market share is relatively fixed for a certain period of time. It is not possible to realize large-scale effects with only a few customers, since much information is needed before, during and after the delivery which results in high transaction costs [25]. If a number of companies outsourced their processes to one organization, this would aggregate the volume and the production efficiency would increase [26]. This would also bring down the transaction costs, since they were created when transferring goods and services [22]. If the transactions occur frequently they are better handled within one single organization, since hierarchical governance facilitates administrative control and coordinated adaptability [27]. Furthermore, customers want to benefit from the knowledge of the supplier, and are reluctant to do business with several suppliers if they want an integrated and global offering [28]. However, the number of actors should be enough to make sure all the components of the offer are delivered by experts [29].

Apart from reduced transaction costs new costs for complementary products may also appear for the provider in the beginning, but will benefit from economies of scale after the transition [30]. Even though IPSE offerings imply customized solutions to achieve economies of scale, they have to be combined with well-defined modular structures at the component level [31-32]. This could also be useful when considering remanufacturing, since parts that are worn out quickly or require frequent upgrading should be placed in an accessible way [33]. Additionally, the IPSE approach would provide the manufacturer with the knowledge of how many products that are entering the process, as well as when they would do so, which would provide the IPSE provider with a remanufacturing plan that is easier to manage [33].

Furthermore, the IPSE provider can economically afford a high level of specialization and technological features due to economies of scale, and can thereby optimize resource consumption and waste production, leading to better eco-efficiency for the company [34]. The provider also often gains a competitive advantage over the customer when it comes to experience and knowledge concerning the product. With information, such as knowledge of how the equipment is repaired across their whole customer base, the provider can optimize maintenance routines and thereby minimize the cost as well as to increase availability and reduce product failures [30, 35]. Economies of scale can also emerge when the provider is in charge of the operations at the site of the customer, when the expertise of the provider in running the equipment can provide reduction in lead time and scale affects [36].

6 RISK

There are various types of risk, namely possible negative consequences from the environmental viewpoint. Reasons for this include an actor's lack of necessary information due to another actor's possession of the information, which was already discussed in the section on information asymmetry. There is another reason as well – non-existence of information.

Whether a product is better from an environmental standpoint for a given need is not necessarily certain at the time the product is first used. Different factors for this originate from the environment (not in the meaning of sustainability) and users. The former includes the speed of progress of the technology used in the product (or product generations) (see e.g. [37]). If a new product is more energy efficient than the original one, and it becomes available before the end of usage, it may be better environmentally to switch to the new product. The user factor includes his/her discontinuity with the need for the chosen product. For instance, a change in demand causing a user to stop using a product after a short time, and owning another product in addition, generates additional environmental impact.

How can these different types of uncertainty be better handled? A provider could do this. If a provider promises a user in a contract that the "best" available technology is provided within the contract period, the user can avoid the uncertainty of the technology progress. For the user's discontinuity of the need, a provider could give an option to a user so that the user can return the product to the provider after a certain period of time. By doing so, a user can shorten the time of holding that risk. The "trick" behind this is scale of economy that enables a provider to cancel different types of risks arising from its users. Thus, variety of the needs by a group of many customers is cancelled.

7 CONCLUDING DISCUSSION

This paper endeavoured to lead theoretical discussion regarding which IPSE factors are expected to increase environmental performance of a life cycle compared to a traditional product sales business. Four aspects from theory were discussed and their relevance was pointed out. In the theory of product development, information about a product is pointed out to be a crucial parameter, although the theory is to be adapted according to the nature of the offering – IPSO as opposed to a physical, traditional product. Then, asymmetry of the information about a product between a provider and a user was identified as a key for IPSE to be meaningful also through comparison with the product sales type business. Economies of scale were brought into the discussion and this remains to be an important issue for IPSE but with different characteristics from the product sales type business. Finally, risk was discussed and pointed out to be a crucial parameter to be controlled after sale and economies of scale were shown to be an enabler to control the risk in a better way. As shown in these four sections, these aspects are interlinked with each other and need to be further investigated. Nevertheless, the paper has provided a first theoretical cornerstone regarding conditions for IPSE to be a meaningful business style and IPSE's influential factors on environmental performance.

Further research is needed and the authors aim to continue to clarify and model the aspects discussed in this paper to more thoroughly explain the environmental advantages with IPSO in comparison to traditional sales.

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Current state of the art on repair, maintenance and serviceability in Swedish automotive industry – a virtual product realization approach

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Abstract

Sustainability with its three aspects, economy, ecology and social, is gaining more and more attention in industry as well as in academia. One way of increasing sustainability is to increase the life length of a product as well as ensuring performance by making it easy to maintain and repair. The consumer trends are moving towards a more positive attitude to buy a function rather than the product itself. By having this approach aspect such as maintenance, service and repair (MSR) is put in a different light. This paper presents a interview study with the intention to investigate the state of the art regarding maintenance and repair in four different Swedish automotive manufacturing companies with emphasis on how virtual product realization is considered and implemented. It was stated during the interviews that the use of simulation and analysis methods with emphasis on MSR differs and that it sometimes can be troublesome to make impact in project discussions etc. due to their difficulty in delivering hard figures e.g. cost, weight, CO2 emissions etc.

Keywords:

Maintenance, service, disassembly, virtual product realization

1 INTRODUCTION

Sustainability with its three aspects, economy, ecology and social, are gaining more and more attention in industry as well as in academia. It is no longer high status to park a huge SUV at your driveway, your neighbors will rater pat you on the back if you park a hybrid or electrical vehicle there. The consumer trends are going in a direction towards a more positive attitude to buy a function more than the product itself. This is the core message of Product Service System (PSS) which is a combination of physical products and services, [1]. In PSS the traditional manufacturer-vendor-user relationship is rearranged, in order to deliver environmental and (for the company) economical benefits. By having this approach, aspects such as Maintenance, Service and Repair (MSR) is put in a different light since the companies will take care of the cost during the life time of the product also. MSR may be defined as, "the combination of all technical, administrative and managerial actions during the lifecycle of an item intended to retain or restore it to a state in which it can perform its required function [2]. Design for maintenance as an important topic for a good design was raised in the early days as for example stated in Asimows "Introduction to design" [3]. Though it has not been explored to a very large extent [4]. The area has been explored but focus has been on maintenance intervals, mathematical models etc. rather than guidelines for design for maintenance and repair.

By maintaining the products and make them easier to repair, the life length will increase and most surely the total life cycle performance will improve too. This in turn will lead to more sustainable solutions. Putting more emphasis on MSR requirements during creation of designing solutions will make it easier to avoid the need of draining different fluids when repairing or decreasing the need of destroying parts a more sustainable product solution is achieved. To achieve these kinds of solutions there is a need for new tools and methods. By using computerized tools i.e. virtual tools it is possible to evaluate a vast amount of different solution, in a short time. By creating a virtual product realization process the need of prototypes is decreased which leads to higher sustainability. Here, virtual product realization refers to simulation, analyses, model creation etc. which is used in order to decrease the usage of expensive and time consuming physical models [5].

1.1 State of the art

MSR are one of the vast amounts of different product characteristics which need to be taken in consideration during the product development process. There are methods and tools which are tailor made for many of the different product characteristics. Under the label Design for X a wide collection of specific design guidelines are summarized. Each design guideline addresses a particular issue that is caused by, or affects the characteristics of a

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product. Design for maintenance (DfM) has not been in focus to a great extent in the design for X area [4].

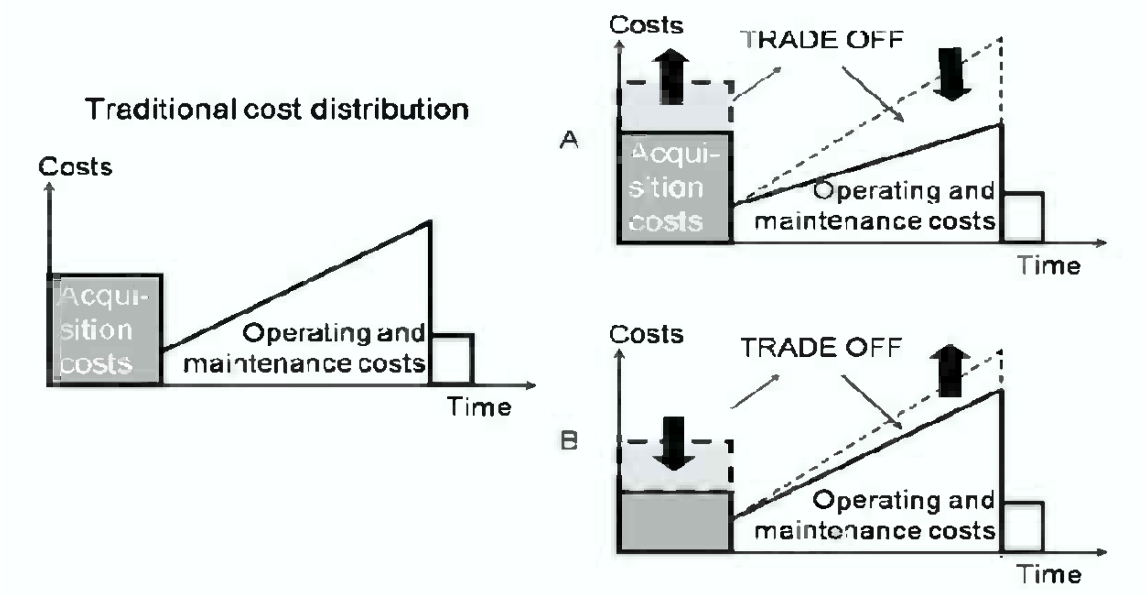

Fig. 1: Strategic courses of action to optimize a life cycle, from [6]

Though the focus has been on the mathematical side calculating maintenance schedules etc. and not emphasizing on the on the synthesis i.e. design for maintenance area [4]. Chiu and Kremer [7] made literature review with emphasis on investigation of the applicability of Design for X tools during design concept evaluation. According to this there are fairly numerous methods and tools present for disassembly and recycling but not for maintenance. A number of DfM guidelines has been proposed by Mital and Desai [4]. In generic design methodology books, DfM is mentioned but not extensively, usually 1-3 pages out of 200-300 pages. For example in "Engineering Design: A Systematic Approach" [8] it is mentioned as Design for ease of maintenance, in "The Mechanical Design Process" [9] it is mentioned as design for test and maintenance, in Product Design and Development [10] it is mentioned as "Ease of maintenance" (sorted as a specific branch of industrial design) and in Engineering design methods [11] mentioned as maintenance under the section "Improving Details". Design for disassembly, which can be considered a subset of maintenance, is a topic that covers several areas of the product life cycle. According to Westkämper [6] the disassembly aspects will influence both during the assembly process in order to repair and disassembly defects caused by assembly. Then in the usage phase there is the service and maintenance part that is of importance. Wübbenhorst [6] states that there is correlation between the acquisition of the product and the Assembly and disassembly operations, see Fig 1. Depending on how big your effort is in the beginning of the product life cycle the cost of operation and maintenance will also differ. He states that there is a correlation between the different aspects. Time is an important aspect when evaluating different maintenance as well as repair solutions and methods. In [12] a number of disassembly time evaluations for automotive industry is presented. There are different methods to come up with the standard times for different work procedures. One of the predetermined systems is the Methods-Time Measurement (MTM) [13].

There are quite numerous quality issues that are related to the positioning of parts i.e. that the part is not positioned as it is supposed to be [14]. In other terms the personnel do not know when the part is in right place/position or not.

1.2 Scoop of the paper

Maintenance and repair aspects of products are essential to ensure their performance as well as to increase the life cycle of the product. By supporting this area with methods and tools during the product development process the possibility to meet the above mentioned aspects increases. According to the Wingquist laboratory research process there is a need to identify both a research challenge as well as to indentify an industrial need [15]. Together they give rise to a research idea. In this paper we present an interview study with four Swedish automotive manufacturers. The presented interview study has two aims. The first one is to increase the knowledge regarding how MSR aspects are considered and treated in automotive industry in Sweden. The second aim is to identify an industrial need in this area. Since the research agenda within the research group, where this research has been carried out, aims at a fully virtual product realization process emphasis has been on how virtual tools are used.

2 METHODOLOGY

In this section the methodology used throughout this paper is instroduced.

2.1 The design of the study

The study was carried out by conducting semi structured interviews with personnel within the participating companies whose responsibility was service and maintenance aspects. Semi structured interviews has a formalized, limited set of questions. It allows for complementary questions during the interview if needed [16]. The approach was exploratory to its nature in order to gain knowledge how vehicle industry in Sweden are approaching MSR in the product development process. The scope of the questions had a twist towards how MSR aspects in particular are taken care of during virtual product realization. The length of the interviews was between 1-2 hours. The interview was performed in group constellations at the companies and not individually. The total number of interviewees was 11 distributed among the four companies. In the first company only one person was interviewed, at the second company there were two persons, at the third and forth company there were four persons interviewed. The interview study was planned in accordance to the methodology presented in [16]. One way, according to Kvale, to accomplish the interview studies is to follow a seven steps procedure, see table 1. These steps are developed for semi structured interviews but can also be used as base when designing the questionnaires. The same questions were posted at all of the interviews. Through the questions was not posted in the exact order during all of the interviews. The setup was more of a conversation where the questions were used as guidance.

Table 1. Seven steps for interview planning, [16]

1. **Thematize.** Conceive the aim of the study and describe the area for the investigation before the interviewing. The investigations *why* and *what* shall be clarified before the question about *how* is formulated.
2. **Planning.** Plan all the stages for the investigation, with respect to what knowledge that will be obtained and with the moral consequences for the investigation in consideration.
3. **Interview**. Accomplish the interviews according to an interview guide and with a reflective attitude to the requested knowledge and to the interpersonal relation due to the interview situation.
4. **Transcription**. Prepare the interview material for analysis, which usually means a transfer from spoken language to written language
5. **Analysis**. Decide from the investigations aims, subjects and foundation of the interview materials point of view witch analysis methods that suits the interviews.
6. **Verification**. Establish the interview results level of generalization, reliability and validity. Reliability assigns to the consistency of the result and validity to if a survey investigates what was meant to be investigated.
7. **Report**. Report the result of the investigation and use the methods in a form that corresponds to science criteria's, that takes the ethic aspects in consideration and leads to a readable product.

2.2 The planning of this study

The planning of this study is here presented.

1. Thematize

The presented interview study has two aims. The first one is to increase the knowledge regarding how MSR aspects are considered and treated in automotive industry in Sweden. The second aim is to identify an industrial need in this area. The study is explorative to its nature and not investigating a stated hypothesis.

2. Planning

The study as whole includes interviews as well a workshop with the participating companies. The workshop is planned to be executed in the middle October.

3. Interview

We were two persons at three of the interviews and one at the final one. An interview guide with the questions was used during the interviews. The questions were not necessary posted in the order written in the guide though it was used to not miss any questions.

4. Transcription

The answers from the interviews were written down in a condensed format during the interviews.

5. Analysis

The answers were clustered to find, if possible, a general opinion. It was considered to be enough documentation level for this kind of interview study.

6. Verification

Four companies within the same type of business are participating so the answers can be considered to be fairly generalized. The study is explorative to its nature why validity and reliability is not considered relevant.

7. Report

The outcome of the study is reported in this paper to in an as consistent way as possible.

3 RESULTS

In this section the results from the interviews are compiled together. The aim of the survey was not to pinpoint either of the companies working procedure in detail. The aim was rather to find a general picture of MSR aspects, with emphasis on virtual product realization, why the answers from all four companies have been clustered together.

The presentation structure of this section is the question posed is written in underlined style and after that a compiled answer based upon the answers from all four companies is presented. At some of the question a short introductions is posted in order to clear out the purpose of posting that question. There are two main areas that were investigated; *MSR aspects in the product development process* and *Information flow between the OEM and service stations*.

During the interviews we identified two diverse but closely connected activities i.e. job assignments, which were equal among all the companies. The first of the two main activities was to improve the design solutions regarding service and maintenance aspects. This activity is to its nature proactive. The second activity was to design and improve MSR methods for the service technicians. One special activity was the development and design of special tools used for the service operations. There are situations where there is a need to have special tools to be able to solve the MSR solutions.

MSR aspects in the product development process

How is your area promoted within the company?

MSR is considered to be an important area within the companies. It was consensus that it sometimes can be troublesome to make impact in project discussions etc. due to their difficulty in delivering hard figures e.g. cost, weight, CO2 emissions etc. This was also perceived among the interviewees to be one of the core issues in order to ensure that the product solutions are easy to maintain and repair. One of the reasons to the current situation has its origin in how maintenance and repair aspects are quite often taken care of within the companies. Since they need the entire model of the vehicle they gets it when it is more or less finalized which leads to a reactive approach rather than a proactive. The current trend within the companies is that MSR requirements are taken more into account during the early stages of the product development process. The introduction of different simulation tools has made this possible.

How is the disassembly and reassembly time calculated and when?

The companies are in general using two types of input for calculation of disassembly and reassembly time, namely standardized methods and laboratory tests. There are several standardized methods for estimating the disassembly time e.g. MTM [13]. The standardized time methods are used when the maintenance and repair methods are created. In the laboratory tests service technicians will carry out the service/repair method two times live in a laboratory workshop. The time of their actions is measured and these times are then used as a basis for the time estimation. These tests are done when the vehicle is in its final development stages. The disassembly and reassembly times are also used by the service stations when they shall do cost models for different service as well as repair jobs.

Which are the main issues with virtually testing and evaluation of MSR aspects?

It was stated during the interviews that the use of virtual tools, as support when developing and evaluating MSR aspects differed, quite much, between the companies. All of the companies did have CAD and PDM systems which they used in the product development process. There was differentiation between virtual tools to analyze and ensure efficient MSR solutions. The same pattern was also identified in the area of method MSR where technical drawings based upon the actual CAD-models are the basis for the creation of MSR methods for maintenance and repair. There are tools which converts the geometrical CAD-models directly into technical drawings or into vector format. These kinds of tools were not used by all the companies. The technical drawings, used for the repair and maintenance handbooks, were more or less performed by hand not using any of the available software's that exists.

The need of appropriate CAD models was also found as one of the core influencing aspects to be able to analyze and simulate maintenance and repair aspects as well as to do the maintenance and repair methods. Since the participating companies was OEM:s (Original Equipment Manufacturer) most of the development work is outsourced to the sub contractors an together with that the detailed CAD-models. In many cases there is a lack in the agreements between the OEM:s and the subcontractors regarding the CAD data. The subcontractors send, quite commonly, the data to the OEMS as a final assembly not including any individual parts. This gives the situation that the OEM:s does not have the CAD models in details which gives much work efforts. To sort this out the engineers at the OEM's, sometimes, needs to do the time consuming work to modeling the geometries from scratch.

Is virtual training used to educate the service and maintenance personnel?

Virtual training is currently not adapted to a large extent within the companies. They see advantages with using virtual tools in this are but they find it quite hard to do an adequate simulation. It is hard to come up with a virtually representation of the surroundings of the service station since it differs quite much. Maintenance and repair jobs at the service stations are not repetitive to its nature especially compared to the production line. It is thereby seen as a challenge how to do the ergonomically evaluations for example when the input parameters are such diverse. They see opportunities to use motion tracking systems to monitor how service personnel are working. The aim with using this device is rather to gain knowledge than using if or virtual training. The training of service personnel is today is carried out at the companies taught live next to the vehicle.

How do you set requirements regarding fasteners to allow for disassembly and reassembly?

There are vast amount of different types of fasteners used. Compared to the assembly line where easy handling of the fasteners, both physically and cognitive, the situation is a little different when disassembly. The disassembly process can incorporate both destructive and non destructive disassembly regarding fasteners, parts etc. The MSR divisions put requirements on different fasteners regarding type and how many times they should be able to disassemble and reassemble. Though there is balancing needed between fasteners used, disassembly time, destructive and non destructive removal. There were no general guidelines her but case dependent.

How do you work with directions and clearance when designing for service and maintenance?

To be able to reach the component when maintaining and/or repairing is essential for the technicians. Here there were quite different situations at the companies. The engineers at some of the companies did not have any special tools when checking directions and clearance in the product development process. It was rather based upon experience among the engineers from earlier MSR solutions from older models. Other ways of doing this was also to use the CAD-models and just move them around as stiff parts in the model to see whether they collided or not. At some of the companies they had access to a robot path planner which was used to automatically analyze and simulate the possibility of disassembly.

How is disassembly connected to ergonomic aspects?

The ergonomically aspects of service and maintenance work is rather unexplored throughout the companies. Compared to ergonomic simulations for production stations these work tasks are most commonly not investigated. Though there is a trend in the companies that these aspects are to be more considered and therefore also highlighted. One reason mentioned for this was that this is not as repetitive to its nature as for production for example.

How do you make sure that the parts are correctly placed and tightened when reassembled?

There are quite many quality issues that are related to the positioning of parts i.e. that the part is not positioned as it is supposed to be. The maintenance and repair methods were made as detailed as needed with use of figures and text to ensure that the service personnel did understand correctly. Within these instruction manuals there were for example torque rating included for screws when needed but not for all actions. According to the interviews most commonly the service technician ends the job with a test drive to ensure the functionality.

There was no use of haptic responses as a feedback to ensure right positions. All of the companies did have service centers where the service technicians were taught how to do the service and repair procedures. It was stated during the interviews that it was a great difference regarding how the different service stations carry through service and repair task. Even if the MSR-department had given them a manual of how to do it they did not follow this but found alternative ways of working.

Information flow between the OEM and service stations.

How do you collaborate with service stations and other customers regarding service and maintenance manuals etc.?

In order to get the service methods and service information out to the service stations and maintenance areas different IT-systems was used, with some low tech alternatives. The IT-systems did, in general, offer service and repair manuals, time standards, spare parts catalogue, communication interface, diagnostic fault tracing and software downloads etc. During the interviews the systems as such was not investigated why the core difference has not been investigated. There is a great difference between the technology levels at the service stations around the world why there is a need of low technology alternatives. Thereby paper copies of the service manuals as well as DVD-discs were still used. It was only pictures and text in the manuals. No movies or other type of interaction was used.

How is knowledge from the service personnel and customers taken care of and brought back into the organization?

The same IT systems used to deliver the maintenance and repair manuals were also used by to get feedback from the service personnel. Within these systems the service personnel had the possibility to give feedback and improvement suggestions back to the service departments. There are also customer complaint departments where customers can give their input to but also input from the service stations. It is not common that the complaints from service personnel as well as end customers are going directly to the product development departments.

4 CONCLUSION

By increasing the ease of maintaining and repair of the product solutions a longer life cycle is achieved which most surely leads to an increased sustainability. The consumer trends are going in a direction towards a more positive attitude to buy a function more than the product itself. This is the core message of Product Service System (PSS) which is a combination of physical products and services Maintenance, service and repair (MSR) aspects are considered of great importance for the companies according to the interviews. MSR will most surely gain greater impact in the organizations if it adapts to a PSS business models, which seems to be the trend today. It was consensus among the interviewees that it sometimes can be troublesome to make impact in project discussions etc. due to their difficulty in delivering hard figures e.g. cost, weight, CO2 emissions etc. If the companies will move more towards a PSS (Product-Service Systems) approach repair and maintenance will be of greater importance and the need to get numbers of these aspects will be highlighted and more focus will be put there.

It was stated during the interviews that the use of virtual tools, as support when developing and evaluating MSR aspects differed between the companies. But the use was on the low side in general. The trend was towards increasing the use of virtual tools in order to give feedback to the product development process before the product is finalized, proactive work.

The need of appropriate CAD models was also found as one of the core influencing aspects to be able to analyze and simulate maintenance and repair aspects as well as to do the maintenance and repair methods.

The following conclusions can be drawn from this study.

- It is of great importance to enable transformation of MSR requirements into hard facts such as cost, weight, CO2 emissions etc.
- There is a need of appropriate CAD-models both on part and assembly level.
- MSR is quite commonly treated in a reactive way than in a proactive way which leads to a situation where it is hard to influence the product solutions.
- Virtual training of service personnel has not been introduced but is seen as positive.
- The final conclusion of this paper is that there is a need to introduce simulation and analysis tools for MSR aspects.

By directing more focus to MSR the possibility to make the design and product more eco friendly and thereby more sustainable will increase.

Future work will be identification of key aspects of MSR that needs to ´be simulated and analyzed. Based upon this new virtual tools will be developed and introduced.

5 ACKNOWLEDGEMENT

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Supporting Maintenance Services by Utilizing Worker's Behavior Sensing and Visualization Based on Mixed-Reality Technology

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Abstract

This paper describes a novel approach to support maintenance services by utilizing mixed reality technologies. To use buildings, plants, and facilities for a long term is a one of the requirements needed to establish sustainable society. In order to manage life cycles of buildings and facilities appropriately, adequate maintenance is required. Not only the improvement of working efficiency but also the improvement of worker's satisfaction is an important issue. In order to solve the issue, we have researched and developed supporting technologies for maintenance services by utilizing worker's behavior sensing and visualization. In this paper, we describe the issues on operations of maintenance services and the supporting technologies to solve them.

Keywords:

maintenance service, mixed reality, behavior sensing, 3-D indoor modeling, visualization

1 INTRODUCTION

To use buildings, plants, and facilities for a long term is a one of the requirements needed to establish sustainable society. In order to manage life cycles of buildings and facilities and to keep safety, stability, and comfort, high quality maintenance services are required. The market sizes of building and plant maintenance services are currently about 3 trillion yen (investigation by Japan building maintenance association [1]) and about 860 billion yen (investigation by Japan institute of plant maintenance [2]) respectively, and the importance of the services is increasing increasingly.

Typical operations in maintenance services are mainly inspection, full equipment, repair, and cleaning. Most of the operations are manually provided by workers and labor-intensive operations except for networked remote monitoring of operational status of devices and facilities, and so most of them are compensated by experience and intuition of workers.

Worker's operations and work contents are written down in work reports, daily reports, notes for handover of operations, and so on. By accumulating work histories and know-hows, the work analysis and redesigning of service processes can be dealt from engineering point of views. It also prompts standardization of workflow and information sharing. Additionally, the standardized workflow can be used for the development of human resources for keeping pace with globalization of maintenance services caused by oversea transfer of manufacturing industry. However, the enforcing to record work histories strictly gives high workload to the workers. Moreover, in building and plant maintenance services, the repetition of move and work occur frequently, and thus recording operations on the site and comprehending states of other workers are often difficult. These are common issues in labor-intensive industries. One of the significant differences compares to arterial industry is the difficulty of comprehending situations in service fields since the ratio of human power is much higher. In addition, the variation of qualities of workers' skill makes strongly difficult to design optimal service processes and its applications.

To present the solution to these issues, firstly visualization of worker's behavior measured objectively and quantitatively in service fields and virtualization of their work spaces are effective in the first place. Based on the service analysis by the visualization, redesigning services and applying the redesigned services to the service field can be possible for running the service optimization loop a.k.a. plan-do-check-action (PDCA) cycle.

For measuring worker's behavior, time study that records time to operate, places to work, and etc. using stopwatches by investigators who track the workers has been applied [3] in large indoor environments such as buildings and plants. But, the method requires much time and human resources for measuring many workers exhaustively. Furthermore, it is difficult to record the detailed information such as moving trajectories of workers in service fields, places in which workers need actions of high workloads, and frequency of the actions. In terms of the visualization of the measured information, managers and analysts cannot understand the meaning of the behavior if the information is not visualized with the service field.

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In this paper, we describe a novel approach to improve service quality, working efficiency, and employee satisfaction by applying worker's behavior sensing and visualization technologies based on mixed-reality technology to service fields. This paper is organized as follows. Section 2 describes the concept of the maintenance service supported by mixed-reality technology, and Section 3 explains about the technologies of the worker's behavior sensing and virtualization of service fields. The operative examples and the summary of this paper are presented in Section 4 and 5.

2 MAINTENANCE SERVICES SUPPORTED BY MIXED-REALITY TECHNOLOGY

We aim at achieving improvements of both working efficiency and employee satisfaction of maintenance services by measuring worker's detailed behavior which is difficult to be obtained by conventional methods and by visualizing it for service analyses and designs. As the measurement and visualization technologies to achieve that, we employ sensor / data fusion [5] and 3-D indoor modeling [6] technologies based on mixed-reality technology [4] that prompts information circulation between real and virtual worlds. These technologies synergistically realize precise measurements of worker's behavior in service fields and creation of high-quality 3-D models of service fields at low costs (Fig. 1).

Based on the workers' information measured and visualized by the technologies, managers of workers can consider effective assignments of human resources and rapidly direct to workers in a broader perspective. For the workers, they can receive appropriate appraisal to their works by evaluating the workload as objective and quantitative indicator by using the measurement technology. Recently, maintenance services are becoming outsourced, so that comprehending positions in which place facilities to be maintenance in the service field are often difficult for the workers who do not well know the service field. In such situation, the workers can work effectively by an indoor navigation based on the real-time worker's behavior sensing and the visualization of the service field. Additionally, the measured data that are places and time to work can be evidences as work histories of workers, and so to measuring worker's behavior enables to support input of work logs. To accumulate these work logs and histories prompts standardization of workflows, and they are used as documents for developments of human resources.

As described above, maintenance services can be improved by utilizing the worker's behavior sensing and visualization technologies, and we believe service innovation that improves working efficiency and employee satisfaction.

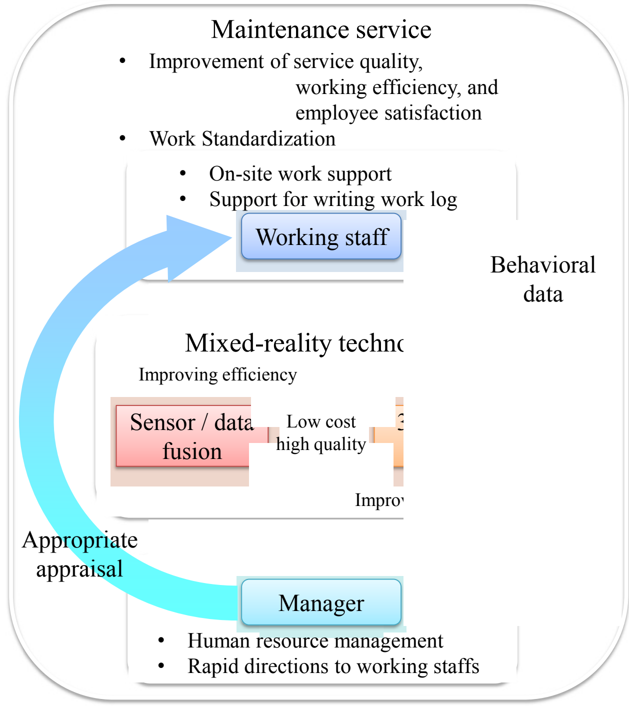

Fig. 1: Conceptual diagram of maintenance service supported by mixed-reality technology

3 MIXED-REALITY TECHNOLOGY FOR WORKER'S BEHAVIOR SENSING AND VISUALIZATION

In this section, we describe the sensor / data fusion for measuring worker's behavior and the 3-D indoor modeling for virtualizing service fields and visualizing the 3-D models of the service fields with the measured data based on mixed-reality technology for supporting maintenance services. The technologies can distribute the costs and realize high-quality functionalities by cooperating each other. The cost distribution makes installation of the technologies to service fields easy [4]. Remains of this section give the explanations of the sensor / data fusion and the 3-D indoor modeling technologies.

3.1 Sensor / data fusion

The sensor /data fusion (SDF) is a measurement technology that estimates worker's position, orientation, and action continuously in large indoor environments where global positioning system (GPS) cannot work [5]. SDF can estimates the worker's position, orientation, and action accurately by probabilistically fusing the relative displacement estimated by the pedestrian dead-reckoning plus (PDRplus: PDR with action recognition) [7] from sensor data of the sensor module (consists of gyroscopes, accelerometers, magnetometers, and a barometer) equipped by the worker, the absolute position estimated by the infrastructures placed in the service field such as active radio frequency identification (RFID) tags, surveillance

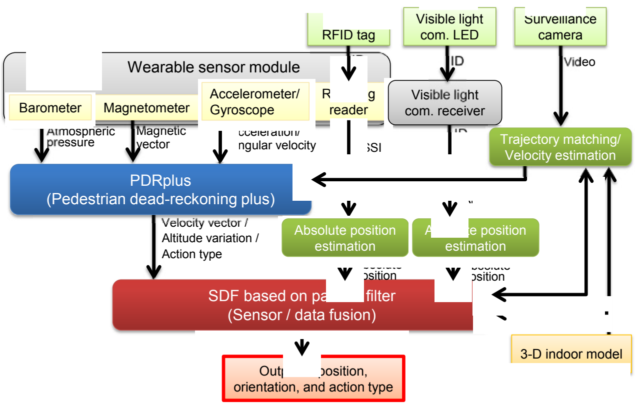

Fig. 2: Configuration of sensor / data fusion

Fig. 3: 3-D indoor model created from photographs

cameras, and LEDs with visible light communication which emit unique IDs, and the 3-D indoor model to be used for visualization. Fig. 2 shows the configuration of the SDF.

The SDF continuously estimates detailed movements by accumulating the relative displacement from PDRplus and corrects the accumulative errors by using the information from the infrastructures in the service field. By this configuration, the infrastructures do not have to be placed densely in the environment, and we can reduce the installation and running costs for the infrastructures. Since, RFID tags and surveillance cameras are often used in service fields for security reason, they can be also used for SDF. Moreover, not only the worker's position and orientation but also the worker's action such as standing up, sitting down, and so on can be estimated by PDRplus, and so we can quantitatively obtain the amount of movements and workload based on the estimated actions.

The SDF based on the particle filter [8] estimates the state of the worker's position and orientation by approximating a set of samples of the state vectors as the probability distribution. If the SDF can have the 3-D indoor model used for visualization etc., the SDF can correct the probability distribution to the one that consists with the actual worker's movement by restricting the distribution on the floor regions in the 3-D indoor models. The map-matching algorithm enables the SDF to track the worker precisely by diverting the 3-D indoor model.

The positioning and the action recognition can work in real-time by transferring sensor data via wireless network remotely from the sensor module equipped by the worker to the SDF server. Off-line processing is also possible by storing all the sensor data in the memory card such as micro SD cards in the module.

3.2 3-D indoor modeling

The 3-D indoor modeling technology [6] allows the user to interactively create photo-realistic 3-D models from multiple photos that capture the real environment effectively. In this 3-D modeling, the user can create 3-D models only from photos captured by an ordinal digital still camera. Therefore, the user can create 3-D models at low cost compared with the other method using specialized devices such as laser-range finders. The time occupying the environment for capturing photos is also comparatively short.

The modeler program utilizing the 3-D indoor modeling technology supports the user to effectively create 3-D models by exploiting geometric constraints estimated from each photo. Additionally, by cooperating with the SDF, the modeler supports to integrate 3-D models and to reduce texture shortages. This cooperation contributes to effective and low-cost 3-D modeling.

Fig. 3 shows a 3-D indoor model of an office environment (floor space: about 1000 m^2) created from 57 photos for about 10 hours. The images in Fig. 3 bottom are the views rendered from parts of the3-D model not photos. From the visualization, we can see the details of the office environments easily and intuitively.

4 SUPPORTING TECHNOLOGY FOR MAINNTENANCE SERVICES

This section presents operative examples of supporting technologies realized by the technologies described above.

4.1 Remote monitoring and workload measurement

To comprehend the worker's behavior and workload during the maintenance service has been difficult in the past. In addition, generally managers do not comprehend the details of each service field where the workers work. Therefore, the consideration based on the meaning of the worker's behavior derived from the service field for improving working efficiency has been difficult.

By utilizing our technologies, the managers can visualize and comprehend the workers' behavior in the service field in real-time. Fig. 4 shows the examples of the remote monitoring of the worker's position and orientation. We can confirm that the worker's position and orientation are precisely tracked by utilizing the 3-D indoor model and the state in the service fields is comprehensible. According to the assessment of the worker's situation by the visualization, the managers can optimize the human resources. For example, the manager effectively directs a worker who had finished tasks to support the other worker who had not finished.

Fig. 5 presents the visualization of the worker's trajectory with the 3-D indoor model. From the visualized trajectory, the managers and analysts can intuitively understand where the movements frequently occurred and how the worker moves in the service field. Furthermore, from the estimation of the SDF, they can obtain the statistical information such as time to work in each workplace, where high-workload tasks occurred in, and the frequency. According to the statistical information, the managers and the analysts can consider that optimal places where equipment used for cleaning should be for reducing the movements of the worker, assignments of human resources for high-workload tasks, and giving appreciation to the worker who is assigned high-workload tasks for improving working efficiency and employee satisfaction.

4.2 On-site work support

In maintenance services provided by outsourcing, the worker also does not well comprehend the service field and where the facilities to be maintained are. This is the one of the reasons that decreases the working efficiency. In our approach, the working efficiency can be improved by navigating the worker to the workplace in which the facilities to be maintained are by using the real-time SDF and the 3-D indoor model. Fig. 6 shows the appearance of the worker who is navigated to a facility to be maintained by the displayed guidance controlled by the worker's position and orientation. The worker can see the bird's-eye or first-person views selectively and can easily make correspondences between the real service field and the virtualized service field. Thus, by following the guidance, the worker can move to the workplace effectively.

The histories of the worker's movements can be used for the evidence of the work. For example, if a system of work reports can automatically input where the worker works in and how long is it, it can contribute to reduce the labor hours and to prevent forgetting reports.

In future, the detailed operation support such as displaying procedures of operations by augmented-reality technology

Walking in corridor

Cleaning sink

Cleaning toilet

Fig. 4: Remote monitoring of worker's behavior (Colors present orientations of samples.)

Fig. 5: Visualization of worker's trajectory

Fig. 6: On-site work support by real-time tracking and visualization (left colum : appearance of a worker, right colum : displayed guidance)

intuitively can be possible by combining our technologies and more precise tracking technology [9] using a camera equipped on the handheld devices. We consider that it can be effective for supporting less skilled workers and for developments of human resources.

5 SUMMARY

In this paper, we describe a novel approach to improve both working efficiency and employee satisfaction in maintenance services by utilizing worker's behavior sensing and visualization technologies based on mixed-reality technology, and we present the supporting technologies which have been developed for maintenance services. Our supporting technologies enable managers and analysts to objectively and quantitatively comprehend the worker's behavior that had been difficult to measure so far. Therefore, we believe that our technologies have strong impact not only on managements of human resources but also on worker's operations and designing services.

As the future works, we need to research and develop more feasible technologies for maintenance services based on feedbacks from actual managers, analysts, and workers in the service fields. Besides, to evaluate effectiveness and worker's workload before and after installation of the supporting technologies is required. By collecting such evaluation data in actual service fields, it is possible to create a cost-benefit model of the supporting technologies, and the model can be useful for spreading them to service fields.

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Battery Life Cycle Management for Automatic Guided Vehicle Systems

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Abstract
Battery management for automatic guided vehicle (AGV) systems is important to reduce costs and increase the efficiency of the AGV systems. Valve-regulated lead-acid (VRLA) batteries, which are generally used in AGVs, should be charged at appropriate time intervals, to avoid the deterioration of batteries and to extend their lives. On the other hand, frequent charging affects the efficiency of AGVs. The cost of chargers, which determines the charging time of the batteries, should also be taken into account. It is not easy to select a proper battery management strategy that considers all these factors. To solve these problems, a battery management simulation is developed for evaluating battery related costs under various AGV operation modes and for designing battery management strategies. To verify its effectiveness, the simulation is applied to a body in white at the finishing line of an automobile manufacturing plant.

Keywords:
automatic guided vehicle (AGV), valve-regulated lead-acid (VRLA) battery, battery management, simulation

1 INTRODUCTION

In recent years, automatic guided vehicles (AGVs) have been widely used to improve the efficiency of material handling in flexible manufacturing systems. AGVs usually employ valve-regulated lead-acid (VRLA) batteries because of their high reliability and low cost. Although VRLA batteries are inexpensive, as compared to other types of batteries, battery related costs of AGVs account for a significant part of their operation costs. The lives of batteries vary depending on their operation mode such as timing of charge. Therefore, to reduce battery related costs, life cycle management of batteries is important.

Although battery management is important for AGVs, limited researches have been carried out on AGVs, according to Le-Anh et al. [1]. Ebben [2] has proposed a cost trade-off analysis to assist AGV system designers in selecting the proper battery type as well as the number and position of battery stations. In addition, he proposed determining the locations of battery charging stations, to minimize effects of charging parameters such as charging time on the efficiency of the system. However, he did not take into account the deterioration of the batteries. On the other hand, Kaiser [3] proposed a cost-efficient battery management system for stand-alone renewable power supply systems (RESs) with a photovoltaic generator, in which the battery life can be extended by taking battery deterioration into account and using a different charging method. However, operation modes of the batteries for RESs are quite different from those of AGVs.

The goal of this study is to develop a methodology for planning a battery management strategy that minimizes battery related costs to increase the efficiency of AGVs. For this purpose, we developed a simulation for evaluating battery related costs in a given AGV operation mode. This simulation system can be used to determine the appropriate battery management strategy.

In Section 2, we discuss the framework of a battery management system for AGVs. In Section 3, Schiffer's model [4] is introduced to evaluate the battery deterioration induced by AGV operation. In Section 4, the planning method for the battery management strategy is proposed and the simulation used for evaluating battery related costs based on the state changes of the batteries during AGV operation is explained. Finally, in Section 5, a case study is presented by considering a body in white at the finishing line of an automobile manufacturing plant as an example.

2 BATTERY MANAGEMENT OF AGV SYSTEMS

Battery management is important for the efficient operation of AGVs. AGVs usually employ valve-regulated lead-acid (VRLA) batteries because of their high reliability and low cost as compared to other types of batteries. The life of a VRLA battery depends on its usage. The best way to use VRLA batteries is to avoid over-discharge and insufficient charging. Thus, to avoid

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battery deterioration and consequently reduce battery related costs, it is important to manage the timing of charge. In addition, battery deterioration affects the efficiency of AGVs. Frequent charging owing to a decrease in the capacity due to deterioration interferes with the AGV operation and reduces the efficiency of the AGV. Therefore, to minimize the total cost, it is necessary to prevent battery deterioration and increase the efficiency of the AGV by determining the appropriate battery management strategy. Fig. 1 shows the relationship between these factors and a battery management strategy as well as battery related costs. As shown on the left-hand side of the figure, the following items should be considered in the battery management strategy.

(a) Charging methods

According to Ebben [2], there are three types of charging methods: battery swapping, using a charging rail, and recharging inside the AGV. In the battery swapping method, a discharged battery is swapped with a charged one and then charged outside the AGV. Using the charging rail, the batteries are charged by running the AGVs under a charging rail. Although this method is effective, it cannot always be used to full charge the batteries. In the case of recharging the battery inside the AGV, the AGV cannot be used while it is being charged. Therefore, AGV systems with heavy usage cannot be charged using this method.

(b) Number of chargers and batteries

It is necessary to have a certain number of batteries and chargers to full charge the batteries. Thus, a limited number of batteries and chargers accelerate battery deterioration.

(c) Timing of charge

Timing of charge is important in battery management, because, on one hand, frequent charging extends the battery life, while on the other hand, it restricts the AGV availability.

(d) Timing of battery disposal

From the viewpoint of cost of batteries, batteries should be used for as long as possible. However, in the case of deteriorated batteries, the number of charging occurrences increases because of their reduced capacity. In addition, there is a risk of AGV stoppage due to energy shortage. Therefore, the timing of battery disposal is an important factor to be considered in battery management.

With regard to cost, the following items should be considered in battery management for AGVs.

(a) Initial cost of batteries and chargers

This depends on the charging method, number of batteries, and number of chargers.

(b) Battery replenishment cost

This is the cost of disposed batteries that must be replaced.

(c) Losses due to AGV stoppage

Improper management of batteries may cause AGV stoppage. Losses induced by AGV stoppage are evaluated by considering the costs incurred to recover the production losses.

(d) Labor cost for charging

This cost is incurred when battery swapping is adopted as the charging method. It is evaluated in terms of the time required for battery swapping.

3 MODELING CHARGE-DISCHARGE AND DETERIORATION CHARACTERISTICS OF LEAD-ACID BATTERIES

3.1 Attributes of VRLA batteries

As indicated in the previous section, identifying the state of batteries is essential for battery management. The state of batteries is represented in terms of state-of-charge (SoC) and state-of-health (SoH). These terms are defined as follows:

(a) SoC: ratio of residual capacity to nominal capacity.

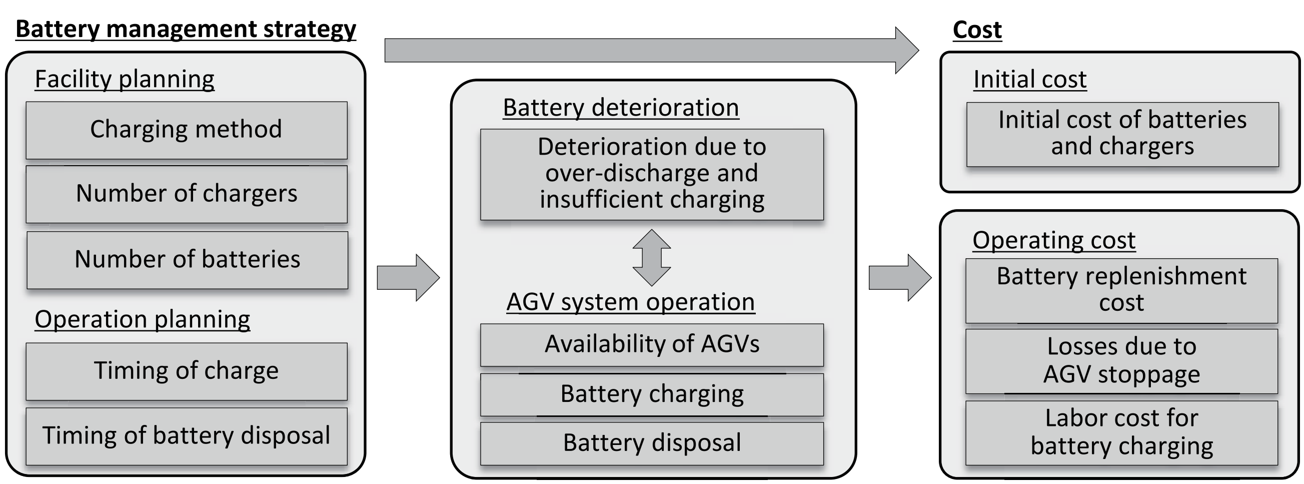

Fig. 1: The relations between battery management strategy and cost

Residual capacity is the stored electrical charge. It decreases as the battery discharges.

(b) SoH: ratio of available capacity to nominal capacity. Available capacity is the actual capacity of a full charged battery. It decreases as the battery deteriorates.

Battery deterioration affects the efficiency of AGV systems and vice versa (here, the efficiency of AGV systems includes that of batteries as well as that of AGVs). These relationships are shown in Fig. 2. Depending on the operation mode of AGVs, the batteries are charged and discharged. The changes in SoC induced by the charge and discharge operations affect the progress of battery deterioration. Decrease in SoH due to battery deterioration affects the way a battery charges and discharges. Typically, low SoH results in frequent charges, which disrupts the AGV operation and restricts the availability of AGVs. On the other hand, excess deterioration of SoH results in the disposal of the battery, as shown in Fig. 2.

Hence, for efficient AGV operation and cost-effective battery management, it is important to estimate the SoC and SoH of a battery.

3.2 Model for estimating available capacity of battery

To evaluate the SoH and SoC of a battery, we used Schiffer's model [4]. With this model, we can evaluate the progress of deterioration of a VRLA battery due to improper battery usage, such as insufficient charge, varying rates of discharge, and varying times between full charging. A simplified flow diagram of the model is shown in Fig. 3. In this model, the following dominant deterioration modes of VRLA batteries are taken into account.

(a) Grid corrosion

Grid corrosion is the main cause for deterioration of backup batteries. This effect is also non-negligible in case of cycle-use batteries, such as those used for AGV. The progress of grid corrosion proceeds with time, and is accelerated with high temperature and high terminal voltage.

(b) Degradation of active material

In the case of batteries used in AGV systems, the main cause for deterioration is the degradation of the active material. As batteries repeat cycles of charge and discharge, the composition of the active material changes, which causes deterioration of the batteries. The cumulative amount of discharge during a battery's life-cycle has a deciding effect on the deterioration of active material. This effect is further divided into two modes: sulfation of active materials and fining of active material particles and adhesion defects. The rate of deterioration of the former mode is accelerated when the batteries remain for long periods in a discharged condition. On the other hand, the rate of deterioration of the latter mode is accelerated when the battery over-discharges during charge and discharge cycles.

Using the model, at each point in time we can calculate the battery's SoH and SoC by setting battery-dependent parameters and inputting operation data such as charging and discharging current and ambient temperature. Battery-dependent parameters can be determined from the battery specifications and operating experiences.

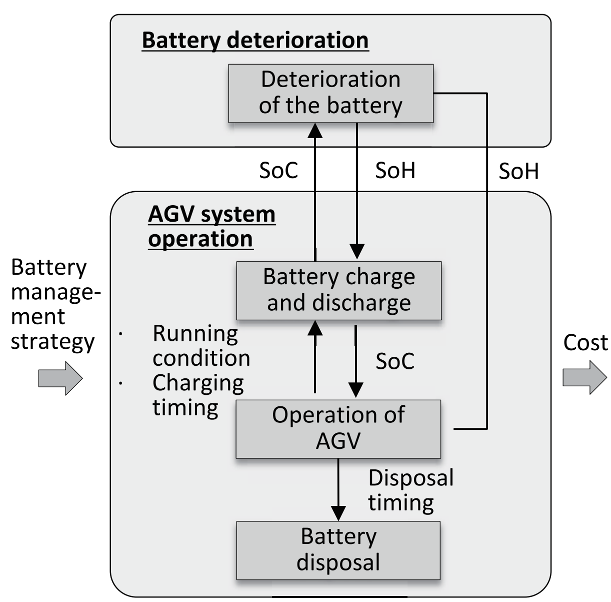

Fig. 2: Relationship between battery deterioration and AGV system operation

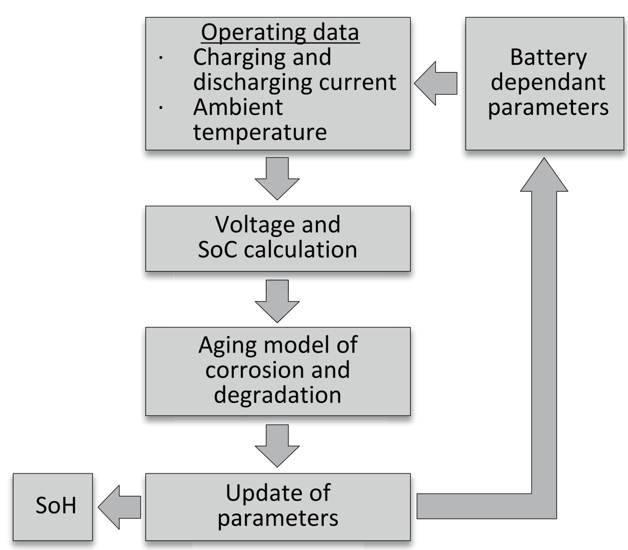

Fig. 3: Simplified flow diagram of model [4]

4 BATTERY MANAGEMENT STRATEGY PLANNING FOR AGV SYSTEMS

4.1 Simulation-based planning of battery management strategy for AGV systems

In planning the battery management strategy, we try to minimize the battery related cost, consisting of:

- "Battery acquisition cost" = "battery unit price" × "number of batteries",
- "Battery charger acquisition cost" = "battery charger unit price" × "number of battery chargers",
- "Losses due to AGV stoppage" = "number of AGV stoppage instances" × "influence rate per AGV stoppage",
- "Labor cost for battery charging" = "number of charging instances" × "labor cost per charging".

The influence rate per AGV stoppage is calculated as the overtime charge required for recovering the losses induced by the AGV stoppage.

The above cost items, except for the battery charger acquisition cost, vary depending on the AGV system operation, which is affected by the SoH of each battery. For example, the charging of a battery may be stopped before being full charged, when another battery on board becomes empty and requires charging. Therefore, it is not easy to analytically estimate the battery related cost. To cope with this problem, we adopt a simulation based approach in determining the battery management strategy.

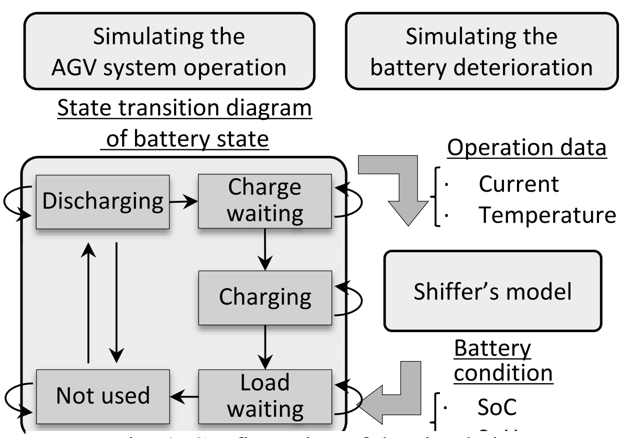

Fig. 4: Configuration of the simulation

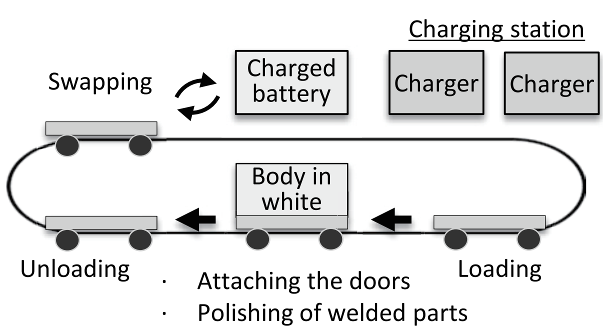

Fig. 5: Outline of the AGV system

4.2 Simulation system

In the simulation, the state of the AGV operation, including battery usage and the state of each battery, is calculated at each point in time. By running the simulation over an evaluation period, we can obtain the number of disposed batteries, number of charging events, and number of AGV stoppages. The configuration of the simulation consists of two modules, as shown in Fig. 4. The module on the left side of the figure is for evaluating the AGV system operation. In this module, the state of the AGVs and batteries are determined from the state transition diagram. The charging and discharging current at each point in time is estimated depending on the states of batteries. The module on the right side of the figure is for calculating the battery conditions. The conditions of batteries, such as SoC and SoH, are estimated using Schiffer's model, by getting from the left-side simulation module the charging and discharging current, as well as the ambient temperature. The state transition is determined by considering the battery state and the AGV location.

5 APPLICATION OF SIMULATION TO AGV SYSTEM IN ASSEMBLING LINE OF AUTOMOTIVE MANUFACTURING PLANT

5.1 AGV system for body in white at finishing line

To demonstrate the effectiveness of the proposed planning method, we take as an example an AGV system used in an automotive manufacturing plant. Fig. 5 shows the outline of the AGV system for a single-loop-type finishing line. In this line, 50 AGVs are used to transport the body in white, while doors, bonnets, and trunk lids are attached to the body in white, and the welded parts are polished. Production is carried out in 2 shifts. It takes approximately

Table 1: AGV system operating conditions

Items	Values
Number of vehicles production in a day	800
Number of shifts	2
Number of AGVs	50
Time of AGV to rotate the line	45 minutes
Battery swapping time	1 minute
Amount of electricity to rotate line	3.6 Ah
Battery type	VRLA battery
Nominal capacity of the battery	65 Ah
Time of full charging	about 6 hours
Location of battery chargers	end of the line

Table 2: Values for cost calculation

Items	Values
Battery price per unit	38,000 yen
Battery charger price per unit	78,000 yen
Influence rate per AGV stoppage	500 yen
Labor cost per charging	100 yen

50 minutes for an AGV to rotate the line. Battery swapping is adopted for charging the batteries. The discharged batteries are unloaded from the AGV and the charged batteries are loaded using a first-in, first-out strategy at the charging station. It takes approximately one minute to swap a battery.

5.2 Execution of battery management simulation

The simulation is executed using the AGV system operating conditions listed in Table 1. The parameters of Schiffer's model used for calculating the battery state are determined primarily based on the values used in Schiffer's paper [4]. They are modified based on the battery specifications and operating experiences. The changing pattern of the discharged current, when the AGV makes a circle in the line, is assumed to be identical, because each AGV rotates in the same loop.
In the simulation, the following set of conditions is chosen as the baseline condition.

- SoC at which the battery is charged: 0.4
- SoH at which the battery is disposed: 0.8
- Number of battery chargers: 100

Each condition is changed from the base line condition, that is, SoC in the range of 0.2–0.5, SoH is set in the range of 0.6–0.9, and the number of battery chargers in the range of 30–150. The evaluation period is set to 10 years. The costs of the various items are indicated in Table 2.

5.3 Results and discussions

The simulation results provide useful information in determining the proper battery life cycle management strategy.

Fig. 6 shows the changes of battery related costs for varying SoC, which is the criterion for charging the battery. The figure shows that the larger the SoC is, the lower the acquisition cost of the batteries becomes. This result is reasonable because larger SoC values are preferable for the battery life. On the other hand, as seen in the figure, the labor cost for battery charging increases as SoC increases. This is because frequent battery charging is needed to achieve larger SoC values. Therefore, to minimize battery related costs, we need to select the proper SoC value as the charging criterion.

Fig. 7 shows the changes of battery related costs for varying SoH, which is the criterion for battery disposal. The figure shows that large values of SoH, which means early disposal of the battery, lead to increased battery acquisition cost. On the other hand, small SoH values indicate that the battery is used even in a deteriorated condition. Since in this condition frequent charging is required, the smaller the SoH becomes, the larger the labor cost for battery charging becomes, as seen in Fig. 7. Therefore, to optimize the timing of battery disposal, we also need to select an appropriate SoH value.

Fig. 8 shows the changes of battery related costs, for a

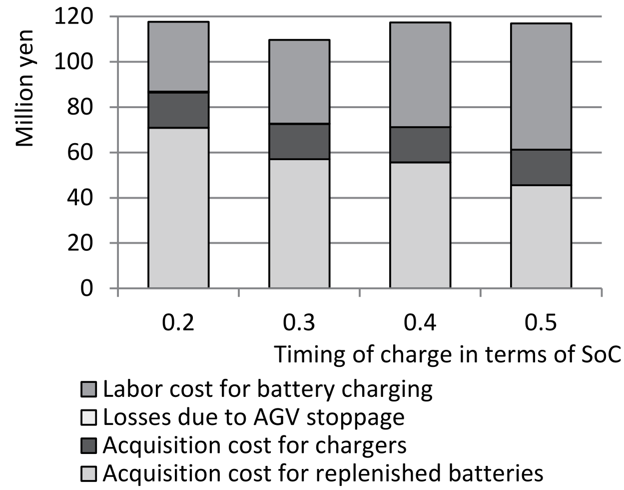

Fig. 6 : Changes in battery related costs with changes in timing of charge

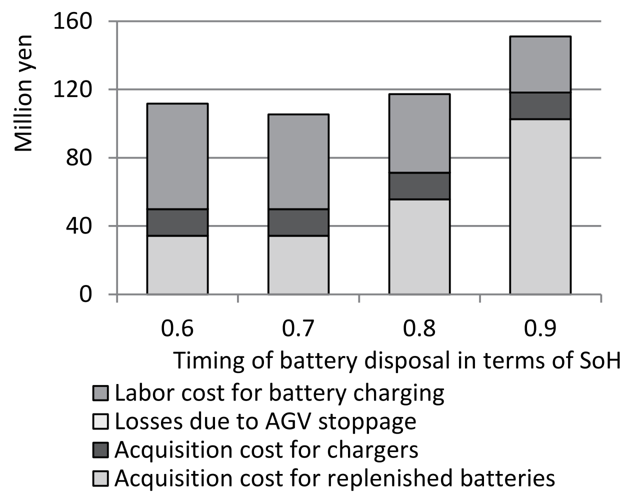

Fig. 7 : Changes in battery related costs with changes in timing of battery disposal

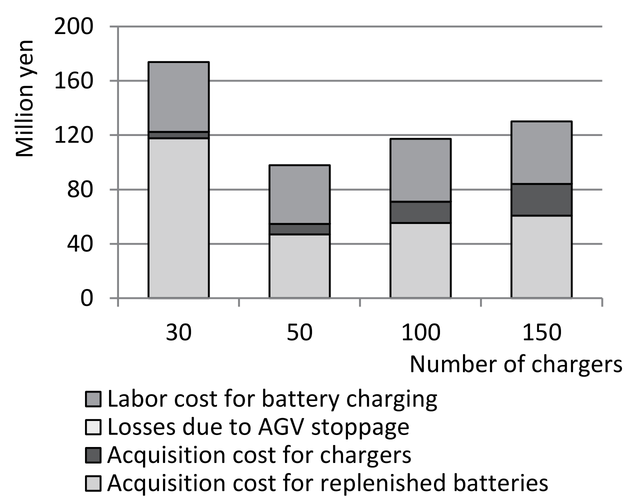

Fig. 8 : Changes in battery related costs with changes in number of chargers

varying number of battery chargers. The figure shows that a small number of chargers lead to an increase of the battery acquisition cost. In this example, the number of batteries is set to the sum of the number of the AGVs and the chargers. Therefore, the smaller the number of chargers means the smaller the number of charging batteries. Since the demand rate of charged batteries is constant, when the number of AGVs in operation is constant, the smaller number of batteries in the charging station results in shorter charging time, which could accelerates battery deterioration. On the other hand, excess number of battery chargers, results in the increase of the acquisition cost of replenished batteries. Because, in this setting, the total number of batteries increases proportionally to number of chargers, the total amount of deterioration due to grid corrosion, which progresses with time, increases. Therefore, to minimize battery related costs, we also need to select the proper number of chargers.

6 CONCLUSION

We have developed a battery management simulation to evaluate battery related costs, in a given AGV operation mode and to plan appropriate battery management strategy. In this simulation, the deterioration of VRLA batteries is calculated using the Schiffer's model. The effects of the battery management strategy on AGV system operation are evaluated by calculating, at each point in time, the states of each AGV and battery. This simulation can be used to plan a battery management strategy that minimizes the battery related costs, which include the initial cost of batteries and chargers, battery replenishment costs, losses due to AGV stoppage, and labor cost for battery charging. To verify its effectiveness, the simulation is applied to a body in white at the finishing line of an automobile manufacturing plant. The simulation results show that to determine the optimal battery management strategy, we need to take into account complicated relationships. For example, in determining the timing of charge and timing of battery disposal, the trade-off relationship between the acquisition cost of replenished batteries and the labor cost for battery charging should be considered. It is also necessary to consider different deterioration modes of batteries in determining the number of batteries. A small number of batteries accelerate the sulfation of the active material. On the other hand, an excess number of batteries induce a large amount of grid corrosion.

Because it is challenging to optimize the battery management strategy when considering these complicated relationships, the next step in our work will be to develop an optimization method for computing battery management strategies.

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Eco-Reliability – A Combined Approach to Balance Environment with Reliability

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Abstract
Over the past years a new concept has evolved to combine eco-optimization with reliability aspects. As a short phrase we have coined the word eco-reliability, which we would like to explain and explore in the following paper.

Keywords:
eco-reliability, trade-off analysis, multi-criteria optimization

1 INTRODUCTION

In a nutshell the accurate life time of a product is an underrated and often diffuse influence on the environmental performance of a product. On the other hand the reliability optimization of a product can lead to an over-use of resources, if an unrealistically long or harsh use time is targeted.

For both domains – the environmental and the reliability aspects – and for the resulting economic implications a better understanding and analysis of the "correct" life time is required. In consequence, there is a need to optimize such situations with domain-spanning trade-off tools, which are not yet available.

Compared to the previous conceptual paper [1] we would like to give more details on the trade-off mechanisms and the directions for devising practical tools in the future.

2 LIFE TIMES AND OBSOLESCENCE DRIVERS

Increasingly, the different concepts for life times of electronic systems are recognized as major influences on the environmental performance. Yet, most assessments have to be limited to one highly aggregated and averaged use case, where the actual expected active use and the ecoefficient life time is determined by such diverse factors as reliability, accidents, technical progress and fashion (see Table 1).

Life times in environmental assessments are usually condensed and averaged use patterns, which are assumed uniformly over the life time. Only in very specific cases are different user groups, or differing sequential use patterns distinguished (such as household or company internal re-use cycles). The life time ends when disposal or recycling is initiated to destroy the shape of the product, although most often inactive shelf storage is not counted as part of the life time. This is most often the case when there is a preselection to investigate energy use rather than material use. When material flows are in the focus of an analysis, especially in the form of dynamic material flow analysis, the model to capture life time is completely rebuilt compared to a standard life cycle assessment.

In the reliability domain we are in contrast dealing with probabilistic life times, which are often based on mixed

Table 1: Obsolescence drivers

Domain	Obsolescence effect
Reliability	Fail due to ageing
Reliability	Fail due to overstress / accidents / misuse
Technical progress	Technical obsolescence due to incompatibility with new standards or e.g. new software requirements
Technical progress	Efficiency obsolescence, when efficiency gains are high enough that early scrapping of equipment is preferable even when including all life cycle aspects
Economics	Economic obsolescence, when total cost of ownership is lower through earlier replacement
Economics of consumables	As a special case, when consumables are either not on the market anymore (see "incompatibility") or when buying a new product costs less than a set of consumables for the old product
Economics of bundle contracts	When a new contract with bundled hardware is more economic for the user, the old hardware is usually obsolete
Fashion	Obsolescence due to changes in fashion or design expectations, while product may still be fully functional

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load mission profiles or on cyclic laboratory load profiles. If a reliable use time in years is defined at all it is by necessity a conservative assumption, based on many boundary conditions about load types, load times and load strengths. In addition, reliability by its main definition means that selected performance or degradation parameters stay within predefined ranges. Out of range values are then classified as fail, and the reliable life time ends. Nevertheless products may still be functioning and in active use, even when the internal parameters declare the product a statistical fail.

In summary terminology for use time and life time is very diffuse and sometimes ambiguous, and we do not intend to set new definitions at this point across all domains involved. For the discussion of eco-reliability approaches and even more so for actual investigations the awareness for the potential mismatch of "life time" concepts in the different domains is an essential factor, however.

3 THE QUESTIONS TO ASK

At the core eco-reliability is a trade-off analysis spanning multiple design domains. A selection of design domains or partial models affected are depicted in Fig. 1.

A conventional trade-off involves sacrificing one result or parameter in order to improve another aspect of the system under investigation. The underlying assumption is therefore that one key performance indicator is improved to the detriment of one or more other performance indicators. In a wider sense, however, the performance parameters do not always have to be at cross purposes, and understanding and quantifying any correlation or linkage – irrespective of signs – constitutes a trade-off analysis. The result of the trade-off is then a better understanding of the mechanisms involved and a subsequent multi-criteria optimization to determine one feasible compromise solution.

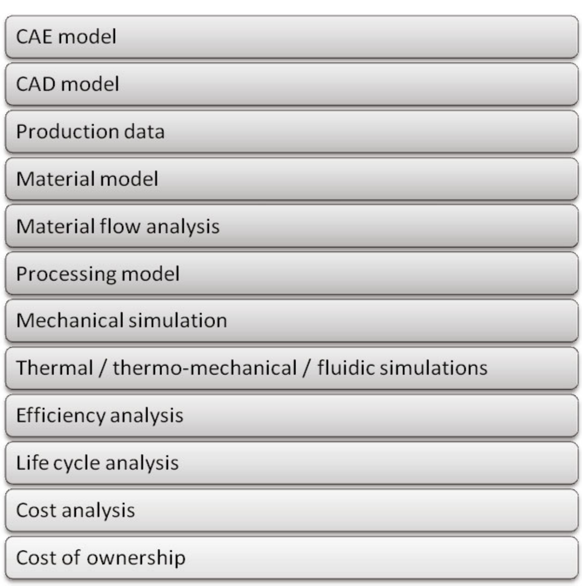

Fig. 1: Example design and modeling domains

Note that the scale directions are not always unambiguous, hence an increase in one parameter and a decrease of another parameter may be an improvement in both cases rather than a traditional trade-off situation. Replacing energy usage with energy efficiency will for example invert one scale of the problem and therefore completely change the optical interpretation without changing any facts.

Where a conventional trade-off would occur within the frame of one modeling approach or in very few cases combining two modeling domains, in the future more complex linkage between various models – and potentially still separate tool environments – will be necessary.

Provided that the software complexity and the data exchange can be solved – what would be the questions which could be answered additionally, more fully or more precisely than before? The following list gives a first impression, which is then referenced in the following case discussions:

- Toxicity vs. energy use
- Production resources vs. use energy
- Reliability vs. resource consumption
- Better sensitivity on life time assumptions
- Better sensitivity on user averaging
- Inclusion of efficiency trajectories

4 MORE DETAILED CASE DISCUSSIONS

4.1 Starting Simple: General Lighting

Energy efficient lighting presents various trade-offs relating to eco-efficiency. With the option of compact fluorescent lamps (CFLs) additional toxic potential has been introduced when compared with conventional light bulbs. But the improved energy efficiency was considered to outweigh the added toxicity, hence leading to the staged phase out of incandescent lamps in the EU under the Ecodesign directive [2][3].

This has been confirmed many times in retrospect: conventional light bulbs emit more mercury via the conventional energy generation mix than could be released from the replacement CFLs by breaking all CFLs at end of use. Therefore despite introducing additional toxicity in products the total toxic potential is reduced. This is a trade-off between differing environmental impact categories – a still contentious topic in the life cycle assessment community, as in the end it is often a societal or political decision, rather than a scientific decision.

The favorable balance for CFLs rests on another key parameter: the expected average life time of each technology. For general lighting the relevant life time is the cumulative use time, sometimes to be analyzed in conjunction with the number of switch cycles. If the difference between average maximum use times of the competing technologies were smaller than the current factor of ten then the amortization of higher production expenditure (for CFLs) and additional toxicity would not be quite as favorable. This is a case of trade-off between the reliability of the product versus its key environmental performance. In reality, however, some CFL products did not reach the declared life time, while some incandescent light bulbs far outlive the test standard of 1000 hours active use.

Hidden behind the average technical life time is the complexity of actual use times. For many lighting situations use times are so low and non-uniform that the mercury emission amortization will never occur. Nevertheless, the average must by definition be a solid base for political decision making, as other replacement bulbs will obviously have to have even better return on invest in terms of energy, mercury emissions or energy costs. This is a case where a more complete inclusion of use cases would bring better understanding of (local or individual) adverse effects of the technology change.

Even though ecoefficiency and eco-reliability are in favor of CFLs compared to incandescent lighting, there remains a potential draw back regarding dissipative use of valuable resources. This trade-off is still not straightforward to evaluate quantitatively, as to some degree a higher use of resources should be permissible to achieve longer life times together with higher efficiency. The root problem here is that resource loss is even more difficult to trade-off against toxicity or energy in one modeling approach. If CFLs were recycled to a large degree then resource loss would not be a problem. However, recent reports have shown that in Germany many CFLs are simply crushed to go into underground special waste sites. If this continues and is done similarly in other parts of the world, then the trade-off between lower energy use and higher environmental burdens in production, toxicity and resource losses would come to the foreground once more.

With the next technology wave of light emitting diodes in general lighting the possibilities for improvement are even better. Toxic materials are drastically reduced and critical resources appear only in small amounts. Nevertheless, these trace amounts should in the future be recovered at end of life.

An LCA comparison of Osram dating from 2009 showed that in a life cycle assessment perspective the LED component and module production has less environmental impact than the production of the aluminum cooler [4]. So even though LEDs are continuously improving in luminous efficacy, the remaining waste heat is still considerable and occurs concentrated in very small areas, leading to high effort for sufficient cooling under all operating conditions.

The current trade-offs are therefore more closely related to the reliability and lighting quality for retrofit, bulb-shaped LEDs. If the thermal design is not sufficient or is not stable over the life time then the lighting efficiency and the technical life time will decrease. Thus, at the current state of LED efficiency and of the power conversion, resource use for the cooling cannot be minimized without compromising the other key performance parameters.

The comparative equivalence of LED compared to CFLs in the production phase once more rests directly on the assumed technical life time. In the Osram LCA study 25000 h were assumed for the LED version, compared to 10000 h for the CFL and the standard value of 1000 h for incandescent bulbs. With these values one LED bulb is slightly better than 2.5 CFLs regarding primary energy consumption, and equal or slightly worse for the environmental impact categories covered. Both are in the same range as the equivalent 25 incandescent bulbs for most impact categories, and score slightly better regarding in terms of global warming potential and primary energy demand. Changing the life time assumptions for example to 20000 h for the LED or to 15000 h for the CFL would change the manufacturing comparison from "roughly equal" to a clear advantage for the CFL technology.

In all cases the use phase by far dominated the total life cycle result, so overemphasizing the differences of the production phase is unfair. Nevertheless this is an example of trade-off between different life cycle phases, and by extension between the different players in the life cycle.

At the 2009 technology generation analyzed in the report LEDs could be shown to just draw equal to the environmental performance of CFLs, both far surpassing the incandescent bulbs, but as mentioned with the potential to improve LEDs further and faster that the alternatives.

This is not a prime example for the importance of efficiency trajectories mentioned above, but it will be worthwhile to investigate at some point, whether replacement of early generation LEDs in high use profiles before they actually fail would be a net environmental benefit.

If so, should they be recycled as fast as possible to replenish the resource base, or should they be kept in storage until the recycling efficiency for certain elements has increased (another efficiency trajectory), or should they be employed for less intensive use cases, where newest technology does not pay off? The questions never end, and so far there are no adequate tools to answer these questions.

4.2 A Look at Energy Harvesting

Mobile and non-mobile local power supplies are another area for making eco-reliability investigations. While not reaching the visibility and the global environmental impact of lighting, consider that these are product types sold in millions in many countries of the world.

Once more, realistic use times and life times are key parameters for comparing established technologies (in particular primary and rechargeable batteries) with new options (such as fuel cells and energy harvesting).

In current work to be presented in a separate paper at EcoDesign 2011 the focus is set on comparing differing energy harvester solutions against the longer term use of batteries for distributed sensor nodes. To put this into perspective, also these products are projected to reach multi-million markets in the next years.

The basic trade-off is between the up-front technology and resource investment for the energy harvester, which then needs no additional energy resupply and – in the best scenario – no further maintenance at all. Batteries in comparison need to be replaced when looking at use cases over multiple years, leading to requirements of accessibility, constant maintenance planning, and either the production of the replacement batteries or the energy conversion for recharging in case of rechargeable batteries.

For now the focus is set on comparing the secure energy availability over a specified time against the environmental concerns such as potential toxicity and use of scarce resources.

For future investigations the reliability of the micro harvesters (technical life time limitations) will be of interest, as will be the trajectory combinations of the batteries and harvesters on the supply side and the sensor or microsystems on the energy demand side.

4.3 General Application Areas

Note that the general lighting examples are the "simplest" examples to introduce eco-reliability as a concept. Much more interesting, but also much more challenging, are similar trade-offs in mobility, alternative energy, industrial electronics and ICT (see Fig. 2).

Life time variation (technical product realization, but also influence of the operating conditions), use time variation (involving overlays of the different kinds of obsolescence, but also a spread of different use cases) and the time dependency are the key parameters to bring together. The resulting base data or scenario variations can then be coupled with any environmental assessment procedure.

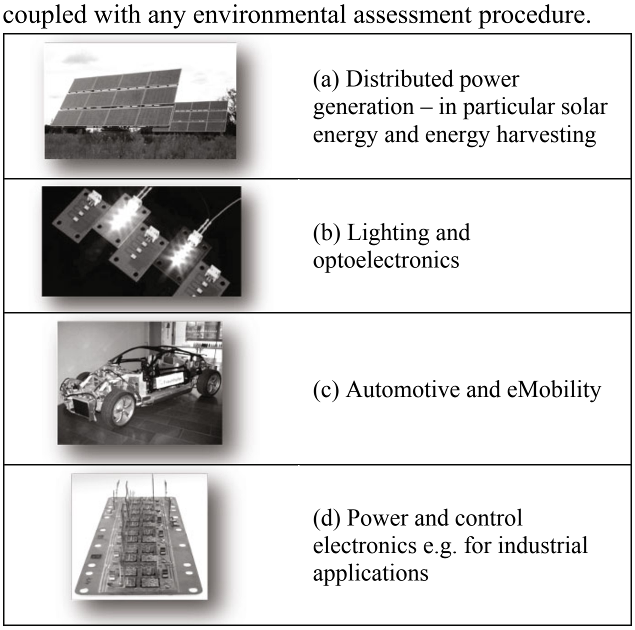

Fig. 2: Application areas for eco-reliability

5 SUMMARY

Seen within the framework of ecodesign of electronic products there are two main configurations where eco-reliability can serve as guidance. The main route of investigations concerns products and systems, where extending the life time or the factual accumulated use time is beneficial for the overall resource balance. These are systems, where additional resources during the generation phase might be justified by the very long use times or by multi-life-cycle concepts.

On the other hand there are systems, where the life time in effect need not be extended, because some form of obsolescence will occur before the technical life time is ever achieved. Reasons for obsolescence can be intentional one-time use, fashion, changing technical standards, or an efficiency race condition. For these systems the optimization path should be to minimize the value of materials used, and to ensure product take back and high grade recycling.

There are many system types between these extremes, where it is necessary to determine trade-offs and conflicting requirements already during the design. Models for parameterized trade-off analysis are therefore the core of the approach. But the modeling still needs to be very specialized depending on the application field, such as lighting, decentral energy generation, electro-mobility or industrial power electronics, and no uniform tool approach can be predicted at this stage.

The new combination of reliability and environmental assessment provides the basis to better distinguish, when to invest scarce resources intentionally, and when to limit their use unless proper recovery management is in place. In the end often a balance between energy efficiency over the whole life cycle and resource efficiency has to be determined, and the reliable life time has a major influence on the overall cost and environmental balance.

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Sustainable design strategies in practice and their influence on business models

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Abstract

Developments towards sustainable product innovations receive a growing attention in business as a result of several driving forces. Incorporating strategies for sustainable product innovations in a firm takes a longitudinal implementation trajectory. During and after the implementation of strategies for sustainable design, sustainable business models can emerge. This paper describes insights from practice – based on an empirical study in business cases- on how the implementation of sustainable design strategies in practice may contribute to business models evolving into sustainable business models. The results suggest two trajectories: sustainability can be added to the standard business model leading only to limited changes, or the implementation of the strategies lead to the development of a new business model that delivers more sustainable outcomes. The influence on the business model is indicated in the study to depend on the choice of strategy for sustainable product innovations and on the maturity of the firm.

Keywords: sustainable design strategy, business models, case study

1 INTRODUCTION

A growing number of firms realises that action is needed in order to follow current developments towards sustainable product innovations. Several types of pressure from various stakeholders thereby make them take action within product design, development and manufacturing [1]. However, incorporating sustainability in a firm asks for a long term transition in order to make product innovations sustainable. Different scholars motivate the importance of studying the implementation process of a strategy for sustainable product innovations, emphasizing that the main challenge of applying sustainable product innovations is not (just) in the development and formulation of a sustainable strategy and vision, but in the implementation of this new strategy in a firm [2], [3], [4]. During this implementation process, the theoretical strategy needs to be translated into practice. Also during, or as a result from the incorporation of sustainable product innovations, sustainable business models are found to emerge in practice. The introduction of such a strategy in the firm -by the occurrence of different activities- can grow in time and finally result into an (un)intended (sustainable) business model [5]. Zott and Amit [6] emphasise that the order of developing and implementing a product strategy or a business model can be interchanged. This paper explores the emergence of these business models during the implementation of strategies for sustainable design. First, literature on (sustainable) business models is briefly described, subsequently followed by the results of a qualitative study that provides empirical insights on the emergence of sustainable business models in practice. This paper thereby aims at linking theoretical and empirical insights on the implementation of sustainability criteria on a product development level, with a higher level in the firm that focuses on business innovation.

2 INNOVATION THROUGH (SUSTAINABLE) BUSINESS MODELS

In comparison to past and recent product innovations that often occur on a technical level, innovation of the business model focuses on a higher level in the firm and aims at adding value for all departments in the firm. Business models therefore link technical inputs and economic outputs of a firm, in other words converting new technology into economic value. The value of products and services forms a crucial element for firms [7]. The creation of value therefore forms a central element in a business model. A business model is defined as a depiction of the content, structure and governance of transactions designed so as to create value through the exploitation of business opportunities [6]. The value thereby refers to the total value that is created in the transactions, regardless of whether it is the firm, the customer, or any other participant in the transaction who appropriates that value. Content, structure and governance are described as the three constructs of a business model [6]. Several other authors consider four main areas in business that need to be covered in a business model: infrastructure, value proposition, financial viability and customer interface. These areas are sometimes further divided into six to ten attributes [8], [9], [10].

A sustainable business model (SBM) can 'tell the story of sustainability' within a firm by showing how sustainability is imbedded in the four main areas, related to content, structure and governance of a firm and its partners. In this

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sense, the incorporation of sustainability criteria in a firm's business model is mentioned as another way to support eco-innovations [11]. However, until now, few theoretical frameworks and empirical cases serve as an example for the development of sustainable business models.

The incorporation of sustainability criteria in the business model is seen by some authors as adding separate attributes next to the four main attributes: social and environmental costs and social and environmental benefits form two supplementing attributes [12], [13]. However, this view of separately adding these attributes might restrict a full integration of sustainability criteria in the business model and thus also in the firm. Traditional approaches are often restricted by such a partial integration [14]. An example is corporate social responsibility (CSR) where environmental and social issues often get relegated to the margins of company activity, stay unrelated to the core activities of the company (such as product design, development and manufacturing), and as a result these issues are not seen as an integral part of the business. More holistic approaches are proposed by other authors. One is proposed in the form of a conceptual framework of business model eco-innovation [5]. The business model canvas of Osterwalder and Pigneur [9] is thereby incorporated in a broader framework that includes the development side of marketable eco-innovations, the incorporation of economic, ecological and social aspects in the model as well as marketing and successful implementation of the eco-innovations. Another holistic approach proposes a system-based sustainable business model that is based on two company cases, in which both the socioeconomic as well as the natural environment are included [15]. The sustainable value framework [16] on the other hand combines sustainability drivers and opportunities with four basic components that create value for the shareholders, which are mapped according to two dimensions: time and activity boundaries (internal versus external). The four components are innovation and repositioning, cost and risk reduction, growth trajectory, and reputation and legitimacy. The availability of these, mostly conceptual, models and frameworks are of great value, although they need further development and verification in practice.

3 INSIGHTS FROM PRACTICE

This paper describes the results of an empirical case study in which eight business cases provide qualitative data and profound insights on the emergence of sustainable business models during the implementation process of sustainability issues in product innovations. In order to select appropriate business cases three criteria have been used. The eight business cases were selected on basis of a) being actively involved in product development and related activities, b) being in the process of integrating sustainability criteria in the firm and in product development, and c) being geographically situated in Belgium (Flanders) or the Netherlands. This geographical boundary limits differences in legislation and national culture, whilst it simultaneously increases the accessibility of the sites to be visited.

A combined set of qualitative data from different sources set [17] is used to analyse and study the business cases: interviews, archives and documentation and observations, of which the interviews form the main data source. In each business case, employees were addressed that are related to both product development and the process of implementing sustainability criteria in product development or in the firm. The analysis of the empirical data has been done in two main stages, of which the first has a descriptive nature, whereas the latter is explanatory. In a first step, different topics that have been touched in the data set were coded and subsequently clustered. A second part of this step contained the description of the phenomenon under study, i.e. the emergence of sustainable business models during the implementation process of sustainability in product development, subsequently followed with an analysis of each case. In a last step, a cross-case analysis between the different business cases has been made. Table 1 presents an overview of the business cases studied.

Table 1: Overview of cooperating firms

Case	Product	Product sector	Firm's size	Experience with sustainability issues
Case 1	creation of durable working, learning and living environments	Furniture	Large	Experienced Since 1990
Case 2	display and visualisation solutions	Electronics	Large	Starter Since 2009
Case 3	ergonomic office chairs	Furniture	Medium	Experienced Since 1997
Case 4	space-saving, functional and modular furniture	Furniture	Medium	Starter Since 2007
Case 5	sheets and films	Chemical industry	Large	Starter Since 2007
Case 6	electronic consumer goods	Consumer goods	Large	Experienced Since 1994
Case 7	quality aluminium systems for external use	Construction industry	Large	Starter Since 2006
Case 8	public lighting systems	Lighting equipment and traffic signalisation	Large	Starter Since 2008

In the study, fourteen people cooperated from eight different firms, in total spread over sixteen interviews and observations during work sessions. Five of the firms have their headquarters in Belgium; the three other firms are situated in the Netherlands. The functions of the respondents vary within the different firms: as a coordinator of Corporate Social Responsibility (CSR), coordinator of quality, health and environment, communication manager, or R&D manager. The business cases do not necessarily have the same maturity level of implementing sustainability in their business innovations; a distinction is made between starters and experienced firms. The starters are considered as firms that recently started their explorative trajectory, trying to find out what fits best to the firm and its products, which should lead them towards more sustainable products. The 'experienced' firms have been mostly incorporating and reporting on sustainability aspects for more than ten years. This does not mean that all the work has been done, as all of them are currently working on improvements in order to reach a higher level of maturity when it concerns sustainability.

4 EMERGENCE OF SUSTAINABLE BUSINESS MODELS

This paper forms a part of a broader study that entails a study of the complete implementation process. In this paper however, we do not go further on the description or analysis of the implementation process of sustainable design in the cases businesses due to space boundaries. This paper is limited to the study results on the emergence of sustainable business models.

4.1 Sustainability in the business model

The empirical data have been ordered according to the four main areas of a business model [8] and thus represent how different aspects related to strategies for sustainable product innovation influence the business model of that firm. In order to limit the space used, Table 2 shows how this is the case for two of the eight firms that cooperated in this study. The complete table points out a selection of findings according to the elements of a business model as described in section 2, suggesting how the implementation of the sustainability strategies influences the content of the business model.

A first indication that comes forward is a variation in impact on the business model between the business cases depending on the strategy and the experience of the firm, e.g. firms that incorporate a product-service system (PSS) versus firms that focus merely on material improvements, eco-efficiency or legislation. Product-service systems are indicated in the data set to occur in business cases 1 and 3 and were indicated to have a larger impact on the sustainable business model –i.e. on customer interface, infrastructure and financial viability- than is the case with e.g. eco-efficiency in product design.

The data also indicate a difference in impact on the business model between cases that have a common vision on and framework for sustainability and cases that do not have this common view on sustainability. In several of the cases that recently started the incorporation of sustainable design, a general vision was indicated to be lacking, whereby adaptation on sustainability occur on an individual project level. In this group of firms, adaptations in the sustainable business model stay limited to the margins of the company activity (e.g. cases 2, 4 and 7). This corresponds with the indication in literature on restrictions of traditional approaches [13].

As an example, the integration of sustainability in business case 4 leads to an improved value proposition and an adaptation of the key activities. On the other hand, the empirical data indicate that in firms with more maturity on sustainability, and where a general vision on sustainability is present -such as in business case 3- the changes that took or take place in the firm concerning sustainability issues seem to affect the value proposition, customer interface, infrastructure and financial viability of the business model. All four areas and the adaptations that

Table 2: Adaptations of the four main areas of a business model through the integration of sustainable design strategies

	Value proposition	Customer interface	Infrastructure	Financial viability
Case 3	Creation of leasing system for office chairs Ensuring closed-loop of products (leasing, take-back and recycling)	Leasing and take-back services for products	Sustainability network - sustainable suppliers - recycling companies - knowledge and research institutes Key activities and resources - take-back system - leasing system - sustainable marketing - ecodesign quality products - eco-efficient development and production - disassembly line	Leasing system Take-back system Material reduction for new products Eco-efficient production and infrastructure
Case 4	Light-weight, space-saving and modular furniture	-	Sustainability network - external experts - knowledge and research institutes Key activities and resources - projects in cooperation with partners from network	Cost-efficiency

occur in the empirical data are discussed below for each area.

Value proposition. It was found that the integration of a strategy for sustainable product innovation led to a new and (more) sustainable value proposition in all the business cases studied. This adaptation or change of the value proposition however does not equally influence the value creation in the different transactions in the other main areas of the business model (i.e. infrastructure, customer interface and financial viability) or towards the different stakeholders (firm, customer, other partners) [6].

Customer interface. The data from the different business cases indicate a low attention for the customer interface. In some of the cases, sustainability is not considered to add value to the customer. In other cases, some elements related to sustainability are identified that can support and strengthen customer relations and customer channels. This occurs mostly in the business cases that changed to offering PSSs, or in allready customer-oriented business cases. These insights suggest that, so far, the customer side of the (sustainable) business model is barely influenced by the implemented strategies, or rather, that the current strategies for sustainable product innovations insufficiently take account of this customer side.

Infrastructure. Cooperation in sustainability networks is mentioned in all firms, independent of the experience of the firm. External experts on sustainability occur in many of the cases, mostly in those that have only little experience with sustainability issues. In-house expertise on the other hand is indicated to occur only in firms with significant experience. A similar situation applies for cooperation with universities and research institutes, and for influence in the supply chain. The data suggests that the business cases that do not have a common vision and framework for sustainable product innovations mostly cooperate with external experts and partners in order to assemble and gain knowledge on sustainability issues. On the other hand, sustainability experts form an asset in the key resources of the other firms. Also in these cases, a sustainability network is indicated to rather have a strategic function with the aim to find allies on the same sustainability level. More and different partnerships thus arise as a result of the integrated strategy for sustainable innovation.

In all cases, key activities are indicated to become affected by the implementation of sustainability criteria in product innovations, next to a larger number and a different type of key partners.. Other, new activities occurred in some of the business cases, such as the development of new in-house expertise, the development and management of leasing and take-back systems, etc.

Financial viability. The data suggests that, especially in the early stage of implementing strategies for sustainable product innovations, low revenue streams are present in the business cases. The incorporation of sustainability criteria thus does not immediately lead to direct revenues for a firm, but it might already lead to cost reduction and efficiency from the start. This type of financial viability was indicated most often in the business cases. This cost-efficiency can also be considered as a part of the value proposition. As a remark, it should also be noted that the data in this study only provided limited information on the financial viability as an aspect of the emerging sustainable business models from the integrated strategies.

4.2 An example of an emerging sustainable business model: business case 3

This section gives an example of an emerged sustainable business model, based on business case 3 of this study. This firm followed an interesting trajectory towards sustainable product innovations, whereby different strategies were applied consecutively: starting from a focus on design for disassembly, the firm broadened their sustainable activities to an own internal disassembly line and a corresponding take-back system. However, in order to complete and ensure the closed material loop of their products, a new strategy was introduced: the leasing of their products. Although leasing is not new as a concept, i.e. for cars, it is an innovative approach in the furniture sector. The four main areas of a business model and how they are influenced by the implementation of sustainable design strategies are described subsequently for business case 3.

Value proposition. In this business case, the value proposition changed significantly by the introduction of a system to lease their products. The company switched from offering a product, i.e. office chairs, towards a product-service system (PSS). For both the firm as well as the customer, this created interesting opportunities, but also a new way of working, selling, distributing, maintenance and usage. For the company, it closes the material loop, because by offering the products as a service, the firm is guaranteed to receive all the leased chairs back. These can subsequently be disassembled, reused (parts) or recycled (materials) and manufactured into new chairs or other products. However, it also demands new methods and approaches for the sales department, as well as for distribution, maintenance and take-back.

Customer interface. Significant changes are indicated above to occur in the customer relationships, whereby much energy and time needs to be invested by the sales department to explain the new product-service combination to possible customers, the benefits of the system for the customers, the environmental gains from the system, and an explanation on the pricing of product and service that shows the financial consequences of the system in comparison to the traditional way of buying office chairs. However, the company did not approach new sales channels nor did it change focus towards other customer segments. The latter can be explained by the aim of the firm to be a frontrunner in a niche market. Entering other markets would mean that the leading position of the firm might get lost or threatened. The choice for using the current sales channels stems from the availability of multiple sales channels that differ depending on the country. This specificity of sales approach could get lost with the development of a new and uniform sales mechanism.

Infrastructure. The infrastructure of the business case was also indicated to have become affected significantly, as substantial changes were needed in the key activities, key resources and the key partners. New key activities were linked to the leasing and take-back system, whereby the sales, maintenance and service and collection of the products needed to get organised well. Moreover, the disassembly of the products happens in-house, which makes that the infrastructure has been adapted (assembly line), but also the employees needed education on the purpose and the procedure to follow. New partners entail recycling companies, suppliers of recycled materials and other sustainable materials, as well as other partners with which the business case cooperates in research and other projects concerning sustainable innovations.

Financial viability. All these changes also have repercussions on the financial viability, in which leasing contracts create constant and long-term revenue streams, as well as a strong and long-term connection with the customers. Moreover, the collection and recycling of materials saves (new) material costs, as well as an eco-efficient production and infrastructure lowers costs. On the other hand, the organisation and fulfilment of the leasing system with extra maintenance and collection asks for an adapted cost structure in which additional efforts and investments are needed for personnel, infrastructure and education. However, in this business case, the financial advantages were indicated to be merged with the other advantages that are created for the customers, the firm and the environment, which makes it a viable and attractive sustainable business model.

In this company, the integration of the applied strategies for sustainable product innovations clearly led to a new and sustainable business model that strengthens their approach and the value they create throughout the complete value chain.

5 CONCLUSIONS

The aim of this paper was to link theoretical and empirical insights on the integration of sustainable design on a product development level, with changes in the business model of that firm, which most often gets developed on a higher level in a firm. The business case data in this study suggest that initial implementation of sustainability in product design and development generally lead to changes in a firm's business model. However, changes range from a limited effect, where sustainability is a mere add-on in the periphery of business activity, to the development of a genuinely new business model. The difference in type of sustainable business model seems to depend on the chosen strategy for sustainable product innovations. The data suggests that focusing on product and process related activities do not lead to substantial changes in business models, whereas developing activities that span beyond products and processes, such as developing product-service systems, have a considerably larger impact on the business model and can thus lead to well-integrated sustainable business models, as shown in the example case. The incorporation of sustainability issues was indicated in all the business cases to lead to a new value proposition, a change in key activities and more and new key partners. Acquiring external experts as new partners seem to occur more regular in inexperienced firms, whereas more in-house experts are present in the more experienced firms. The customer side of the business model is indicated to be underexposed in several of the business cases and merits more attention in order to raise the total value creation of the business.

This study provides valuable insights on how sustainable business models emerge during the implementation of strategies for sustainable design, based on a qualitative study of eight business cases. Further research is recommended that focuses on a larger sample of business cases, whereby common strategies and approaches for sustainable design can serve as a starting point to study how the application of these strategies affect the firms' business models. Quantitative research can provide valuable insights and simultaneously measure the impact of certain aspects on the development of sustainable business models, which on its turn can support the integration of sustainable design in business.

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Design for Remanufacture: Organisational Factors Influencing Successful Integration into the Design Process

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Abstract
Remanufacturing, the process of returning a used product to a like-new condition with a warranty to match, is widely recognised as an environmentally preferable end of life strategy for many products, being both an energy and material saving solution. How the product was designed can have a significant effect on how easily it may be remanufactured, and it is from this understanding that the concept of 'design for remanufacture' (DfRem) has emerged. The aim of this research is gain an understanding of the organisational factors that enable the successful integration of DfRem considerations into a company design process, through a series of case studies in the mechanical/ electromechanical sector. This paper presents the findings from case studies of two companies currently remanufacturing their products- one that is involved in DfRem, one that is not. A comparison of the two case studies has revealed that factors such as customer demand, remanufacturer communication and business priorities may have a significant effect on DfRem integration.

Keywords:
Remanufacture, design for remanufacture, organisational factors

1. INTRODUCTION

Remanufacturing is now widely recognised as an environmentally preferable end-of-life strategy for many products, being both a material and energy-saving process as well as reducing waste to landfill. The process involves returning a used product to original specification or better through inspection, disassembly, cleaning, reprocessing, reassembly and testing; and therefore much of the value from original manufacture is retained (Figure 1). A remanufactured product may be sold at a reduced price yet with a warranty that is equal to or better than a newly manufactured equivalent [1]. Products that are suitable for remanufacture can typically be described as durable (able to withstand the remanufacturing process plus multiple lifecycles) and of high value to ensure that remanufacture is profitable. There of course must be customer demand for the product once it has been remanufactured, which is most likely when that product is technologically stable. Examples of commonly remanufactured products include automotive parts, photocopiers and off-road equipment.

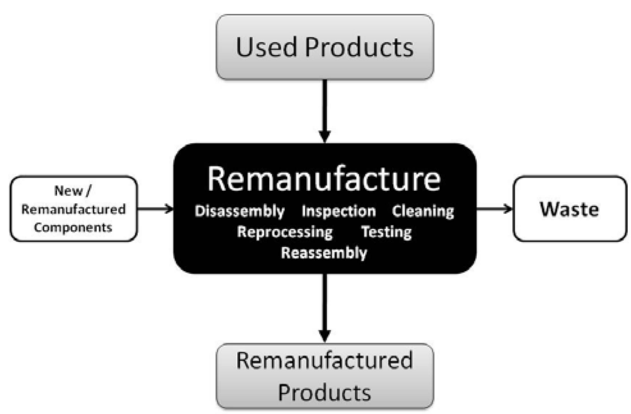

Fig. 1: The remanufacturing process

Previous research has indicated that the efficiency and effectiveness of the remanufacturing process can be greatly influenced by product design features and properties such as material choice, durability and ease of disassembly. It is from this understanding that the concept of 'design-for-remanufacture' (DfRem) has emerged, a design activity focused upon facilitating the various remanufacturing steps, thus promoting less

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waste and more component reuse. However, very few products are currently designed for remanufacture, often limiting a producer's potential to maximise their gains from end-of-life processing. The reasons behind this lack of DfRem activity have yet to be fully explored, in particular organisational issues, the focus of this paper.

2. RELATED LITERATURE

DfRem has been a fairly popular topic in remanufacturing research over the past 15 years or so, and it is now widely recognised that there are certain product properties that can have a positive or negative effect on the remanufacturing process, depending upon how that product was designed. For example, if a product is designed to be more easily disassembled without damage this will improve remanufacturing efficiency, and if more durable materials are selected the product will be more likely to survive multiple lifecycles [2, 3]. Much of the previous research in DfRem has focused upon design methods and tools developed specifically for remanufacturing issues, either quantitative metrics and calculations [4, 5] or more qualitative design aids [6]. Others have proposed the use of existing methods and tools to enhance remanufacturability, such as modularisation [7] or QFD [8]. These papers offer new or innovative ways to consider remanufacturing during the design phase, however they do not consider how such methods and tools could be integrated into a complex company design process. Indeed it has not been considered whether the provision of DfRem methods and tools alone is sufficient for successful integration.

Similar research in the field of 'design for environment' or 'ecodesign' would suggest that organisational factors could also have a significant impact on DfRem integration into the design process. McAloone [9] found that designer and management enthusiasm were key factors in ecodesign integration success, as well as the timing of environmental decisions. Boks [10] focused upon the 'socio-psychological' factors of integration and concluded that issues such as cooperation and organisational complexities could be more important than technical issues such as tool development. Ammenberg and Sundin [11] emphasise the importance of having ecodesign as a prominent fixture in the design process, and propose greater inclusion of product design considerations in a company's environmental management system. Johansson [12] compiled a list of success factors based upon ecodesign integration literature, which included organisational concerns such as management, the development process and competence. These papers provide a framework for identifying the organisational factors that affect DfRem integration. However, although DfRem is often considered to be under the wide umbrella of design for environment issues, it cannot be assumed that research findings for ecodesign are mutually compatible with DfRem. Studies have shown that most companies will choose to remanufacture primarily for profit, and a company is extremely unlikely to remanufacture for environmental reasons alone [2], thus making the incentives and goals of DfRem different to that of ecodesign.

3. INVESTIGATION

Considering the current state-of-the-art in DfRem research and the indications provided by research conducted in similar fields, the focus of this study is upon understanding the *organisational factors* that impact upon DfRem integration into the design process. What kind of organisation can successfully integrate DfRem, and how may this be achieved? Answering this question involves viewing DfRem not as an 'add-on' task but as part of a wider system that incorporates management and business operations as well as individuals' attitudes and motivations.

The investigation is following a multiple case study methodology with OEMs producing mechanical/ electromechanical products, one of the most mature remanufacturing industry sectors in the UK [13]. Interviews with engineering management, design engineers, aftermarket engineers and remanufacturing personnel are being used to map the organisational conditions that will enable successful design for remanufacture, either to enhance current remanufacturing activity or effectively prepare for remanufacturing activity in the future. Interview data was also supplemented with observations of company manufacturing and remanufacturing processes, and access to documentation such as environmental policy and checklists.

4. FINDINGS

Two case studies have been carried out to understand the organisational factors that affect DfRem integration within OEM-remanufacturing companies: OEMs (original equipment manufacturers) which are currently remanufacturing their own products (as opposed to contract or third party remanufacturing). Previous work has found that this business scenario is the most likely to involve DfRem, as the OEM has a direct incentive to reduce remanufacturing costs [14]. Company A manufacture diesel engines for the off-road and power generation market, Company B manufacture pumps for the oil and nuclear industry. Both these product types are naturally suited to remanufacture, and it has been found to be a profitable aftermarket solution for both businesses. However, Company A is actively involved in DfRem, whilst Company B is not. Interviews were conducted to determine the drivers and barriers to DfRem within each organisation, utilising within-case and cross-case analysis. Figure 2 illustrates the relevant factors and the relationships between them, as identified through this research.

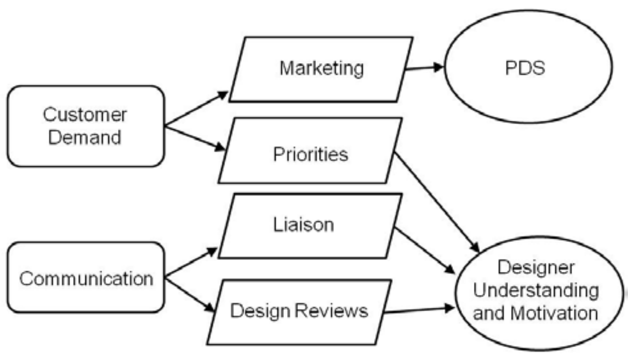

Fig. 2: Identified factors affecting DfRem integration in the case study companies

Customer demand was identified as a key driver to DfRem. If there is customer demand for remanufactured products- or low cost spares- the research found that **marketing** are most likely to be in support of remanufacture. As design specifications are typically written in collaboration between engineering and marketing, this means that the interests of remanufacturing will be included in the product design specifications (PDS) documentation. This finding would concur with similar findings in the field of ecodesign integration [15]. Commitment to DfRem at this early stage, when few design decisions have been made, is of significant importance for successful integration. This enables DfRem to become a natural part of a designers' every day work: the PDS documents of Company A contain DfRem specifications, and interviewed design engineers did not consider DfRem to be a particularly difficult or troublesome task, it was simply viewed as one of the many considerations to be made when developing a new engine. This somewhat contradicts popular views in the literature that DfRem requires specialist tools and that designers' lack of DfRem knowledge is a barrier [2]. Customer demand would appear to be one of the more striking differences between Company A, who design for remanufacture, and Company B who do not. Whilst Company B remanufacture their products, their customers in the oil and nuclear industry do not specifically demand remanufacturing- they have demanded a high speed service that Company B have chosen to address through remanufacturing. Because the customer is not concerned with the specific benefits of remanufacturing, DfRem is not highlighted as a key design feature when developing specifications.

Whilst customer demand may increase incentives to design for remanufacture, these case studies have found that customer demand and other pressures such as legislation may have the opposite effect, even simultaneously. For example, the increasing pressure of emissions regulations upon design engineers working for Company A means that remanufacturing issues are often discarded due to a conflict of **priorities** in which remanufacturing is most often considered least important. Similarly, the bespoke nature of Company B's products comes hand in hand with very specific customer demands, leaving little room in the design process for DfRem considerations. Designers are under great pressure to meet these demands; if it is a case of compromise between DfRem and another, greater priority, DfRem considerations are most likely to lose out.

Furthermore, this research has found that DfRem understanding and motivation amongst designers, whilst influenced by priorities, may also be reinforced by standards of **communication** between the remanufacturer and OEM design engineering. Both companies in the study cited communication as an area that could be improved to enhance DfRem activity. Without effective communication between both business sectors, there is little opportunity for the remanufacturer to provide design-related feedback that will inform designers of the potential to enhance remanufacturability. Without this communication, designers will remain uninformed and unmotivated with regards to DfRem, and remanufacturing issues will remain low priority in the design process, even in instances where the benefits of DfRem are high. Similarly, a company that solely relies upon historical and experience-based remanufacturing knowledge may fail to address the most relevant and challenging DfRem issues of the day. Both companies in the study designed their products based on historical knowledge and data on remanufacturing: Company A make use of long-established standards and guidelines and design management at Company B felt that because their current products are based on a long-established pump design, there is no longer a need to consider remanufacturability.

To expand upon the communication factor, key considerations are 'who' and 'when'. *Who* communicates will have an impact on how effectively DfRem feedback can be integrated into the design process: their background, their expertise and their relationships with both remanufacturing and design engineering. Company A have a **'remanufacturing liaison'** who is able to pass information between both parties and raise DfRem issues during product development, however it is possible that direct communication between designer and remanufacturer would be most effective. *When* communication takes place is also of significance because there is a short window of time during which DfRem design changes will be feasible: after a certain point in the design process significant changes are considered too costly and time consuming [15]. Therefore, the earlier in the design process this communication can take place, the more influence remanufacturing concerns may have on the final product design. Early **design reviews** were identified to be a strong opportunity for improved OEM-remanufacturer communication: one of the differences between Company A and Company B is the attendance of aftermarket representatives at design reviews.

5. DISCUSSION

This paper has presented some of the key factors affecting an OEM-remanufacturing organisation in the integration of DfRem into the design process, namely customer demand (market support and prioritisation) and communication. Whilst external factors such as customer demand and legislation have a strong control over designers' priorities, they are mostly outwith the control of the design engineer. However, this is not to say that an OEM that does not have strong customer demand for DfRem or an OEM that has other critical issues to prioritise could not benefit from more remanufacturable products. For example Company B in this study did not have specific customer demand for DfRem, yet improving the efficiency and effectiveness of their remanufacturing operations could have a high impact upon company profitability, as aftermarket is the company's main source of revenue.

The factor most within OEM control is communication. If OEM design engineering and remanufacturing can establish regular, responsive feedback between both parties, then the specific needs of the remanufacturer could be better understood. Whilst remanufacturing issues will most likely always struggle to compete with demands such as high performance and low cost, improved communication will increase designer awareness of DfRem issues, and having the direct voice of the remanufacturer will make their needs less easily compromised. This of course must be combined with an understanding of remanufacturing's role within the business and the benefits of improving remanufacturability. Based upon case study findings, one possible way to introduce this understanding is through design reviews, which could present an ideal opportunity for the remanufacturer to voice their ideas and concerns, at a time when design changes remain possible. In both case study companies, designers would most likely learn about company remanufacturing operations and DfRem through experience (such as attendance at design reviews where remanufacturing personnel are present) rather than formal training. The best approach to establishing effective communication between both parties remains unclear and will require further investigation- for example, is the use of a 'remanufacturing liaison' better than direct communication? There would appear to be advantages to a liaison (a dedicated member of staff) and disadvantages (a diluted sense of relevance and significance).

6. CONCLUSIONS

Previous research in the field of ecodesign has suggested that organisational factors, as well as the provision of specialised guidelines or design tools, could have a significant impact upon the integration of remanufacturing issues into the design process. This paper presents findings from a study that aims to result in an organisational roadmap towards successful DfRem integration, focusing upon two companies in the mechanical sector that are currently involved in the remanufacture of their products. Comparing the similarities and differences between these two companies has highlighted customer demand and communication as significant drivers for DfRem integration, as these factors will have an impact on both design engineer understanding and motivation, and the inclusion of remanufacturing issues in design specifications. Design reviews have been identified as a potential opportunity to enhance communication and therefore DfRem integration. However, to develop a true and relevant organisational map towards DfRem integration, further case studies are required that look beyond OEM-remanufacturer organisations. OEMs that use contract remanufacturers, and OEMs that are not currently involved in remanufacturing are likely to face different challenges, possibly more difficult to overcome.

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Ecodesign Maturity Model: the Ecodesign Practices

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Abstract

Ecodesign is essential to companies that have recognized that environmental product responsibility is vital to long term success. However, its application has not reached companies worldwide over the last decade. It is still not clear which ecodesign practices should be selected and how to manage the process of integration into the product development process and continuous improvement. The paper presents the Ecodesign Maturity Model (EcoM2), a model that aims to guide companies in the Ecodesign implementation, and focuses the discussion on the Ecodesign Practices, one of the EcoM2 components.

Keywords:

Ecodesign Maturity Model, ecodesign practices, guidelines, tools

1 INTRODUCTION

Ecodesign can be defined as a proactive environmental management approach that integrates environmental issues into the product development process in order to minimize environmental impacts throughout the product's life cycle (from raw material extraction and manufacturing to use and end-of-life), without compromising other essential criteria such as performance, functionality, quality and cost [1] [2].

The application of ecodesign is essential to companies that have recognized that environmental product responsibility is vital to long term success, since it promotes image improvement, cost and risks reduction, product innovation and development of new markets [3]. However, the application of ecodesign has not reached companies worldwide over the last decade mainly due to:

I. There are no systematization of the existing ecodesign practices;

II. There is an intense development of new ecodesign methods and tools in detriment of the study and improvement of the existing ones [4];

III. There is a lack of integration between ecodesign and the broad context of the product development process and product life cycle management [5][6][7][8];

IV. Ecodesign is poorly integrated into corporate strategy and management [4];

V. The Ecodesign implementation in companies is not supported by a roadmap for continuous improvement;

VI. The selection of ecodesign practices is not in accordance with the company´s current maturity level on Ecodesign.

Moreover, it is still not clear to companies which strategies, guidelines and techniques/tools should be selected and how to manage the process of integration into the product development process and continuous improvement. Consequently there is a need to propose models that help companies to implement ecodesign in their product development processes in an effective way.

In this context, it was developed, validated and tested the Ecodesign Maturity Model (EcoM2), which aims to guide companies into the effective implementation of ecodesign practices into the product development process in accordance with the organization´s strategic objectives and drivers.

The paper presents the concept of the EcoM2 and focuses the discussion on the Ecodesign Practices, which is one of the main elements of the model. It will be presented the methodology employed to collect and classify the ecodesign practices, the systematization adopted in the EcoM2 and also the interrelationship among the different practices and how they can be applied by companies.

The next section presents the goal and the elements of the Ecodesign Maturity Model (EcoM2): Ecodesign Practices, Ecodesign Maturity Levels and Application Method. Section 3 details the methodology employed in the development of the Ecodesign Maturity Model and in the systematization of the Ecodesign Practices. The Ecodesign Practices are detailed in Section 4. Summary and Outlook, Acknowledgments and References are presented in sections 5, 6 and 7, respectively.

2 ECODESIGN MATURITY MODEL (ECOM2)

The Ecodesign Maturity Model is a framework with an evolutionary approach composed by three main elements (Figure 1): Ecodesign Practices, Maturity Levels and Application Method. The goal of the Ecodesign Maturity Model (EcoM2) is to guide companies in the effective implementation of ecodesign practices into product

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development process and related processes in accordance with their strategic goals and drivers.

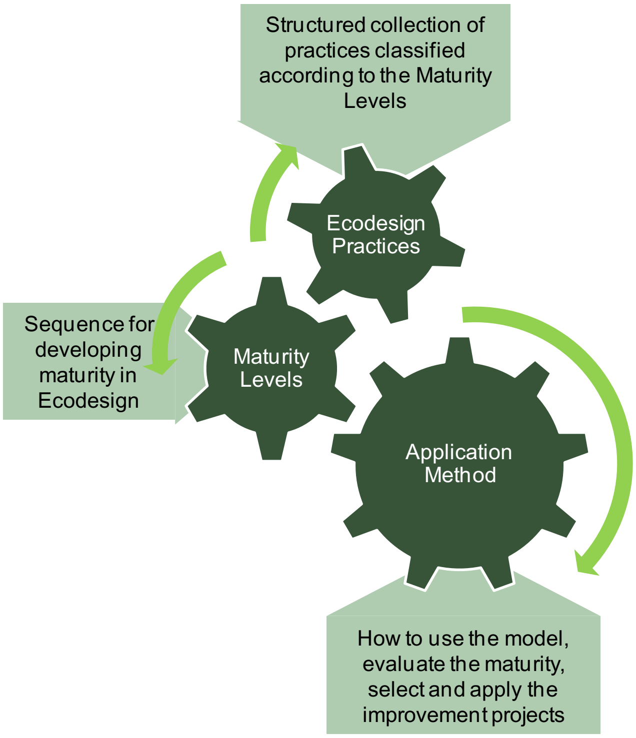

Fig. 1: Elements of the Ecodesign Maturity Model

The Ecodesign practices corresponds to the best practices currently developed and adopted by companies for the integration of environmental concerns into the product development process – it is composed by management practices and operational practices associated to ecodesign techniques and tools (see section 4).

The Ecodesign Maturity levels represent company evolution level in applying the environmental issues into the product development and related business processes. It is obtained by the combination of the evolution level of a practice and the capability level of its application. The evolution level on ecodesign can go from low knowledge and implementation levels, passing through pilot projects and process integration and culminating with the strategic consideration of ecodesign and exploitation of associated eco-innovations opportunities. The five capability levels adopted by EcoM2 assess the way in which a practice is applied by the company (incomplete, ad hoc, formal, control, optimize) (adapted from [9]). The ecodesign maturity levels defined in the Ecodesign Maturity Model can be summarized as follow:

- Level 1: Company has no experience on ecodesign and does not yet apply practices to improve the environmental performance of the developed products.
- Level 2: Company does the first moves in the application of Ecodesign, is already familiar with some practices and with the potential benefits. It is observed punctual and not consolidated approaches for the use of ecodesign practices.
- Level 3: Company recognizes the importance and benefits of Ecodesign by the application results. It is observed the technical integration with the first insertions of ecodesign practices into the processes and first steps to structure the environmental approach and common patterns.
- Level 4: The ecodesign practices are systematically incorporated into the product development process, since the initial phases (e.g. idea generation and portfolio management). Functionality analysis is now applied to conduct ecodesign.
- Level 5: There are the incorporation of environmental issues into company's corporate, business and product strategies. Environmental issues are considered jointly with technical and economic issues to support the decision making process.

The application method presents the way in which companies can use EcoM2 for process improvement. It contains a scheme for continuous improvement (like PDCA – plan, do, check, act) based on Business Process Management (BPM) approach [1]. It is composed by a method for diagnosis of current situation, development of an ecodesign maturity radar which presents the current profile of a company in the ecodesign application considering the capability level of the applied practices, identification of critical ecodesign subject for improvement, definition and prioritization of improvements projects, establishment of implementation roadmaps, development of the projects and assessment of obtained results by means of performance indicators.

The application of EcoM2 provides a benchmarking of ecodesign practices; an assessment of weaknesses and strengths concerning ecodesign practices application; a common language and a shared vision across the organization on ecodesign implementation; a guide for integrating ecodesign into product development processes; and a roadmap for improvement of product development process towards environmental sustainability.

EcoM2 was already theoretically validated by a set of 14 Ecodesign Experts from Europe, United States of America (USA) and Brazil and applied in large multinational companies of capital and consumer goods. The results of EcoM2 application were satisfactory and have led to the implementation of proposed improvement projects by those companies. This paper focuses on the Ecodesign Practices, a component of the EcoM2.

3 METHODOLOGY

The development of the Ecodesign Maturity Model (EcoM2) can be divided into three main parts: (1) Systematization of Ecodesign Practices, (2) Definition of Ecodesign Maturity Levels and (3) Development of an

[1] BPM IS frequently used to denote a software. In the case of this paper, it is an approach for improving business process based on an evolution of the PDCA cycle.

Application Method to support EcoM2 implementation into companies. As previously mentioned, this paper focuses the discussion on the Ecodesign Practices, which is one of the main elements of the model.

The Ecodesign Practices were obtained and classified. i.e. systematized, by means of a systematic literature review, the way by which the researcher can map the existing and previous developed knowledge and initiatives in a specific research area. Besides the analysis of previous discovery, techniques, ideas and ways to explore topics, the systematic review also allows the evaluation of information relevance to the issue, its synthesis and summarization [10] [11]. The main goal of the systematic review was the determination of the state of the art in ecodesign practices.

The phases carried out in the systematic review correspond to problem formulation (identification of the goal of the review, target and context, beneficed areas and expected results), data collection (identification of the relevant databases, keywords and strings), data evaluation (application of the inclusion/exclusion criteria for the selection of the relevant studies and representation standardization), data analysis and interpretation (synthesis of the studies and definition of the criteria for classification) and presentations and conclusions [10] [11].

Along the literature review, it was obtained 2145 studies (generic name attribute to papers, thesis, dissertations and books). It was performed an initial studies selection, which were then analyzed according to the inclusion/exclusion criteria (studies that presented relevant ecodesign practices). It was then carried out a review to certify that relevant studies had not been excluded. The valid studies were then analyzed in order to extract the relevant information about the ecodesign practices.

It was identified a huge amount of practices during the systematic literature review (more than 600). They were sorted out according to its characteristics into three groups: Ecodesign Management Practices (those that deals with ecodesign in the management of the product development process), Ecodesign Operational Practices (related to technical design issues during detailed design) and Ecodesign Techniques and Tools (artifacts that support the application of management and operational practices). Once the Ecodesign Practices were classified, the interrelationships and dependencies among each practice of a given group and also among the three groups by means of a correlation matrix were analyzed in detail.

The description of Ecodesign practices is presented in the section 4: Ecodesign Practices.

4 ECODESIGN PRACTICES

According to PMBOK [12], practice is defined as "a specific type of professional or management activity that contributes to the execution of a process and that employ one or more techniques and tools". Technique is defined as "a defined systematic procedure employed by a human resource to perform an activity to produce a product or result or deliver a service, and that may employ one or more tools" [12] and tool is defined as "something tangible, such as a template of software program, used in performing an activity to produce a product or result" [12].

Ecodesign Practice is the general label attributed to ecodesign activities that aims at integrating the environmental issues into product development process and which application can be supported by ecodesign techniques and tools. In the Ecodesign Maturity Model (EcoM2), the ecodesign practices were classified into two main groups: Ecodesign Management Practices and Ecodesign Operational Practices. These practices are interrelated among them (Figure 2), and are presented in detail in the next sections.

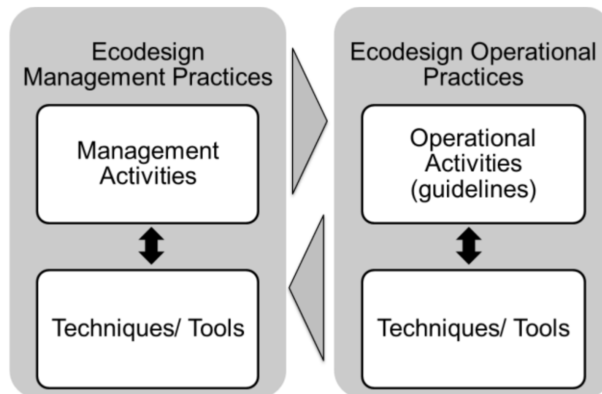

Fig. 2: Ecodesign Practices

4.1 Ecodesign Management Practices

The Ecodesign Management Practices are related to management activities of product development that addresses environmental issues and can be supported by ecodesign techniques and tools (Figure 2).

By means of a systematic literature review, it was identified and classified 75 Ecodesign Management Practices. It was performed an analysis to identify which ecodesign techniques/tools could support their application and the relationships among them were established.

It was assigned a code to each practice that gives information on the phases of a reference model for product development process [13] where the practice should be preferably applied (product strategic planning, project planning, informational design, conceptual design, detailed design, production preparation, product launch, product monitoring and take back of products). It includes also two support process: business process management for ecodesign (which application is essential to form the basis for Ecodesign implementation) and environmental impact assessment. The support processes, the phases of the reference model [13] and the associated codes are presented in the table 1.

Besides enabling the easy update and addition of new practices, the codification also enables the identification of the phase of the product development process and/or support processes where the practices should be applied.

Table 1: Code scheme for the classification of Ecodesign Management Practices

Code	Classification of Ecodesign Management Practices
100xx	Support Process - Business Process Management for ecodesign
200xx	Support Process - Environmental Impact Assessment of Products
300xx	Generic Activities
400xx	Product Strategic Planning
500xx	Project Planning
600xx	Informational Design
700xx	Concept Design
800xx	Detailed Design
900xx	Production Preparation
1000xx	Product Launch
1100xx	Product accompanying and monitoring

For example, one of the ecodesign management practices is “20001: Assess the environmental impact of products”. In order to support the application of this management practice, there are a set of 42 ecodesign techniques and tools that can be used, ranging from complex methods such as Life Cycle Assessment (LCA) [14][15][16][17] to more simplified and abridged ones, such as MET (Material, Energy and Toxics Matrix) [18][19] and MECO (Material, Energy, Chemicals and Others Matrix) [20][21]. The most suitable ecodesign technique/tool to be used can be obtained by the selection according to the company needs, current maturity level and the criteria used to classify the techniques/tools [12][22].

Other examples of ecodesign management practices includes “10011: Ensure commitment, support and resources to conduct the activities related to ecodesign”, “10015: Make ecodesign tasks a part of the daily routine for the relevant employees”, “10019: Formulate and monitor mandatory rules concerning environmental issues for the enterprise to comply with law/regulations”, “10023: Implement a life-cycle thinking in the company”, “30002: Clearly define the environmental indicators and the methodology to be used during the gates (phases assessments)”, “40013: Clearly define goals to improve products environmental performance (according to law, benchmarking, phases/aspects with higher improvement potential, etc.)”, etc.

It is important to note that it can be established relations of dependence among the ecodesign management practices, i.e., there can have pre-requisites for the application of certain ecodesign management practices. For example, in order to apply the practice “10002: Deploy and maintain an environmental policy for products” it is required to have previously applied the practice “10001: Formulate a company environmental policy”. The practice 20001 is also a pre-requirement for the application of the management practice “80001: Analyze and select the suitable ecodesign strategies according to the environmental goals and phases/environmental aspects of the product life cycle in which the environmental improvement opportunities are higher”, since it supports the identification of the environmental hot spots of the product under analysis. The application of ecodesign management practices can also be supported by the ecodesign operational practices (figure 2).

The Ecodesign Management practices are moreover classified according to the evolution level defined by EcoM2 (see section 2) and are used to assess the maturity level of companies in applying ecodesign, by means of the assessment of the capability levels of the application of each practice during the diagnosis. As a result, it is built Ecodesign maturity radar which guides the establishing of a roadmap for process improvement towards environmental sustainability.

4.2 Ecodesign Operational Practices

The Ecodesign Operational Practices deal with the technical issues of product design and is composed by ecodesign operational activities (guidelines) which can be linked to ecodesign techniques and tools (Figure 2).

The ecodesign operational activities were obtained by the consolidation of a summary of ecodesign guidelines for product design with more than 480 operational activities identified and systematized.

The guidelines were grouped on six ecodesign strategies: “Minimize Energy Consumption”, “Minimize Material Consumption”, “Extend Material Life Time”, “Optimize Product Life Time”, Select Low Impact Resources and Processes”, and “Facilitate Disassembly” – adapted from [23]). The guidelines of the strategy “Minimize Material Consumption”, for example, are: “Minimize material content”, “Minimize scraps and discards”, “Minimize or avoid packaging”, “Minimize materials consumption during usage” and “Minimize materials consumption during the product development process”.

In order to explicit the way in which the guidelines can be achieved, the EcoM2 also presents the design options, which provides more detailed ideas of product design (adapted from [23]). For example, some of the design options of the guideline “Minimize material content” are: “Dematerialize the product or some of its components”, “Miniaturize”, “Digitalize the product or some of its components”, “Avoid over-sized dimensions”, Reduce thickness”, “Apply ribbed structures to increase structural stiffness”, “Avoid extra components with little functionality”, “Reduce the material content by integrating functions”, etc. The Ecodesign Operational Practices should be customized by a company, according to the characteristics of the developed products.

Each guideline was also classified according to the phase of the product life cycle (pre-manufacturing, manufacturing, distribution and packaging, use and maintenance and end-of-life) and to the environmental aspects (material, energy consumption, solid waste, waste water and emissions) - adapted from DfE Matrix [24].

This classification indicates where the guideline can influence the environmental performance of a product and supports the selection of the most appropriated operational practices according to the characteristics of environmental impacts over the whole life cycle of the product under development. The guidelines are also associated to ecodesign techniques and tools that can support their application (Figure 2).

For example, if the hot spot [2] of a product under development is at the end-of-life of products, concerning to solid waste, the strategies “Facilitating Disassembly” and “Products Life Time Optimization” should be more adequate. Focusing on “Products Life Time Optimization” and assessing its guidelines, it can be concluded that “Facilitating Remanufacturing” is of higher importance. To support the application of this guideline, there are also a set of ecodesign techniques and tools such as EDIT (Environmental Design Industrial Template) [25], ELDA (End-of-Life Advisor) [26] and LCP (Life Cycle Planning) [27] that can support its application.

4.3 Ecodesign Techniques and Tools

Ecodesign Techniques and Tools can be defined as systematic means for the application of ecodesign that can support the application of both Ecodesign Management and Operational activities (Figure 2).

It was identified and classified 105 ecodesign techniques and tools. In order to support the selection of the most suitable ones for companies according to their needs and current maturity level, they were classified according to 6 criteria:

(1) Nature of the main goal (Prescriptive/Comparative/Analytic);

(2) Type of the tool used (Checklist/Guideline/Matrix/Software);

(3) Nature of input and output data (Qualitative/Quantitative);

(4) Product Life Cycle Phases (pre-manufacturing, manufacturing, distribution and packaging, use and maintenance and end-of-life),

(5) Application evolution (Theory/Experimental/Consolidated);

(6) Evaluation of Environmental Impacts (Yes/No).

The classification criteria used in the Ecodesign Maturity Model and the results obtained are presented in detail in paper [22].

Some examples of Ecodesign techniques and tools were presented previously in sections 4.1 and 4.2 in relation to ecodesign management and operational practices. The selection of the most suitable tool/technique to be used to the application of a specific activity must consider the current maturity level (see section 2) of the company and can be supported by the classification criteria.

2 The identification of the hot spots (most important environmental impacts of a product) can be performed by means of the application of the management practice “20001: Assess the environmental impact of products” using a set of different ecodesign tools and techniques.

5 SUMMARY AND OUTLOOK

The paper presented the general concept of the Ecodesign Maturity Model (EcoM2) and focused the discussion on the Ecodesign Practices, which were classified into two main groups according to their characteristics:

- Ecodesign Management Practices;
- Ecodesign Operational Practices;

and associated Ecodesign Techniques and Tools.

This work enabled the mapping of the state of the art and the classification of Ecodesign Practices. During the systematic literature review on ecodesign, it was identified 75 management practices for ecodesign (related to the management activities and tasks of product development process that addresses the environmental issues) and more than 450 ecodesign operational practices (related to technical design issues). These practices were interrelated among them and with the 105 identified ecodesign techniques and tools.

The classification of the Ecodesign Practices reinforces the importance of the consideration of strategic, tactic and operational levels when applying Ecodesign concept into companies. It is a result of a comprehensive bibliographical review and consolidates the knowledge on Ecodesign field.

The Ecodesign Maturity Model is inedited and aims to guide companies in the continuous improvement of their product development process with the incorporation of the environmental dimension striving for sustainability in their business. It considers the individual needs, drivers, characteristics, maturity levels and strategies of companies to support the product development process. Besides the contribution to companies, the Ecodesign Maturity Model should also contribute to the organization of the knowledge in the ecodesign and PLM (product life cycle management) research areas, structuring the practices and establishing interrelationships among them.

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"Create Competitiveness In A Sustainable Society – Use Ecodesign, In Cooperation"

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Abstract

This paper will describe a new methodology for the use of Ecodesign, where various competences are combined to obtain high quality results. The competences needed are: Environmental experts, who can evaluate the environmental performance of a product or service through Life Cycle Assessment, LCA, material- and process experts for the materials and processes in the targeted product or service, experts of the final product or service who can provide high quality data for the LCA. This cross functional team can develop new products or services, with high performance combined with low environmental impact, applying ecodesign when cooperating closely. Using this methodology is a feasible way to obtain improved competitiveness for the industry in a sustainable society.

Keywords:

Ecodesign, Life Cycle Assessment, Cooperation, Cross functional team

1 INTRODUCTION

As the understanding of the climate change increases, the quest for sustainable development has received widespread acceptance. At the same time, it is of great importance to have a competitive industry. Ecodesign is a way to create sustainable development and industrial competitiveness simultaneously, i.e. in ecodesign we minimize the environmental impact of a product while we maximize the performance/use of the product.

One common tool in ecodesign is Life Cycle Assessment, LCA, [1], [2] where the environmental impact from a product can be assessed over the life cycle (raw material, manufacturing, use, end of life, and transportation) in relation to a specific functional unit. Here is described how LCA in combination with product-, process- and material expertise is used to develop new products and processes with low environmental impact and improved performance.

2 SWEREA ECODESIGN, A PROJECT TO DEVELOP ECODESIGN METHODOLOGY

The Swerea Ecodesign is a project running from 2010-2012, where a methodology for creating optimal solutions is developed. "Optimal" is considered to solve environmental as well as other aspects of importance for the companies such as economical aspects, functionality of the products and processability. The methodology has shown to be successful because it combines all the necessary competences for the relevant materials and processes with competence on environmental analysis. Hereby optimal solutions can be obtained.

The ecodesign methodology is applied in some 10 case studies of different products and manufacturing processes in close cooperation with companies. The products and manufacturing processes will be assessed from the environmental perspective alongside with other perspectives such as technical performance, economical performance, safety etc. The environmental performance of current products and manufacturing processes is assessed with "screening LCA". Experts on the relevant materials and processes from companies and research institutes cooperate to gather the best available data sets. The result from the LCA can identify if a certain process, a certain material or substance has a significant detrimental environmental impact. Such processes/ materials/ substances are usually called "hot spots". The next step in the ecodesign process involves development work to improve the processes/materials/substances identified as hot spots. In order to improve the product or manufacturing process, the necessary expertise is used. A second LCA is performed to verify that the suggested redesign or process adjustment is improving the environmental performance of the product. Involvement of the companies ensures that economical viable solutions are developed, and hence the competitiveness is strengthened.

Ecodesign means integrating environmental issues throughout the usual product development process [3], in the following way:

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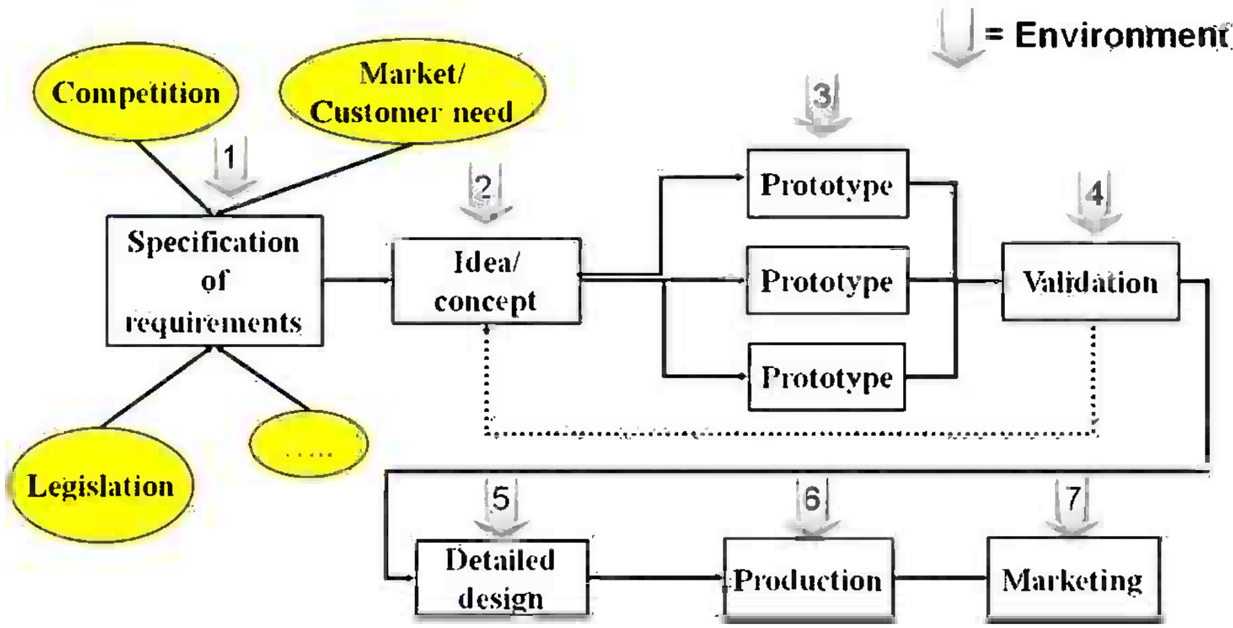

Figure 1 : Rough description of the ecodesign process

1. *Specification of product requirements.* Life cycle assessment, LCA, of ”existing” product to find out which life cycle phases and/or components and parameters are of greatest environmental importance overall. Legislative requirements and customer needs can involve single environmental issues. The results are fed into the specification of product requirements.
2. *Idea/concept.* The results of the first LCA can give lots of ideas on how to improve the environmental performance of the product, e.g. using brainstorming technique and cross scientific team of experts. These ideas are implemented in conceptual product designs.
3. *Prototype.* Prototypes are developed to fulfill environmental parameters decided in the earlier steps.
4. *Validation.* Validation (of the improvement) of the environmental performance of the different concepts. Since more data is available at the validation stage, the LCA calculations can be refined. This gives information to choose the best concept to continue with.
5. *Detailed design.* Detailed design of the chosen concept with due consideration to critical parameters and environmental aspects related to the product. The team is chosen in order to provide the needed expertise for that particular product, process or service. A second LCA is performed to verify that the suggested redesign or process adjustment is improving the environmental performance of the product.
6. *Production.* Management of environmental aspects related to production (compare with 4.4.6 Operational control in ISO 14001).
7. *Marketing.* May involve self-declared environmental claims (ISO 14021), environmental labeling (ISO 14024), environmental product declarations (ISO 14025), all of which requires verified environmental information about the product.

3 CASE STUDIES

The methodology has been tested in case studies of products and manufacturing processes. The different projects have identified different kinds of “hot spots”, and a methodology to find the best expertise for different kind of projects has been developed. In the case studies it was found that it is not enough that the cross functional scientific team work in the same project, everyone within his or her expertise, but the key to success is the close cooperation between the experts.

Some of the case studies are described below:

3.1 Substitution of SF_6 in high pressure die magnesium casting process

In the die casting process for magnesium, Mg, there is a need for gas covering of the melt. Today Sulphur hexafluoride, SF_6, is often used, but due to the high climate impact, the allowed use is limited to 850 kg/year and company in Sweden. Sulphur dioxide, SO_2 has been used as alternative but has caused explosions [4], and the industry is hesitant to use it due to the risk of injuries. The aim of the case was to find and investigate safe, cost effective and environmentally sound alternative cover gases.

To run the project, a group of experts from industry and the Swerea group was used. The project was lead by an expert of magnesium casting from Swerea SWECAST, research institute for Casting. Other members of the group came from the expertise of

- environment (running LCA)
- work environment (performing a work environment screening, including risk assessment and chemical risk assessment)
- metallurgy providing data and knowledge
- corrosion
- Experts from Mg die casting companies (providing data and knowledge about the processes)

Three different protective gases were tested with SF_6 and SO_2 as references.

The results of the project were that SO_2 can be used as a cover gas and that the risk for explosions can be reduced by using new materials in the crucible wall of the foundry oven. This solution was unexpected, and new, and was only possible due to the cross scientific competence in the project group.

3.2 Green office walls

Green office wall is the term used here to describe a vertical plant filled partition that can be used to divide a room. Studies have shown that these walls increase the well being of the personnel [5]. Whilst well being is difficult to quantify, green office walls have measurable positive effects such as improved air quality as the wall humidifies the air and reduces levels of certain types of VOCs such as formaldehyde which plants used in the green wall are known to absorb. The wall also provides sound absorption as it contains a thick layer of sound insulating mineral wool.

The aim of the project was to evaluate the environmental impact of this product and improve the overall environmental performance of it, if needed.

The functional unit was a 10 m^2 office space to reveal if the green office wall reduces the environmental impact of this functional unit or not. This was done by comparing the LCA of an office with a green office wall and an office with a set of systems that would achieve the equivalent air quality and sound absorption. This first comparison showed that over a 10 year period the office space with a green wall performs better than an office space without a green wall in terms of climate change (measured as carbon dioxide equivalents).

An option to go further and improve the overall environmental performance, was to compare the current type of green office wall made from steel and a new design of green office wall made from a bio-based composite material. The latter is derived from renewable resources, wood and grasses. Such materials store carbon dioxide which could make them a better choice than steel from an environmental point of view.

The second comparison showed that using a renewable bio-based composite material instead of steel does improve the environmental performance by 20%. In this product this results in a saving of 200kg of CO2 equivalent. Consequently the room with a biobased wall has a lower impact on global warming than the room without the wall after 7 years

The new bio-based composite materials that are used here present a number of challenges. The challenges lie in designing for these materials and manufacturing as well as the LCA. The LCA relies heavily on the whole team working together to clarify and estimate the necessary parameters.

However, although changing the material does have some impact on the environmental impact, it is important to note that the transportation needed for installation and maintenance has the single highest environmental impact during the product lifecycle. This is important information for the company selling the green wall and different solutions have been suggested for reducing the impact from transport. The company is now evaluating the use of a delivery firm that specialising in plants transport.

The new design of green office wall in bio-based composite material is being built and tested and will be on display at different fairs by the end of the year. This case study was performed in collaboration between Vegtech, the producer of the green wall, Amroy, producer of a pineoil based resin, APC, the composite manufacturing company producing the biobased composite wall structure, Swerea SICOMP and Swerea IVF. The study was financially supported by the involved companies and by FP7 project WOODY and the Eureka project Polywall.

3.3 Recirculation of steel casting residues in a roll casting company

There is a common problem in the casting industry regarding metal containing dust that leads to increased environmental impact and high costs for deposition. In addition the material has a value due to its high metal content which could replace some of the raw material in the process. Therefore there is a twofold possibility to decrease the environmental impact of these products, if recycling was possible. In order to enable recycling, a cross functional team of experts was composed. The represented competences covered metallurgy, steel casting, leaching, LCA, chemical risk assessment and regulations regarding deposition. Åkers, a company serving the global rolling mill industry was involved in the project, and a roll of 70 metric tons was used as an example.

The project started with mapping of energy and material consumption in all process steps within the manufacturing.

In order to get the right data, it was done in close cooperation with the company. To secure that the best solutions was found, and sub optimization avoided, the full life cycle was assessed in a LCA. The findings of the first study was that the raw material, and that the amount of fluoro components had a high environmental impact. Furthermore the energy consumption within the process showed to be quite high.

Development of a re-melting process focusing on solving the identified challenges started. Metallurgy combined with casting expertise, the company knowledge and process development expertise resulted in a re-melting process for the dust, feasible for the company, giving high yield and low environmental impact.

The quantified result showed savings of 1 ton of carbon dioxide, CO_2 and 5,6 MWh of energy per produced roll, in addition to the economic savings due to less need for raw material and for deposition.

In addition to the results regarding this specific product, the company have due to the analysis and work done, been even more focused on energy and toxic compounds.

3.4 Green Flagship

Sail yachts are considered environmentally friendly, due to the use of wind to create movement. Still there are possibilities to reduce the environmental impact from sail yachts. A cross functional team of experts was built, in order to improve the environmental performance of a sail yacht from Najad. The team included experts in the field of metallurgy, flow simulation, corrosion, casting, motors and fuel cells, solar panels, composite materials, textiles, LCA and environment.

As a first step a LCA was performed in order to find hotspots, life cycle stages and components of interest for improvement. The main environmental impact in terms of CO_2 was the use of diesel to run the main engine and the second largest was the use of diesel to run the second engine providing the boat with electricity during the life of the boat. Other things of importance in terms of photochemical smog were the use of solvents for composite materials in the production phase of the boat, and in terms of toxicity, the zinc which contain cadmium for the offer anodes.

The team started searching for solutions regarding diesel consumption for the main engine by looking at the geometric shape through flow simulation, and possible production methods for the keel. Other solutions tested for prototypes were cooling solutions to minimize the use of air conditioning and hence electricity during the use phase, new technologies to prevent corrosion by electric potential and bio composite materials to minimize the environmental impact of the composites. Ideas about how to implement and use solar cells and fuel cells to replace the main engine were developed and tested theoretically.

The results show that there are many feasible possibilities to improve the environmental performance of a sailing yacht.

4 SUMMARY

The Swerea Ecodesign project has developed a methodology where “traditional” Ecodesign methodology [6], [7] has been combined with a methodology to create successful cross functional teams. The methodology has been tested in some ten case studies, showing that cross functional teams of relevant experts together with experts from the companies involved, can create new, unexpected, technical and economical feasible solutions with improved environmental performance. In the case studies it was found that it is not enough that the cross functional scientific team work in the same project, everyone within his or her expertise, but the key to success is the close cooperation between the experts.

5 ACKNOWLEDGEMENT

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Critical Analysis of Fair Trade Marketing in Japan

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Abstract

This paper explores fair trade marketing in Japan by conducting a review of the historical development of the fair trade movement and its acceptance by consumers. Japanese fair trade marketing is illustrated through the evaluation of three case studies, deploying standard business analytical frameworks. This research shows that regional adjustments of marketing strategies are required to promote fair trade products in Japan. Corporate social responsibility is increasingly important to the advocacy of fair trade, particularly among powerful corporations.

Keywords:

liberalisation, sustainability, localisation, fair trade, nonprofit organisation, alternative trade organisation, transnational corporation, corporate social responsibility

1 INTRODUCTION

The forces of globalisation, industrialisation, and neo-liberalism have stimulated social inequality and environmental degradation, while also promoting important, new advocacies that aim to create a more socially and ecologically sustainable world [1]. Following this trend, increasing numbers of consumers are seeking to purchase ethical and eco-friendly products such as fair trade, organic, and Forest Stewardship Council-certified items.

This paper focuses on the growth of fair trade, induced by concern among consumers in the North. The purpose of fair trade, growing out of neo-liberal market principles, is to counter the practices of production that depreciate and exploit deprived people and the environment, especially in the poorer areas of the Southern hemisphere [2].

The fair trade movement was initially led by alternative trade organisations (ATOs) and non-governmental organisations (NGOs). Powerful companies, including transnational corporations (TNCs), normally considered the main actors in market liberalisation, have also taken up such advocacy since the late 1990s. Accordingly, marketing methods of fair trade products are also changing, provoking struggles between conventional advocates and TNCs that have differing perspectives on what constitutes fair trade.

This research explores the current promotional efforts of fair trade products in Japan. Few English-language academic journals referring to the Japanese fair trade movement are currently available. This paper will be the precious English-written research that deals with Japanese fair trade advocacy analysed from the perspective of marketing strategies.

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2 LITERATURE REVIEW

2.1 Sales Growth of Fair Trade Products

Although fair trade items account for a relatively small share of the world market, the sales of such products continue to grow, restructuring conventional North-South linkages [2]. Since the 1980s, fair trade sales have accrued at a remarkable rate of 30% annually [3] owing to the labelling scheme and mainstreaming marketing fuelled by the scope of economies of fair trade products.

Despite the effect of the recent credit crisis, consumers paid 2.9 billion euros for fair trade certified goods in 2008 [4]. The estimates of the size of the Japanese fair trade market vary; according to scholars, fair trade has also expanded in recent years. Nagasaka [5] estimates the size of the Japanese fair trade market to be 52.3 million euros in 2007, the most recent year for which data are available.

This fast market growth derives from the mainstream market strategy of fair trade items. In Japan, Tsujimura [6] writes that fair trade coffee sales increased 13 times in volume between 2002 and 2005 owing to the sales effort of powerful retailers such as AEON and Starbucks. In the next section, we examine the pros and cons of the mainstream strategy from a historical perspective.

2.2 The Shift from Niche to Mainstream

Despite the fact that it originated in the ATO movement, fair trade products have been distributed via large, non-ATO channels since the early 1980s. European ATOs embarked on labelling fair trade items to enable their entry into conventional markets in the late 1980s. In 1997, a common labelling scheme was introduced under Fairtrade Labelling Organisation standards (FLO).

These labelling initiatives boosted the availability of certified items for consumers over the past two decades. In general, fair trade products are available through three major channels: dedicated retail outlets, supermarkets, and mail order. According to the European Free Trade

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Association (EFTA) [7], supermarkets have become indispensable sales channels for companies selling fair trade products. Supermarkets account for 33% of Tradecraft's total sales in the UK, 27% of sales by GEPA in Germany, and 24% of EZA's sales in Austria.

Although a mainstreaming strategy provides small producers with the chance to supply their products to the sector's powerful corporations, it may weaken the appeal of fair trade products as alternatives to corporate product offerings. There may be no need to go to third world shops any more to buy such products owing to the emergence of supermarket channels.

Despite these apprehensions, fair trade organisations actively began to look for business partnerships with powerful corporate actors to gain further market shares. Certainly, TNCs' participation in an alternative movement contributes to the increasing consumer awareness towards fair trade. However, we need to recognise the difference between ATOs and TNCs from the perspective of their objectives to pursue fair trade practices. Since TNCs must continually seek profit growth to satisfy shareholder interests, this may not lead to a reduction in the gap between the North and the South.

2.3 Fair Trade Consumer Portraits

2.3.1 Western Consumers

Recent surveys confirm strong positive consumer perceptions of the premise underlying fair trade and fair trade products. FLO's 2008 Consumer survey, conducted in fifteen countries, found that approximately half of the public recognises the FAIRTRADE Mark [4]. However, fair trade's positive image does not necessarily ensure its popularity across all sections of the public.

Blend and Van Ravenswaay [8] state that educated and wealthy consumers are more likely to buy eco-labelled items over ordinary ones. Further, Loureiro and Lotade [9] note that females with higher incomes and greater interest in environmental protection are more likely to choose differentiated goods such as fair trade, organic, and shade grown goods. In contrast, male and older consumers are less likely to buy such products [8], [9].

2.3.2 Japanese Consumers

Ikegami [10] notes that ethical consumption requires a relatively high living standard. In Japan, only 33.9% of people are willing to support ethical consumption, whilst in France, the proportion is 73% (ibid.).

This reflects the low fair trade recognition rate among Japanese consumers. According to a 2008 nation-wide survey of consumer perception towards fair trade in Japan, only 17.4% of respondents properly recognised that fair trade was a keyword associated with poverty and the environment [11].

As we confirmed in the previous section, Japanese fair trade customers also tend to be young females (mainly 30-49 years old) with at least a bachelor's degree and a slightly higher income than the average Japanese [12].

2.4 Summary

In Findings, we explore the actual marketing effort for the fair trade movement in Japan by examining three case studies to intensify the discussion.

3 FINDINGS

3.1 Overview

We explore three case studies of fair trade marketing in Japan. In each case analysis, theories of Ansoff Matrix [13] and Grant's sustainable competitive advantage (SCA) analysis [14] are applied where appropriate. At the end of this chapter, a brief summary of the findings is provided.

3.2 Case 1: Ministop

Although only a small number of fair trade items are available in Japan, increasing numbers of companies have taken up fair trade product development. The Ministop convenience store chain has grown its fair trade business, providing fair trade drinks and sweets in the past five years. Ministop decided to launch fair trade initiatives as part of its corporate social responsibility (CSR) initiatives, following the CSR policies of its parent company, AEON.

The uniqueness of Ministop's fair trade marketing comes from the astute market adjustability in product development. Although the market share of Japanese fair trade coffee in 2006 was only 0.04% [5], AEON's annual sales of fair trade products continues to increase rapidly due to the expansion of its product line to include ground coffee, drip coffee and canned coffee. A recent hit product in Ministop is fair trade canned coffee.

'Top Valu Fair Trade Canned Black Coffee' is the first FLO-certified canned fair trade coffee in the world. Ministop started to sell this item in 2006 at 137JPY/280g. The price of this product is approximately 8.3% higher than conventional canned coffee. Compared to other premium coffees such as 'Canned Starbucks Double Shot Espresso' (170JPY/140g), this canned fair trade coffee seems to be reasonably priced.

Overall, the marketing of canned fair trade coffee has been successful, although there are two key difficulties associated with further market growth. First, it takes time to diffuse the concept of fair trade; presently Ministop is just selling the canned coffee, ignoring the idea diffusion.

The second problem is that the coffee market is said to be led by males rather than females. In fact, 80-90% of canned coffees customers are males [15]. Since Japanese fair trade customers tend to be young and female, there is a significant mismatch between canned fair trade coffee and its prospective consumers.

According to Yomiuri Online [15], females prefer chilled cup coffee to canned one, and in 2005, the market size for chilled cup coffee was two twice the size it was in 2000.

Following this trend, all Ministop stores began to sell chilled cup 'Fair Trade Café Au Lait' in June 2009. This is the first FLO-certified product that is served in a chilled cup. This product was released onto the market recently, so sales data are not yet available. However, chilled cup fair trade coffee will have more marketing opportunity than canned type.

The Ansoff Matrix is now deployed to assess a series of Ministop's marketing strategy. Given that the fair trade market is a new market, Ministop first undertook market development strategies with conventional grind and drip fair trade coffee. They next embarked on diversification strategies with canned and chilled fair trade coffees.

Market Growth		Existing Products	New Products
	New Markets	Market Development Strategies Grind Fair Trade Coffee Drip Fair Trade Coffee	Diversification Strategies Canned Fair Trade Coffee Chilled Cup Fair Trade Coffee
	Existing Markets	Market Penetration Strategies N/A	Product Development Strategies N/A
		Product Growth	

Fig 1: The Ansoff Matrix with Ministop

Although market development strategies involve moderate risk because of new consumers' lack of unfamiliarity with the product, diversification strategies are far more risky, involving two unknowns: new markets and new products. In Ministop's case, the company diversified to deploy surplus productive capability that derives from the strong financial position of AEON group.

Although retailers need to lead consumers to new markets, such astute marketing strategies eventually become obsolete because consumption trends also change swiftly. For Ministop, it is still essential to undertake both market development and diversification strategies to spread the risks of fair trade business.

Through the lens of Grant's analysis, Ministop's high appropriability presents risks to the company's SCA, for it is dependent on the leadership of one individual. In addition, Ministop has experienced difficulties in ensuring the penetration of fair trade concepts among its employees, because most sales staff consists of part-time workers. This means that the loss of a particular corporate champion could affect the sustainability.

Durability comes from intangible assets such as corporate reputation as long as a firm sustains its innovative, productive, and high-quality features. While Ministop is recognised as one of the leading convenience chains in Japan, its reputation is largely derived from its conventional services and merchandising rather than from its fair trade initiatives. Accordingly, the durability of Ministop's fair trade business is not assured.

Furthermore, the low durability may allow new entrants to manufacture similar items, stimulating lower prices through competition and making fair trade products unprofitable. Other convenience store chains are able to follow the fair trade initiatives because of Ministop's high appropriability with low durability in fair trade business. The innovation of Ministop's fair trade marketing comes not from capabilities embedded in complex organisational routines, but from container changes on fair trade drinks that are relatively easy to replicate.

Overall, Ministop's fair trade marketing assumes a venture business character regardless of its mainstream status in Japanese retail markets. Its sustainability in the fair trade business depends on the longevity of CSR policy to support fair trade initiatives. It requires more involvement of corporate staff in Ministop, which will result in SCAs from the perspective of organisational learning in the fair trade business.

3.3 Case 2: People Tree

People Tree is a fair trade specialty brand, merchandising fashion items as well as conventional food products. People Tree was founded in Tokyo in 1995 by Safia Minney, and at present, the company has partnerships with 60 producer organisations in 20 countries throughout Asia, Africa, and Latin America.

While fair trade items in Europe are mainly FLO-certified foods and sundries, People Tree is renowned as a pioneering fashion-intensive clothes retailer. It sells such items not only in fair trade speciality stores, but also via mail order catalogue and internet channels. Currently, around half of company's sales come from fair trade clothes [5].

Since 2002, the turnover has grown at 3%-15% annually, reaching 0.7 billion in 2007. Minney [16] believes that fair trade clothing will become more prevalent if customers purchase it not because of its concept, but rather its cute design. This order is almost opposite to the historical development of fair trade popularity in Western nations.

At the outset of its efforts to sell fair trade clothes, People Tree faced obstacles because such clothes were not well aligned with Japanese preferences in design and size.

Currently, the company provides improved designs for the Japanese market, with local producers who maintain their indigenous techniques for apparel manufacture. To maintain quality and meet shipping deadlines, People Tree contacts local producers almost daily.

In the early days, indigenous suppliers sometimes resisted high product standards imposed by People Tree. The company's efforts including direct instruction on manufacturing techniques and annual invitations of local representatives to Japanese markets contributed to the decrease of such struggles [17].

Improved manufacturing techniques based on the high product standards imposed by People Tree could lead to the market expansion of fair trade garments to other developed nations. Moreover, since clothes manufacturing involves many processes such as weaving, embroidery and sewing, each process enables People Tree and the local producers to acquire experimental knowledge in clothes manufacturing to Japanese market.

Overall, People Tree's product development contributes to the promotion of fair trade fashion. Nevertheless, promotional efforts by advertisements are also indispensable for further penetration of such new markets.

In the last seven years, People Tree has placed advertisements in a variety of publications, as other fashion retailers do. Particularly, collaboration with Vogue Nippon in 2007 contributed to the expansion of People Tree's sales channels. People Tree's advertisements also revised conventional images of fair trade items among the readers of Vogue Nippon and people in the apparel industry as unfashionable.

In that collaboration plan, four designers from Foundation Addict, Bora Aksu, Richard Nicoll, and Thakoon provided designs for People Tree, and local producers in India and Bangladesh manufactured 100 clothes with organic cotton. Those clothes were sold at United Arrows in addition to the current sales channels in People Tree. Fair trade clothes in 'People Tree Collection 2008' were also retailed at Takashimaya. Following the success of the collaboration project, Bora Aksu, Richard Nicoll, and Thakoon continued to supply their designs to People Tree.

A series of promotional efforts did not emphasise the conceptual message of fair trade. People Tree first attracted the attention of young Japanese for its fashionable clothes. Then, the company shared the embedded messages of fair trade with local producers in the South. This strategy can be effective to draw attention of laypeople towards the fair trade movement, because many people tend to regard foreign loan words used in the context of civil society, for example, fair trade as alien.

From the perspective of the Ansoff Matrix, the marketing strategy of People Tree is mostly opposite that of Ministop: it moves away from diversification strategies toward market development strategies.

Market Growth		Product Growth: Existing Products	Product Growth: New Products
Market Growth	New Markets	**Market Development Strategies** Market-Adjusted Fair Trade Clothes Mainstream Sales Promotions	**Diversification Strategies** Ethnic Fair Trade Clothes Ethnic Fair Trade Handcrafts
Market Growth	Existing Markets	**Market Penetration Strategies** N/A	**Product Development Strategies** N/A

Fig. 2: The Ansoff Matrix with People Tree

The company continues to modify indigenous fair trade clothes towards 'mainstream' fair trade fashion, shifting the designs from ethnic tastes to Japanese preferences, and promoting them through 'celebritised' promotional efforts. Such modified fair trade clothes are considered comparable to other products sold in mainstream retail outlets.

This structural change of merchandising helps spread the monetary risks that are critical in the sustainability of small- to mid-size fair trade business, for, unlike Ministop, People Tree does not have the financial support of a large corporation. As a result, diversifying growth strategies is essential for the business sustainability of People Tree.

Grant's analysis, applied to the case of People Tree, reveals a contrasting approach compared with Ministop. Product development in People Tree derives largely from organisation-specific routines sustained by collaboration among local producers. In addition, most staff members are familiar with fair trade products, which can lead to stronger sales promotions and delivery of the conceptual messages of the fair trade movement. While mainstream retail outlets can facilitate advertisements such as posters and promotion boxes, these advertisements are less effective regardless of the staff members' passion for fair trade initiatives. These factors confer low appropriability, replicability, and transferability on People Tree's approach.

One possible weakness of People Tree comes from its low durability with respect to its reputation and business continuity. It may lose its corporate identity when the charismatic founder retires from the role of president. For People Tree, Minney is the greatest champion of fair trade fashion. Consequently, a key to the company's enduring success will be a smooth succession.

In conclusion, People Tree is now transitioning from a venture business to a mainstream retail outlet. People Tree will undertake market penetration strategies following the current two strategies to increase sales volumes through economies of scale when it has become one of the leading retailers in Japan.

3.4 Case 3: Choco-Revo

In the above case studies, we explored the various marketing strategies of private companies that sell fair trade items. This final case examines a Japanese NPO, Choco-Revo, which is a fair trade movement promoter.

Choco-Revo, established in 2006 by Tomoko Hoshino, engages in various activities associated with fair trade such as consumer surveys, CSR consulting, event hosting and advertisements. The demand for Choco-Revo's services, particularly among listed companies, is increasing because many companies e.g. SONY and Ministop seek to improve their CSR strategies. For instance, the reason Ministop decided to promote fair trade products originated in the conference, 'Exploring the Safety of Chocolates' supported by two Japanese NPOs, Choco-Revo and ACE. Those NPOs explained the human rights associated with chocolates production in the South.

Hoshino [18] believes that support of companies' 'something good' activities could satisfy the needs from business society on account of the increasing concern for CSR. People Tree [17] also explains that collaborations with companies in People Tree reflect the growing importance of fair trade as part of CSR strategies. As such, a company's CSR policy could boost fair trade movement, and the successful implementation of CSR depends on the deployment of fair trade-related NPOs.

Based on such embedded intentions, Takashimaya decided to collaborate with Choco-Revo to sell organic and fair trade chocolates named 'Zotter' during the St. Valentine's season in 2008. This marketing strategy was designed to build a strategic win-win relationship between Choco-Revo and Takashimaya. While the former could maximise its fair trade advocacy, the latter could retail 'something different' chocolates effectively. In 2009, other renowned retailers such as Odakyu, MUJI, Yurakucho Hankyu, and I.D.E.A also prepared for fair trade or organic chocolates recommended by Choco-Revo during the same season.

In addition to involvement with the private sector, Choco-Revo embarked on a collaborative relationship with public sector organisations such as the Japan International Cooperation Agency (JICA).

These collaborations led by Choco-Revo represent the organisation's optimal use of diverse strategic assets in the clients. Such collaborations with powerful actors allow Choco-Revo to acquire new sales channels, merchandising opportunities and reliability of its fair trade advocacy at low cost.

Choco-Revo's adoption of mainstream strategies may cause tensions with traditional and alternative market philosophies and practices. Ironically, it may be inevitable for fair trade NPOs to pursue the mainstream nature of fair trade movement due to the current lack of awareness about fair trade products in Japan. Hoshino [19] pointed out that environmental advocacy as a part of CSR strategies is generally more accepted by Japanese consumers than advocacies led by the government or NGOs.

On the whole, the tendency of adopting 'enlarged' mainstream strategies through collaborations will continue among powerful corporate actors as long as fair trade items are considered to be 'alternatives' of conventional commercial goods.

3.5 Summary

Each organisation discussed above has its unique marketing strategy of fair trade. In contrast with their Western counterparts, Japanese suppliers are required to produce more region-specific fair trade items.

Additionally, some NPOs began supporting such marketing efforts owing to increased concerns about CSR. This trend could accelerate the mainstream adoption of Japanese fair trade initiatives.

Because of the immaturity of the Japanese fair trade market, it remains hard to predict the future of Japanese fair trade marketing. It is clear, however, that the Japanese market will follow a different path from that observed in Western nations.

4 CONCLUSION

4.1 Major Research Findings

A short summary of the major research findings is presented in this sub-section.

4.1.1 Market Expansion through Product Development

These case studies demonstrate that localised products are required to expand the Japanese fair trade market. For instance, Ministop strives to adjust fair trade coffees to the local market through container and flavour development tailored to suit the Japanese market. Ministop has launched fair trade initiatives despite substantial financial risks, feeling such expenditures are necessary to support the company's CSR strategies.

In contrast, People Tree engages in fair trade as part of its core business. This leads to intense communication with local producers through the process of product development. Although People Tree exploits indigenous manufacturing technology, the organisation seeks to popularise its fair trade items with Japanese-specific clothes preferences.

4.1.2 Differing Relevance of Fair Trade Advocacy

Contrary to the West, the fair trade philosophy can be an obstacle to the fair trade movement. Since Japan is geographically and historically far from most local producers, few Japanese understand the importance of the concept. In fact, the consumer awareness of fair trade continues to be low despite its launch in the early 1990s. As a result, the laypeople in Japan tend to recognise fair trade not for its social relevance, but for the freshness of fair trade products promoted using Japanese-specific marketing strategies.

4.1.3 Enlarged Mainstream Strategies

Fair trade movement in Japan also shifts from 'grassroots' to 'mainstream', which is observed in its historical development in the West. In addition, Japanese fair trade suppliers increasingly seek to enlarge their mainstreaming strategies through collaborations with diverse actors such as the mass media, NPOs, governmental organisations, and major retailers.

4.1.4 Fair Trade Initiatives as Part of CSR

Since most 'mainstream' actors in Japan, are listed companies, they need to manage the growing concern for CSR imposed by various stakeholders such as shareholders and the global civil society. Nowadays, not only manufacturers, but also retailers take up fair trade businesses as part of their CSR strategies.

In addition, Japanese NPOs do not try not to pressure listed companies to adopt fair trade practices, but rather promote fair trade through the consultations of CSR strategies. In this sense, the relationship between fair trade

NPOs and listed companies in Japan can be described as cooperative rather than antagonistic.

4.1.5 Passionate Individuals Lead the Movement

In Japan, fair trade suppliers still suffer difficulties garnering public attention. Except for some speciality shops, most suppliers also remain unfamiliar with the idea of fair trade, even though they have already begun to develop fair trade items. Unlike the West, it is hard to imagine that laypeople in Japan have the competence to lead fair trade advocacy, irrespective of some passionate individuals, for example, Okamura (Ministop), Minney (People Tree), and Hoshino (Choco-Revo).

4.2 Future Predictions of Japanese Fair Trade

The present Japanese fair trade market is generally unattractive for mainstream actors given its market scale. In such a small market, fair trade businesses may not be profitable because companies cannot fully deploy economies of scale.

In contrast, corporations could pay the cost of such business when they regard it as the consideration of CSR that will contribute to the public penetration of fair trade concept. If powerful beverage makers were to perceive fair trade a part of their CSR activities, the Japanese fair trade market could become increasingly competitive, thereby driving mid-small roasters out of the competition.

Currently, Suntory contracts with Starbucks Japan to retail Starbuck's brand canned and chilled drinks at an approximately 50% higher price than conventional drinks. This implies that Suntory may develop fair trade drinks as part of value-added canned or chilled drinks. In reality, some companies began to consider fair trade coffees as value-added goods that may raise the total sales in the coffee category. However, if those companies seek sustainable profits from such items, fair trade coffees they will need to deliver high quality in addition to the humanitarian value. One of MUJI staff revealed that many customers recognise fair trade as an attractive brand, which eventually leads to constant purchase of fair trade drinks in the company [20]. As such, many fair trade actors will gradually look for the quality of fair trade products to promote repetitive purchase of such items.

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A Cause-Related Marketing Strategy with a Character Brand –The Case Study of Projects at Solar Bear Fund, a Japanese Non-Governmental Organization

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Abstract

Today's society is full of complexity and faces difficulties in inviting future generations to have discussions in order to move towards sustainability. Cause-related marketing (CRM) is a good tool for companies and non-governmental organizations (NGOs) to collaborate in order to improve society. A new CRM strategy with character brand is discussed here in order to investigate strategic possibilities and explore the key factors around how to design the strategy. This is done through a case study of the projects at Solar Bear Fund, a Japanese NGO, and the companies working with the NGO. Recommended discussions for the future are also provided.

Keyword

Cause-Related Marketing, CRM, Character Brand, Sustainability, Stakeholder Dialogue, Solar Bear Fund, Solarbear.jp

1 INTRODUCTION

1.1 Background

Society today is confronting ecological and sociological challenges that have affected the ecosystems and caused critical social problems [1]. On the one hand, in order to deal with these issues move society towards sustainability, efforts have been made to increase and enrich conversations among stakeholders [2]. On the other hand, challenges have been identified, two of which are described below. Firstly, the complexity in society has grown tremendously and the diversity of values among people has increased substantially [3]. It might therefore be difficult to share common goals and see how to reach those goals easily. Secondly, one of the key points in moving towards sustainability would be pursuing the satisfaction of our needs without compromising the next generation's [4]. However, for children, when it comes to understanding the ecological and sociological challenges and taking action themselves, it may not be clear how to satisfy their needs within the current society.

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1.2 Cause-Related Marketing

Cause-related marketing (CRM) is generally known to be a marketing communication tool in order to put corporate social responsibility into practice [5]. CRM can function successfully only when consumers, business enterprises and non-governmental organizations (NGOs) collaborate. Consumers can indirectly contribute to social action programs simply by purchasing a product and service. For business enterprises, CRM is not only a way to contribute to social action programs, but it also brings two other possibilities. The one is that the sales of the product and service will increase and the other is that the stakeholders will value the company more highly. It might increase the brand value of the company in the long term. CRM also allows NGOs to raise funds in order to conduct social action programs and to communicate efficiently what they have has done to society [5].

For example, American Express has set up a program to donate money linked to customers' spending in order to restore the Statue of Liberty [6]. Kirin MC DANONE Waters Co.,Ltd has donated money to the construction of wells based on sales of Volvic water products in African countries [7]. The authors were inspired by the idea that benefits that the companies can obtain from CRM are so highly valued that cost intensive advertising can be less worthwhile [5]. The authors have started to investigate the possibility of CRM to overcome the two difficulties mentioned above, that is to keep simplicity without losing important factors to understand the issues and to provide the change to invite next generations into the conversation. Character brand could help convey the message more simply and intuitively in order to understand the issue and the goal. Investigating the case study of combining CRM with a character brand could provide some findings.

2 RESEARCH PURPOSE AND METHODOLOGY

2.1 Research Purpose

The aim of this research is to raise the authors' awareness of the issue by examining a CRM strategy of companies such as Sony Corporation, which is making use of character brand to support a Japanese NGO (the subject of this paper). Both expanding the possibility of this strategy and specifying what should be investigated and discussed in the future would also be included in the scope.

The research questions that would be addressed are:

1: How has a CRM strategy with a character brand been conducted in the real business case in Japan?

2: What would be the key factors to design a CRM strategy with a character brand to invite many stakeholders including children to discuss and to take action to move society towards sustainability?

2.2 Methodology

The process of the research includes conducting literature reviews and questioning via email a board member of the NGO. Firstly, articles, scientific journals, CSR reports and the websites of the NGO were researched.

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3 RESULTS

3.1 A CRM Strategy with a Character Brand: A Case Study

Solar Bear Fund

The NGO has conducted educational activities to promote the increased use of renewable energy and to provide environmental education for children and do administrative work about license of the character of 'Solar Bear'[8]. As shown in figure 1, the character of 'Solar Bear' is displayed on the product and service of the companies that are taking a proactive step towards reducing carbon dioxide emissions in their marketing strategy. Part of the sales of the target products and services will be donated to the NGO, which provides solar panels to kindergartens or nursery schools and also provides sustainability education to children [9].

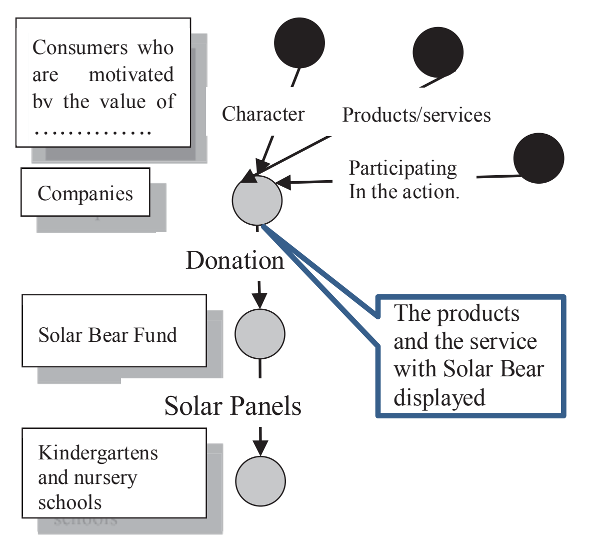

Fig. 1: The model of CRM with a character brand

Design-in the concept of the character at the advisory meeting

Founders of the NGO consist of directors of other NGOs and representatives from companies which support the NGO. As well as the board of directors, there is an advisory board, the representatives of which are supplied by the companies which support the NGO [10]. Based on these facts, it can be assumed that since the foundation of the NGO, the stakeholders have addressed important aspects, such as the concept that they aimed to create and whether the strategy was practically acceptable and applicable for Japanese companies.

It seems to be reasonable that if the NGO aimed to collaborate with Japanese companies to impact on society, understanding their needs and designing them into the concepts and services that the NGO would provide was crucially important. Therefore, the governance of the NGO has affected the CRM strategy.

Installation of the character

The symbol in this strategy is 'Solar Bear', which is developed by Mr. Shinji Katoh, the original creator, and Sony Creative Products Inc. This strategy uses the motifs of polar bears, which are threatened because of the impact of climate change, as shown in figure 2 [11]. The background of this story is that the brother polar bears were separated in childhood from their mother when the arctic glaciers melted due to climate change [12]. Solar is named after the sun that

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Fig. 2: The character Solar and Bear [14]

the NGO would like to disseminate with solar panels and Bear is named after polar bears [13].

Creation of Character Brand Recognition

When it comes to building this strategy, it is essential to create the character brand so that consumers easily recognize it. Constructing the easy recognition of the view of the world is a way to market the character brand. In order to do that, the publishing of the picture books 'Solar Bear' and DVD have been used [11][15]. In order to publicize the character brand to as wide an audience as possible, media such as newspapers and magazines have been utilized. Simultaneously, PR activities have been conducted at locations most attractive to customers. For example as shown in picture 1, the 'Solar Bear' monument has been installed and events have been held at Mediage, a shopping mall at Odaiba in Tokyo [16], as figure 3 shows.

Moreover, branding goods such as soft toys, kitchenware

Fig. 3: Solar Bear Monument

and groceries have added value to these products based on the license contract [9] [17]. These comprehensive approaches have contributed to an increase in reputation of the character brand.

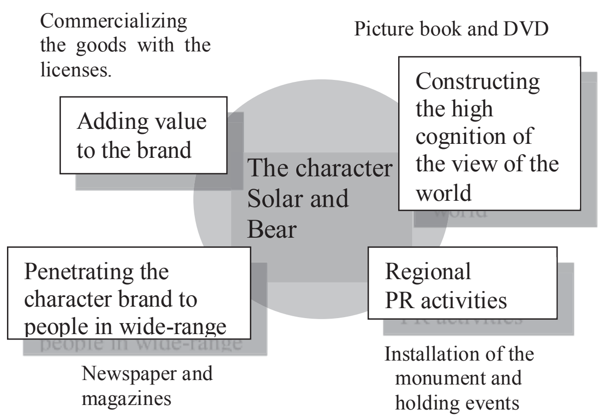

Fig. 4: Create of Character Brand cognition

Installation of solar panels and conducting educational activities

The NGO has installed solar panels in order to reduce carbon dioxide emissions (20 solar panels have been installed in schools in Japan based on donations to the NGO) and the electricity generated from them totals 29.715kWh and 8.65t-CO_2 emissions have been reduced excluding electricity sold as of December 2010. CRM is primarily a marketing strategy. At the same time, however, revenue from the marketing strategy is donated directly to reduce the impact on the environment [18].

The knock on effect of this strategy

The companies working with this strategy will now be discussed in order to see if any patterns emerge.

Sony Corporation donates a part of the revenue generated from the sales of batteries and battery chargers in packaging that display "Solar-bear" campaign characters [19] and the campaign message of 'Let's foster green electricity together' [9]. Sony Corporation also has a campaign to donate 100Yen for every VAIO™ customer in 2010 who has submitted the customer service survey [19].

Sony Life Insurance Co.,Ltd has allowed new policyholders to opt to obtain their policy guide on CD-ROM instead of in paper form. When they select the CD-ROM, Sony Life Insurance Co.,Ltd donates 10 Yen [19].

Sony Assurance has conducted a program to encourage a car-users' behavior change towards environmental conservation. The policy holders declare the estimated distance to be driven at the start or renewal of the contract. When policies are renewed, if the actual distance driven is below the estimated distance, Sony Assurance donates 1 Yen per kilometer to the NGO as a token of the contribution to environmental conservation [19].

Citizen watch Co.,Ltd has developed Eco-Drive, a wrist watch fitted with solar cells, so that users can use them without changing the batteries in order to decrease the environmental impact of using watches [20]. A portion of Eco- drive sales are donated to the NGO and character branded gifts such as key holders accompany the watches [9].

3.2 The pattern of the CRM with a character brand

The 4 key factors to design the content of the CRM strategy

By comparing the business cases as described in 3.2, some common characteristics about this strategy can be seen as shown in table 1. Some of them could be integral in designing a CRM with a character brand. It is not yet known if these characteristics are key or not.

1.Types of incentives

There are two types of incentives for consumers to participate in the program. The companies decide on the target products/services and donate a part of the revenue from the target product/service to the NGO. This shows very clearly and directly what percentage of the revenue would be donated and highlights the relationship between the consumers' and how much is donated. Alternatively, there is an indirect contribution. For example, in the campaign of Citizen Watch Co. Ltd, consumers do not know how much the company donates to the NGO when they purchase a watch. However, in the campaign of Sony Life Insurance Co. Ltd and Sony Assurance, it is clear that if a policyholder takes the agreed action in advance, a specific amount of money would be donated to the NGO.

2.Correlation of the products/services and the purpose of the NGO

One of the main aims of the NGO is to take action to decrease carbon dioxide emissions. To what extent the products/services provided in the campaign relate to the purpose of the NGO could be important to the campaign. For example, in the Sony Assurance campaign, the motivation to decrease using private cars would directly relate to the NGO's goal. In Sony Corporation's battery and chargers campaign of, the charger and rechargeable batteries would relate to the goal However, the campaign involves selling batteries, and their contribution to the NGO's goal is not clearly defined.

3.The extent to which children are invited to take actions in the campaign and to learn about sustainability

As mentioned in 3.1, regarding the creation of character brand recognition, some children know about Solar Bear and their story and some of them might want to take action to help them if presented with the opportunity. With this in mind, it could be crucial for the products/services to be displayed with a character brand that is tangible for children so that they question their parents about it. For example, in the campaign of Citizen Watch Co.,td, children might ask their parents to buy these watches because they want to have the accompanying Solar Bear key. In the battery and battery chargers campaign of Sony Corporation, a character brand can be located in-store that children can easily such as in front of the cash register. During the phase when those products/services are used, children can learn something around sustainability and how to take action. For example, in the campaign of Sony Assurance, they can learn how to decrease carbon dioxide emissions and how they can contribute to it by taking action themselves if their parents can explain the contract.

4.Whether the campaign promotes consumers' behavior changes beyond the campaign

The ultimate goal of the NGO should be to spread environmental education to people and collaborate with companies in order to accomplish the goal.

If people can continue to buy the products/services which have less impact on the environment thanks to a campaign, the campaign could be said to be more successful. For example, if a family tried to adopt the car usage in the campaign of Sony Assurance and change their lifestyle such as cycling or walking in their area instead of driving, even after the campaign, their behavior would continue. In the battery and battery chargers campaign of Sony Corporation, children who can learn to use a battery charger might opt for reusable batteries in the future.

The 4 factors to design the process of the CRM strategy

As this mentioned in 3.1 'design-in the concept of the character at the advisory board', it could be important to have 'stakeholder dialogue' from the earliest stage to build an understanding of needs between companies and a NGO and then to design them in to the concept, the process and the content of the campaign.

Table1: A Comparison of the examples

Company	Produce/Service	Types of incentives	Correlation of the products/services and the purpose of the NGO	To what extent children can understand the campaign.	The consumers' behavior changes more than the program
Sony Corporation	Batteries and battery chargers	Indirect	Some Clear: decreasing the waste material from batteries, which will decrease CO2 emissions The other Not really clear	Possible to contribute to the purpose of the NGO especially at purchasing the products	Possible
Sony Corporation	Personal computer	Indirect	-*1	-*1	-*1
Sony Life Insurance Co.,Ltd	Life Insurance	Direct	-*1	-*1	-*1
Sony Assurance	Auto insurance	Direct	Very Clear: Reduction of CO2 emissions from private cars	Possible to contribute to the purpose of the NGO especially at using the services	Possible
Citizen watch Co.,Ltd	Eco Drive (a wrist watch)	Indirect	Very Clear: Using Solar energy	Possible to contribute to the purpose of the NGO especially at purchasing	Possible

*1=the information is too limited to describe some conclusion here.

4 CONCLUSION

4.1 Summary

This is a case study that examines a CRM strategy that is making use of character brand. The process of designing-in the concept of the character and the process of the efforts to build the character brand in this CRM strategy have been described. It has helped to compare the case studies and come up with key components of this CRM strategy.

A CRM could be successful because of the benefits of CRM and character brand combined. CRM could be a bridging tool between companies and NGOs and a character brand could work to share the concept towards sustainability in a simple and empathetic way. It seems to function in the context and create the possibility to lead to both collaborations with future generations and to behavior changes today.

4.2 Areas for Further Research

This research is the first step towards understanding the business case of a CRM strategy with a character brand, and one of the contributions of this paper should be identifying the areas of further research.

First, a way to measure how the character brand directly contributes to increasing sales has not been established. Hence, the strategy should be investigated quantitatively. If this could be clarified and the validity of this strategy higher, more companies could decide whether to employ the strategy. Secondly, in this paper, building up the character brand has been the focus. However, a strategy to maintain the long-term value of the character brand is also necessary. Thirdly, this research has been done by literature review. Interviewing and/or conducting questionnaires of the companies working in this strategy and consumers would provide more information to scrutinize the authors' work. Sample questions could be:

- How has the character affected consumers' decision to buy the products/services?
- To what extent are children educated in the campaign?
- Has it caused a behavior change in consumers?

Fourthly, investigating the key factors that are described in 3.2 with more information and/or finding if there is a correlation between the key factors might be useful to expand a CRM strategy with a character brand.

Fifthly, there has been a framework for strategic sustainable development (the FSSD) developed in order to overcome the complexity without ignoring parts of reality [22]. Investigating where this marketing tool is located in the FSSD might be useful to the sustainability practitioners in the future.

Finally, we appreciate the generous support from Mr. Masahiro Ishino at Sony Corporation for providing and reviewing this information.

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Business Strategy Planning Based on Sustainable Society Scenarios

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Abstract
Companies start to describe sustainability scenarios in order to make long-term strategies toward a sustainable society. However, the support in making such strategies is inadequate. In this paper, we propose a method for supporting planning processes of such business strategy scenarios. For this purpose, we formalize a business strategy scenario consisting of four parts and we take an approach to use existing sustainable society scenarios for describing environments surrounding the company. For verifying availability of the proposed method, a case study of solar panel business is carried out. As a result, it is revealed that planning of business strategy scenarios is efficiently supported by detailing an existing scenario.

Keywords:
scenario, sustainability, strategy, business, solar panel

1 INTRODUCTION

Companies have started to make long-term strategies toward enhancing their sustainability under many uncertainties in the real world. It is difficult to make long-term strategies because it is very tough to predict the future of environments around business. For dealing with this problem, describing scenarios is a promising approach for drawing a variety of futures and planning a variety of strategies in each future. Some companies have, in fact, described long-term strategies in the form of scenarios. For example, Ricoh [1] drew their visions and strategies in 2050 based on Emission Scenario written by Intergovernmental Panel on Climate Change (IPCC) [2].

Scenario planning [3] is a typical method for describing scenarios, helping to make strategies in the scenarios. The method of scenario planning is explained as follows: (1) a scenario writer selects some factors that have a crucial impact for business, (2) the writer draws some changes of the factors as scenario, and (3) the writer makes strategies based on the scenario. However, describing such scenarios is not well-supported.

The objective of this paper is to propose a method for supporting planning process of business strategy scenarios. Business strategy scenarios here refer to scenarios that describe business strategies based on various possible business environments. A business environment means an external environment around business. In this paper, we employ existing scenarios for helping to describe possible business environments. Additionally, we extend the stractual scenario description method [4] for representing business strategy scenarios.

2 CONCEPT OF DESIGN SUPPORT METHOD FOR BUSINESS STRATEGY SCENARIOS

2.1 Requirements for supporting design of business strategy scenarios

From our literature reviews on scenario planning methods we identify three requirements for supporting design of business strategy scenarios as follows:

(1) Various business environments should be described for examining uncertainties of future business environments.

(2) Business strategy scenarios should be formalized and gradually detailed in a stepwise manner so that the scenario writer can derive various business strategies based on various business environments assumed in the scenarios.

(3) The relationship between business environments and strategies should be clarified because the present situation will change in the future and, therefore, descriptions of business environment and strategies should be updated then.

[redacted]

Fig. 1: Basic Structure of Business strategy scenario

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2.2 Approaches

In order to meet the above requirements, we take the following approach in this paper.

To meet the first requirement, a scenario writer employs one or more existing sustainable society scenarios in describing business environments. A sustainable society scenario means a scenario that shows visions of future societies toward sustainability. The method intends to help the writer to assume environments around business easily by reusing hypotheses and data in existing sustainable society scenarios. To meet the second requirement, we formalize a business strategy scenario consisting of four parts (see Fig. 1); *i.e.*, problem, vision of a company, future business environments, and business strategies. Details of this representation are explained in Section 3.1.

For the third requirement, we use the structural scenario description method [4] for expressing business strategy scenarios. The method has the advantage of representing logical relationship between descriptions in a scenario, thereby enabling to articulate the relationship between a business environment and associated business strategies.

2.3 Structural scenario description method [4]

To comprehend a structure of scenario, we define four levels to represent scenarios as follows.

- Scenario Level: shows the structure of sub-scenarios.
- Expression Level: shows the relationship between texts in a scenario.
- Word Level: shows the relationship between words in a scenario.
- Data Level: shows the simulations that underlie a scenario.

In each level, we express a scenario as a directed graph, using nodes and links. Nodes express an element of each level, while links express the relationship between two nodes.

3 METHOD FOR SUPPORTING DESIGN OF BUSINESS STRATEGY SCENARIOS

3.1 Basic structure of business strategy scenario

In this paper, we formalize a business strategy scenario in following way. For making strategies, we clarify targets that a company aims to achieve. For considering strategies easily, we distinguish a set of possible futures that the company cannot control from actions that the company may take. In other word, we divide descriptions in the scenario into external or internal descriptions. In this paper, we model a business strategy scenario as a combination of four elements; (1) Problem, (2) Vision and Target, (3) Business Environments, and (4) Business Strategies (see Fig. 1).

(1) Problem: setting about the business strategy scenario, such as topic and coverage about region and time horizon of a business strategy scenario. And it shows motivation of describing a business strategy scenario.

(2) Vision and Target: a goal of a company. It becomes a guide of business strategies in designing a business strategy scenario.

(3) Business Environment: the environment around business uncontrollable by the company, such as needs of consumers and competitors' actions.

(4) Business Strategy: sets of actions to achieve the target in various business environments.

We divide this business environment into two parts; namely, Sustainability Society Scenario and Detailed Business Environment. In sustainability society scenario part, the scenario designer uses existing sustainability society scenario as the outline of the business environment in order to help assume the future. In detailed business environment part, we add more information that is not described in sustainable society scenario (for example, competitors' actions and legislation).

3.2 Expression of business strategy scenario

We use the structural scenario description method [4] to express business strategy scenario. While this method is proposed for representing general structure of scenarios, the method does not express distinction between elements of a business strategy scenario. Thus, we extend this method for representing the scenario structure proposed in Section 3.1 by introducing Business Level. In Business Level, we express structure of business strategy scenario using nodes and links shown in Fig. 2. We define seven types of nodes (problem, vision, target, sustainable society

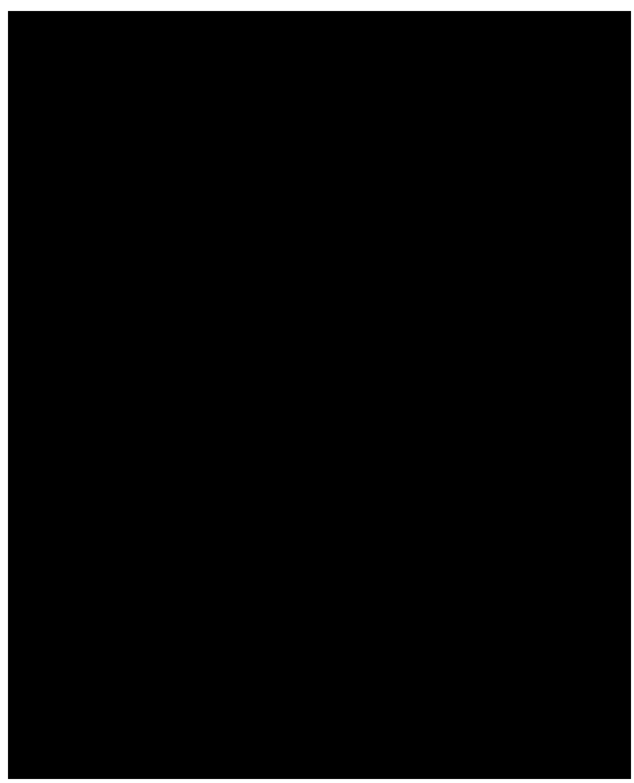

Fig. 2: Expression of structured scenario (Business Level)

Table 1: definition of Business Level

Type		Definition
Node	problem	A contents of problem setting
	vision	A goal that the company aims to achieve in a distant future.
	target	A mid-term goal that should be achieved to reach the vision.
	sustainable society scenario	An existing scenario used as a base of describing the business scenario.
	detailed business environment	A business environment deployed from descriptions of sustainable society scenario.
	business strategy	A set of strategies or actions that the company may take, under a business environment.
	conclusion	Conclusions that indicate final suggestions for the company, which are derived from the described business strategies.
Link	derive(A, B)	Node B is derived from node A
	detail(A, B)	Node B is a detailed description of node A.

scenario, detailed scenario, business strategy, and conclusion) and two types of links (detail and derive) in this level. Table 1 describes definitions of nodes and links of the business level.

3.3 Design process of business strategy scenarios

Along the basic structure of business strategy scenario as shown in Fig. 1, we describe a business strategy scenario in the following four steps.

Problem setting

For clarifying a topic and coverage of business strategy scenario, the designer describes a problem by defining seven items of Table 2. These items involve background, objective, actors of the business strategy scenario, region, and time horizon.

Vision and Target setting

In this step, visions and targets of the company are described. The designer describes a vision for clarifying a goal which a company wants to achieve in future (for example, reducing 30 percent of CO_2 emission in a company from 2010 to 2050). The designer then describes clearer targets to achieve the vision (for example, reducing 10 percent of CO_2 emission from 2010 to 2020).

Describing business environment

In this step, the designer describes environment around the business such as consumers' needs, competitors' actions, lifestyle, legislation, and so on. We divide this business environment into two parts; Sustainability Society Scenario and Detailed Business Environment. As the part of sustainability society scenario, the designer selects existing sustainability society scenarios.

Table 2: Problem description of a scenario

Item	Description
Title	Title of the scenario
Background	Motivation for describing the scenario
Objective	Objective for describing the scenario
Region	Targeted region in the scenario
Time horizon	Starting and end year of the scenario
Main Actor	Main stakeholders in the scenario
Actors	Stakeholders involved in the scenario, other than the main actors

In a detailed business environment part, we add more information that is not described in sustainable society scenarios (for example, competitors' actions and legislation). The designer describes a detailed business environment in two steps:

(1) The designer assumes changes about critical factors for the business, as a guide of describing detailed business environment.

(2) The designer details description of sustainable society scenarios along with the changes that are assumed in Step (1).

Describing business strategy

In this step, the designer describes business strategies, which the company may take based on each business environment described in the previous step. The designer describes business strategies in two steps:

(1) The designer makes a lot of business strategies based on each business environments.

(2) The designer organizes and selects business strategies to achieve the targets and visions.

4 CASE STUDY

4.1 Overview of the case study

For verifying availability of the proposed method, we carried out a case study of describing a business strategy scenario for a solar panel manufacturer. As an existing sustainable society scenario, we used Energy Technology Perspective 2010 (ETP2010) [5] because this scenario mentions dissemination of solar panels in the world until 2050. We described four detailed business environment based on the two sub-scenarios of ETP2010, and then derived various strategies from each business environment.

4.2 Problem setting

In this business strategy scenario, we defined main actor as a solar panel manufacturer. We assumed that the

Fig. 3: Business Level of the business strategy scenario

company produces two types of panels (crystalline silicon cell and thin-film sell). To consider long-term strategies in this company, we set problems as shown in Table 3.

Fig. 3 shows Business Level structure of the business strategy scenario. We expressed the problem setting described in Table 3 as a problem node (node (A)) in Fig. 3.

4.3 Vision and Target setting

We set a vision of this solar panel manufacturer as contributing to a sustainable society by providing solar panels. To achieve this vision, we set target that their products accounted for 10 percent of the world solar panel sales in 2020 and 15 percent of those in 2030. In Fig. 3, we expressed the vision of the company as node (B), the target in 2020 as node (B-1), and the target in 2030 as node (B-2).

4.4 Describing business environment

First, to describe business environment, we selected ETP 2010 as existing sustainable society scenario used in the business strategy scenario. In ETP 2010, two scenarios (Baseline scenario and BLUE Map scenario) are described, each of which differ in dissemination of energy technologies. While Baseline scenario assumes that governments introduce no new energy and climate policies, BLUE Map scenario examines the least-cost measures of achieving the goal that global energy-related CO2 emissions are reduced by half from the 2005 level by 2050 through the deployment of existing and new low-carbon technologies. In Fig. 3, we described the descriptions of Baseline scenario as node (C-1) and the descriptions of BLUE Map scenario as node (C-2).

Second, we described detailed business environment. We focused on changes of silicon prices as a critical factor in the solar panel business and make four detailed business environments based on the difference of silicon prices as shown in Table 4; that is, we created two detailed business

Table 3: Problem of the case study

Item	Description
Title	Business strategy scenario for solar panel manufacturer
Background	The solar panel market worldwide becomes more and more competitive as demand for solar panels is increasing due to pressures on global warming problems and energy security.
Objective	To plan long-term strategies for solar panel business.
Region	World (especially Japan, US, EU, China, India)
Time horizon	2010-2050
Main Actor	A solar panel manufacturer, which is based in Japan. This company deploys its business globally and produces solar panels with the two types of cells, i.e., polycrystalline silicon cells and thin-film cells.
Actors	other solar panel manufacturers, consumers, manufacturers of materials, governments

Table 4: setting in detailed business environment

		ETP2010	
		Baseline	BLUE Map
Silicon prices	Fixed	Any policy about solar panel is not introduced. Solar power is not so popular. Price of silicon is not changed.	A lot of policy about solar panel is introduced. Solar power is popular. Price of silicon is not changed.
	High	Any policy about solar panel is not introduced. Solar power is not so popular. Price of silicon is twice from now.	A lot of policy about solar panel is introduced. Solar power is popular. Price of silicon is twice from now.

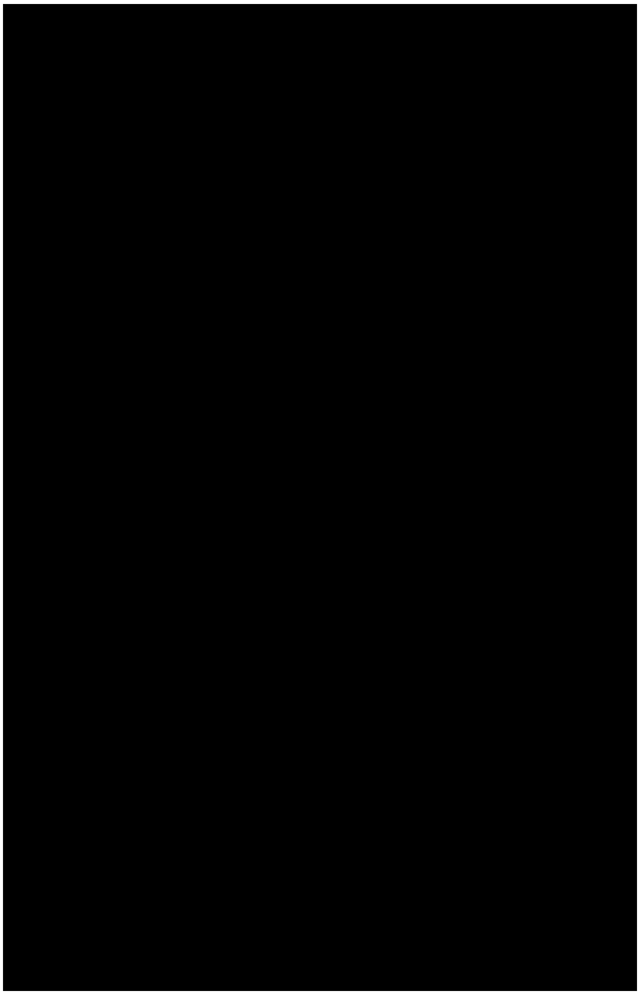

Fig. 4: Scenario description (BLUE Map)

environments for each of Baseline scenario and BLUE Map scenario. In Fig. 3, we created two detailed business environment (node (C-1-1) and (C-1-2)) based on Baseline scenario (node (C-1)), and two detailed business environment (node (C-2-1) and (C-2-2)) based on BLUE Map scenario (node (C-2)) There were two reasons we focused on silicon prices. First, silicon prices directly affect cost of crystalline silicon solar panel, which the company produces. Second, in the last decade, the share of solar panel manufacturers has been largely changed because of high silicon prices in the real world.

We detailed descriptions of sustainable society scenario by adding more descriptions as shown in Fig. 4, which is a part of description of the business strategy scenario. In Fig. 4, node (a) represents a hypothesis of ETP2010. The hypothesis represents that electricity generation by solar power in BLUE Map is 5 times as much as in Baseline. We assumed two different trends of silicon prices; *i.e.*, hypothesis (b) means that silicon prices remain unchanged from 2010-2050, while hypothesis (c) means that silicon prices will become 5 times higher in 2050 from node (a). Next, we estimated payback period with each materials of panels and describe in node (d). In this estimation, we used data in Solar Power Roadmap (PV2030+) [6] node (e)). Fig. 5 represents the result of the estimation. Fig. 5 tells that crystalline silicon costs as much as CIS-type solar panels (Fig. 4 node (f)) and that the payback period will become more than twice compared to CIS type (node (g)).

Fig. 5: Estimation of payback period by solar panel type, expressed as hypothesis (d)

4.5 Describing business strategy

From each of the four business environments, we derived various strategies. We described business strategies in each business environment as business strategy nodes (A-1-1, A-2-1, B-1-1, and B-2-1) in Fig. 3. A part of description of business strategies are shown in Fig. 4. Strategy (node (h)) that we continue to produce crystalline silicon solar panels is derived from description of business environment (node (f)). In the same way, strategy (node (i)) that we sell CIS-type solar panels when silicon price increase by 5 times is introduced from node (g).

From those strategies, we derived that we should sell CIS type when silicon prices become over twice higher as a conclusion (node (j) in Fig. 4). We described conclusions of the business strategy scenario in conclusion node (node (D)) in Fig. 3.

5 DISCUSSIONS

In this case study, a business strategy scenario was designed in the four steps (problem setting, vision and target setting, describing business environment, and describing business strategy).

Table 5 shows number of descriptions in the business strategy scenario. Table 5 indicates that about 60 percent of descriptions in the business strategy scenario are from the underlying scenario, ETP2010. In other words, we succeeded in employing the existing sustainable society scenario efficiently in designing the business strategy scenario. From this discussion, we achieve a part of the first requirement in Section 2.1 by using a sustainable society scenario, but in this method, description of business environment depends on contents of existing sustainable society scenario. On the other hand, about 25 percent of descriptions in the business strategy scenario

Table 5: Number of Expression Nodes in the business strategy scenario

Element		Number of Nodes	Percent age
Problem		9	1.3
Vision and Target	Vision	1	0.1
	Target	2	0.3
Business Environment	Sustainable society scenario	421	60.4
	Detailed business Environment	173	24.8
Business Strategy	Business Strategy	83	11.9
	Conclusion	8	1.1
Total		697	100.0

correspond to descriptions of the detailed business environment, where we added data and hypotheses about solar panel business. This means that, while the first requirement in Section 2.1 is supported to an extent, the main task of designing business strategy scenarios using our method is to detail business environments from existing scenarios.

By extending Structural scenario description method, we clarified the difference between each business environments. We also clarified relationship between business environment and business environment. In other words, we clarified the arguments of business strategies by using the method. For example, in this case study, we created four business environments. When comparing descriptions in detailed business environment nodes (Fixed silicon prices (BLUE Map) and High silicon prices (BLUE Map)), there is a difference about payback period between node (f) and node (g) (see Fig. 4). It is thus easy to follow arguments by following links. For example, in Fig. 4, arguments of node (h) are derived from nodes (a, b, d, e, and f). Therefore, the third requirement is achieved by clarifying the relationship between a business environment and its associated business strategies.

6 CONCLUSIONS

This paper proposed a method for designing long-term strategies using existing sustainable society scenarios. This paper also proposed a representation method for business strategy scenarios in order to clarify business environment and business strategies. In the case study, we created a business strategy scenario for a solar panel manufacturer. In this scenario, four business environments are assumed based on the existing sustainable society scenario IEA ETP2010 and various strategies are derived from each business environment.

Future works include developing support in describing detailed business environment part and describing business strategy parts.

ACKNOWLEDGMENTS

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Proposal of a methodology for supporting generation of new eco-business ideas

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Abstract

As global environmental issues have become aggravated, "Eco" become one of competitive advantages in the business because of increasing consumers' environmental consciousness. However, it is difficult to lead eco-business to the success in both of environmental and economic aspects because of four features of eco-business; external economy, unrecognition of environmental value in the market, difficulty of evaluating, necessity of repeatedly reforming. For solving this problem, it is effective to support finding out eco-business ideas. This paper proposes the methodology that supports generation of eco-business ideas, which is developed through our investigation of eco-business. This paper also verifies its effectiveness through a workshop.

Keywords:

eco-business, business design methodology, idea generation, eco-innovation

1 INTRODUCTION

In order to achieve sustainable society, greater development in eco-innovation is required. Today, many firms are required by their stakeholders to maintain a high level of environmental consciousness and to take on a greater role in the continuing trend towards eco-innovation. For firms, operating eco conscious business has become vital, because "eco" has become one of the keys to a competitive advantage in business.

We can find several methodologies for supporting generation of new business ideas. 'TRIZ' is an inventive problem solving tool, by which new ideas are generated through six steps; problem analysis, problem definition, generating solutions, etc. 'The 9 building blocks[1]' is also one of these methodologies, by which new business ideas are investigate through nine perspectives: customer segments, value proposition, channels, etc. We can also find methodologies for supporting the development of environmental consciousness such as 'Life Cycle Assessment (LCA)' and 'Life Cycle Design[2].'

Furthermore, recently several concepts for eco conscious business are offered, such as 'Product Service System(PSS)[3],' 'Servicizing[4],' and 'Selling function[5].'. However, there has been a low incidence of success in both business and eco consciousness [6].

This study is to propose a methodology for supporting generation of new eco-business ideas for those that are in new project development and planning team in firms. We propose the methodology based on our investigation of existing eco-business. The investigation clarifies definitions, distinctive features and practical creation process of eco business. And we ran a workshop to verify its efficiency and to identify issues or subjects that need to be addressed.

2 FUNDAMENTAL MODELS

2.1 Investigation of existing eco-business

We investigated existing eco-business shown in Table 1 by literature review and interviews to business associates. For each business, we obtained summary of eco-business, customer needs, contents of service, way to provide service, profit model, sales promotion, triggers of starting the business, competitors, critical issues at the time of starting the business, and point of innovation.

Table 1 :List of investigated eco-business

No	Theme	Business	Company
1	Waste Management	Sub-critical processing technology	REMATEC Corporation
2		Solution business	AMITA HOLDINGS CO.,LTD.
3		Waste and re-resource electron dealings market	Recycle One, Inc.
4		Battery reuse	HAMADA CO.,LTD.
5	Reuse	Abandoned bicycle reuse	BIKE OFF Corporation
6		Secondhand book sales	Bookoff Corp. LTD.
7		Used car sales	Gulliver International CO.,LTD.
8		Liquid crystaldisplay reuse	Repro Electronics Corp.
9		Nursing bed reuse	France Bed CO., LTD.
10		Ink cartridge reuse	Ecorica Inc.
11	Technology Development	Water free urinal	INAX Corp
12		LED lighting	Toshiba Lighting & Technology Corporation
13		Biotechnology polyethylene	Braskem S.A., Toyota Tsusho Corp.
14		Reverse osmotic membrane	Toray Industries, Inc Nitto Denko Corp.
15		Micro Hydro-pow er	The Tokyo Electric Generation
16	PSS	Lease of materials for packing	EcoBiz.CO.,LTD.
17		Water sales business	Kurita Water Industries LTD.
18		Matching of empty truck	Brix Corporation
19		Lease of fluorescent lamp	Panasonic Electric Works CO.
20		EV battery exchange & rental system	Better Place, Inc
21		Rental of consumer electronics	TOSHIBA SERVICE & ENGINEERING CO.,LTD.
22		Rental of reuse tablew are	Space fuu, Incorporated nonprofit organization
23		Abolition heat transportation	Sanki Engineering CO.,LTD.
24		Net print service	Fuji Xerox CO., LTD.
25	Energy Saving	Energy Service Company	The First Energy Service Company Limited.
26		Small w ind pow er generation	ZEPHYR CO.,LTD.
27		Geothermal pow er generation	Fuji Electric Systems CO., LTD. Mitsubishi Heavy Industries, LTD.
28		Biodiesel fuel made from disposed vegetable oil	REVO INTERNATIONAL CO., LTD

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2.2 Distinctive feature of eco-business

We here define eco-business as business that directly or indirectly reduces environmental loads to the society and, at the same time, makes economic profits.

The following four features distinguish eco-business from traditional business:

1) Existence of external economy

Eco-business provides value to various stakeholders, such as 'neighbors', 'nature', through the reduction of environmental loads, eg. a reduction of carbon emission, pollution and industrial wastes.

Therefore, in generating and evaluating eco-business, 'society' which includes 'neighbors', 'nature', and other stakeholders has to be taken into consideration.

2) Unrecognition of environmental value in the market

The environmental value eco-business provides to customers can be classified into the following four kinds: i) cost reduction, ii) avoidance of risks, iii) improvement of service quality, and iv) improvement of customers' image [7]. Much of these environmental value is not perceived as currency value in the market. For example, nobody buys "mitigating the risk of climate change that can happen in 50 years."

Therefore, we have to grasp the environmental loads to the society in generating and evaluating eco-business.

3) Difficulty of evaluating eco-business

It is difficult to evaluate eco-business, because companies begin eco-business are likely asked to restructure business models or supply chains. For example, in the case of 'No.16 lease of fluorescent lamp,' a company does not sell lamps, sells the service and changes a revenue model.

Therefore, a methodology for supporting generation of new eco-business ideas has to support not only to generate and build an eco-business but to evaluate it.

4) Necessity of repeatedly reforming

Through the investigation described in Section 2.1, we modeled the process of new eco-business development as show in Fig. 1. In the process of new eco-business development, repeatedly reforming an eco-business idea is needed to increase its feasibility.

The process can be divided into three phases. In the first phase, a core concept of eco-business idea is created and extracted from just ideas. In the second phase, an eco-business model is built and repeatedly revised by combining other ideas with the core concepts of eco-business ideas created and extracted in the first phase in order to improve the feasibility. We here define a business model as a mechanism generating profits, which consists of customers, a way to purchase/produce, product/service, price, a way to distribute, promotion.

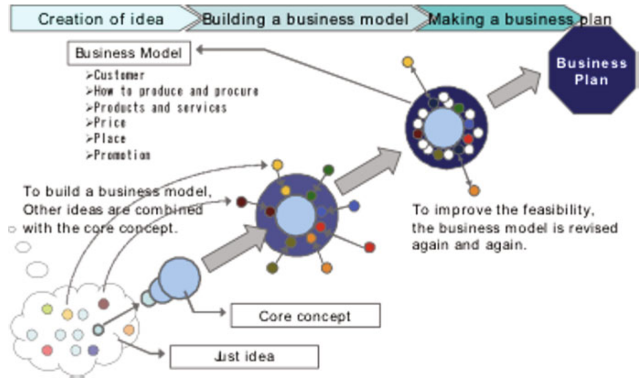

Fig. 1 : Process of establishing eco-business

And after superior's approval of an eco-business model, in the third phase, an eco-business plan is made, which contains the detailed plans and budgets showing how the operational and financial objective of a business.

Therefore, the methodology has to have a process of repeatedly reforming eco-business ideas and models.

2.3 Rules for eco-business idea generation

To succeed in business, 'value' provided to customer shall exceed 'cost' for customer as shown in Fig. 2. Through the investigation described in Section 2.1, in the case of eco-business, 'value' consists of 'environmental value' in addition to 'function' provided by the product or the service, and 'cost' consists of 'inconvenience' and 'risk' as well as 'price of product or service'.

We extracted 18 rules for designing eco-business by categorizing eco-business ideas according to Fig.2, which are derived from the cases described in Section 2.1. These rules can be divided into four types; i)Promoting environmental value, ii)Adding other function, iii) Lowering cost, iv) Changing market segment. And Table 2 describes these 18 rules.

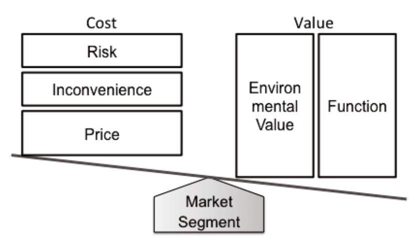

Fig. 2: Condition of the success for eco-business

Table 2 : Rules for designing eco-business

-Promoting environmental value	
1	Use of lower environmental loads materials (in production)
2	Introduction of lower environmental loads process
3	Expansion of product's life
4	Enhancement of product's environmental loads efficiency
5	Change to lower environmental loads utilities
6	Managing product usage and environmental loads
7	Managing life cycle of product
8	Use one more time
-Adding other function	
9	Receiving contracts for environmental loads
10	Combining various business values; e.g. function sale
11	Developing new service with knowledge
-Lowering cost	
12	Making environmental loads visible
13	Timesharing (of product); e.g. sharing and rental
14	Change revenue stream; e.g. lease, servicizing, and ESCO
15	Expansion of the business scale
16	Utilizing knowledge or technology in other fields
17	Financial support or charge from other stakeholders
-Changing market segment	
18	Change target segment of customers

3 PROPOSAL OF THE METHODOLOGY

As described in 2.2, in the methodology for supporting generation of new eco-business ideas, i) society has to be taken into consideration as one of stakeholders, ii) environmental loads to the society, such as waste and pollution, also has to be taken into consideration, iii) a process of repeatedly reforming eco-business ideas and models is necessary, iv) we support for building an eco-business model and evaluating it, .

Therefore, the methodology for supporting generation of new eco-business ideas has three features as below.

3.1 Divergent and Convergent process

The methodology has to have a process of repeatedly reforming eco-business ideas and models as described in Section 2.2. And we found eighteen rules for generating eco-business ideas as described in Section 2.3.

Therefore, we propose the 8 steps methodology shown in Fig.3. In STEP 1 – 3, the design team specifies the business, which is a starting point of generating eco-business ideas. STEP 4 is a divergent step, in which eco-business ideas are generated by applying eighteen rules to the business specified in STEP 3. STEP 5 – 6 are convergent steps, in which eco-business ideas generated in STEP 4 are combined into core concepts of new eco-business, and we evaluate these core concepts. STEP 7 is again a divergent step, in which we reform the core concepts by combining other ideas and build business model. And, finally, STEP 8 is a convergent step, in which we evaluate eco-business models and select them.

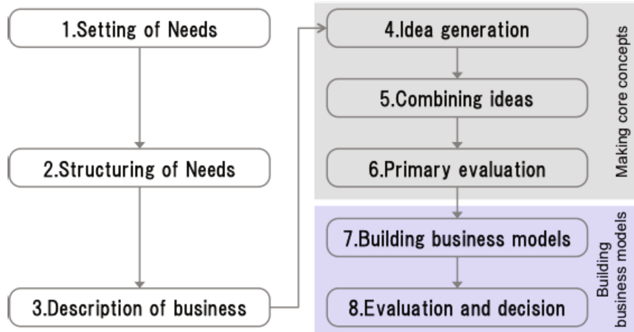

Fig. 3 : Eight steps for eco-business creation

In this methodology, we support the phases from creating core concepts to building business models in Fig. 1.

3.2 Modeling eco-business

For modeling eco-business, we propose the scheme shown in Fig. 4. As shown in this figure, we represent 'society,' and 'Eco-business provider,' in addition to the stakeholders of general business, such as 'Product provider,' 'User,' 'User's user,' as stakeholders of eco-business. 'Society' is defined as those who are affected by environmental external economy, and 'Eco-business provider' is defined as one who manages eco-business.

Also, we represent 'Waste/pollution', in addition to 'Product/Service' and 'Money', which are dealt between stakeholders.

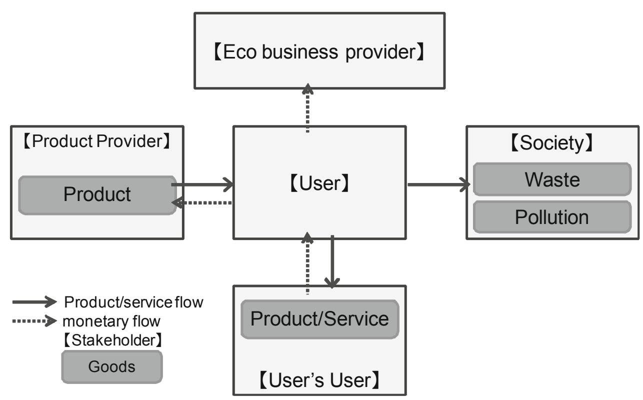

Fig. 4 : Structure model of eco-business

3.3 Evaluation of eco-business ideas

In STEP 6 in Fig.3, we have to evaluate core concepts of eco-business ideas created in STEP 5 not only from the point of view of its market attractiveness, from the point of views of environmental consciousness and company's suitability.

Therefore, for the evaluation, we combine the framework of 'Value portfolio [8]' and the 'BMO method [9].' 'Value portfolio' evaluates business ideas from the view points of the feasibility and the harmonization with company's vision. We evaluate the feasibility of eco-business ideas by using 'BMO method', in which 6 chapters of 'attractiveness' and 6 chapters of 'suitability' are given a full score of 10 points. In addition, in this methodology, as 'composition of vision', environmental consciousness is given a full score of 30 points.

4 CONSEQUENCE OF A WORKSHOP

4.1 Summary of the workshop

We ran a workshop for creating eco-business ideas starting with 'Production & Sales of air conditioners,' in which three experts on environmental issues participated. Within the time limitation of four hours, we were able to run through STEP 1- STEP 6 and created five core concepts of eco-business. The highest scored core concept was "managing the operation and selection of air conditioners by visualizing energy use and earning financial supports from an electric power provider by offering a peak time usage reduction."

4.2 Consequence of the workshop

In this Section the results of the workshop is shown step by step (in Fig.3)

1) STEP 1 Setting of needs

In this step, the design team sets the main requirements of upcoming business to satisfy customer needs. At first the design team gathers a list of needs by brainstorming, and then groups similar needs by using the KJ method [10].

In the case of 'Production & Sales of air conditioners', the design team gathered 'to make a room cool', 'to control humidity in a room', 'to save energy', etc.. And after grouping these needs, 'To make a room comfortable' is set as the main requirement.

2) STEP 2 Structuring the needs

In the workshop, we structured the needs as shown in Fig. 5 in order to find the needs, which another business satisfied.

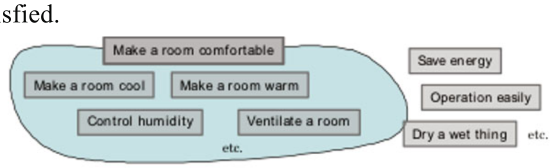

Fig. 5 : Setting of Needs

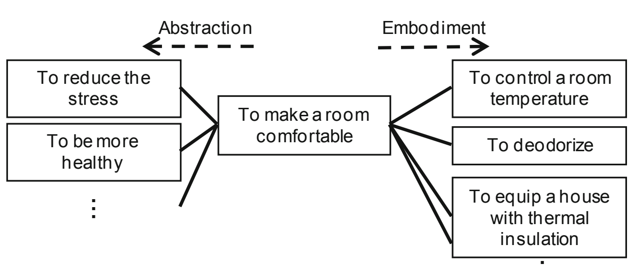

Fig. 6 : Structuring of needs

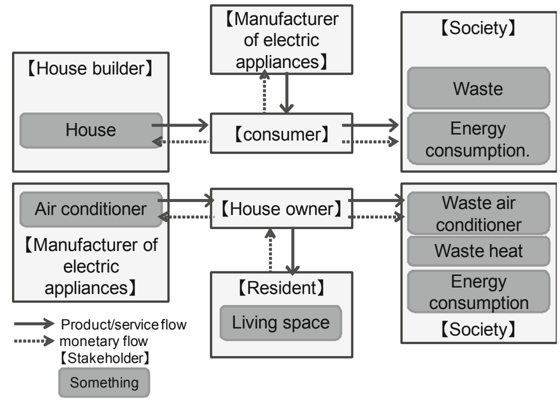

Fig. 7 : Description of existing business

3) STEP 3 Description of business

In this step, the design team selects the needs structured in STEP 2 and describes the business satisfies these needs according to the structure model of eco-business described in Section 3.2.

In the case, the needs "To control a room temperature" and "to equip a house with thermal insulation" are selected as the starting point of idea generation and modeled as shown in Fig. 7.

4) STEP 4 Idea generation

Eco-business ideas are generated by utilizing the 18 rules shown in Table 2. In other words, we combine these rules with the business description shown in Fig. 8 and generate ideas.

In the workshop, 25 eco-business ideas were generated in this step (see Table 3). For example, the idea, '(14) Rental of an air conditioner,' was generated by applying 'Rule13 Timesharing'.

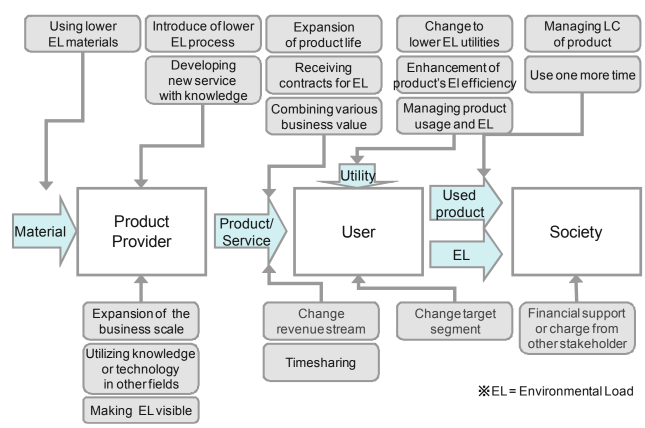

Fig. 8 : Application of Rules

Table 3 : eco-business ideas generated in STEP 4

№		Rules	Idea
-Production and sales of air conditioner			
(1)	1	Using lower EL materials	Using reusable parts
	8	Use one more time	
(2)	1	Using lower EL materials	Repairing and re-using of air conditioners
	8	Use one more time	
(3)	1	Using lower EL materials	Selling as a used product
	8	Use one more time	
(4)	3	Expansion of product's life	Expanding the life of product's parts
(5)	3	Expansion of product's life	Selling air conditioners designed for repairing easily
(6)	4	Enhancement of product's EL efficiency	Cooling a room in the morning and insulating it
(7)	4	Enhancement of product's EL efficiency	Selling air conditioners with high energy efficiency
(8)	4	Enhancement of product's EL efficiency	Managing operation and selection of air conditioners
	6	Managing product usage and EL	
	11	Developing new service with knowledge	
(9)	5	Change to lower EL utilities	Selling air conditioners with natural energy
(10)	6	Managing product usage and EL	Selling air conditioners contributing peak shaving.(Cooperation with electric power company)
	16	Utilizing knowledge or technology in other fields	
(11)	7	Managing LC of products	Using heat exhausted from an outdoor unit as a warm air
	8	Use one more time	
(12)	8	Use one more time	Magnets of motors are taken out for reuse
(13)	13	Timesharing	Sharing an air conditioner
(14)	13	Timesharing	Rental of air conditioners
	14	Change revenue stream	
(15)	18	Change target segment	Useing the air-conditioner outdoor unit as a drier
-Construction and sales of house			
(16)	1	Using lower EL materials	Using natural energy in a house
(17)	1	Using lower EL materials	Selling houses made of recycled resource
(18)	3	Expansion of product's life	Expanding the life of a house
(19)	4	Enhancement of product's EL efficiency	Selling houses with high insulation efficiency
(20)	4	Enhancement of product's EL efficiency	Sharing a room
(21)	4	Enhancement of product's EL efficiency	Sharing one air conditioner with several apartments
(22)	6	Managing product usage and EL	Managing energy use entirely on a house
(23)	11	Developing new service with knowledge	Advicing on energy saving in a house
(24)	13	Timesharing of products	Renting a room
	14	Change revenue stream	
(25)	16	Utilizing knowledge or technology in other fields	Selling the evaluation system for energy efficiency of buildings

Table 4 : Generated core concept in STEP 5

No	idea	Modified Idea
A	(2) (3) (12) (14)	Rental of air conditioners. Repair and re-use of air conditioner or reusable parts (e.g. magnets in the motor).
B	(3)(14)	Selling rented air conditioners as used products
C	(6) (8) (10)	Managing operation and selection of air conditioner by visualizing energy use. (e.g. Cooling down in the morning contribute peak shaving)
D	(11)	Selling the facility to dry laundry by the warm air exhausted from the air-conditioner outdoor unit in the veranda.
E	(13)	Sharing a big air conditioner between neighborhoods.

5) STEP 5 Combining ideas

The design team selects a couple of novel ideas and combines these with other ideas in order to create core concepts of upcoming eco-business.

In the case, five core concepts of eco-business were generated as shown in Table 4. For example, Idea B, 'Selling rented air conditioners as used products' was generated by combining '(3)Selling as a used product' and '(14)Rental of air conditioners'.

6) STEP 6 (Primary evaluation)

In this step, the design team evaluates the core concepts of upcoming eco-business ideas generated in STEP 5.

In the workshop, Idea C, 'Managing the operation and selection of air conditioners by visualizing energy use', was revised through the discussion in the evaluation, and was added the idea 'earning financial supports from an electric power provider by offering a peak time usage reduction'.

As a result, revised Idea C was scored the highest in evaluation (see Table 5).

Table 5 : Results of evaluation in STEP6

			Modified Idea No.				
			A	B	C	D	E
Contribution of the creation business value	Attraction	Market scale	3	4	6	2	3
		Incremental	4	5	9	2	4
		Risk	8	8	6	8	6
		Competitive pow er	3	5	8	4	4
		Reconstruction of the trade	2	4	7	1	4
		Other advantage	4	4	8	4	4
		Max 60	24	30	44	21	25
	Suitability	Funding capability	8	8	5	10	7
		Marketing pow er	4	4	7	8	5
		Manufacturing pow er	10	10	10	10	9
		Technological strength	8	8	6	10	7
		Raw material procuring pow er	10	6	6	10	8
		Management support pow er	3	5	3	5	3
		Max 60	43	41	37	53	39
	Sum	Max 120	67	71	81	74	64
Environmental consideration		0 : Deterioration 10 : No change 20 : Improvement a little 30 : Improvement	20	20	30	15	10

4.3 Discussions

We evaluate this methodology through the workshop from the perspectives of 1) time efficiency, 2) novelty of ideas, and 3) effectiveness.

1) Time efficiency

In the workshop, we generated 25 ideas. We then created 5 core concepts based on these ideas, along with their evaluation, in a period of 4 hours. By directing the flow of the discussion, it was acknowledged that the participants were able to stay focused and productive in a short period of time. On the other hand, the process of structuring the needs (STEP 2), was pointed out to be low in time efficiency, because we just selected proper needs and business (STEP 3) in spite of taking a lot of time for structuring the needs.

2) Novelty of ideas

Participants pointed out that the 18 rules were effective for generating ideas. But they also pointed out that just proper existing business applied to 18 rules, 'Production & sales of air conditioners' and 'Construction & sales of houses', were described in STEP 3 and undermined the novelty of ideas.

3) Effectiveness

Several rules were not applied in STEP 4 in the workshop; they are '2. Introduction of lower environmental loads process,' '9. Receiving contracts for environmental loads,' '10. Combining various business value,' '12. Making environmental loads visible,' '17. Financial support or charge from other stakeholders.' Rule 12 and 17, among the rules not applied in STEP 4, were used in combining ideas (STEP 5). And other rules were supposed to have been applied, because several other ideas 'to use natural energy in the factory' related rule 2 and 'to sell the function of air conditioning' related rule 10 are conceivable.

Regarding the effectiveness of this methodology, participants pointed out improving the interface and the difficulty of evaluating environmental consciousness and business feasibility.

5 SUMMARY

This study is derived from investigation of existing eco-business and proposing a methodology for supporting of generation of new eco-business ideas. Through the workshop to generate eco-business ideas by using this methodology, we verified the feasibility, especially in generating eco-business ideas by 18 rules, combining with other ideas and evaluating it from three perspectives, such as market attractiveness, company's suitability, and environmental consciousness.

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Greening the Design Brief

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Abstract

Front End Innovation is a hot research topic, but there is still little research done in its relationship to design for sustainability. This paper explores the challenges of integrating environmental sustainability in this early stages of an innovation process and the design brief. The study is based on a content analysis of 35 design briefs from Belgian SMEs and multinationals, and a focus group with representatives from 14 Belgian companies. This study assumes a limited uptake of sustainability in Belgian design briefs. Furthermore, it argues that the use of certain strategies, such as front-loading, pushing sustainability upstream in the briefing process and sustainability opportunity identification in the front end, could help in greening the design brief.

Keywords:

Design Brief, Sustainable product innovation, Front End Innovation, New Product Development

1 INTRODUCTION

With an overpopulated planet, hungry for electricity and resources, sustainability will be one of the biggest challenges in the future. The challenges and opportunities for sustainable innovation are immense. And the time horizon is shrinking. Companies can play an important role in the transition process towards a sustainable and smarter world with an improved quality of life. Such a transition will likely require powerful new business models, with a rich playground for visionary ideas, products and services. Sustainability can be the ultimate fuel for long-term growth. Progress towards this goal will requires a multidisciplinary approach; political, social, economic and technical solutions must work in symbiosis to obtain sustainable development.

Staying competitive in an uncertain world is quite a challenging task. Companies must seek new ways of looking at products. The choices they make for which products to develop, and which targets to set for their sustainability performance will have a significant effect on the successfulness of our transition to a more sustainable world. The saying “don’t bring a sword to a gunfight” illustrates the problem of selling old products and services in a new world [1]. As the economist Joseph Schumpeter (1883-1950) put it, ‘innovation is a process of creative destruction’[2]. It both creates and destroys.

The very early phase in the innovation process, the so called front end of innovation, is often described as being the root of success for any company hoping to compete on the basis of innovation [3]. It is the phase with the largest impact on the end result of the project [3] [4] and the highest payback to one’s investments [4]. It is in this phase that businesses determine which development projects to start and which targets to set for those projects. The outcome of that process is reflected in the design brief. The decisions made in the design brief influences all the subsequent phases of the innovation process. It is a common sense that one can significantly improve products sustainability by focusing on sustainability already in the front end. This paper argues that sustainable design projects would be far more effective if commencing from an environmentally responsible brief, providing guidance to the design, engineering, marketing and management team.

Notwithstanding the logic behind integrating sustainability in the early stages of an innovation process and the design brief, in practice it is flawed. Front End Innovation is a hot research topic, but there is still little research done in its relationship to design for sustainability. There are a number of tools available to guide designers, engineers and managers in the design process after the specifications of the product or service are already set, but methods supporting goal finding for sustainable innovations are rare [6]. There is still little understanding on how to best bring environmental considerations into the design brief. Little guidance is given in literature how to effectively translate a sustainable commitment into project proposals that are both sustainable and make business sense [1].

The research in this paper aims at gaining understanding on how a design brief is established in the early stages of an innovation process and how environmental sustainability is integrated. The first part elaborates what is meant by a design brief, and how it is integrated in the early stages of an innovation process. The second part looks to the current practice of integrating environmental considerations in a design brief. Different research results are described and discussed in order to identify successful patterns for further research.

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2 LITERATURE REVIEW

2.1 The Design Brief

In the past, briefing had been dominated by a highly mechanistic view of the design process, it seemed, that a good brief could turn design into something close to painting-by-numbers [7]. But the landscape changed. Today, every designer knows there is a intimate connection between briefing and design. Defining a design brief has become an integral part of the design process.

A design brief is a written description of a project that requires some form of design. It is an agreement, or contract between the parties involved in the project. Often times, it is also a point of transfer between different professionals, where the project is handed over from marketing to design, or from a product manager to an external design agency. It is also a road map and project-tracking tool, that defines the various steps that will be followed [8]. The role of a design brief is to provide the foundation to the entire design process in the shape of a functional document that can efficiently capture the information of a final product's attributes [9].

Ultimately briefing is the capture of knowledge of the user and the client, the expert, and the design and management team. Successful briefing is about clear and comprehensive communication and how information is structured [7]. It is important that the brief contains all the information and data necessary for every stakeholder in the process [8].

Previous research, based on data collected from major electronics multinationals in Japan and South Korea, has identified the use of environmental checkpoints, reviews, milestones and roadmaps as a most important success factor regarding the integration of sustainability considerations in the early stages of the product development process [10]. The design brief can play an important role in achieving this.

The focus of this paper is 'Industrial Design Briefs', briefs for the design of a new industrial product or a product-service system. Design is a broad term, with a variety of design disciplines (e.g. industrial design, package design, communication design). Each discipline requires different information in a truly useful design brief [8].

It should also be mentioned that design assignments are not always called 'design briefs'. There is a lot of diversification of terminology among literature and practice. People use a variety of terms, they also refer to them as new product development brief, creative brief, project brief, project sheet, innovation brief, or marketing brief [11] [8] [7].

Essential Elements of the Design Brief

When it comes to design briefs, there is no magic formula. If design is a problem-solving discipline, then design must start with a thorough understanding of the problem to be solved, which is best found in a design brief [8]. A single one-size-fits-all design brief format does not exist, but there are some key ingredients that any good design brief should contain. Kim Zarney [12] compares design briefing to stir-fry cooking, a rapid process that works best when you have all your ingredients ready before beginning to cook. It's helpful to start a design process with the information the design team really needs. Phillips [8] describes 8 essential elements of a design brief: (1) project overview and background, (2) category review, (3) target audience review, (4) company portfolio, (5) business objectives and design strategy, (6) project scope, timeline and budget, (7) research questions, (8) appendix. The '*project overview and background*' serves as an executive summary of the project, it clearly articulate the scope, the business needs, objectives, desired outcomes and ownership of the project in terms non-design business partners can understand. It contains all the essential information: what, why and who of the project. The '*category review*' refers to the industry in which the product or service is involved. Designers need to understand their audience before beginning the design process. This part is represented in the '*target audience review*'. The company and its activities is described as completely as possible in the '*company portfolio*' chapter. The section '*business objectives and design strategy*' provides a clear understanding of how design strategy is matched to business objectives. Time and budget requirements in every phase of the project are presented under the chapter '*project scope, timeline and budget*' in order to complete the project successfully. During the discussions with the design brief team, it is quite likely that a number of questions that are critical to the success of the design project remain unanswered. One can find these questions under the second last chapter. The '*appendix*' is an optional section and might contain documents that summarize research data, competitive analyses and visual material.

Insights

Doing a sustainable design project would be far more successful when starting from discussing and identifying sustainability opportunities in every chapter of the design brief. More research is needed how to best bring environmental sustainability in every section of a design brief.

2.2 Front End Innovation and the Design Brief

The innovation process may be divided into three areas: the front end, the new product development process, and commercialization [4]. The end result of the front-end area should be a written brief that links the creative objectives with the business objectives [12] [13].

Formulating a design brief in the front end of an innovation process is a creative, iterative and interactive process and is best developed in partnership [8]. Ultimately briefing does not progress linearly, the development shifts and jumps back and forth between different departments in a company and the design team.

Figure 10 shows the relationship between influence, cost of change, and available information during the innovation process. At the front end, the degree of freedom and influence on the project outcome is high, while little information is available and the cost of changes are low. At later points in the process one has more information available, but now the cost of change has increased.

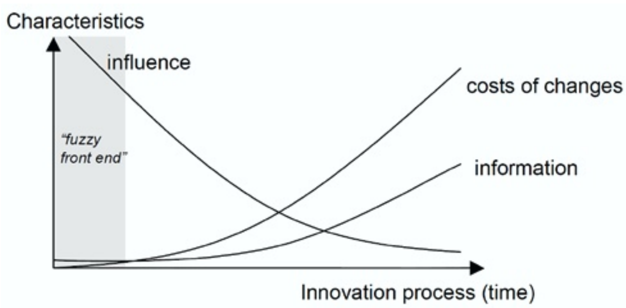

Fig. 1: Influence, cost of change, and available information during the innovation process ([15])

It is at this early stage and under this circumstances that the design brief is defined. Also quality, costs, and timings are mostly set during the front end [15]. Important decisions are made here, and will follow the product trough the project. Formulating a design brief has a lot to do with decision making in uncertain conditions and dealing with so called 'wicked elements'. One strategy to deal with this is 'front-loading', where one attempts to shift the information curve to the left. Front-loading is defined as "a strategy that seeks to improve development performance by shifting the identification and solving of problems to earlier phases of a product development process" [16]. By spending more energy in the front phase on analysis and strategic design one get more information while the influence is high and the cost of change low.

3 RESEARCH DESIGN AND QUESTIONS

The research in this paper aims at gaining understanding on how a design brief is established in the early stages of an innovation process and how environmental sustainability is integrated in the design brief and the front end. Based on the insights from literature and previous explorative studies [1] , [17] three main research questions has been formulated in order to address the research objective: Do companies take environmental parameters into consideration in their design briefs, and if so, how? And where is the focus placed? What are the drivers and barriers for companies for integrating environmental sustainability in the design brief?

To understand this phenomenon and the relationships between key elements, two exploratory studies has been conducted with a focus on Belgium SMEs and multinationals at varies industries.

In study 1, a focus group session was organized with representatives from 14 Belgium SMEs and multinationals in May 2011. Because relatively little research has been conducted regarding environmental parameters in a design brief, a qualitative approach has been chosen to get insights in themes and patterns which are relevant.

In study 2, a content analysis of 35 industrial design briefs from 35 Belgium based companies was used as research methodology.

Figure 2 [18] shows the different levels of knowledge using different research techniques. Talking to people provides insights in knowledge and thinking that is explicit to these people. This research technique was used in study 1. What people do can be observed. This was done in study 2 by looking at the design brief and the design brief process.

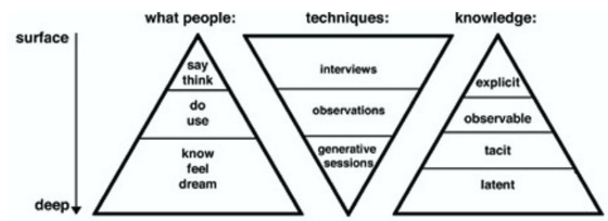

Fig. 2: Different research techniques access different levels of knowledge [18]

The grounded theory has been chosen as underlying strategy both for research and analyzing data.

4 RESEARCH

4.1 Focus Group

Research Background & Methodology

In order to get more insights in the drivers and barriers for integrating environmental sustainability in the design brief, a 3h focus group session was organized with representatives from 14 Belgium SMEs and multinationals in May 2011. All participants were members of VOKA, Flanders' Chamber of Commerce and Industry, and VOKA's Learning Network on Product Development and Design. All persons volunteered on the focus group after a call for participation sent by VOKA. Background of the participants ranged between senior management, project management, R&D, product design and engineering.

During the first part (1.5h) of the session a presentation was given on sustainable product innovation with a special focus on the design brief and integrating environmental considerations in the early stages of an innovation process.

The second part of the session (1.5h) was organized as a interactive group setting where participants were divided in teams of 4 to share their experiences and insights in integrating sustainability in the early stages of a design process and the design brief. Each team could make notes and schemes on big sheets of paper in order to visualize their thoughts to the other team members. Findings were summarized and presented plenary to the whole focus group at the end.

The second part of the focus group session was recorded with notes and partly with audio.

Analysis and results

The session and final presentation was transcribed chronologically by use of sentences, key words and statements. The relevant parts of the sheets of paper were analyzed and summarized.

Two general outcomes could be defined out of this focus group session. Firstly, integrating sustainability in a design brief is for many people a matter of 'want' and/or 'need'. Either you want to do it because you see opportunities (market demand, cost reduction, product differentiation, marketing), or you need to do it because it is required (legislation, retailer demands). 'What are the risks of this activity and what will be the return?' is a question often heard. Answering this question is not obvious, due to the characteristics of the front end phase as explained in Figure 1. Trying to have a clear view on this topics in the very early design brief stage (cfr Front-loading in chapter 2.2) can give a real boost to the integration of environmental sustainability in a design brief.

Secondly, there is a huge difference between a 'request for proposal', a strategic brief and the real design brief.

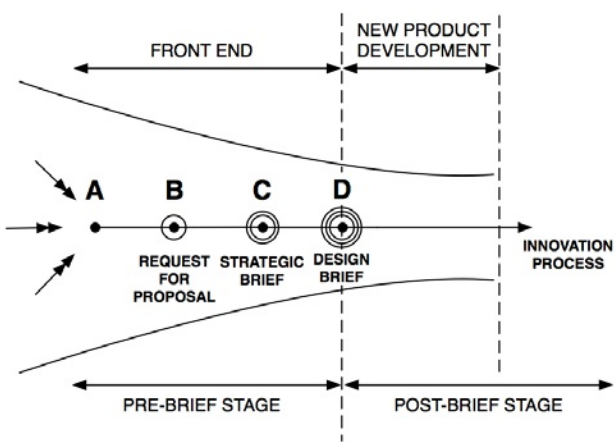

Fig. 3: The various stages of a design brief in an innovation process

The briefing process starts when someone in the company defines a business objective or need. This 'need' (A) can be a 'gut' feeling based on previous experience, a recommendation from a client or user, or a result of research. The need will be translated in a document, the '*request for proposal' (B)*, sometimes also called 'statement of need'. This document contains some basic information and goes to the management level in the organization where the team can decide whether it is worth pursuing, mostly decided after conducting a feasibility study. When the projects gets a 'go', the request for proposal will be upgraded into a '*strategic brief' (C)*. This document is usually created for the in-house design team or for an external design agency. The '*design brief*' (D) is developed and written in the next stage, in co-creation with the design group after considerable thought and discussion about the project. Figure 3 shows the various stages of a design brief at the front end of an innovation process. The different elements of the diagram does not represent actual time frames.

Pushing environmental sustainability upstream in this briefing process will result in a higher success rate on integrating sustainability into the design brief.

4.2 Analysis of 35 Design Briefs

Research Background & Methodology

A design brief is a crucial communication document between the client organization and a design agency, and usually provides a good insight into the level of environmental sustainability a company wants for the future product. But do companies take environmental parameters into consideration in their design briefs, and if so, how? And where is the focus placed?

To answer this question a content analysis of 35 industrial design briefs from 35 Belgium based companies was used as research methodology. Among those companies, 25 are categorized as small and medium-sized enterprises (SMEs), while the other 10 are classified as multinationals. Divers sectors and industries are covered, varying from the electric and electronic industry, lighting, furniture, medical equipment, building, engineering, technology and plastic industry.

All the described design assignments are performed by the design team of the Industrial Design Center Howest (IDC Howest) in Kortrijk, Belgium, a knowledge and research center specialized in Industrial Design Engineering. IDC Howest offers several design services for the industry, working in close collaboration with the master's program Industrial Design Engineering at Howest University. The level of innovation proposed in the design briefs varies from average to high. Projects with a low innovation level, such as product upgrades or incremental innovation design projects, are not accepted by IDC Howest due to a strict mission statement. The 35 design briefs are random selected among the total design assignments performed in the period between 2009 and 2011 by IDC Howest.

The IDC Howest standard design brief template contains 7 chapters, including project overview, objectives, quality requirements, policies on intellectual property, budget, design methodology and timing. There is no section devoted to the environmental impact of the product, environmental requirements can only be noted under the quality requirements section by answering a yes or no question.

In most cases, the client organization firstly contacts IDC Howest with a request for proposal or strategic brief. This document becomes a design brief after reviewing and discussing the problems and needs with both parties. Various meetings are preceded before the two parties sign the design brief. All projects studied in this case have one project owner from the company itself and one project leader from the IDC design team, each with specific tasks. Both are responsible for completing all the relevant sections of the design brief format.

The classification of the Life Cycle Design Strategies is utilized during the content analysis of the design briefs, as shown in Table 1.

Table 1: Life cycle design strategies

Lifecycle Design Strategies			
Product Level		Strategy	Substrategy
Product Concept Level	0	New Concept Development	Dematerialisation
			Shared use of the product
			Integrations of functions
			Functional optimisation of product
Product Component Level	1	Selection of low Impact materials	Cleaner materials
			Renewable materials
			Lower energy content materials
			Recycled materials
			Recyclable materials
	2	Reduction of materials usage	Reduction of weight
			Reduction in (transport) volume
Product Structure Level	3	Optimization of production techniques	Alternative production techniques
			Fewer production steps
			Lower/cleaner energy consumption
			Less production waste
			Fewer /cleaner production consumables
	4	Optimization of distribution system	Less / cleaner / reusable packaging
			Energy-efficient transport mode
			Energy-efficient logistics
	5	Reduction of Impact during use	Lower energy consumption
			Cleaner energy source
			Fewer consumables needed
			No waste of energy / consumables
Product System Level	6	Optimization of initial lifetime	Reliability and durability
			Easier maintenance and repair
			Modular product structure
			Classic Design
			Stronger product-user relation
	7	Optimazition of end-of-life system	Reuse of product
			Remanufacturing / Refurbishing
			Recycling of materials
			Safer incineration

The Lifecycle Design Strategies Wheel or LiDS Wheel, also called EcoDesign Strategy Wheel [19] presents eight EcoDesign strategies: new concept development (0), selection of low-impact (1), reduction of materials usage (2), optimization of production techniques (3), optimization of distribution system (4), reduction of impact during use (5), optimization of initial lifetime (6), and optimization of end-of-life system (7). Strategy 1 to 7 represent the product life cycle. Strategy 0 is either 'strategic', working on the product concept level, while strategy 1 and 2 relates to the product component level, strategy 4, 5 and 6 to the product structure level and strategy 6 and 7 tot the product system level. All life cycle design strategies are divided in multiple sub-strategies. Every design brief is systematically scored on each dimension of the Strategy Wheel. Also the way how strategies are handled, is indicated as being quantitatively or qualitatively. No distinction is made in the analysis between projects that are initiated with the intention of doing something sustainable vs. projects without a specific sustainability focus.

Limitations of the content analysis

It should be mentioned that the used methodology, design brief content analysis, has some limitations which are important to acknowledge when interpreting the results.

A design brief says nothing about the sustainability of the final product, as earlier research already showed. Petala et al. [11] concludes in the Unilever case study report on 'The role of new product development briefs in implementing sustainability' that the incorporation of sustainability in the new product development briefs not guarantee results. Several organizational issues could function either as success or failure factors for the entire process. The opposite is also possible, projects where environmental sustainability was not a fundamental concern in the design brief can turn out in environmental friendly products or services when new insights are obtained during the innovation process.

Secondly, the chosen methodology does not provide deep insights in push and pull mechanisms regarding sustainability, that can show up in meetings and discussions with the project team prior to the design brief. Also the influence of the project leader(s) or other design team members on the final outcome of the design brief remains unclear.

Results and findings

An overview of the results of the content analysis is shown in Fig. 4 and 5.

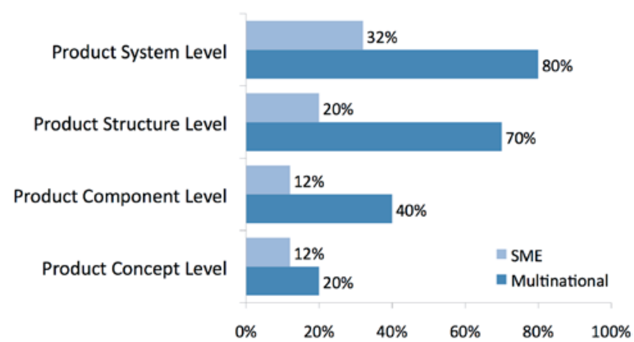

Fig. 4: Environmental profile of the design briefs on product level

Figure 4 gives an insight in the environmental profile of the design briefs on the different product levels. Figure 6 gives presents the most frequently used strategies in the design briefs. A distinction is made between SMEs and multinationals, demonstrated in the two bars.

The strategies 'optimization of initial lifetime' and 'reduction of impact during use' are most commonly found in the overall design briefs. While the most popular sub-strategy is 'reliability and durability' followed by 'modular product structure', 'lower energy consumption' and 'cleaner / recyclable materials'.

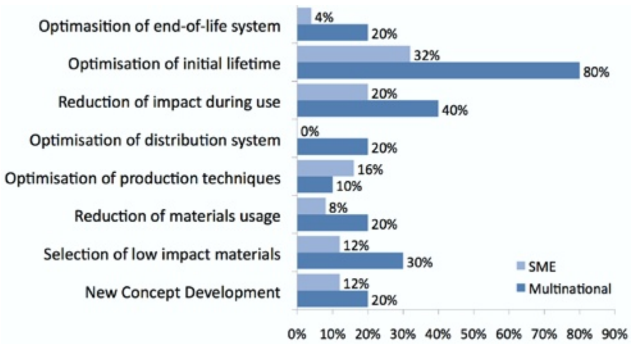

Fig. 5: Environmental profile of the design briefs on strategy level

This study shows that the uptake of environmental considerations into design briefs is still very limited in the analyzed briefs. In 14 SME design briefs there was no uptake at all. The findings indicates that multinationals more frequently integrate environmental considerations into the design brief comparing to SMEs. Quantitative environmental targets were absent in all the design briefs. This appear to be related to the innovation level. Defining quantitative environmental targets in the early stage of an innovation project appears to be very difficult for innovation projects with an average or high innovation level.

5 CONCLUSIONS

This study assumes a limited uptake of environmental sustainability in Belgian design briefs. Due to the limited number of research entities, and the fact that all participating companies where Belgian, no general conclusions could be made. The main conclusions on how to best 'green' the design brief can be summarized as follow: Firstly, using the front-loading strategy in the early stages of an innovation process can give a real boost to the integration of environmental sustainability in a design brief. It will brightening up sustainability opportunities (market demand, cost reduction, product differentiation, marketing) and requirements (legislation, retailer demands). Secondly, doing a sustainable design project would be far more successful when starting from discussing and identifying sustainability opportunities in every chapter of the design brief with the project team. More research is needed how to best bring environmental sustainability in every section of a design brief. Thirdly, pushing environmental sustainability upstream in the briefing process, starting with the request for proposal over the strategic brief to the design brief, will result in a higher success rate on integrating sustainability into the design brief.

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Creating the New Brand Equity through EcoDesign of Cosmetics

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Abstract

Taking measures for environmental conservation is one of the CSR-related activities that is becoming more significant as environmental awareness grows. Especially in the cosmetic industry, which benefits from natural substances, each firm is pursuing its unique environmental conservation programs under the umbrella of Green Action. Recently, it has become possible to see Green Action that is directly linked to the cosmetics, in other words, EcoDesign of cosmetics. In this context, through the analysis of several cases, this paper aims to examine how Green Action as a CSR is influencing cosmetic brand equity.

Keywords:

cosmetics, green action, EcoDesign, sustainability, brand equity

1 INTRODUCTION

In recent years, many companies around large ones are putting their efforts into Corporate Social Responsibility, and its concept has multiple aspects that vary as times change.

According to Kagata, the concept of CSR was born in the 1920s, when, in the US, the large modern companies arose and their social impacts started to become significant. Since then, the scope of the issue expanded, and *Mécénat* and philanthropy began under the concept of the Good Cooperate Citizen. In recent years, as globalization has advanced, Sustainable Development, which encompasses a variety of issues—such as the environment, the North and South problem, poverty, unemployment, and race relations—has arisen as a problem[1].

Following this tide, cosmetic companies have come to engage in many CSR activities: the Avon Foundation for Women started in 1955[2], Estée Lauder's Breast Cancer Awareness Campaign, started in 1992[3], and the L'ORÉAL Group's L'Oréal-UNESCO Awards for Women in Science, started in 1998[4].

Since global warming and the destruction of nature are currently discussed widely, emphasis has shifted to "conservation of the environment." For cosmetic companies, which customarily offer new products every season, the standard Stock Keeping Unit (SKU) is around 1,000[5], but they must be consumed or dumped after a few months; moreover, natural ingredients are necessary for their products. Against the background of this trend, traditional brands have pursued new technology and have also made new developments recently. It could be said "Green Action directly linking to products."

Based on my twenty years' experience in the cosmetic industry, this study discusses how Green Action relates to brand equity, considering the difference the Green Action of the three companies from the traditional CSR.

2 METHODS

This paper focuses on three leading companies in the cosmetic industry: CHANEL, GUERLAIN, and L'ORÉAL Group.

Based on the experience of one of the authors as a beauty editor, we selected information concerning Green Action from press releases about cosmetic products. This study, therfore, clarifies the main points of the activities of each company. Since press conferences are held only for the media, the documents distributed there are as a rule closed. Some companies publish them on their official website; the three companies we address here never do so. This study, then, analyzes documents that cannot be obtained by the public.

3 CASE STUDIES

3.1 CHANEL

CHANEL has a close relationship with plants; it created fragrance "N°5" in 1921 and has its own fields for jasmine and Rose de Mai in Grasse, in the South of France. When they produced Sublimage Essential Revitalizing Concentrate in 2010, they distributed to the media a public booklet about their approach to conservation of nature. Having observed the cosmetic industry for twenty years as a beauty editor, we believe this was the first time they mentioned their engagement in the conservation of nature. According to the booklet *FROM GRASSE TO THE HIMALAYAS…*, CHANEL "started to walk on the road toconservation of nature" when they developed Sublimage (Fig.1) in 2006, now their first-class skin-care series.

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Fig. 1 CHANEL/Sublimage
(source: CHANEL press release)

Sublimage is a skin-care series compounded with an active ingredient extracted from vanilla planifolia of Madagascar by an original process. As they used golden champa grown in the Himalayas for the Sublimage Essential Revitalizing Concentrate, launched in 2010, the company entered into a partnership with LSTM (Ladakh Society for Traditional Medicines), an NGO there, and began a new project to protect natural resources and traditional knowledge by constructing a network for communication among the Amchi and supporting women and children in the whole area.

Furthermore, at the press conference for Sublimage la Crème in 2011, they mentioned the establishment of "Shader, a special plant which recreates the most appropriate environment for cultivation of vanilla planifolia."

As the booklet argues, "we cannot say that we take the environment into consideration without taking all things concerning the natural environment into consideration and thinking of their future.[6]" The CSR activity, which CHANEL finally exhibits, is a large-scale conservation effort that aims to protect not only nature but also the people who should protect it.

From my experience as a beauty editor, I understand that, at the press conferences for new skin-care products, the company tends to strongly emphasize the innovativeness of the materials and technology, and their effects on the skin. This applied at the press conference for the first product of the series in 2006. Meanwhile, however, they had launched the project. After it became firmly established, they announced it in their press release, and they placed the special content on the website to inform the public about it. These facts indicate that, for CHANEL, Green Action is an important brand strategy today.

3.2 GUERLAIN

Fig. 2 GUERLAIN/Orchidée Impériale
(source: GUERLAIN press release)

Orchidée Impériale (Fig. 2) is a first-class skin-care series of GUERLAIN that extracts its essence from the orchid, a flower associated with long life, and compounds the original active ingredient. When releasing its Cream in 2006, they started an unprecedented project: establishing their own research platform, called the Orchidarium.

The aim of this platform is to analyze and illuminate the vital energies of the orchid. Under the direction of GUERLAIN's institute, it consists of three complementary research centers: the Agrobiology Center, an experimental garden near the border between France and Switzerland; the Phytochemistry Center, an institution for basic study at the University of Strasbourg in France; and the Biodiversity Center, a natural conservation area for research in Yunnan in China. Each center has a specific mission, and specialists for each field pursue that mission. From this platform, they succeed in both the protection and harvest of orchids, operating a program for natural conservation based on the Rainforestation Jungle Farming System; they secure a stable supply of active ingredients extracted from the orchid, and then activate the economy around this area by sharing the profit[7].

Fig. 3 GUERLAIN/Abeille Royale
(source: GUERLAIN press release)

In addition to Orchidalium, GUERLAIN established the Abeille Royale Research Platform when it produced a new skin-care series in 2010, Abeille Royale (Fig. 3), whose chief ingredient comes from honey.

GUERLAIN uses the honey of the black bee, which lives only on Ouessant Island in France, as the chief ingredient for Abeille Royale. The reason for their use of this honey is that, since the island has a good natural environment, there are 30 districts for apiculture, and they are able to gather honey of the highest purity. Through researchers from outside, GUERLAIN continues to conduct research on the island on the bee and ingredients that stem from honey. In addition, backing up the activity of L'Association Conservatoire de l'Abeille Noire Bretonne (ACANB), they save the supply route of the material by conserving the black bee and supporting honey production on Ouessant Island[8].

After the establishment of these two platforms, the style of GUERLAIN's press conference concerning the two series changed. At the conferences for both series, the managers of the skin-care products started by explaining the platform before the products. About half of the conference was devoted to the presentation of this platform, and they showed video letters from agriculturists and professors of pharmacy. thus, they evidenced their pride: Other companies have not started such advanced activities.

GUERLAIN is a brand that has produced various products of fragrance, make-up, and skin-care in the course of its history of over 180 years, spurred by a policy of innovation. It is assumed that Green Action has recently become one of its brand policies.

3.3 L'ORÉAL Group

The L'ORÉAL Group is a cosmetics company established by a chemist, Eugène Schueller, in Paris in 1909 that now has 31 brands in 100 countries and regions. As mentioned previously, they support a variety of activities concerning CSR, and in 2009, their centennial anniversary, they announced they had launched 100 new social causes[9].

They have also begun to engage in CSR through the development of Pro-Xylane, a new anti-aging molecule produced in 2007. It was revolutionary in the development of ingredients in that it was the first time the L'ORÉAL Group adopted Green Chemistry, an eco-friendly synthesis process. They explain this process as follows:

> The chief material of this revolutionary ingredient is natural Xylose, a sustainable material, which is extracted from the beech commonly seen in West Europe. Only two steps of chemical synthesis are required to produce Pro-Xylane; we use less energy and produce less waste. Also, Pro-Xylane is biodegradable, not persistent, bioaccumulative and toxic chemicals. In brief, Pro-Xylane meets the strict standard for Green Chemistry whose aim is natural conservation[10].

Fig. 4 Footprint of LR 2412

(source: LANCÔME Visionnaire press release)

Beginning with the development of Pro-Xylane, the L'ORÉAL Group has continued to develop ingredients based on the concept of Green Chemistry. Their next one is Bio-Cellulose, a natural non-synthetic organic material that is generated by fermentation of bacteria[11]. L'ORÉAL applies this material to a sheet mask.

Furthermore, in August 2011, they introduced the new ingredient LR2412, developed after a research process of 20 years. LR2412 is also produced by Green Chemistry called "Hydrogénèse in one-pot." The press release specified the percentage of molecule use (77%) and synthetic yield (98%), in addition to various footprints (Fig.4)[12].

Another interesting point of the Green Chemistry initiative within the L'ORÉAL Group is the fact that all the three ingredients were first introduced through LANCÔME (Fig.5).

Fig. 5 LANCÔME/from left, Absolue βx Beauty Essence (Pro-Xylane), Génifique Mask (Bio-Cellulose), Visionnaire Serum (LR 2412)

(source: LANCÔME official website)

NIHON L'ORÉAL is currently developing eighteen brands categorized in four business groups: Consumer Products, Professional Products, Luxury Products, and Active Cosmetics. Instead of other brands, the company chose LANCÔME which belongs to Luxury Products to start its green initiative that will then be expanded to other brands.

As for the latest LR2412, the company gave priority to LANCÔME, and its expansion to other brands is not scheduled at the moment.

This leads us to ask, Why LANCÔME? The reason seems to be related to the fact that the brand was the L'ORÉAL Group's first luxury brand. When L'ORÉAL corporatized LANCÔME, this brand, which was founded in 1935, had already been developed globally as a total luxury brand of French elegance. The acquisition of LANCÔME served as a stepping stone to luxury strategies for the group. Thus, the importance of the brand was huge, and cannot be overstressed. Pierre Yves Arzel, then CEO of NIHON L'ORÉAL, spoke about his brand strategy in an interview with the fashion magazine *Marie Claire Japan*[13]*,* for which one of the authors worked as senior beauty editor.

> We are not interested in merely growing the company. However, it is important to develop continuously. Thus, we consider carefully which brand to invest in and how to produce and grow it. In so doing so, we enable the company and brands to complement each other and engage in a win-win relationship.

He also said,

> We must never develop all brands at the same place by the same people. If you want to become a top brand, you will need to provide the perfect products and special experiences. The brand should be desired by consumers and provide exclusive experiences that they cannot have with any other brand.

The company has chosen to introduce this new eco-conscious ingredient, which is based on the newest science and technology, through luxury products instead of starting with brands that have a group name or take medical approaches. This case study demonstrates the deep relationship between contemporary Green Action and the brand equity.

4 FINDINGS

In this research, we analyzed the latest case studies of three companies, including CHANEL, GUERLAIN, and L'ORÉAL GROUP. Table 1 below summarizes the characteristics of each brand.

Previously, the social responsibility of big global companies has been realized through individual rights protection, personal information protection, disclosure, and social activities under the form of *Mécénat* or philanthropic activities. However, the case studies discussed earlier prove that CSR, as "Green Action directly linking to products," has become more concrete since the twenty-first century began.

Table 1 Key points of Green Action in three companies

Company	Brand/ Product	Key Ingredient	Action
CHANEL	Sublimage	Vanilla Planifolia of Madagascar	・Establishment of "Shader" ・Partnership with native people
		Golden Champa of Himalayas	・A new project to protect natural resources and traditional knowledge in the whole area ・Partnership with LSTM
GUERLAIN	Orchidée Impériale	Orchid	Establishment of Orchidarium
	Abeille Royale	Honey of the black bee on Ouessant Island	Establishment of Abeille Royale Research Platform
L'OREAL GROUP	LANCÔME／Absolue	Pro-Xylane	Green Chemistry
	LANCÔME／Génêfique Mask	Bio-Cellulose	Green Chemistry
	LANCÔME／Visionnaire	LR2412	Green Chemistry "Hydrogenèse in one-pot"

5 DISCUSSION

We could identify two commonalities among the three case studies: (1) directly linking to products and (2) managed systematically and globally. Table 2 below shows corrélation between these two elements.

Focused on the correlation between the elements "directly linking to products" and "managed systematically and globally," the activities of the three companies will be categorized as belonging to the (A) group in table 2. The (B) group includes traditional CSR activities, such as *Mécénat* or philanthropy, while the (C) designation indicates cases in which CSR is based on the use of natural and fair trade ingredients, known as "organic cosmetics."

Table 2 Factors of Green Action

	Managed systematically and globally	
Directly linking to products	(A) ○／○	(C) ○／×
	(B) ×／○	(D) ×／×

Such Green Action efforts as seen in three companies are globally managed and not limited to mere use of organic or fair-trade ingredients in order to secure a comprehensive return in production regions from the long-term standpoint.

The long-term standpoint seeks ecological and social environment sustainability. It also promises, at the same time, brand sustainability.

6 LIMITATIONS

This study argued that "Green Action directly linking to the product, and managed globally and systematically" is an important element for today's cosmetic brands equity. In the future, we must examine cases of the other cosmetic brands, in particular, the cases of Organic Cosmetics that are increasing rapidly nowadays. There are two points to address in this consideration.

First, the cosmetics called Natural Cosmetics, Ethical Cosmetics, and Organic Cosmetics, which have become popular in the last 10 years, are not produced through sufficient Green Action. These cosmetics are often displayed as Eco-friendly Cosmetics in stores. However, as a beauty editor, I have observed that these companies do not adhere to a global standard for certification of Organic products and that each has its own standards. Moreover, I observe that, even though many products that do not have certification are compounded with organic materials, the percentages of the composition is unclear or the management of materials—actually, the OEM deals with this—is insufficient.

Second, among the cosmetic companies producing Organic Cosmetics, WELEDA, for example, has followed a brand philosophy of symbiosis between nature and society since its establishment in 1921. By making comparisons with such companies, furthermore, we can clarify the luxury strategy of the cosmetic companies in terms of Green Action.

7 MANAGERIAL IMPLICATIONS

Through analyzing the cases of these three companies, this study proves that "Green Action directly linking to the product, and being "managed globally and systematically" are important elements of the luxury strategy for today's cosmetic companies. This conclusion may also apply to other industries, such as food, drink, and furniture.

Through "Green Action directly linking to products," consumers can directly or indirectly contribute to society by purchasing certain products. In addition, it enables the brands and consumers to share in the project's Green Action. This fact must serve to make these brands favorable and reliable for consumers.

As *Marketing Management* (2006) says, "One conception of holistic marketing views it as 'integrating the value exploration, value création, and value delivery activities with the purpose of building long-term, mutually satisfying relationships and co-prosperity among key stage holders.' According to this view, holistic marketers succeed by managing a superior value chain that delivers a high level of product quality, service, and speed. Holistic marketers achieve profitable growth by expanding Customer share, building Customer loyalty, and capturing Customer lifetime value.[14]" That is to say, Green Action as seen in three companies is now an important factor that should be added to a holistic marketing framework.

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A Culture without Trash: The Strategy of Green Design Development in Museum Exhibitions

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Abstract

Exhibition is the bridge between a museum and its audiences, as well as the most energy and material consuming project with short life-cycle amongst all the other museum functions. In Taiwan, cultural performances can be divided into thirteen categories such as visual art, craft, design and drama that being conducted around fifty thousand times a year. The materials that used in these performances, whether they are recyclable or non-recyclable, become one of the sources causing environmental pollution and energy consumption after the dazzling shows. Therefore, instead of preserving human cultural heritages and promoting educations, a museum should also devote to environmental protection as one of its social responsibilities, as cultures can only be inherited and developed with our earth unharmed.

The aim of this study is to propose the idea of 'green museum' by applying green design as the exhibition strategy in practicing environmental protection. Observational survey and in-depth interview are used as the methodology to reflect the current situation of the exhibition projects amongst the national cultural and historical museums in Taiwan, in terms of environmental protection issues. There are ten experts being interviewed in this study, including the researchers and curators in the museums, exhibition designers and scholars of green design who, have had their expert working experiences for at least fifteen years.

The results of this research are:

1. The museum exhibition designs in Taiwan are still focusing on the dimensions of content interpretation, object preservation, aesthetic presentation and budget evaluation, whilst environmental protection is rarely being considered and practised.
2. Even though most of the museums have not taken further actions on environmental protection, they still agreed the necessity of introducing the idea of green design to exhibitions, and willing to practice in the future.

This study also suggests that, only through the joint development of environmental protection industry, policy making, and identification to environmental care of both museum researchers and audiences, green design exhibitions of museums in Taiwan would possibly be falling into place.

Keywords:

Museum, exhibition, green design

1 INTRODUCTION

According to the cultural statistics in Taiwan, there are around fifty thousand performances being showed a year under the thirteen cultural performance categories, including exhibitions. When the exhibitions come to the end, the materials, paints and cements left from the dazzling decorations then all become large refuse in both quantity and size, whether they are recyclable or not. The materials of the exhibition decoration come from forests, mines or fields (natural or artificial). After the exhibitions are finished, the left materials not only take space to store, sometimes they will also interact with the surroundings, release toxic chemicals and flux to the earth or water; sometimes even during the process of recycling would also release harmful substances into the air, soil and water we use every day, and consume even more energy.

Serious damages and pollutions in our environment has been revealed from all kinds of phenomena and statistics, which results in growing severeness of environmental backlash that forces all walks of life start to aware the importance of our environment, including museums.

The main functions of a museum include collection, research, exhibition, education, entertainment and service; in which exhibition is the bridge between a museum and its audiences, as well as the most energy and material consuming project with short life-cycle amongst all the other museum functions.

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In the process of museum exhibition design by far, it has showed a general shortage of green application, as well as the database of the life cycle assessments (LCA) for materials in the making process of exhibition. However, the trend of museum future is believed to be as environmental protection-oriented. In the past, the trend of museum development has been leaded to the orientation of relic conservation and audience service; but in response to recent international issues of environmental protection, international museum organizations have also started to take these issues as part of their social responsibilities.

The main objective of this research is to promote the idea of green museum, which is to apply green design as the museum exhibition strategy to practice environmental protection, and so to reach a sustainable development of culture.

This study takes in-depth interview as the main methodology to analyze the process of exhibition project, and the status of environmental protection issues in a national history/cultural museum in Taiwan. Aiming to such status and process in museum exhibition, a progressive environmental protection strategy is also proposed in this study.

2 LTERATURE REVIEW

2.1 Sustainable development and green design

On 5th June 1972, the United Nations held the 12-days 'Conference on the Human Environment' (also known as the Stockholm Conference) in Sweden. As the first international conference amongst different States, it discussed contemporary environmental problems and strategies, and also announced the famous 'Declaration on the Human Environment' that invoking all the governments and peoples to protect and improve our environment for present and futures generations. 5th June also became the 'World Environment Day' (WED).

In 1987, UN's 'World Commission on Environment and Development' (WCED) pronounced a report on sustainable development, which defines sustainable development as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' that received a common agreement amongst different States. With the international supports to the report, it then being published and titled as 'Our Common Future'.

In June 1992, the 'UN Conference on the Environment and Development' (UNCED, also known as the Earth Summit) adopted the 'Agenda 21' as the global environmental protection programme. This environmental action plan has 40 chapters that covers social, educational, scientific and economic fields, including: combating poverty, protecting and promoting human health, protecting atmosphere, conserving biodiversity, taking environmental and developing issues into the process of decision making, managing toxic chemicals, hazardous and radioactive wastes, strengthening the fair development of women and, the role of indigenous people and local communities, and promoting education and training.

In order to reiterate the importance of the environmental conferences held in 1972 and 1992, the 'World Summit on Sustainable Development' (WSSD, or Erath Summit 2002) was then convened in South Africa in 2002, gathered 104 leaders of States and 17,000 representatives from 192 countries. This conference reviewed and discussed issues such as human development and environmental protection promises and protocols, and focused on the themes of biodiversity, agriculture, energy consumption, water, environmental and public health.

As a gesture of supporting the Earth Summit 1992, the Executive Yuan in Taiwan established the 'Working Committee on Global Environmental Change Policy' in 1994, and later further expanded the committee as the 'National Council for Sustainable Development' (NCSD) in 1997, dedicated to sustainable development policy making, environmental protection and ecology conservation.

'Sustainable development' includes three principles: fairness, sustainability and commonality. **Socially**, it advocates equitable distribution to meet the needs of the present and future generation; **economically**, it advocates a continuous economic system on the basis of preserving the natural system; **ecologically**, it advocates a harmony relationship between human and nature.

For pursuing a sustainable development of the living environment of human, a green revolution is being taken amongst all the fields; applications such as green architecture, green product and green exhibition are expanding toward to a more diversified development.

The trend of green design lies in the use of natural and economical material, multipurpose and recyclable product design. This trend echoes to what Victor Papanek wrote in the *Design for the Real World*, emphasising the problems that designers now truly facing are ethical values and the concern for communities. For him, the very function of designing is not to create commercial values, nor competing the novelty of style and boxing with other companies, but an element in leading an adequate social revolution; it is even more about paying attention to the problem of energy using, and serve for our environment. There were only few can understand what he was trying to express when this book was first being published, however, ever since the energy crisis broke out in the seventies, his thesis about the limited resources was then being recognised and valued, and green design has also become one of the contemporary interests.

Studies of green design have proposed ideas with more and more Rs after the first theory of 3R (Reduce, Reuse, Recycle) was brought up. Based on the theory of 3R, ideas such as redesign, remanufacture, reorganise, rethink and re-repair have been practiced as part of green design to reach the aim of sustainable development. For instance, Burall (1994) sees the green design of products lies in the 4R (reduction, reuse, recycling, regeneration), then Brewer (1994) further combines the 4R with the principle of KISS (keep it simple & stupid) to avoid complicate design with less material and package.

The core idea of green design is taking the environment and pollution protection into the process of product design. Aiming at environmental performance, it strives to minimise the negative influences of the product towards environment; not only to reduce the consumption of material and energy, and the emission of hazardous substances, but also to efficiently recycle and reuse every parts of the product. These concepts of green design, 4R and KISS will be the foundation of discussing the environmental strategy of the design of museum exhibition in the following text.

2.2 Theories and practices of green design in museum exhibition

In the aspect of practising, museums take environmental protection mainly in economise the use of energy and material, and reuse the display cabinets. However, in the aspect of research, although studies of museum exhibition almost covered all kinds of topics, such as the nature of exhibition (e.g. construction, function and connotation), the connection with other museums, exhibition and the social system, exhibition and knowledge (culture), and exhibition case study (Wang, 2007), there are only few researches discussed the development strategy of exhibition design in regard to green exhibition, instead of the reusability of exhibition facilities and toxicity test of materials.

In 1993, Kathleen McLean proposed some ways and thoughts such as reduce the amount of materials, design sustainable, recyclable and repairable items, and educate the people with green exhibitions for museum green design in her published book *Planning For People In Museum Exhibition*. Although these ideas were only mentioned in the appendix, showing that environmental issues are still not the focus of museum studies, it still revealed that museums are starting to pay attention to such issues.

Further, the American Institute for Conservation (AIC), which has been the vital academic institution in promoting relic conservation and education in the field of museum and cultural heritage since it was established in 1972, has also founded the Green Task Force in 2008, evaluating the awareness of conservation, and promoting and planning the sustainable development of museum management and cultural heritage conservation within the U.S.. The Green Task Force also did a global survey in regard to the continuity of sustainable development amongst different institutions in 2009, revealing environmental protection is being more and more valued in the field of museum study.

The Green Task Force of AIC is the indication of practising environmental protection in museums, suggesting that in addition to dedicating in conserving the cultural heritages of human, museums should also take more responsibilities in protecting the environment for our only future.

3 METHODOLOGY

3.1 Research approaches

This study takes the ideas of 4R and KISS from Burall and Brewer, discusses the environmental protection strategies of museum exhibition design.

3.2 Research methods

This study is an exploratory research. In order to deepen the quality of the research questions, this study takes the semi-structural interviews (focused interviews) as the main methodology. Interview questions are listed beforehand, but discussions are opened during the interview in accordance with the backgrounds of different expert interviewees to explore as many aspects as possible.

Interview questions in this study including: how the interviewees observe the museum exhibition design in Taiwan, the dilemmas during the practice of exhibition design, and factors that obstruct the practice of green design. The development strategies of green exhibition proposed in the following text are based on the conclusion of the above questions.

3.3 Interviewees

The pattern of the execution of museum exhibition projects can be varied according to the structure of the institutions, including total outsourcing, partial outsourcing and in-house. The process of exhibition project can be divided into periods of formation, content research, concept design, basic design, detailed design and construction. Though the focal point in different stages of the project would vary, a project can only be completed with the cooperation from all members of the exhibition team. An exhibition team usually includes: decision maker (or funder), curator, subject researcher, relic conservation expert, exhibition designer and exhibition producer.

Henceforth, the interview subjects in this study include five expert fields: curating, relic conservation, exhibition design (including green design), production and supervision. There are three experts being interviewed in each field, fifteen effective samples in total.

3.4 Analytical methods

The interview content is recoded with verbatim script, which then being edited and categorised according to the messages in the content, and induced into conclusions.

4 RESEARCH ANALYSIS

4.1 Exhibition design and its levels of priority

In Taiwan, museum exhibition projects are affected by factors such as topic, funding resources, budget, preparation and exhibition period schedule, spatial scale and human capitals. Most of the cases value the aspects more on the topic interpretation, relic conservation and aesthetic presentation, seldom see environmental protection as a factor that needs to be concerned. A curating team combines different experts in different areas, including the curator (overall planning and set the main theme), designer (spatial, graphic and multimedia design) and executive producer, some teams would even invite philosophers to involve with the project.

From studying the five stages of formation, concept design, basic design, detailed design and construction of an exhibition project, this research has shown the following facts: different aspects would be taken seriously at different stages, or even different experts. However, the degree of importance of the content correctness, relics safeness and construction quality stays the same; secondly comes to aesthetics, and finally some would think about the problem of environmental protection, but most of the time it is never the point of concern.

4.2 The practice of green exhibition design

Material reuse

Popular materials in an exhibition include paper, metal, wood, electronic devices, acrylic, glass, paint and adhesives; in landscaping it usually uses fiberglass materials. In most of the cases, stock materials and devices will be evaluated first, to see whether they fit the requirements of reuse.

It is common to see display cabinets and electronic devices being reused; protective non-acid materials would also be reused as much as possible for its pricy status; other dismantle materials usually will be sorted and abandoned by the contract unit.

Energy saving

In order to attract audiences, it is popular amongst museums to use interactive multimedia devices. Power loading data of the devices will be calculated during the process of designing, but it is for the purpose of avoiding excess the power load, not for environmental protection. Only a few exhibition designs would use timing devices and dynamic light sensors as the strategy for energy saving.

Environmental protection materials

It is true that the museum curating teams do not have sufficient knowledge in environmental protection materials; some might even think these materials must cost more because they are ‘not that popular’.

By far, the most frequent environmental protection materials that being used and showed are low-toxic paints and adhesives; it is because these products have been well developed and certified by the national authorities.

The development of the application of green design

Dismantable and modular display boards are also very common to see during the design process of museum exhibition, but it is not entirely for the purpose of environmental protection; rather, it is for enhancing the efficacy of exhibition facilities with limited budget. Nevertheless, because of the molded forms, apparent divisions and poor visual effects, these boards usually will only be used in short-term or touring exhibitions.

Also, internet marketing is now a popular approach of promotion.

4.3 Summary

To sum up, museum curating teams in Taiwan are commonly short of the awareness, motive and activity of environmental protection, and insufficient in the assessment and research of the replaceability of environmental protection building materials. Meanwhile, factors such as the scarce of environmental protection development, limitations of the administrative rules and purchase law in the public sector, and the lack of governmental rewards and punishments would also influence the development of museum green exhibition.

5 CONCLUSION AND SUGGESTION

The difference between the ‘green exhibition design’ and ‘traditional exhibition design’ is that, green design applies the environmental protection ideas of 4R and KISS during the process of concept design. Comparing to the traditional exhibition design, it lays more emphasis on the principles of fairness, sustainability and commonality of sustainable development.

This study has also found that in the views of the experts, to practice green exhibition in Taiwan, it needs to start from improving the awareness, material and techniques, and policies of environmental protection of both the public and government.

5.1 Promote the museum recognition to environmental protection

The development of museum is deeply influenced by the social ideologies and critical issues. Comparing to the trends of the cultural relic conservation, exhibition interpretation, audience learning, cultural tourism and entertainment, such a global recognition of environmental protection would definitely becomes the focus of museums in the future.

To promote museum green exhibition projects, it has to start from establishing the determination and recognition of environmental protection at all the parts of museum budget, decision makers, executive teams and audiences.

The experts that being interviewed in this study have all showed the expectations of promoting the green exhibition projects; but with the fact of limited budget and immature material knowledge in Taiwan, it seems still having a long way to go.

5.2 Watch and learn: Establish the exhibition database of green materials

In addition to establishing the recognition and determination of environmental protection, museums need more actions than saying. Since museum specialties do not familiar with green design and industry, the construction of green materials and their lifecycle database would be the front burner for museum green exhibition. Further, museums can cooperate with material manufacturers to produce efficient green materials to obtain the balance between the ecological and economical demands.

Although the manufacture and architecture industries of green design have been developed for a long time, referable study for museums yet stays rather rare. This study suggests future researches to develop interdisciplinary green approaches such as module and dismantable design, green mould, energy saving and recycling applications to museum exhibitions.

5.3 Develop museum exhibitions from green ideas

A mature green exhibition needs to take environment and the ideas of 4R/6R into consideration from the very step of idea design in the stage of exhibition formation, to every processes of production and remove.

5.4 Set up a platform for exchanging exhibition materials

Sale or exchange exhibition facilities not only can enhance the chances of reusing the exhibition facilities, lighten the problem of exhibition disposals, but also can gain some cash reward for the next exhibition project.

5.5 Promote environmental protection regulations and evaluations with both reward and punishment approaches

The international museum exhibition evaluation by far is still audience-learning oriented. To promote green museums, it has to be guided by the official evaluation indicators, and museums will therefore be rewarded or punished by the results of evaluation in accordance with legal regulations.

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The Role of Business Sector to Achieve Sustainable Society -The Example of a Restaurant Company-

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Abstract

The importance of the role that the business sector plays in achieving sustainable society, and their need to make environmentally conscious decision, becomes recognized in these days. For business organizations to make environmentally conscious decision and action, it seems to be important to have the clear and strong vision of the president, and to set measurable long-term environmental objectives. This paper introduces the example of Aleph Inc., a Japanese restaurant company, while focusing on its business philosophy and measures taken for reducing three types of food wastes; kitchen garbage from restaurants, kitchen waste from factory, and used edible oil from household.

Keywords:

business sector, corporate social responsibility, restaurant, food waste, compost, biogas, bio diesel fuel

1 INTRODUCTION

The importance of the role that the business sector plays in achieving sustainable society, and their need to make environmentally conscious decision, becomes recognized in these days. For example, the Business and Biodiversity Initiative launched at the 9th Conference of the Parties to the Convention on Biological Diversity (2008) aims to intensify the engagement of the private sector in achieving the objectives of the Convention. Similarly, Resolution X. 12 that was adopted in 10th Meeting of the Conference of the Parties (2008) to the Convention on Wetlands (Ramsar Convention) focuses on the role that business sector plays in achieving the conservation and wise use of wetlands, recognizing "that the business sector is not only part of environmental problems but can also be part of the solutions."

This paper introduces Aleph Inc., a Japanese restaurant company, and its challenge of environmental load reduction, especially waste reduction, as a material to think about the role that business sector plays in solving the environmental problem and in achieving sustainable society.

There are some "good" companies which are well-known for their excellent contribution to environmental protection and environmental load reduction. For business organizations to make environmentally conscious decision and action, it seems to be important to have the clear and strong vision of the president, and to set measurable long-term environmental objectives. In section 2,examples of "good" worldwide companies are introduced to show that they have clear commitment of the president and ambitious objectives of environmental load reduction.

Section 3 briefly introduces Aleph's coorperate profile, its business philosophy and its approach to environmental problem. Section 4 shows Aleph's three measures which have been taken for food waste reduction of restaurants, factory and society. Section 5 is the brief summary.

2 EXAMPLES OF "GOOD" COMPANIES

This chapter shows two examples of "good" companies. Attention is paid to their vision and long-term objectives.

2.1 Danone

Danone is the French manufacturing company famous for yoghurt and bottled water. Danone group takes an action for protecting water supply, supports Ramsar Convention on Wetlands, and raised the Danone Fund for Nature's offset initiatives, that contributes to restoring wetlands in Africa and India.

Danone's founder was aware of importance of social value for the company as early as 1970's. In 1972 Danone set the concept of "dual economic and social project", that is still valid today. Present CEO Franck Riboud says [1], "it is common to oppose the "social" and "economic" spheres, where social needs are perceived as a cost and therefore generally detrimental to a company's competitiveness. I see things differently. Take food and its contribution to health, which is at the core of Danone's mission. (…) Food companies like Danone should offer solutions that please consumers and respond to public health concerns in each country. (…) The same is true for the environment: reducing energy and raw materials consumption and developing clean technologies are good for the planet, and also for business."

In 2000 Danone set its ten-year objectives of reducing unit energy consumption by 20%, reducing unit water

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consumption by 30%, reducing unit packaging by 10% and recovery of waste by 80%. They were all achieved by 2008, Danone set its next ambitious goal of reducing its carbon footprint by 30% from 2008 to 2012.

2.2 Ricoh

Ricoh is the Japanese manufacturing company famous for copier, printer and multifunction peripheral (MFP). Ricoh is a signatory of the Leadership Declaration of Business and Biodiversity Initiative at COP9 of the Convention on Biological Diversity. Its Gotenba factory is the first site in Japan which acquired the certification of ISO 14001, and it achieved zero emission of waste in 2000.

Chairman Masamitsu Sakurai and President Shiro Kondo say [2], "We have long made protecting the environment central to all aspects of our business. That is because we believe that corporate growth can, and must, be compatible with social sustainability". Its sustainability concept "Comet Circle", established in 1994, presents its stance of reducing environmental impact of entire lifecycle.

Ricoh have set its ambitious objectives of reducing lifecycle carbon dioxide emissions by 30% by 2020, and by 87.5% by 2050 from the 2000 level. Ricoh also set its objectives of reducing new input of resources from 2007 by 25% by 2020, and by 87.5% by 2050.

3 ALEPH INC. PROFILE

3.1 Corporate profile

Aleph Inc. was established 1968 in Morioka city, Iwate. We manage about 300 restaurants all over Japan. The mainstay of our restaurant divisions is the hamburger steak restaurant chain "*Bikkuri Donkey*" (Fig. 1). We also operate 7 factories that process materials to supply through the restaurants.

Fig. 1: "*Bikkuri Donkey*" restaurant

3.2 Business philosophy

At the time of foundation, the founder Akio Shoji was deeply influenced by the spirit of the seminar named *Shogyokai* (Commercial World). It is the seminar for merchants. Many merchants from around the country have been taught how "true" business should be, for example, "Shops exist for the customer." "Think first whether it will

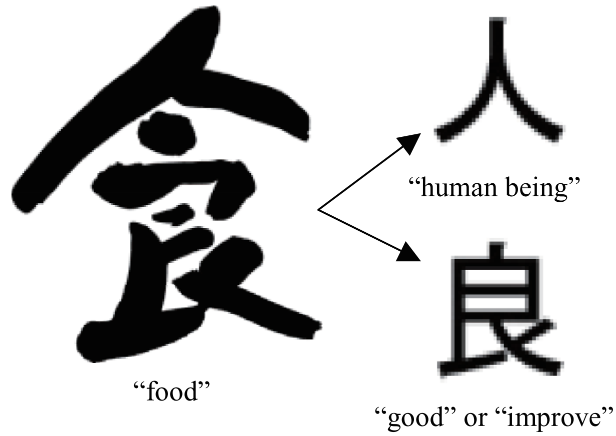

Fig. 2: Interpretation of Chinese charactor "food"

be right or wrong before thinking whether it will make loss or not." "The raison d'être of the company is solving the problem of society." Although they have been taught for over 50 years, they are similar to recent concept of corporate social responsibility.

At the restaurant branch of *Syogyokai*, Akio Shoji was taught as follows: Chinese character of "food" appears the meaning of "eating" and "cuisine". The character "food" consists of two Chinese character "human being" and "good or improve" (Fig. 2). We can interpret the meaning of character "Food" as "good effect for human being". So we've been taught that the food industry should make good effect for human being. Our business philosophy is based on the thought of this character.

3.3 Agricultural and environmental activities

Aiming to provide customers with high quality meals, we launched an experimental farm in 1988 and started to work on sustainable agriculture. Then we had made an effort to decrease chemicals in our procured materials. For example, we started "less agrichemical rice" project in 1996. This is Aleph's private-label rice. The rice is produced with only one application of herbicide, and no other chemicals, based on Aleph's strict specifications. Since April 2006 we have been able to serve our private-label rice in all *Bikkuri Donkey* restaurants.

The deeper we got into agriculture, the more keenly we felt the importance of nature as indispensable to our business. After starting the recycling of kitchen garbage from our restaurants in 1996, Aleph has taken a variety of environmental measures, including waste reduction, the saving of energy and resources, and biodiversity conservation through the merchandising of ingredients.

In 2003 the Aleph Environmental Action Plan was set. We have been challenging to environmental issues within set up targets. At first we set the policy and five targets ; reduction of energy consumption, reduction of water, reduction of waste, use of products with low envionmental load and enlightenment of employee. The targets are reviewed every three years. After we had signed the

Leadership Declaration of the Business and Biodiversity Inisiative in 2008, we added biodiversity conservation targets.

The founder Akio Shoji said in his last years, “Environmental problem causes a rises in cost in recent years.” “Measures against environmental problem is an investment in the future, and it is a hedge against risk of the exhaustion of resources or climate change.”

4 ALEPH’S FOOD WASTE REDUCTION

This chapter shows some examples of Aleph’s measures for reduction of food wastes. We are aiming to contribute to realization of sustainable society through recycling.

4.1 Kitchen garbage recycling system

Recycling of kitchen garbage from restaurants is Aleph’s first project to solve environmental problem. Kitchen garbage from one restaurant amounts to about 30 kg a day. It accounts for 40 to 50% of all restaurant waste. In 1996 Aleph set up kitchen garbage recycling project, and investigation of kitchen garbage recycling was conducted. Then in 1997 Aleph began to install kitchen garbage recycling system, which consists of two mutually related elements; installing of kitchen garbage recycling machines in restaurants and using treated garbage as organic resource for agriculture.

Fig. 3: Kitchen garbage recycling machine

Fig. 3 shows one of kitchen garbage recycling machine at *Bikkuri Donkey* restaurant shop. This machine carries out primary treatment of kitchen garbage on the spot. Kitchen garbage thrown into the machine is stirred by the rotating blades, dried by hot air, disintegrated by microbes and reduced to about one-fifth. 99 machines have been installed in directly managed restaurants. For some restaurants at which kitchen garbage recycling machine cannot be installed because of the lack of space, a waste disposal operator carries garbage to his own treatment plant and treats it.

From the beginning, we attached great importance to cooperation with farmers because it seemed significant for establishment of sustainability that treated garbage of good quality is properly returned to farmland and comes to

Fig. 4: Compost production at a cooperated farm

life again as agricultural products. Primarily treated kitchen garbage is taken out approximately every two month and carried to cooperated farms. It is mixed with cattle excrements or farm residuals, and they are fermented to become compost (Fig. 4). Treated kitchen garbage from our restaurants accelerates fermentation, because it contains rich microbes and nourishment. Among compost that is made in cooperated farms, some is used as fertilizer by cooperated farms, some is sold at home center and some is used as fertilizer at flower beds of *Bikkuri Donkey* restaurants. Some fertilizer is used for production of vegetables we procure for material of our restaurants. We have partly built the cycle which contains supply chain and in which kitchen garbage from restaurants returns to the restaurants as food or fertilizer.

4.2 Biogasification of factory waste

We also adopt another way of reducing and recycling of food waste, biogasification.

Hokkaido factory, that began to run 2007 in Eniwa city, produces hamburger putty and sauce for *Bikkuri Donkey* restaurants in Hokkaido district (Fig. 5). Kitchen garbage from the factory amounts to about 500 kg a day. This is carried to neighboring cooperated farm and thrown into biogas plant there with other kitchen garbage and cattle

Fig. 5: Hokkaido factory

Fig. 6: Biogas plant in cooperated farm

excrements. Fig. 6 shows the biogas plant. Biogas produced in this plant contains about 60% of methane. Then it is desulphurized, refined to gas of 90% methane. This refined gas is compressed, plugged into cylinders, carried to Hokkaido factory, and used as a fuel for boiler. We had usually used kerocene boiler or heavy oil boiler for sauce production in other factories. But at the time of design of Hokkaido factory, we set the CO2 emission target of the factory 50% lower than when it would be constructed in the former way, and decided to use biogas and wooden pellet as a fuel of boiler instead of fossil oil.

Through this system we have realized another cycle in which kitchen garbage from factory returns to the factory as fuel and we succeed in solving two environmental problems at the same time, reduction of waste and CO2 emission.

4.3 Collection and recycling of used edible oil

Last example shows Aleph's action to reduce food waste of society.

In 2006 Aleph began to collect used edible oil of household at some restaurants in Hokkaido. Any customer may bring their used edible oil to the neighboring restaurant, and the oil is exchanged for Eco Action Point of the Ministry of the Environment. The collected used oil is carried to Hokkaido factory and made into bio diesel fuel (BDF; methyl ester fuel) at the BDF plant of the factory.

BDF can be used instead of light oil. BDF made from Hokkaido factory is used for the fuel of trucks that deliver foods from factory to restaurants, tractors that are used in cooperated farm for agriculture, school buses in Eniwa city, and power generator that is used for outdoor concert.

We conduct educational program with some primary schools in Eniwa city (Fig. 7). Pupils go through seeding, harvesting and oil pressing of rapeseed, cook with rapeseed oil, and visit BDF plant with used rapeseed oil to study about recycling of edible oil. Then we also collect used oil through primary schools.

Used edible oil of household is usually abandoned as waste because of lack of recycling way, in contrast to used

Fig. 7: Educational program with primary school

oil for business use. The aim of this project is to reduce food waste of households by offering place for collection in a community, and to contribute to society by solving the environmental problem of the society. We have increased collection point up to 55 restaurants in Hokkaido and Kanto district. In recent years about 35,000 liters of used oil are collected a year.

4.4 Visions in the future

Aleph's recycling rate of kitchen garbage is now over 80%, due to recycling system mentioned so far. Our next objective is to raise recycling rate to 100% by 2020.

Another direction is to spread this recycling system on the restaurants that are managed by franchised company. Both effort of cost reduction and promotion of understanding of franchised company are necessary.

5 SUMMARY

This paper presented the business philosophy and measures of reducing food wastes of Aleph Inc., as a material to think about how private company can play a role in achieving sustainable society. In section 2 it was also presented that, companies that are paid high honor by the society for their environmentally conscious business activities, have clear vision of the president that business activities and sustainability of the society are inseparable from one another. For companies to make environmentally conscious decision and action, it seems to be crucial how they think about their raison d'être, that is, "For what does the company exist?"

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Product Standards for Multiple-Function Products in Product Policy

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Abstract

Emergence of multiple-function products (MFPs) poses a variety of challenges and risks for achieving sustainable consumption and production as well as fair consumer society and universal design. We overviewed MFPs from these viewpoints and then, focusing on product standard as a means to create mechanisms to reduce environmental loads from products, elucidated advantages and limitation of five approaches of standard-setting for MFPs. The five approches examined were (1) neglecting a multiple function, (2) individual presentation of every function, (3) integrated evaluation of functions, (4) segementation of products, and (5) use of frontier analysis.

Keywords: multi-functionality, product standards, frontier products

1 INTRODUCTION

Technology development, coupled with modern lifestyles, has triggered the emergence of multiple-function products (hereinafter referred to as "MFPs"; see ref [1] for a marketing view). Examples of MFPs include integrated TV/DVDs, personal computers that can display TV programs, and mobile phones with camera. Although such products can reduce material use by the degree of sharing parts by different functions, if consumers do not use a function, product integration causes unnecesary material consumption. Hence, development of MFPs needs careful consideration on sufficiency of environmental objectives.

Environmental product policy aims to reduce the lifecycle environmental impacts of products. One of the key instruments is product standards. As it is often stated, as much as 60-80 % of the life cycle environmental impacts of a product is influenced by the design choices. Environmental product standards are expected to guide more environmentally conscious design while reducing burdens of transaction and increasing compatibility, and in some cases leveling the playfield of business competition. However, complex MFPs pose many challenges to standard-setting.

We therefore looked at product standards of MFPs for promoting eco-design. There are two concerns about product standards: One is that standardization is an industry-driven process, which may limit access of governments and citizens, and the other is that how to set standards in a meaningful way [2]. This study focused on the latter. The structure of this study is as follows. First, we looked into different categories of MFPs and discussed their sustainability potentials and risks. Identifying risks would give us insight on what aspects need to be included in product standards for MFPs. Second, we reviewed the current state of product standard setting in several schemes in EU and Japan. The intention was to identify insufficiency of current approaches to standardization. Third, we categorized and examined approaches to take account of multiple functions of products in product standardization. Data regarding environmental performances and sales of TVs and air conditioners sold in Japan were used to obtain a deeper understading about advantages and limitations of the different approaches. Finally, we made some conclusions on the challenges in standard-setting for MFPs based on our investigation and analysis.

2 MULTIPLE-FUNCTION PRODUCTS FOR SUSTAINABLE CONSUMPTION AND PRODUCTION (SCP)

2.1 Types of multiple-function products (MFPs)

In this study, we preliminarily proposed and used the term "multiple-function products (MFPs)" for the following three combinations of functions: two-or-more conventional functions (referred to as "multiple conventional-function products (MCPs)"; e.g. cooling/heating function of air conditioners), conventional and advanced functions (referred to as "advanced products (APs)"; e.g., higher definition of TVs), and conventional and combined functions (referred to as "Combined products (CPs)"; e.g., TV/DVD). Further, we can distinguish two types of product functions: output functions and intermediate functions. The former refers to functions that users can use directly while the latter refers to functions that serve for another function and users do not use directly (e.g., power supply). "Functions" mentioned above are all output functions. As the concept of PSS (product service system) shows, functions can be served by replacing sales of products with that of services, but this was left out of the scope of this study.

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2.2 MFPs and Sustainability of MFPs

MFPs have potentials to contribute positively to achieving SCP in several ways, for instance:

- Raising utility of the use of products (e.g., convenience for advanced products, no need to own and/or carry two-or-more products for combined products).
- Dematerialization (for combined products).
- Cost reductions for both producers and consumers, especially consumers (The marginal cost of adding a new function is relatively small; see [1]).

However, there are also potential problems:

- Decrease in user-friendliness and utility as the number of function exceeds a certain level (Ref [3] expressed this kind of status, "feature fatigue"). As a result, consumers do not use a new function.
- Increase in difficulty in product choice.
- More complex product design process.
- A risk of increased consumption (e.g., product cycles may become shorter).
- Duplicated possession of a certain function, which results in increased resource use (for combined products; e.g., camera function of a digital camera and a mobile phone).
- Possible promotion of the symbolic values of products (i.e., a new combination of functions attracts consumers and increase consumption).

Thus, the environmental potential of MFPs can be difficult to realize.

The use of MFPs may cause the following phenomena, which could affect above-mentioned advantages and/or problems:

- Cascade use of multiple functions (e.g., consumers keep hold a product for the use of a non-main function and it may extend product life span. A study discussed cascade use of multiple function systems theoretically [4].)

Table 1 summarized several points, which would link to setting environmental product standards, distinguishing the three MFPs. Among the abovementioned points, frequency of the use and duplication of functions would relatively affect the amount of environmental loads. Due to the so-called feature fatigue, some consumers do not use an advanced and combined function (e.g., some consumers do not like texting on mobile phone and others do not take photos with them). If a consumer owns many combined products, the consumer would have duplicated functions. This is not the case or not significant for advanced products because advanced functions come with a core function. There is a limitation in the number of the same type of products a consumer owns. However, consumers may use combined products longer for the cascade use as pointed out above. For example, some consumers finish using a mobile phone as a phone and start to use it as an alarm clock instead. This extends the life span of products. Little data is available on the use of advanced and combined products which can be used to determine a method of measuring, for instance, their electricity consumption. The reasons are that consumers have not established specific ways of using them and it is rather difficult to find the user of these functions. .

Table 1 Main characteristics of three categories of multiple-function products (MFPs)

	MCP	AP	CP
Frequency of the use of the functions	Relatively high	Can be low	Can be low
Duplication of functions	Low	Low	Potentially high
Possibility of cascade use of the product	No	No	Yes
Data availability of the utility and frequency of the use of the functions	Yes	Very low (Too new)	Very low (Too new)

3 REVIEW OF PRODUCT STANDARDS FOR MULITIPLE-FUNCTION PRODUCTS

Regarding voluntary standards for assisting eco-design measures, there are examples of standards that promote multi-functional thinking during the design process. IEC 62430 is probably the most striking example. For instance, in the list of examples of possible considerations in the design and development process, it states in the context of eco-design: "*Functionality; considering opportunities for multiple functions, modularity, automated control and optimization; comparing the environmental performance to that of products tailored for specific use;*" (B.4, a), p.27) [5]

A guide to the Japanese top runner program explains its outline, concepts, standard-setting, etc. [6] Among ten principles of the top runner program, principles 2 to 7 are about standard-setting. Principle 4 refers to MFPs and states, in essence, that additional functions are, in principle, not considered when setting differentiated targets. Principle 4 clearly states that the program excludes combined functions. However, this rule does not apply when setting an energy efficiency target for a product would create a situation where there is a high likelihood that products with the additional function withdraw from the market due to their failure of meeting the targets, although the needs for the products with the function are large.

"Eco-Mark" is the so-called ISO Type I eco-labeling scheme in Japan. Although most of the products with Eco-Mark criteria are single function products, at least two products covered by the Eco-Mark are MFPs: a printer and a copy machine. The award criteria for a printer is set for MFPs and that of copy machine is set for both single function products that can expand their function and MFPs. Neither of the criteria document state that combination of different functions itself is a condition of awarding certification.

The Eco-Mark applies differentiated standards taking multi-functionality into account. For instance, the level of standard for energy consumption is different between a single-function printer and a multiple-function printer (e.g, those with a copy/scanner/facsimile function) and that of MFPs seems to be lenient.

Green procurement schemes also involve setting of standards to indicate what constitutes green products when a government or other actors purchase products or services. The Green Procurement Law in Japan (Act No.100 of 2000, relevant ordinances, etc.) puts forward standards [7] that national government and governmental institutes on national level follow. It covers various goods and services. Regarding printers and copy machines, the same approach as Eco-Mark is taken.

As for other MFPs, we found two examples of different views on multi-functionality in the Japanese Green Procurement. One was mobile phone. A article of a standard stated that any one of the following conditions must be met: (a) equipped components and functions are simplified, (b) application software is upgradable without replacing the product itself, and (c) product design considers parts reuse or material recycling,…. We can interpret that the article (a) regarded that multi-functionality of mobile phones was not environmental preferable. The other was heated toilet seats. The article of the standard set a criterion for its electricity consumption. The seat-heating function is an advance (side) function, which is not necessarily required for the use of toilet but provides better comfort. In this case, the side function itself seemed to be accepted even though it would increase the energy demand: instead, how to reduce energy consumption of the side function by increasing efficiency was considered. The main difference between these two cases is consideration of necessity of functions in product standards.

4 FIVE DIFFERENT APPROACHES TO ADDRESS MULTI-FUNCTIONALITY

The next question concerns possible approaches to take into account multiple functions of products. The first approach is to neglect multiple functions and focus on the main function. For instance, a standard method to measure energy consumption of TVs in Japan states that BS (Broadcast Satellite) antenna and additional functions (except for EPG (Electronic Program Guide) function) are turned off if possible. The approach is simple and has the advantage of being easy to apply. However, it does not reflect actual product performances and raises questions regarding consumer protection, accountability of producers, and product liability. Furthermore, it will not prevent development and addition of energy-consuming functions.

The second approach is to present each product performance of all functions while leaving the judgment on product superiority to consumers. For instance, performances of cooling and heating functions of air conditioners are presented separately. This approach utilizes market mechanisms without determining details of standards. According to the degree of supports in a market, i.e., sales of products in the market, producers put importance on developing the technology of the function. This approach has the advantage that it is easy to set and implement standards, and holds producers accountable for the performance of their products. However, a premise of this approach is that consumers can understand and judge such product information. As discussed earlier, multi-functionality increases difficulty in selecting products.

The third approach is to integrate environmental performances of different functions into a single value. An example is APF (Annual Performance Factor) of air conditioners used in Japan (The same idea is applied in other counties, too). APF is defined as the sum of cooling/heating capacity (kW) in a year over the sum of electricity consumption for cooling/heating (kW) in the same year. It can be seen as an indicator integrating two energy performances with hours of using each function. This approach does not have the above-mentioned shortcomings, i.e. the difficulty of understanding and judging performances. However, agreeing and revising standards are difficult and tends to be time consuming . Moreover, this approach neglects the various uses of products. For a case of air conditioners, some consumers do not use the cooling function at all and others use only cooling function. Information about the integrated performances of MFPs is meaningless for these consumers.

While these three approaches focus on a boundary of product performances to be considered, two other approaches focus on product groups. The fourth approach is to segment products based on one or a few functions/specifications and set different product standard for each product segment. This approach is being employed in the Japanese Top Runner Program. It sets different electricity consumption standards for based on the size, on types of screen such as CRT (Cathode Ray Tube) and LCD (Liquid Crystal Display)/PDP (Plasma Display Panel), and other additional functions (e.g. video function). Basically, this approach employs a relatively easy methodology and promotes more environmentally preferable products within the same product segment. Application of this approach is useful when seeking to reduce environmental impacts from respective product segments without compromising diversity of products in markets and fair market competition.

The number of segmentation for TVs and air conditioners in Japanese top runner program is, however, large. Currently 20 product segments are used for CRT TVs, 64 for LCD/PDP TVs, and 13 for air conditioners for household use. It is questionable whether or not appropriateness of segmentation is retained for such many segments. In addition, many segmentations could lower understandability. Examining what are the criteria for appropriate segmentation of product categories remains as a future task.

What is more important is that this approach has negative potentials for letting environmental loads increase. This approach cannot prevent and stop an inappropriate shift of product selection toward a product category with a lower environmental performance. Despite the improvement of energy performance of products in respective product segments, the approach may fail to reduce total environmental loads [8].

The fifth approach possibly applied is the use of frontier analysis. DEA (data envelopment analysis) is a methodology to identify efficient performers (e.g., companies; referred to as DMU (Decision Making Unit) in DEA) taking multiple inputs and outputs of the performers into account and supposing frontier of performances. For instance, which of the companies with two different performances of (6, 10) and (10, 6) is more efficient? In DEA, both are on a frontier, which is the line between the two coordinates and the best performers. How about a company of (7,7)? The frontier line crosses at (8,8) and the company is not on the frontier. Thus it is not regarded as a frontier company (see Charnes et al. (1978)[9], Coelli et al. (2005)[10], etc. for the details of the methodology). DEA has been used for identifying and benchmarking MFPs, e.g. printers (Doyle,1991 [11]), cars (lo Storto, 1997 [11]), and smart phones (Mustafa and Peaw, 2005 [13]). Features of this approach are that it can identify frontier products unlike the first and second approaches, and that it can reduces arbitrariness of methodologies, which has been seen as to the fourth approach as arbitrariness of segmentation. The difference from the third approach is that while the third approach determines a fix weighting factor for different product performances, this fifth approach does not determine any weighting factors and allows every performers to use most advantageous weighting factor to them. Consequently, this approach can identify of frontier products based on larger number of criteria compared to those identified by the third approach without losing scientific objectivity. Although this approach has not been applied in the product standard process yet, it could complement the four other approaches. In the next section we performed DEA for MFPs to find out its pros and cons in addition to simple statistical analysis.

5 THE CASE

5.1 Data and method

We chose TVs and air conditioners sold in Japan as a case for analysis. We collected POS (Point-of-Sales) data in Japan from fiscal years (FY) of 2008 to the middle of FY2010 (Fiscal year starts in April in Japan), which is provided by GfK Marketing Services Japan. The data contained information on a number of product performances and sales. In 2009, the POS data covered a large percentage of industry statistics on domestic shipment (75% for TVs, and 55% for air conditioners). To make comparisons between different years, we used data for the first half of the Japanese fiscal year (April to September).

DEA was applied on condition that scale assumption was CRS (Constant Returns to Scale). Input-oriented, multi-stage or two-stage model was used. Functional performances were used as output parameters and environmental performances were used as input parameters (some parameters were binary, 0 or 1; 1 means a product has the function). Average products price was used as input parameters only for TVs (The reason was that the number of parameters for air conditioners was large and that for TVs was, on the contrary, very small). For performing DEA, we used DEAP ver. 2.1 [14].

5.2 Results of TVs

It was difficult to find out the trend of environmental performances without distinguishing different sizes of TVs. We firstly focused on a size of TVs, 26-inch TVs. The trends of 26-inch flat-panel TVs for three parameters (electricity consumption, product weight, and average price) were decreasing from 2008 to 2010. According to an interview with a person of a producer, three factors would be contributing the reduction of the weight of LCD TVs. One was that main circuit board became smaller as the circuit was integrated. Second was that lamps used as back light were replaced with LED. Third was that the internal components, frames and covers became lighter and required strength of materials and material use were subsequently reduced.

DEA was applied to 26-inch TVs for each year between 2008 and 2010 with annual electricity consumption, product weight (as a proxy indicator for material resource use), and average product price as input parameters. There was no output parameter, so output parameter was set as one as a dummy parameter. Among 114 TVs (for which all parameters for DEA were available), 15 TVs were identified as frontier products as shown in Fig. 1. The frontier of environmental performances of TVs had been shifting toward less environmental loads. It is difficult to identify what products are frontier products especially when the number of product performances considered is more than two. DEA can provide us such results on scientific, objective bases utilizing linearity and convexity.

Subsequently, we analyzed all sizes of TVs adding a parameter of video function for the data of 2010. The size was a troublesome product parameter for DEA. DEA is based on parameter linearity, and therefore the size cannot be used as a parameter of DEA. Hence, we standardized parameters by dividing them by the size. The size of TVs is one dimension. However, it is more natural to consider that the energy consumption and the weight of TVs is proportional to two or three dimensions (area or volume).

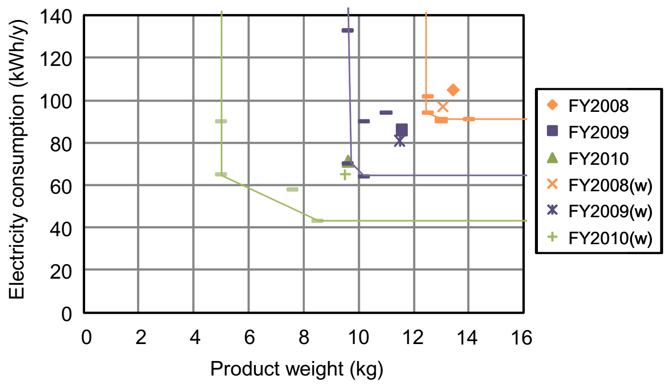

Fig. 1: Frontier lines of 26-inch flat-panel TVs sold in 2008 to 2010 in Japan. (plots: frontier TVs; w: weighted mean of all TVs by sales in number)

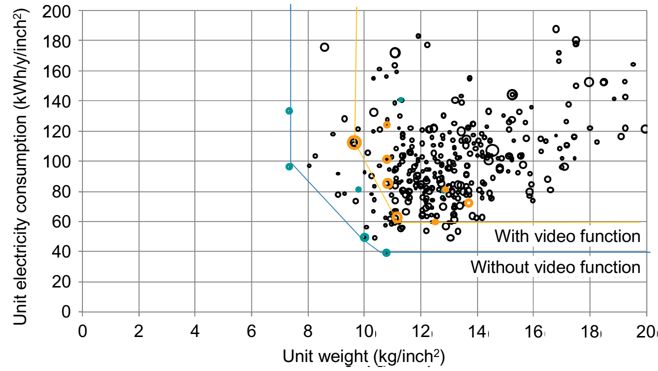

Fig. 2: Frontier products of flat-panel TVs sold in 2010 in Japan, identified by DEA.

Comparing these relationships between each three input parameter of TVs and the size, the square of the size, or the cube of the size, the best parameter, the square, was thus used for standardization.

DEA showed 15 frontier products among 493 TVs as shown in Table 2. Compared TVs with and without video function, frontier TVs with video function showed inferior environmental performances (In Fig. 2, upper-right area). It is natural that addition of function requires some parts and subsequently the product weight increases. But why did it also apply in the case of electricity consumption? The electricity consumption does not include those consumed by playing nor recording videos. This fact suggested that some parts relating to video function require standby power when a TV is on, or parts of power supply or something else requires additional capacity, etc. and then they consume more electricity even when video function is not used.

The Japanese top runner program takes this difference into account. The electricity consumption of TVs with video function was higher than that without video function (18-20kWh/y), and the program therefore set targets of electricity consumption for TVs with and without video function with differences of 15kWh/y for the 2008 target and 12kWh/y for the 2012 target. The program imposes stricter standard than the real difference; however, the question why video function is to be taken into account in the energy consumption standard still remains. Such consideration may prevent development of energy-efficient video functions attached to TVs. On top of that, usefulness of video function can be judged in the market. There seems to be a lack of distinction between the existence of the difference in product performances and the necessity of differentiated product standards.

Table 2: Frontier products of all sizes of flat-panel TVs sold in 2010, identified by DEA

Product #	Size	Output	Input			Data		
		Video function	Unit electricity consumption (Wh/y/ inch²)	Unit weight (g/inch²)	Unit price (yen/ inch²)	Electricity consumption (kWh/y)	Weight (kg)	Price (yen)
434	32	0	**39**	10.7	65	**40**	11.0	66,964
199	52	0	**50**	10.0	80	*134*	*27.0*	*215,841*
74	32	0	**60**	12.4	50	**61**	12.7	**51,356**
326	52	**1**	**63**	11.1	*108*	*169*	*30.0*	*291,551*
30	42	**1**	72	*13.5*	73	*127*	*23.9*	*128,742*
13	32	0	80	12.7	**37**	82	13.0	**37,901**
171	32	0	81	**9.8**	**46**	83	10.0	47,198
90	42	**1**	81	12.8	54	*143*	*22.5*	94,608
33	47	**1**	85	10.8	*97*	188	*23.8*	*214,597*
234	26	0	96	**7.4**	52	**65**	**5.0**	**35,386**
15	22	**1**	101	10.7	76	**49**	**5.2**	**36,861**
158	26	**1**	*112*	**9.6**	*140*	76	**6.5**	94,560
470	22	**1**	*124*	10.7	63	**60**	**5.2**	**30,351**
231	26	0	*133*	**7.4**	**48**	90	**5.0**	**32,336**
361	32	0	*141*	11.2	**35**	*144*	11.5	**35,466**
Avg.	33	23%	106	13.4	90	110	15.5	104,306

DEA analysis: Input-oriented, CRS, two-stage
Number of products analyzed: 493
Italic and underline: Worse than average products
Bold: Features of the frontier products
Avg. includes non-frontier products

5.3 Results of air conditioners

DEA was applied with annual electricity consumption and product weight as input parameters and cooling/heating capacity and five advanced functions (see Table 3) as output parameters. The results showed 41 frontier products among 230 air conditioners, and Table 3 shows 12 frontier products with 2.2kW of cooling capacity. Worth noting is that no products without the five advance functions was identified as a frontier product. The main reason was that products with these functions had better energy performances. It is likely that producers prioritize good energy performance for new products, which tends to have many functions.

5.4 Discussion

Our insights gained from the trial DEA analysis were (1) DEA can identify frontier products with multiple products performances (including environmental performances) in a more scientific, objective way, and (2) DEA cannot be applied to all types of product performances. It suits quantitative performances where more (or less) is better. Some performances are not taken into account at all, and others may need appropriate normalization, ranking, etc., and (3) DEA does not inform us how to set product standards. Therefore, we finally tried to interpret the results of DEA for standard-setting.

Table 3 showed that there was no frontier product with an air cleaning function. There is no need to use this function for product segmentation. It also showed that two heavy products (76kg) had better energy performance. Hence, standard setters can differentiate between energy performance of products with different weight. Besides, DEA also identified frontier products with an inferior environmental performance to the average products. Whether to refer to such products when performing standard-setting should be cautiously decided.

6 SUMMARY

Existing product standards for MFPs seem to be set on an ad-hoc basis and often lack careful attention on how to deal with multi-functionality of products. The five approaches examined would be beneficial for a holistic understanding on standard-setting for MFPs; however, our examination showed there are more tasks to be undertaken. DEA is a useful tool, but it is not sufficient, and a complementary procedure of standard setting is needed.

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Table 3: Frontier products of air conditioners sold in 2010, identified by DEA (only 2.2kW of cooling capacity showed)

Product #	Input							No. of func-tions	Output		Dat			
	Cooling capacity (kW)	Heating capacity (kW)	Air cleaning	Filer cleaning	Heat exchanger cleaning	Reheating dehumidifying	Air-flow control		Unit electricity consumption (kWh/y /kW)	Unit weight (kg/kW)	APF	Electricity consumption (kWh/y)	Weight (kg)	Average price (yen)
6	2.2	2.2	1	1	0	0	0	2	345	13.6	5.8	760	30	72,667
7	2.2	2.2	1	0	1	0	0	2	308	*15.2*	6.5	678	34	63,309
22	2.2	2.2	1	0	0	1	0	2	345	13.0	5.8	760	29	55,364
26	2.2	2.2	1	1	1	0	0	3	345	*16.1*	5.8	760	36	68,367
62	2.2	2.5	1	1	1	1	1	5	282	*34.5*	7.1	621	*76*	*125,890*
70	2.2	2.2	1	1	1	0	1	4	308	*18.2*	6.5	678	40	103,169
85	2.2	2.2	1	0	1	0	0	2	345	13.0	5.8	760	29	47,298
97	2.2	2.2	1	0	0	1	0	2	345	13.0	5.8	760	29	45,962
120	2.2	2.5	1	1	1	1	1	5	295	*18.6*	6.8	648	41	83,344
121	2.2	2.5	1	1	1	1	0	4	340	*17.0*	5.9	747	38	101,505
143	2.2	2.5	1	1	0	0	0	2	345	13.9	5.8	760	31	60,063
203	2.2	2.5	1	1	1	1	1	5	282	*34.5*	7.1	621	*76*	*127,465*
Avg.	3.6	4.1	83%	72%	67%	48%	37%	3.1	357	15.0	5.7	1,306	49.2	117,801

DEA analysis: Input-oriented, CRS, two-stage Number of products analyzed: 493

Italic and underline: Worse than average products Bold: Features of the frontier products

Avg. includes non-frontier products

Eco-Rating; Communicating Sustainability to ICT Consumers, and Rewarding Supplier Product-Design Leadership

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Abstract

To move to a more sustainable society, business needs to drive change in supply chains, and to drive awareness and engagement with consumers. In Sept 2010 Telefónica UK (O2) launched a new consumer-facing tool to grade mobile phones' sustainability credentials in both its online store and its high street shops. The Eco-Rating tool was a World-first and represented a culmination of 14 months collaboration with Forum For the Future, the UK's leading sustainable development NGO, towards a tool that helps drive industry change and helps customers see the overall sustainability performance of the handsets they choose (not just their environmental credentials, but the *whole* sustainability performance; supply chain ethics, packaging, chemical substances, recyclability, energy performance, functionality, etc). It's about rewarding leadership in the supply chain, and using this to empower customers & influence their decision-making. The approach behind the tool is based on a combination of, consumer feedback and a genuinely collaborative approach with our supply chain to achieve a simple, comprehensive tool, that's based on life cycle thinking, sound science and manufacturers' own (often confidential) supply-chain sustainability research to deliver what UK consumers want – a single source of truth; a one-stop assessment of *all* the major sustainability parameters affecting handsets. Not just carbon. Not just environment. But everything that matters to them. This paper outlines the process, the tool and the results.

Keywords:

Eco-rating, ICT, mobile phones, sustainability, life cycle thinking, consumers, suppliers

1 INTRODUCTION

Telefónica UK Ltd (more commonly recognized via the O2 brand), is a leading communications company for consumers and businesses in the UK, with over 22 million mobile customers and over 700,000 fixed broadband customers (as at 30 June 2011).The company's aim is to be recognised as a UK leader on sustainability by 2012.

Telefónica UK's Think Big programme (www.o2.co.uk/thinkbig) represents Telefónica UK's range of community and environmental initiatives under the broad areas of People and Planet. Think Big for Planet is about fresh ideas – about looking at problems differently, and using technology to improve the world around us. Telefónica UK Eco-Rating is an example of this.

From O2 customers' point of view, the tangible element of the service is the mobile handset they choose; it's their gateway to Telefónica UK's network. Increasingly, overall sustainability performance is becoming an influencer in Telefónica UK consumers' purchasing choices.

In short, market research told Telefónica UK that consumers wanted an indication of the manufacturers' and their products' *overall* sustainability performance. Telefónica UK's ambition therefore is to help to inform customers on the impact of their purchases.

Telefónica UK and their partner, Forum for the Future (the sustainable development NGO), were mindful that there were other rating systems already available, but none had such a diverse scope, they weren't independently developed, and they weren't a collaborative exercise involving the people most affected by the tools: the manufacturers themselves.

This independent rating tool is Telefónica UK's response to their customers' expectations and offers a simple and accessible tool for them to assess their phones.

2 BACKGROUND

2.1 Growing Consumer Awareness of Sustainability Issues

Telefónica UK has been conducting research into UK consumers' views to sustainability (environmental, ethical and social) issues since 2008. The company was aware of an increasing familiarity of sustainability issues within O2 customers, together with a mounting appetite for greater visibility and greater transparency of information on environmental, ethical and social issues affecting mobile phone. Telefónica UK's own research has shown that sustainability credentials have some influence on 44% of consumer respondents in terms of buying a mobile phone, with 11.5% stating that sustainability credential have a strong influence on purchasing decisions. This is echoed in independent research. For example, between the years of 2007 to 2009, the Concerned Consumer Index focusing on the mobile operators sector has shown a rise of 7% in

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terms of consumers, who when asked to identify the issues they were most concerned about, expressed environment (e.g. manufacturing process, disposal of handsets) as a primary concern. In the same survey, those who expressed pricing as an issue (e.g. roaming charges) dropped by 4%. [1]. See Table 1 below.

Table 1: Concerned Consumer (mobile operators) selected results (2007 - 09) [1]

	May-07 (%)	May-08 (%)	May-09 (%)	Variation (%)
Health	26	26	32	6
Children's safety	41	38	32	-9
Pricing	22	21	18	-4
Environment	11	15	18	7

Additionally, 2008 research conducted by Telefónica UK across their consumer segments also showed consumer frustration about the variations on sustainability topics which different ICT manufactures, retailers etc communicated. Consumers requested more a simplified communication on overall sustainability performance. Such analysis demonstrated the potential for a single metric to communicate overall performance to a consumer audience.

2.2 Rewarding supply chain leadership

At the same time Telefónica UK recognized that communicating sustainability performance to consumers alone is of limited value without encouraging improvement in the supply chain. Through Telefónica UK's supply chain auditing process going back many years, the company was aware of the spectrum of sustainability performance across the manufacturing base.

Whilst standards can be improved across all manufacturers via local and international regulation, only a few manufacturers are willing to go beyond the norm to deliver sustainability excellence. Such leaders are recognized by businesses and their procurement specialists, but their leadership is rarely communicated to consumers. Telefónica UK, therefore, sought to develop a system tool that could drive, recognize and reward leadership in the supply chain, and communicate overall performance to an increasingly aware consumer-base.

3 APPROACH

3.1 Over-arching principles

The Eco-Rating project began in August 2009 and was launched in September 2010 both on the Telefónica UK online store (www.o2.co.uk) and across all O2 stores in the UK. The purpose of this project was to develop a simple, transparent rating system that evaluates the sustainability credentials of handsets and rewards innovation by visibly promoting leading products' performance to consumers through a simple logo depicting each product's score. Forum for the Future led on the development of the tool based on direction from Telefónica UK.

The rationale behind the tool's development was that it should:

a) Cover Telefónica UK's three sustainability elements of environment, ethics and social performance, in response to consumer research. The environmental elements of the tool are based on principles of streamlined Life Cycle Assessment (LCA). The ethical and social elements are based on sustainability leadership principles derived from Forum for the Future's work with business and industry and Telefónica UK's own sustainability procurement expectations, together with preceding industry systems; specifically the E-TASC tools designed to help companies to effectively implement a common approach for assessing and managing supply chain corporate responsibility risk (www.e-tasc.com), which Telefónica UK use;

b) Be simple, quick and straightforward to use. The front-end of the Eco-Rating tool is a binary Excel spreadsheet, built on a series of questions covering the two areas of Corporate and Product performance. It's based on a simple Yes/No drop-down answer menu, with a 'Yes' answer to any question in the assessment sheet always indicates the more sustainable handset option. There is no option to answer 'Don't Know'. It is designed to allow completion of the complete questionnaire by suppliers in about 20 minutes of less;

c) The Eco-Rating assessment spreadsheet is designed on the principle that most of the information should be publicly available or readily available to the manufacturer;

d) Recognize the important issue of Functionality. As mobile handsets become more complex, diversifying across a range of capabilities (from GPS and navigation to web-browsing and entertainment), a methodology needs to be developed to allow comparison between such advanced products and the basic 'candy bar' phones; and

e) Be a collaborative development, in conjunction with manufacturers themselves. This principle proved to be one of the secrets to Eco-Rating's success; because manufacturers were actively contributing to Eco-Rating's development from the start, the final tool was something that manufacturers could work with from launch.

Corporate Eco-Rating section

Eco-Rating is not only looking at company products [i.e. mobile phones] but also at the business conduct of the companies producing these products.

The areas in which handset manufacturers answer questions are:

- Policy
- Management systems
- Supply chain requirements
- Supplier management
- Communications
- Social inclusion and community
- Climate change and energy
- Resource use – handset obsolescence & waste kit
- External recognition

The ‘Corporate’ Eco-rating assessment is comprised of 34 questions.

Product Eco-Rating section

The product rating takes a whole-life thinking approach to handset environmental impacts and functionality. Forum for the Future used two main sources as the starting points for Eco-Rating:

(1) The European Commission’s Integrated Product Policy (IPP) Pilot Project 2005 reports [2], [3]

(2) Manufacturer-reported data in the public domain. Additionally, Forum for the Future received support research from several manufacturers on a collaborative basis.

The IPP project justified the Eco-rating’s use of proxy indicators for assessing the life cycle impacts of mobile phones, thereby facilitating easier use of the tool by manufacturers, completing the product questionnaire via engineering data readily to hand.

The Eco-Rating ‘Product’ rating section totals approximately 60 questions divided into six areas:

i) Raw materials and manufacturing impacts
ii) Substance impacts
iii) Packaging and delivery
iv) Use impacts
v) Disposal impacts
vi) Functionality

Overall Eco-Rating section

Each product’s final Eco-Rating score is weighted to take functionality into account. Within the overall Eco-Rating score, direct handset impacts have been allocated a weighting of 75% of the overall Eco-Rating score. Functionality accounts for 25% of the overall Eco-Rating score. Table 2 illustrates the weightings.

Table 2: Weightings for Eco-Rating scores

Overall Eco-Rating score	
[1]	Corporate impacts: 11%
[2]	Raw materials and manufacturing impacts: 26%
[3]	Substance impacts: 7.5%
[4]	Packaging and delivery: 7.5%
[5]	Use impacts: 19%
[6]	Disposal impacts: 4%
[7]	**Functionality: 25%**

The weightings (above) allocated to the direct handset impacts and the Eco-rating score as shown above are derived from:

- The European Commission studies [see above];
- Publicly available manufacturers’ life cycle data
- Life cycle data received in confidence from manufacturers;
- Current best practice in the industry as shown by the Eco-Rating data itself.

It is these overall weighted Eco-Rating scores that are the primary benchmark of each device’s sustainability performance, and it is these scores that are used to calculate the final Eco-Rating communicated to consumers in O2 stores and online.

3.2 Communicating results to Consumers

It took approximately 12 months to develop Eco-Rating to a point where device manufacturers were delivering consistant and auditable data with which they, Telefónica UK and Forum for the Future were confident. Once this was achieved and running as a mandatory, business-as-usual element of the supplier relationship, Telefónica UK focused its efforts on developing a mechanism to communicate the overall sustainability score of each device to consumers. This was led by Telefónica UK’s marketing and brand teams, in conjunction with Forum for the Future.

Scores for each product are given from 0.0 to 5.0, with 0.0 being the worst possible score, and 5.0 the best. A logo was developed through consumer-testing that visually depicted each handset’s performance across this range, in a manner that allows quick and easy comparision with alternatives. Figure 1 shows the Eco-Rating logo for a very high-performing handset with a score of 4.3 out of 5.0. (The highest score achieved, to date).

The logo was included within the key-features summary label that accompanies each handset at the point of sale in store. Additional to the label a short, explanatory pamphlet was provided for customers who sought more detailed information on EcoRating, with stakeholders seeking more comprehensive information being directed to a dedicated web-site (www.o2.co.uk/thinkbig/planet/sustainableproducts/ecorating) and associated PDF information report. [4]

4 RESULTS & DISCUSSION

4.1 Driving change in the supply chain

At the time Eco-rating was launched at the end of August 2010, with scores provided in store and online for 65 devices, this represented 93% of the then O2 range of handsets. Six manufacturers were participating in the scheme (Nokia, Sony Ericsson, HTC, LG, Samsung and Palm) with more following.

The highest scoring handset was the Sony Ericsson Elm

Fig. 1: Eco-Rating score logo

with an Eco-Rating of 4.3 out of 5. Six phones then tied in second place with a score of 4.0. These were (in alphabetical order), Nokia 1800, Nokia 6700, Samsung GT-S8500, Sony Ericsson Xperia X10 mini, Sony Ericsson Xperia X10 mini pro and the Sony Ericsson Zylo. The average Eco-Rating score across the range at launch was 3.40.

By January 2011, the number of handsets with Eco-ratings had expanded to 77 units and the distribution of scores is shown in Figure 2. The average score had risen to 3.59 across the O2 range.

Improving standards in the supply chain

A key reason for the increase in average score across the range, has been Eco-rating's success in driving improvements in manufacturers' performance. As the scores are highly visible in the retail environment, manufacturers are keen to see their products' performing

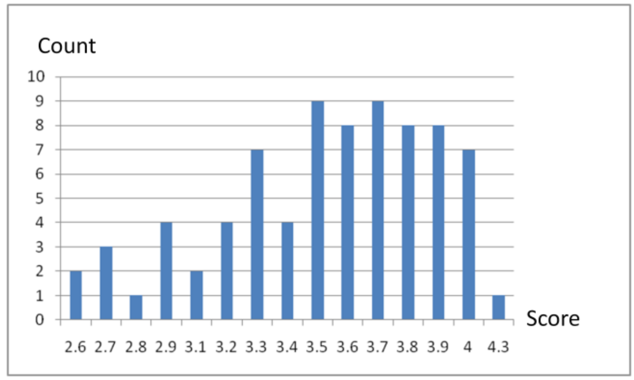

Fig. 2: Eco-rating score distribution (Jan 2011)

well. This has driven interest in the tool across all manufacturers, and driven change in their practices. For instance, one manufacturer who was supporting the initiative from the outset, elected not to participate in Eco-rating at launch as they chose to implement both new corporate- and product-level processes and policies that would improve their scores. Now, they are the most improved suppler to date.

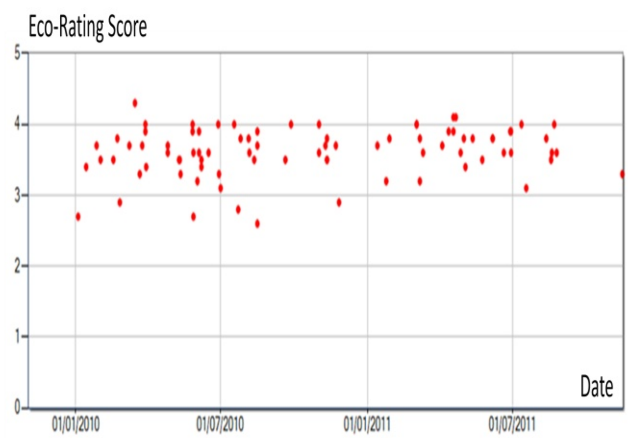

Fig. 3: Eco-rating scores (Jan – Aug 2011)

Figure 3 shows the complete range of Eco-Rating scores for handsets ranged by Telefónica UK in 2011. This demonstrates that this gradual upward trend continues. Since Eco-rating's launch Telefónica UK and Forum for the Future have observed a diversity of supply-chain improvements, most notably in the areas of packaging, corporate governance and policy.

4.2 Consumer Awareness

Telefónica UK has conducted research to observe consumers reaction to Eco-rating. Although Telefónica UK had known from previous research that sustainability is an influencer in consumers' purchasing decisions, it is was not seen to be a primary influencer. Consumers all placed either cost or ease-of-use as the primary influencer in the purchasing decision. Other factors ahead of Eco-

Rating included aesthetics, camera capability, web-access and operating system. That said, Eco-rating did show as being an influencer, and has some bearing in consumers' decision-making, with the level of influence being low and dependent on consumer segment.

Post-purchase research on the reaction to Eco-rating of 300 consumers' (across all market segments) conducted in spring 2011 revealed some key consumer reactions.

With regards to actual use of Eco-Rating by consumers, the market research results show this associated with a limited number of consumers. Figure 4 shows that out of those surveyed, 4% have used it within their purchasing decision.

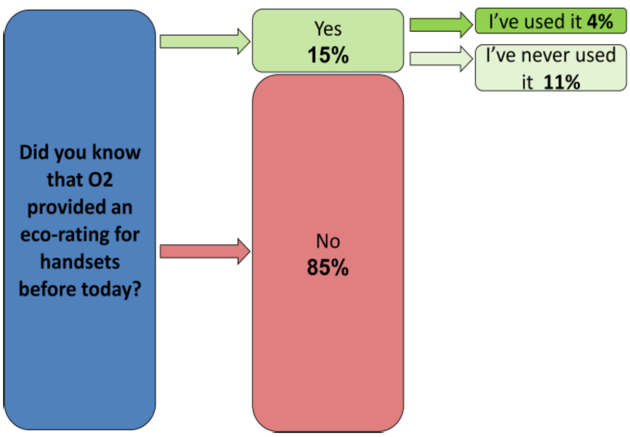

Fig. 4: Consumer awareness

Nonetheless, with regards to general awareness of Eco-rating, whilst low, this is more considerable; 15% surveyed were aware of the tool, with 26% of those actually using it (i.e. 4%).

The key findings from post-purchase research, which consisted of both quantitative questionnaires and qualitative group interviews, are that:

- There is an appetite for sustainability ratings , and the main benefit of Eco-ratings is they are 'at-a-glance';
- Consumers liked the feeling they are being ethical and environmentally conscious, but don't want it to expend effort on this; Eco-rating effectively means that the retailer has done the work for them;
- Consumers expect to see Eco-ratings listed as part of a phone's specification, but they have mixed feelings about being told unprompted about Eco-ratings. They want the ratings to be there, but don't want to be 'forced' to use them; and
- Eco-rating alone is not a key factor in purchasing decisions. However, it can be helpful in tipping the balance between similar handsets.

5 CONCLUSIONS & NEXT STEPS

Both Telefónica UK and Forum for the Future are encouraged by the reaction to Eco-Rating. This positive reaction has come from both suppliers and consumers, and also from a wider stakeholder group including peers in our sector (and beyond) at local, regional and global levels.

5.1 Supply Chain improvements

Clearly, Eco-Rating is driving change in the supply chain, and strongly demonstrating to manufacturers both Telefónica UK's commitment to sustainability leadership and the firm place that sustainability now has in the decision-making line-of-sight of O2 consumers. Through Eco-Rating, manufacturers' ambition on sustainability has clearly been catalyzed.

5.2 Supporting Consumer

For consumers too, Eco-rating has responded to the expectation that devices' sustainability credentials should be communicated at point-of-sale. 15% of consumers are aware of the tool, with 26% of those who are aware currently use it in aiding their purchasing decision. Clearly, whilst research shows that consumers do not want heavy-handed awareness-raising from O2 store staff, there is a role for retail employees to promote the tool, and retail training is being provided on Eco-Rating along with Telefónica UK's other sustainability programmes.

5.3 Next Steps

It is the intention of both Telefónica UK and Forum for the Future that Eco-Rating be made available to the digital communications sector and beyond, to further sustainability performance and awareness across the supply chain.

A first step in this process is already underway, with the uptake for Eco-Rating by Telefónica UK's parent company, Telefónica SA, who are now seeking to integrate the tool within Telefónica SA's own Green Customer Experience, a programme launched in 2010 which seeks to encourage awareness and reward the purchase of more environmentally-conscious handsets. Additionally, Telefónica Germany launched Eco-Rating (as Eco-Index) in summer 2011.

Interest from other organizations in the communications sector and beyond has also been strong, and Telefónica SA shares the ambition to make the tool more widely available. Discussions are now taking place within the International Telecommunication Union (ITU) to make Eco-Rating available to the wider industry. Meanwhile Telefónica UK and Forum for the Future continue to investigate the tool's application to wider electronic devices.

If you require more information on Eco-Rating please visit http://www.o2.co.uk/thinkbig/planet/sustainableproducts/ecorating and http://www.forumforthefuture.org/project/o2-eco-rating-assessing-sustainability-mobile-phones/overview

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Applying the Theory of Problem-Solving and AHP to Develop Eco-innovative Design

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Abstract

Technology advancement and industry development not only bring people diversified products and convenience in using goods but also causes high pollution to environment. For recent years, people have begun to reflect on environment and emphasize on environment protection, and many enterprises have begun to think about how to balance products and environment. Therefore, the concept of "eco-innovative design" is more and more valued by various fields. This study utilizes theory of inventive problem solving (TRIZ) to generate eco-innovative principle and further uses AHP (Analytic Hierarchy Process) to find out optimal design scheme under multi-criteria decision-making. An example of O'right's green product "ECO-Bottle:treeInTheBottle" is used to demonstrate feasibility of method proposed in this study. This study is divided into three stages. The first stage, data collecting, adopts literature discussion and focus group discussion. KJ method is used for classification and three aspects of green design strategy are obtained: green material, environment safety and expenses. The second stage is data mapping, which maps 40 inventive principles in contradiction matrix of TRIZ into 39 engineering parameters so as to form innovative principles. At the third stage of decision weight, expert questionnaire and 9-point scale about previous-stage data are used to generate a weighted model of relationships between target, sub evaluation criteria and detailed rules. Finally, eco-friendly recycled bottle is used for verification, questionnaire survey is implemented among 10 experts and 10 consumers, and ANOVA is adopted to test consistency. Therefore, this study applies TRIZ into "ECO-Bottle" and proposes eco-innovative design rule as well as optimal design scheme chosen through multi-criteria decision-making. From the viewpoint of green enterprise business, this study establishes green product strategy and evaluation, weighs various hierarchies including green materials, environment safety and expenses, and finally sets up eco-innovative design rules and weight model that can be used as a reference for future researchers and scholars.

Keywords: AHP, TRIZ, Kansei engineering, Eco-design, Innovative design

1 INTRODUCTION

Enterprises always care about product costs and efficacy, and seldom pay attention to consequent recycle and reuse. Due to increasingly-serious environment pollution, many countries have implemented environmental protection regulations to reduce influences of industry on environment such as WEEE (Waste Electrical and Electronic Equipment Directive), RoHS(Restriction of Hazardous Substances Directive) and EuP (Energy Using Product). Through innovative methods and tools, designers can convert product design problems into eco-friendly designs, improve environment by design products, and express environment-friendly concept (Karlsson and Luttropp. 2006; Knight and Jenkins. 2009; Dangelico and Pontrandolfo. 2010). This study mainly maps TRIZ with eco-innovative principles, which are integrated with AHP to find out an optimal design scheme under multi-criteria decision-making.

2 LITERATURE DISCUSSION

2.1 Eco-Design

There're many terms concerning green design, which represent different meanings and scopes. Internationally, terms of green design include Eco Design. Eco combines prefix of ecology with prefix of economy, which means the design takes environment and economic development value into consideration. Green design, an international design trend appearing in late 80s of 20th century, represents people's reflection on destructions to environment and ecology caused by modern technology and culture, as well as their return to morality and social responsibility. Central idea of green design is "Life Cycle Design (LCD). Fundamental difference between "green design" and "traditional design" lies in that the former emphasizes on saving energy consumption, using renewable easily-assembled-or-disassembled products or materials to reduce destructions to natural environment and ecological balance, as well as viewing product performance and cost as equally important design indicators. Therefore, scholar Jui-che Tu (2002) proposes principle of green product design, all parts of which are interrelated. Enterprises can utilize green innovation to enhance productivity, improve enterprise image, develop new market and increase competitive advantages (Hart , 1995 ; Petts, 1998). Holt (1988) thinks innovation is a process of using new and useful relevant knowledge or

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Table1 Contradiction Matrix

	Avoiding degradation parameter (ADP)					
Improving Parameters (IP)	Engineering Parameters	...	# 21 Power	# 22 Loss of Energy	# 23 Loss of substance	...
	...	...	...		...	...
	# 16 Duration of action by stationary object	...	# 16		#27 ,#16, #18,#38	...
	# 17 Temperature		[illegible]	#21,#17, #35,#38	#21 ,#36, #29,#31	...
	# 18 Illumination intensity	...	# 32	#13,#16, # 1,# 6	#13,# 1	...
	...	...	...	...	...	...

key information to create or lead to useful things. To maintain competitive advantages and correspond to pressures from environmental protection, enterprises begin to improve products, manufacturing processes, service and technology so as to take advantage of future opportunities (Hunt, 1995). Hawken et al. (2004) said in their book “Natural capitalism: creating the next industrial revolution” that: the 21st century is an “environment century”; in a circular society, 3R principles of “reduction, recycle and reuse” should be used to enhance resource utilization efficiency.

2.2 TRIZ

TRIZ began in 1946 when G. Altshuller, a mechanical engineer, began to study patents in the Russian Navy. This approach has widely been taught in Russia, but did not emerge in the West until the late 1980s. Several different solution systems have been derived by abstracting inventive principles from the ongoing analysis of patent data. Several of these solutions focus on contradictions or trade-offs in identifying innovative solutions (see Fig.1). There are three premises on which the theory may be viewed: (a) the ideal design with no harmful functions is a goal, (b) an inventive solution involves wholly or partially eliminating a contradiction, and (c) the inventive process can be structured. Each of these premises will be dealt with in turn. Finding the ideal solution to a needed function or effect with no harmful or negative effects is referred to in TRIZ circles as Ideality:

$$\text{Ideality} = \frac{\text{All useful functions or effects}}{\text{All harmful functions or effects}}$$

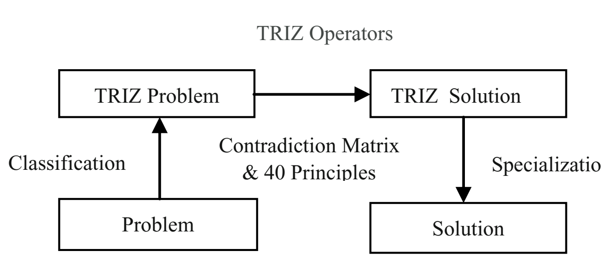

Fig. 1. TRIZ problem solving process

Altshuller went on to classify them into 39 parameters and 40 common principles that are repeatedly used in patented solutions. To display the possible technical contradiction combinations, he produced a 39×39 matrix and identified which of the 40 inventive principles were more commonly associated with specific combinations of contradiction parameters (see Table 1). This matrix is called the technical contradiction matrix.

The TRIZ approach has applied to numerous design problem solving such as the relation between seven eco-friendly elements of WBCSD and engineering parameters of contradiction matrix (see Table 2) (Chen and Liu. 2001), computer-aided design software integrating TRIZ into eco-design tool (Chang HT and Chen JL, 2004) , the design features of different water filters, washing machines and power drills to correlate the elements of eco-efficiency and the principles of TRIZ (Issac Lim Sing Sheng and Teoh Kok-Soo, 2010), generation tool within cleaner production projects (Johannes Fresner , J.ürgen Jantschgi, S. Birkel, J. Bärnthaler and C. Krenn, 2010).

Table 2 The eco-friendly elements of WBCSD and engineering Parameters adapted by this study.

	Eco-friendly elements of WBCSD	Element engineering parameter
Eco-efficiency	A. (material)	1~8,12,14,23,26,32,39
	B. (energy reduction).	1,3,5,7,17-22,33,39
	C. (toxicity reduction).	13,23,26,28,31
	D. (material retrieval).	9-11,28,29,32,36,38
	E. (resource sustainability).	14,30,34
	F. (product durability).	13-16,27,30,33-37
	G. (product service).	9,15,16,24,25,27,35,39

A. (Material)Reduce the material intensity of its goods and services

B. (Energy reduction) Reduce the energy intensity of its goods and services.

C. (Toxicity reduction) Reduce the dispersion of any toxic materials.

D. (Material retrieval) Enhance the recyclability of its materials.

E.(Resource sustainability) Maximize the sustainable use of renewable resources.

F. (Product durability) Extend the durability of its products.

G.(Product service) Increase the service intensity of its goods and services.

2.3 AHP

Analytic Hierarchy Process (AHP) was firstly proposed by Thomas L. Saaty in 1971, 1980. When making decisions on specified problems, people propose many choices as judgment reference, define importance of these choices, form hierarchical system between choice items, use pair wise comparisons to establish these items one by one, and then make an optimal decision (Saaty & Vargas, 1991). AHP is a kind of multi criteria decision making technique. Especially, for dealing with multicriteribute decision, decision makers establish an overall goal, develop criteria and sub criteria according to this goal until achieve the last level of criteria, utilize 1-9 scale to conduct pair wise comparison (Saaty,1990) (see Table 3), obtain eigenvector as weight between each criteria, and finally get order of priority through weighted aggregate (Kamal, 2001; Lipovetsky S.& Michael C.W., 2002; Mohammed I., 2002).

Table 3 The pairwise comparison judgment

Intensity of importance	
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2, 4, 6, 8	Intermediate values
Reciprocals	Inverse comparisons

Application of AHP into decision making contains the following three steps:

Step 1: establish pair wise comparison matrix of each hierarchy.

After hierarchical structure is constructed, pair wise comparison must be conducted between each indicator of all levels. If there're n elements, "pair wise comparison" should be conducted for n（n-1）/2 times. Results of pair wise comparison will be stored by means of matrix and called "pair wise comparison matrix", eigenvectors of which will then be used to obtain relative weights between each indicator as shown in formula (1).

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{1n} \\ \vdots & \vdots & 1 & \\ 1/ajn & 1/a2n & \cdots & 1 \end{bmatrix} \quad (1)$$

Step 2: calculate the maximum eigenvector and eigenvalue.

In accordance with above matrix, eigenvector mapping with the maximum eigenvalue can be obtained, i.e. weight distribution and maximum eigenvalue $\lambda_{\max}$ as presented in formulas (2) and (3).

$$A\bar{w} = \begin{bmatrix} W_1/W_1 & W_1/W_2 & \cdots & W_1/W_n \\ W_2/W_1 & W_2/W_1 & \cdots & W_1/W_n \\ \vdots & \vdots & \vdots & \vdots \\ W_n/W_1 & W_n/W_2 & \cdots & W_n/W_n \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ Wn \end{bmatrix} = n \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ Wn \end{bmatrix} \quad A\bar{w} = \lambda_{\max} \times \bar{w} \quad (2)$$

$$\lambda_{\max} = \frac{1}{n}\left[\frac{W_1}{W_1} + \frac{W_2}{W_2} + \cdots \frac{W_n}{W_n}\right] \quad (3)$$

Step 3: consistency test

When eigenvalue doesn't equal n, difference between λ max and n can be used as a standard of measuring consistency between expert's judgments, and this process is called consistency test. Saaty suggests to judge consistency of matrix through consistency index (CI）and consistency ratio (CR). As presented in formulas (4) and (5), consistency of matrix is high when C.R. is below 0.1.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (4) \qquad C.R. = \frac{C.I.}{R.I} \quad (5)$$

3 RESEARCH METHODS AND EXPERIMENT DESIGN

The design of this study can be discussed through three stages, which are described in details as below and illustrated in figure 2:

Stage 1: data collecting

1. Product information collecting: define product problems, utilize TRIZ to get improving parameter (IP) and avoiding degeneration parameter (ADP), conduct in-depth interview with relevant managers and generalize problem points.

2. Evaluation factor collecting: implement focus group discussions with general manager, marketing manager and factory director. KJ method is used for classification and three dimensions of green product design strategy are obtained as: green materials, environment safety and expenses.

Stage 2: data mapping and weight establishing

1. 39 engineering parameters obtained from stage 1 will be mapped with contradiction matrix of TRIZ, so as to generate innovative principles and improve products. A, B and C schemes of innovative product are formed.

2. By means of expert questionnaire and 9-point scale, above-mentioned four evaluation aspects are used to establish a weight model of relationships between goal, sub evaluation criteria and detailed rules.

3. An optimal design scheme is obtained through comparing each evaluation weight with above three schemes.

Stage 3: design verification

Questionnaire survey is conducted among 10 experts and consumers. ANOVA is used to verify if the decision results of this study conform to investigation results.

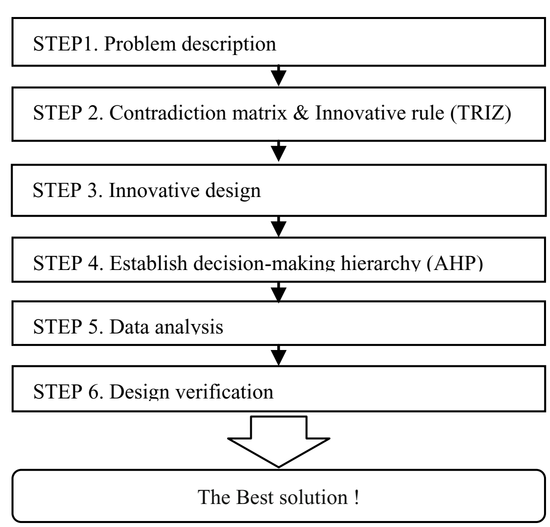

Fig. 2 Research process framework

4 THE CASE STUDY

This paper maks a case study of Eco-Bottle produced by a manufacturer in Taiwan-O'right. O'right, a distributor and manufacturer in local hair styling industry, mainly specializes in R&D, production, agency and sales of hair styling products. Transforming from OEM into ODM and OBM industry, this company develops based on "green" (environment-friendly) and encounters many contradictions and conflicts between production and strategy during decision making and manufacturing processes. Therefore, this study uses TRIZ to solve conflict problems and adopts AHP to assist in problem solving and making optimal decision.

4.1 Problem description

At first, confirm product problems and then have interviews with general manager and managers of production and design. Interview contents are briefly described as the following: under "green" policies, life cycle assessment (LCA) is discussed through five parts: raw material, manufacturing, transporting, use and recycle. Raw materials: natural materials; manufacturing: increase green factories, reduce carbon emission and promote users' (consumers) green conceptions; product: plastic containers bring great convenience to modern life, but traditional plastic containers (PET, HDPE) always produce harmful substances during manufacturing and waste disposing and thus severely pollute the environment. If using friendly plastics (Poly Lactic Acid, PLA), it's necessary to avoid generate harmful substances and pay expenses three times higher than traditional plastic containers. Therefore, four improvement targets are summarized as below:

1. Reduce carbon emission. 2. Reduce second pollution resulted from recycled materials. 3. Increase green energy development and reuse. 4. Enhance sustainable environment.

4.2 Innovative rule of parameter matrix transformation

According to problems about current situations and discussions between experts and relevant managers, two major contradictions are indicated:

Contradiction I: Improving the Loss of Energy (#22) and avoiding the degradation Temperature (#17) , Power (#21), Productivity (#39) and Ease of operation (#33).

Contradiction II: Improving the ease of Adaptability or versatility (#35), and avoiding the Ease of manufacture (#32) and Ease of operation (#33).

Above-mentioned contradiction parameters (IP & ADP) are mapped to generate some innovative rules described as the following and shown in table 4:

Innovative rule of sustainable energy:

#19 Periodic action, #38 Accelerated Oxidation,#7 Nested, #3 Local Quality, #28 Mechanics substitution, #10 Prior Action, #29 Pneumatics and hydraulics. #35 Transformation of Properties, #32 Color changes, #1 Segmentation.

Innovative rule of sustainable materials:

#1 Segmentation, #13 Inversion, #31 Porous Materials, #15 Dynamics, #34 Discarding and recovering, #16 Partial or excessive actions.

Table 4 TRIZ contradiction parameters are mapped to generate following innovative rules

Item Descript	IP	ADP	Principles
Sustainable energy Carbon emission reduction; green energy development and reuse	#22 Loss of Energy	#17 Temperature	#19 Periodic action, #38 Accelerated Oxidation, # 7 Nested
		#21 Power	# 3 Local Quality, #38 Accelerated Oxidation
		#39 Productivity	#28 Mechanics substitution, #10 Prior Action, #29 Pneumatics and hydraulics, #35 Adaptability or versatility
		#33 Ease of operation	#35 Transformation of Properties #32 Color changes # 1 Segmentation
Sustainable materials Reduction in using recybled materials; increase in sustainable environment	#35 Adaptability or versatility	#32 Ease of manufacture	# 1 Segmentation, #13 Inversion, #31 Porous Materials
		#33 Ease of operation	#15 Dynamics, #34 Discarding and recovering, #1 Segmentation, #16 Partial or excessive actions

4.3 Innovative design

With a reference to sustainable and innovative rules, use #1 Segmentation,#3 Local Quality, # 7 Nested, #10 Prior Action, #15 Dynamics, #19 Periodic action, #28 Mechanics substitution, #31 Porous Materials,#34 Discarding and recovering to develop three design schemes: A, B and C. Scheme A, which adopts low-cost PET and HDPE materials in need of recycle, is low-cost and low-environment-friendly. Scheme B, adopting degradable PLA material, is high-cost and high-environment-friendly. Scheme C adopts degradable PLA materials, and place a seed at the bottom of the bottle to make the environment green. Therefore, it is a high cost and high-environment-friendly scheme with additional creativity. These three schemes are shown in figure 3.

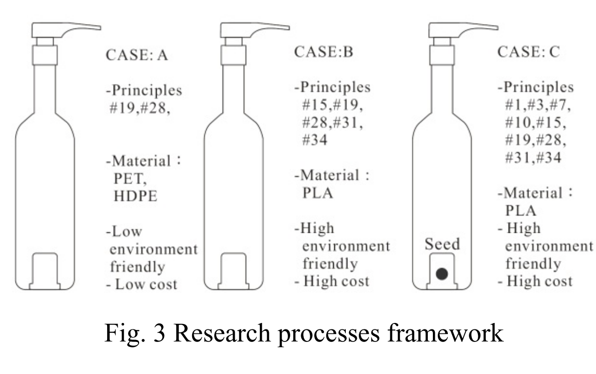

Fig. 3 Research processes framework

4.4 Establish decision-making hierarchy (AHP)

This study uses AHP evaluation to make decision on an optimal design scheme for the company. Production manager suggests taking into consideration not only innovative design rules but also cost and environment issues. According to chapter 3, level-wise comparison is conducted with ECO-Bottle as the Goal, Green Material, Environment & Safety and Cost as main criteria, recycling material, decomposition, other materials, ECO environment, operation environment, use safety, material cost, labor cost and manufacture cost as sub criteria. Hierarchy weights are compared as shown in table 5. Consequently, costs of A, B and C cases are compared as in table 5. Finally, as shown in figure 4, pair wise comparisons are conducted between three cases and each criterion.

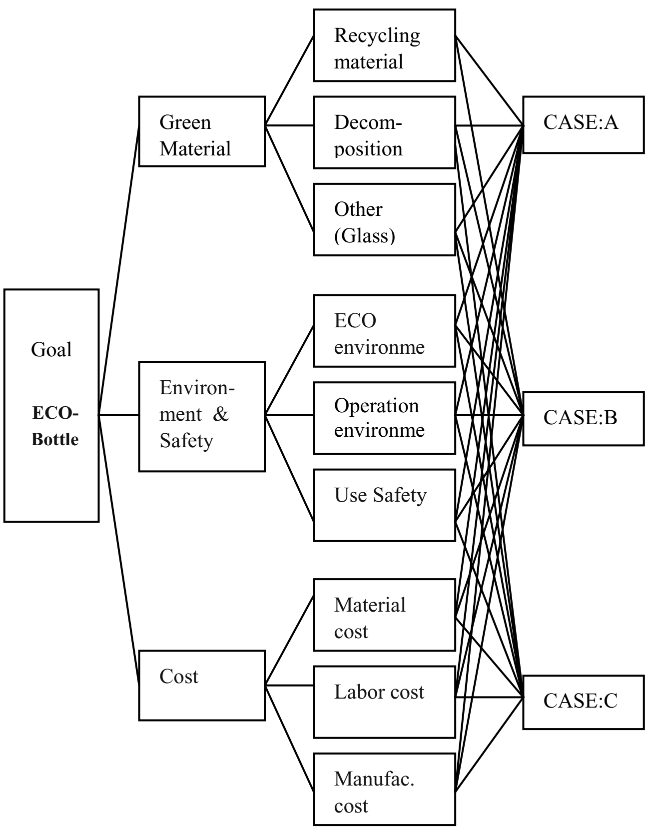

Fig.4 Decision mode hierarchy of AHP in this study

4.5 Data analysis

Hierarchy wise comparison shows that weight of Green Material, Environment & Safety and Cost is 0.5679, 0.3339 and 0.0982 respectively. C.R. value (0.0213) < 0.1 means internal consistency is high; C.R. of sub criteria are also below 0.1 and represent a high internal consistency. Weight sequence of main criteria is: 1. Green Material, 2.Environment 3. Safety and Cost; that of sub criteria is: Material, ECO environment, Deco. material (PLA), Recycling material (PET/HDPE), Use Safety, Operation environment, Manufacture, Labor, Other (Glass); as shown in table 5.

Hierarchy analysis of each scheme shows case C is the best, and the next is B and A. After final aggregated weight evaluation, table 6 presents the order of optimal scheme is C, A and B. Therefore, after a hierarchy analysis of criteria and schemes, case C (ECO-Bottle) is the optimal choice.

Table 6 Aggregated weight evaluation of optimal scheme

CASE	A	B	C	*weight*
A	*0.0909*	*0.0769*	*0.0943*	**0.0874**
B	*0.1818*	*0.1538*	*0.1509*	**0.1622**
C	*0.7273*	*0.7692*	*0.7547*	**0.7504**

Notes λ_{max}=3.0055, CI= 0.0028 ,CR=0.0048

4.6 Design verification

After experiments are completed, this study conducts questionnaire survey among 10 consumers and 10 experts, thus to compare whether there're significant differences between testees' criteria of these three schemes and determine whether the decided scheme conform to settings of each criteria. According to ANOVA, experts and consumers all believe each criterion reaches significance level (P<0.05) and consistency is verified.

5 RESULT

This research maps TRIZ innovative principles into green design, uses hierarchy analysis to conduct multi-attribute decision, and adopts a real example of ECO-Bottle: treeInTheBottle to make verification. Therefore, the way of problem solving proposed in this study is feasible as shown in figure 5. With regard to raw material, manufacturing, transporting, use and recycle of Life Cycle Assessment (LCA), this paper only discusses and

Table 5 Weight relations and orders of each hierarchy

Goal	Main Criteria	*weight*	Rank	C.R.	SubCriteria	*weight*	Rank	C.R.
ECO-Bottle	Green Material	0.5679	1	0.0213 [a]	Recycling material (PET/HDPE)	0.4353	4	0.0109 [b]
					Deco. material (PLA)	0.4866	3	
					Other (Glass)	0.0782	9	
	Environment & Safety	0.3339	2		ECO environment	0.5794	2	0.0465 [c]
					Operation environment	0.1865	6	
					Use Safety	0.2341	5	
	Cost	0.0982	3		Material	0.6327	1	0.0079 [d]
					Labor	0.1749	8	
					Manufacture	0.1924	7	

Notes [a]λ_{max}=3.0247, CI= 0.0123 ,CR=0.0213 ; [b]λ_{max}=3.0126, CI= 0.0063 ,CR=0.109; [c]λ_{max}=3.0539, CI= 0.0270 ,CR=0.02465 ; [d]λ_{max}=3.0092, CI= 0.0046 ,CR=0.0079.

improves product manufacturing. Other stages of product cycle evaluation can still be tested by TRIZ as shown in table 7. As scholars say, with green spirit as basic principle, enterprises will win advantages in market. After transforming into "green" oriented enterprise in 2002, the case in this study has doubled and redoubled its turnover, which demonstrates green concept is highly acceptable in consumers' daily supplies. Therefore, green trend and life is a future problem should be confronted and reflected at present.

This study proposes several conclusions and suggestions as below:

1. TRIZ, a systematic thinking mode different from traditional linear thinking, provides innovative principles that can bring extensive space for imagination, design through Top-Down and Bottom-Up thinking modes, as well as deal with problems about conceptual design in addition to mechanical or physical problems.

2. Regarding decision making model, besides AHP, other multi-criteria decision making methods can be used for difference comparison (ex. SAW,ANP,LAM,TOPSIS…). It is demonstrated that whether different ways of decision making produce the same results.

3. Future researches can begin to combine with application of Kansei Engineering. In consuming market, green products are usually highly spoken of but not popular finally. Try to find out green kaisei factors, which will be integrated into products through design, activity and experience.

4. Artificial intelligence system can be integrated with case-based reasoning (CBR). Previous cases and experiences can be analogized and deduced through such system, thus to find out recommended schemes, which will be corrected into optimal scheme at last.

Table 7 Applicable TRIZ rules in each LCA stage

LCA	Implementations	TRIZ rules
Raw material	obtain raw materials locally	#2,5,19,21…
Manufacturing	Green factory Green energy development (wind and solar energy) and water recycling use	#3,10,11,15,27,29,34,35,36…
Transporting	Carbon reduction during transporting: reduce transportation in batches	#1,5,25…
Use	Develop envrionmental products and establish envrionment-friendly concept	#10,19,20,23…
Recycle	Replacement of recycled materials with degradable materials	#10,16,22,34…

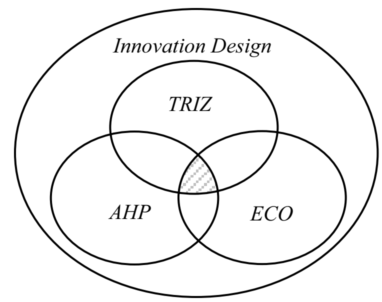

Fig.5 Way of problem solving in this study

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Axiomatic Design Approach in the Research of Green Product Design Reviews

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Abstract

The green product design is different from the design of other products. While designing green products, it is necessary to obtain the best balance among the environment, customers, and enterprises. In response to the rapid changing market, the design goals should not only meet consumers' demands, but also minimize the environmental impacts. The axiomatic design method is considered as a rational means which provides a new systematic approach to system design and product review. During the process, it helps designers to select the best design.

Thus, based on the characteristics of green quality and the users' point of views, the study uses the axiomatic design method to examine the energy-saving power supply (PAT. M395242). The researcher firstly analysed the product steps to use and the setting of the original interface. After the parameters of Customer Attributes (CAs), Functional Requirements(FRs), and Design Parameters (DPs) in the axiomatic design were defined, a design matrix could be used to analyze. According to the requirements of independence axiom, the assessment was employed to check whether the design met the consumer needs.

The result indicates the decoupled design between FRs and DPs. Moreover, the computer power control, the auxiliary automatic switch for appliances, and the computer power supply path do not meet the principles of independence axiom, which will cause inconvenience for users. Therefore, the design for the above three functions should be ameliorated. The axiomatic design approach should be effectively applied to any problems happened to green product design. At last, the application of this approach and the possible research directions in the future will be discussed.

Keywords:

Axiomatic Design, Green Design , *Energy Saving*, Power supply

1 INTRODUCTION

Today, there are a wide range of customer needs affecting decision makers in many decisions on product design and system design to find the most appropriate alternatives. To be competition conditions have carried customer needs to an effective position in all decisions related to service and production systems(Kulak, Cebi and Kahraman, 2010).

Traditionally, system design is based on experiences of knowledge, attemp and error. However, mistakes resulted from such empiricism may cause expensive cost. As system performance depends on design quality, the design of mechanical system is quite complicated and lack of interactions between software and harware, as well as human factors always exist, therefore, the greatest difficulty in system design is model construction (Suh, 1997). In modern design, customers' demands affect decision-maker's decision of product design and system design. Principle of Axiomatic design (AD) provides a h (Kulak,Cebi and Kahraman, 2010).

AD adopts Independence Axiom and Information Axiom as theoretical basis and rule, simplifies design procedures and provides a reference for considering problems about design decisions (Suh, 1990). In recent years, AD has been used by designers as solutions to design decision making in many special fields. Researches show that most AD principles are used for providing solutions to design problems (Kulak,Cebi and Kahraman, 2010). Consequently, AD can be viewed as a rational means extensively applied into engineering projects (manufacturing included), from design to construction and operation. Design through AD is a reasonable method and can act as a system framework with the design and technology of program system as a representative (Suh, 1997).

With design of energy-saving power supply(ESPS) as an example, this study uses principles, frame and processes of AD to conduct product function decomposition, confirm design parameters, verify whether the design

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confirms to design axiom, and thus to find out if the design meets users' demands.

2 AXIOMATIC DESIGN AND ITS PRINCIPLES

Suh's AD mainly elaborates four domains and two axioms. Four domains contain consumer domain, functional domain, physical domain and process domain. Consumer domain refers to consumers' demands and emphasizes on customer attributes (CAs). Consumers' demands must be considered and converted into Functional Requirements, abbreviated as FRs. Scuh functional requirements can be satisfied through product design aims. At this time, we must choose design parameters (DPs) most suitable for meetings these functional requirements. Then, such DPs may have diversified process variables (PVs). Fig1.

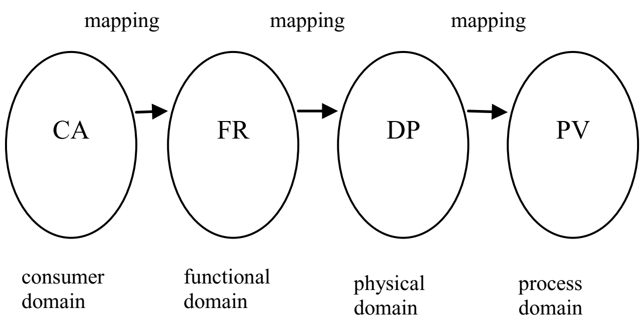

Fig 1 Four domains of AD (Suh, 1990)

Two axioms refer to independence axiom and information axiom, which are two wide-accepted conceptions (Kulak,Cebi and Kahraman,2010).

Axiom1: The Independence Axiom: maintain independent functional requirements.

Axiom2: The Information Axiom: minimum information contents. Under principle of independce axiom, each function must be satisifed and shouldn't have interrelationship with other functions. Therefore, must meet "an uncoupled design" or "decoupled design" (Suh,1990; Kulak,Cebi and Kahraman, 2010).

(1) uncoupled design: a good design should be uncoupled design, and its feature is a diagonal deisgn metrix. Through design parameters (DP), FR of a good design can meet independence axiom. Its metrix is presented as the following:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

(2) Decoupled design: when design metrix is lower triangular or upper triangular, DP can only meet independce axiom after being adjusted. Such design is called decoupled design. Its metrix is as below:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix} = \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

(3) Coupled design: other design metrixes being neither "uncoupled design" nor "decoupled design". Changes in FR value can result in changes in many design parameters (DP). Such design is inferior and the following is its metrix:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{pmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} = \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

Using independence axiom to design products can avoid interactions between two attributes, thus to reduce quantity of design parameters combinations and simplify processes of product design. According to AD theory, different deisgn parameters must meet different functional requirements. Therefore, people can choose different design schemes, but a good design must confirm to The Independence Axiom. FR and DP is one-to-one correspondence, changing one DP just affects its corresponding FR. Consequently, in design plan, the quantity of DPs must be equal to or higher than that of FRs. Otherwise, such design is coupled design and FR is not independent (Suh, 1990).

Independence axiom and information axiom can be applied into developing new products, processes and systems as well as evaluating and improving existed products, processes and systems. At first, independence axiom is used to identify decoupled design and coupled design, and effectively control the number of design schemes. If there are still more than two schemes, information axiom will be sued to find out the best scheme that has minimum information content. Alternatively, we can utilize independence axiom to find out inappropriateness of design at the first stage, and decouple the design through corresponding methods.

3 APPLICATION OF AD INTO GREEN DESIGN

AD has been extensively used for solving problems about product design (Suh,1990; Kulak,Cebi and Kahraman,2010). With regard to its application into green design, Stiassnie and Shpitalni(2007) take envrionmental factors into consideration and use AD to establish methods of evaluating environment performance.

Most manufacturers believe the basic functional requirement of manufacturing system is to obtain maximum Return On Investment (ROI). Therefore, FR_1=maximum ROI. Such requirement causes conflicts between envrionment, customer and enterprise. Manufacturers should provide updated prodcuts to meet consumers' requirements, correspond to ever-changing market, and minimize impacts on envrionmet. For the purpose of environment, higher-level function demands (FRs) should be proposed. DP_1 =manufacturing system, which is aimed at proving a good product meeting customers' demands and envronmental requirements. These four functional requirements are as the following (Stiassnie and Shpitalni, 2007):

FR11 = Increase the sales revenue

FR12 = Minimize manufacturing cost

FR13 = Minimize manufacturing investment

FR14 = Decrease economic environmental penalties

The corresponding basic DPs are:

DP11 = Manufacture products and/or service to maximize customer satisfaction

DP12= Target production cost

DP13= Investment in production facilities and machines based a long term analysis of expected products

DP14= Design a manufacturing system that complies with legislation standards.

Due to interactions between revenue, cost and investment, following four DPs are chosen as minimum coupling, and the design metrixes are shown in fig 2:

		DP_1			
		DP_{11}	**DP_{12}**	**DP_{13}**	**DP_{14}**
FR_1	**FR_{11}**	×	○	○	○
	FR_{12}	×	×	○	○
	FR_{13}	×	×	×	○
	FR_{14}	○	×	×	×

Fig 2: Hierarchic chart of AD metrix (quoted from Stiassnie and Shpitalni, 2007)

According to AD principles, such demands in product domain (users' expected product attributes) must be converted into functional requirements {FRs}.Then, FRs should be analyzed to guarantee independence between them. To satisfy these FRs, corresponding design parameters should be chosen. Therefore, we can consider as below: FR=realize the maximum product benefits and DP=manufacturing system, aiming to provide a good design satisfying customer demands and envrionmental requirements; by means of information axiom, choice can be made from envrionment-protecing and green data (Stiassnie and Shpitalni, 2007).

4 ANALYSIS OF ESPS PRODUCT

This study uses Suh's axiomatical design method to make a break-down explanation of mechanical design of an ESPS product patented under M395242, so as to verify whether it satisfy users' demands, find out problems in usage and propose points to be improved.

4.1 User interface analysis

To find out problems in usage by means of AD, the first things is to analyze steps of using product and settings of original product interface, and then define parameters of three domains in AD: CAs(customer attributes) , FRs(functional requirements) and DPs (design parameters). After corresponding CAs to FRs, an analysis of design matrix is made to check if the design meets users' requirements. The object of this study is an ESPS (patent application number: 099212842, patent number: M395242), applied for patent by Canfeng Technology Co., Ltd in July 2010. Its appearance and overall structure are shown in figs 3 to 6.

This power supply is designed to make the connected assistant electric appliance closed once the main electric equipment is turned off, so as to save energy, enhance life convenience and avoid accidental discharge of electric wire. This model of power supply has excellent features, but whether it has defect in design or points to be improved is still under discussion.

Common people always purchase power supply for extending power cord or increasing socket, and steps of user interface thus differ. According to these diversified demands, use order and operation instructions are presented as below.

This ESPS is composed of a socket, a power cord and a USB wire. Internal structure includes a relay and a power cord, one end of which has a power plug and the other end is connected with relay of this socket for supplying electricity to each hole and making the relay control electric current. The USB wire has a USB port at one end, and the other end is connected with the relay; in this way, the relay is open when the current passes through the USB wire, so as to form a circuit between power cord and each socket hole. When the current transmission of the USB wire stops, the relay is closed and the circuit between power cord and socket hole is broken. The distribution is shown in fig 4.

In this papted example, main electric equipment is computer host(40). Other assistant electric appliances can be connected with the socket (10). When user wants to use the computer and thus turn on the host(40), electric current will pass through USB wire(30). At this time, current formed from the 5V voltage of USB wire (30) becomes signal, whicih conducts the power of the realy (12), turns on the relay and thus forms a circuit between power cord (20) and metal blade of each hole (11). Therefore, power cord(20)also supplies electricity to assistant equipment. On the contrary, when user stops using computer and turning off the host (40), the relay (12) is also closed and makes the power cord (20)stop supplying electricity to assistant appliance.

This power supply connects the main electric equipment with USB port (31), and turn on or off the relay through closing or opening the main equipment, so as to avoid wasting electric power of assistant appliances and achieve energy saving. In addition, it reduces electromagnetic wave resulted from long-term openness of electric equipment, and people don't have to stay in harmful environment long. The power supply of assistant electric appliance is cut off after main equipment is turned off, so that risk of accident discharge is prevented. It is especially suitable for sites like offices that have no people during night, and small-scale store. It's quite beneficial.

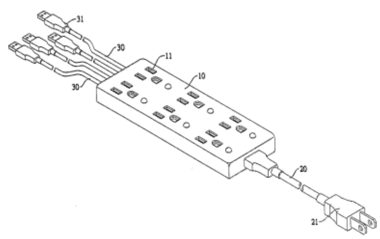

Fig 3 Apperance of ESPS

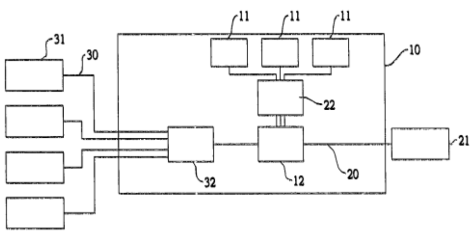

Fig 4 Structure of ESPS

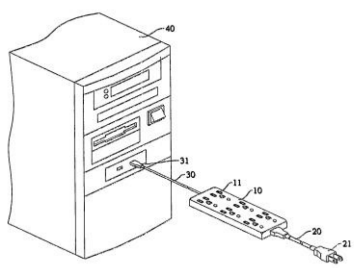

Fig 5 State of using ESPS

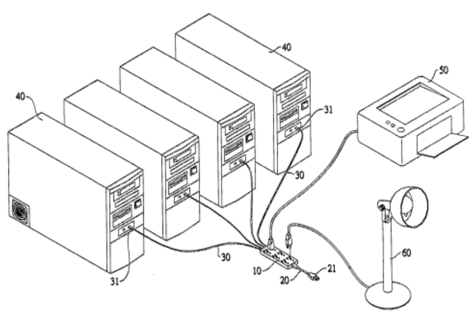

Fig 6 State of using ESPS with several USB wires

Table 1 is a technological efficacy matrix made for the ESPS patented under M395242. In this table, "efficacy" and "technology" is equivalent to "Functional Requirement (FR)" and "Design Parameter (DP)" of AD respectively.

Table 1 Technological efficacy matrix of patented ESPS

(DP) / (FR)	UBS wire	Socket (hole)	Power cord(power plug)	Relay	Ballast	Safety device
Main computer on/off	*		*	*	*	*
Current circuit control	*	*	*	*	*	*
Assistant electric equipmetn on/off		*	*	*	*	*

4.2 Analysis of design parameters

According to AD principle, it's necessary to control independence of each functional requirement and choose corresponding design parameter. We can consider it in this way: FR=realize power on and off, DP=power control apparatus. This is overall functional requirement of power supply. FR can be described in detail as below: FR_1=main computer power control, DP_1= main computer power apparatus; FR_2=circuit control, DP_2=circuit design scheme, FR_3=automatic on and off of assistant electric equipment, DP_3=current device of assistant electric equipment. Moreover, this patented power supply is designed to save energy, so green demands check should be conducted then.

Here, main computer power control refers to turning on devices that can open or close main computer, such as on/off device, USB wire, circuit device, power cord, power plug, etc. Circuit design scheme refers to design measures used for automatically controlling assistant electric appliances. To realize simultaneous power control with main computer, it's not necessarty to press on/off button on assistant equipment. For the purpose of satisfying work performance requirement of overall design, the first step is to confirm circuit design scheme (DP_2) because main computer power control (FR_1) as well as automatic on/off of assistant electric equipment (FR_3) both relate to such scheme (DP_2). Besides circuit design scheme, automatic on and off of assistant electric equipment (FR_3) is also related with main computer power apparatus. Therefore, the first level design formula is obtained through analyzing relationship between functional requirement and design parameter:

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix} = \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

There're 3 function modules at this level. In following sections, FR_1, FR_2 and FR_3 will be decomposed respectively:

(1) Decomposition of FR_1

FR_1 can be decomposed into: FR_{11}=computer on/off, DP_{11}=computer on/of control device, FR_{12}=computer power path，DP_{12}=computer power device.

FR_{11} is computer on/off requirement, so it must be jointly accomplished by DP_{11} and DP_{12}. However, this power supply is planned to achieve power control without pulling out power plug. Therefore, FR_{11} (computer on/off) can be completed by DP_{11} (computer on/off control device) independently. FR_{12} (computer power path) correlates with computer on/off and path of power device. Consequently, the second-level design formula is obtained through analyzing relationship between functional requirement and design parameter：

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \end{Bmatrix} = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix} = \begin{Bmatrix} DP_{11} \\ DP_{12} \end{Bmatrix}$$

As FR_{11} has met requirement of independence axiom, FR_{12} (computer power device) can be decomposed as: FR_{121}=current conduction, DP_{121}=computer USB wire, FR_{122}=power supply, DP_{122}=power supply pack (including power cord and plug). As current conduction mainly depends on USB wire and power supply is realized through power supply pack, the third-level relationship between FR12 and DP_{12} can be written as:

$$\begin{Bmatrix} FR_{121} \\ FR_{122} \end{Bmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{Bmatrix} DP_{121} \\ DP_{122} \end{Bmatrix}$$

(2) Decomposition of FR_2

In the design of this power supply, safety device and ballaster are designed for safely using electric equipment, and each functional requirement should possess this design parameter. The present study is aimed to investigate correspondence between functional requirement and design parameter. Therefore, to avoid excessive design parameters that interfere with main functional requirements, these two design paramters about safety won't be discussed here.

Circuit control of FR_2 needs a relay that controls current, and line configuration between main computer, assistant electric equipment and power. FR_2 is decomposed into: FR_{21}=current control device, DP_{21}=relay, FR_{22}=line configuration, DP_{22}= line configuration design. Relay and line configuration design are independent design parameters, so the second-level design formula is as below:

$$\begin{Bmatrix} FR_{21} \\ FR_{22} \end{Bmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{Bmatrix} DP_{21} \\ DP_{22} \end{Bmatrix}$$

(3) Decomposistion of FR_3

FR_3 can be decomposed into：FR_{31}=power path of assistant electric equipment, DP_{31}=power device of assistant electric equipment (power cord, plug and socket), FR_{32}=current control of assistant electric equipment, DP_2=circuit design scheme.

No matter FR_{31} is on or off, its power device must be on; that's to say, assistant electric equipment is not turned off and the plug is not pulled out. Therefore, FR_{31} (power path of assistant electric equipment) can be completed by DP_{31} (power device of assistant electric equipment) independently. FR_{32}(current control of assistant electric equipment) relates to DP_2(circuit design scheme), so second-level design formula is obtained through analyzing relationship between functional requirement and design parameter：

$$\begin{Bmatrix} FR_{31} \\ FR_{32} \end{Bmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{Bmatrix} DP_{31} \\ DP_{2} \end{Bmatrix}$$

(4) Decomposition of green requirement

This patented power supply is designed to save energy and enhance life convenience, and its usage has been verified by AD method. Then, green product check will be conducted. Description about materials and disposal processes of this power supply is not available, so we can only propose improvements in envergy consumption of office or househould power supply. This study adopts energy saving as FRs and analyzes its DP.

According to above descriptions, this power supply utilizes on and off of main electric equipment to cause on/off of relay, so that power of assistant electric appliances can be cut off after main electric equipment is turned off. In this way, power loss of assistant equipment can be avoided and effect of energy saving can be achieved. Therefore, green requirements inlcude: FR_4=reduce energy consumption, DP_4=relay control apparatus. FR_4 can be decomposed as: FR_{41}=main equipment controls openness of assistant appliances, DP_{41}=circuit design of main equipment and assistant appliances, FR_{42}= main equipment controls closeness of assistant appliances, DP_{42}= circuit design of main equipment and assistant appliances.

Seeing from relationship between FR_{41} and FR_{42}, these two functional requirements are both controlled by circuit design of main equipment and assistant appliances. Circuit control and above DP_2=circuit design scheme are the same device, so DP_{41} and DP_{42} are replaced by DP_2. A second-level design formula is obtained through analyzing relationship between functional requirement and design parameter：

$$\begin{Bmatrix} FR_{41} \\ FR_{42} \end{Bmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{Bmatrix} DP_{2} \end{Bmatrix}$$

After decompose above functions, we can get a power supply design matrix with 13 functional requirements and 11 design parameters (13 x11), as shown in table 2. 1 means being interrelated.

To find out goals of using matrix analysis, it's necessary to check if the design is coupled. Analysis results show: except FR_1(main computer power control), FR_3(automatic on/off of assistant electric equipment) and FR_{12}(computer power path) belonging to coupled design, other functions are all uncoupled design or decoupled design. According to AD principles, coupled functional requirement causes problems in product usability. Therefore, FR_1, FR_3 and FR_{12} should be further improved.

Table 2 matrix of ESPS design

	DP_1	DP_2	DP_3	DP_{11}	DP_{12}	DP_{21}	DP_{22}	DP_{31}	DP_{32}	DP_{121}
FR_1	1		1							
FR_2		1								
FR_3	1	1	1							
FR_{41}		1								
FR_{42}		1								
FR_{11}				1						
FR_{12}				1	1					
FR_{21}						1				
FR_{22}							1			
FR_{31}								1		
FR_{32}									1	
FR_{121}										1
FR_{122}										1

Note: 1 means FR and DP affects each other (interrelated). Blank is 0, representing FR and DP are not interrelated.

5 CONCLUSIONS

With ESPS as the object, this study uses Suh's AD method to analyze problems about design interface and use requirements, sufficiently considers interrelations between each functional requirement during product deisgn analysis, and finally finds the design of this product is rational. This paper also observes whether it comfirms to independence axiom through design matrix, so as to analyze if product design meets use requirements and find out design defects.

An analysis of AD method finds that "main computer power control", "automatic on/off of assistant electric equipment" and "computer power path" should be improved, so we'll investigate solutions to problems of these three functions.

Concerning functions "main computer power control" and "computer power path", besides the openness or closeness of computer on/off control device, smoothness of power circuit is also a key point for computer on/off. Main computer current must form a current path through circuit, and this is a necessary design parameter for "main computer power control". However, in the design of this patented product, circuit design scheme is a fixed and smooth design mode. Therefore, FR_1 "main computer power control" doesn't need improvement although it is coupled design.

With regard to FR_3 "automatic on/off of assistant electric equipment", openness and closeness of assistant equipment is affected by computer on/off and power circuit smoothness. Modern printer always has other functions like copy and fax, and doesn't need using computer, so it's unnecessary to turn on the computer. If someone wants to just use desk lamp or printer, he/she still has to open the switch of main computer to form current circuit. This process increases operation inconvenience. AD analysis shows that this function can cause problem in usage, so improvement is needed.

Moreover, FR_2, FR_3, FR_{41} and FR_{42} can only be completed through DP_2. This part is not coupled design but decoupled design. According to AD principles, to meet requirements, it's necessary to keep watch for operation order. From a viewpoint of energy saving, as FR_{41} and FR_{42} are both limited by circuit control, it's quite envergy-conservation and safe because power of assistant appliance is cut off once main equipment power is off. When main equipment power is on, assistant appliance power is also ready for use, so it doesn't meet the requirement of energy saving and thus needs to be improved.

Finally, future research directions are presented according to conclusions of this study:

(1) This paper makes a research on a patented ESPS. It analyzes design structure in detail, but analysis of product life cycle is not available due to limietd data collection. In the future, we can look for products with complete life cycle information to implement AD analysis from a green viewpoint, thus to get more achievements.

(2) This study just proposes how to make product analysis through AD and thus find out product design defects. It doesn't indicate improvement strategy. How to decouple should be studied in the future.

(3) It's suggested to use methods of this study to collect users' viewpoints and experiences of using product and make further discussion.

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An Upgrade Design Method for Environmental Issues Based on the Concept of Set-Based Design

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Abstract

With worsening environmental problems such as the depletion of natural resources and global warming, environmentally conscious design is required. This paper proposes an methodology of upgrade design of product for environmentally conscious design based on the concept of set-based design. Usually the prediction of upgrade performance or upgrade-time would have uncertainties caused by the future situation of design. So there are some possibilities that the upgrading will affect geometry of the target module, performance of non-target modules, cost, life and environmental load of product. And also, upgrade design problem requires multi-objective evaluation of those various design items about target modules and non-target modules while handling the uncertainties. In our previous study, we propose a preference set-based design (PSD) method that can obtain a ranged set of design solutions that satisfies multiple performance requirements concurrently such as physical performance, environmental indication, and cost by representing uncertain design information as ranged sets with designer's intention. This study proposes the fundamental concept and a concrete method for upgrade design based on PSD method, and then we obtain design solutions of product by a predicted range of upgrade performance. The proposed method applies to robot arm design and we obtain multi-objective ranged solutions of the design, which satisfies predicted range of upgrade performance, including environmental issue. Finally, we discuss the availability of the proposed PSD method for upgrade design with uncertainty and environmental issues by evaluating multi-objective items including product performance and environmental load by upgrade.

Keywords: upgrade design, set-based design, preference, flexible and robust design, early phase of design.

1 INTRODUCTION

With worsening environmental problems such as the depletion of natural resources and global warming, environmentally conscious design is very important and required to be solved. Some of options of environmentally conscious design are recycle, reuse and upgrade. Recycle and reuse aim at reducing environmental load at the end of life of product. Meanwhile, upgrade design can extend the life of product along with increasing its value for customers by exchanging parts or modules while in service. So, upgrade design aims at the reduction of environmental load while in service. This study considers an upgrade design methodology.

Usually the prediction of upgrade performance or upgrade time would have uncertainties caused by the future industrial situation of design. Umeda et al. [1] proposed an upgrade method where upgraded modules or parts are selected from parts database based on development prediction in future manufacturing industry. They should also handle uncertainties in the future for upgrading the database. However, this method only can handle physical performance. In contrast, we consider that in addition to physical performance, the upgrade design should require multi-objective evaluation such as cost, life and environmental load of product. Because there are some possibilities that the upgrade affects the performances, geometry, cost, life and environmental load of upgrade target module and non-target modules.

In our previous study, we propose a preference set-based design (PSD) method [2] that can obtain a ranged set of design solutions that satisfies multiple performance requirements at the same time such as physical performance, environmental load, cost and so on by representing uncertain design information as ranged sets with designer's intention.

The present study investigates the fundamental concept and a practical method for upgrade design based on PSD method. We can evaluate the upgrade effect on the ranged

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sets of design solution and enable the designer to see the results of upgrade design expressing some uncertainties caused by future situation of design, based on the proposed methodology.

2 A PREFERENCE SET-BASED DESIGN

A preference set-based design (PSD) method enables a flexible and robust design while incorporating a designer's preference structure. PSD method generates a ranged set of design solutions that satisfy various kinds of performance requirements. PSD method introduces the number for preference to reflect the designer's intention. The number can be given for the ranged set of performance and design variable of product, and is defined between 0 and 1. The preference number, 0, means the allowable range and the number, 1, being the most preferable range, as shown in Fig. 1.

At the 1st step of PSD, that is, set representation, all of the required performances and design variables are represented as ranged sets with preference number by product designer, shown in Fig. 1. The ranged set of performances calculated from the ranged sets of design variables is called possibilistic distribution of performance. This process is the 2nd step of PSD that is called set propagation. In the case that possibilistic distribution calculated by the entire range of each design variable does not completely satisfy each ranged set of required performances given by designer, the ranged set of each design variable is divided into some smaller regions. The combinations of the divided region of design variables are propagated to the performances. The dividing is repeated until the combinations meet every ranged set of required performances. This process is called set narrowing that is the 3rd step of PSD. In the narrowing process, as evaluation criteria of compatibility between ranged sets of possibilistic distribution from design variables and performance required by designer, satisfaction degree and robustness of the ranged set solution are introduced.

3 UPGRADE DESIGN

There are two assumptions for update design in the present study. The first is as follows. Usually the performances to be upgraded are obtained by the prediction of future situations of industries and customers. This means upgrade performances, including the issues of technical, economical, environmental load and time progress, would have uncertainties based on the future prediction. So, in this study, we apply PSD method to treat the uncertainties of upgrade performances as a range set, not as point-based performance.

The second assumption is that a product consists of modules. In the view of the present study, there are two kinds of module, such as target and non-target modules of upgrade. So, design solutions for each module is developed as range-based solutions. There are two cases that upgrade of target module affects the design of non-target modules and do not affect. For understanding the functional relationships between target module and non-target modules, we use a functional structure diagram as shown in Fig. 2. The diagram shows input-output relation

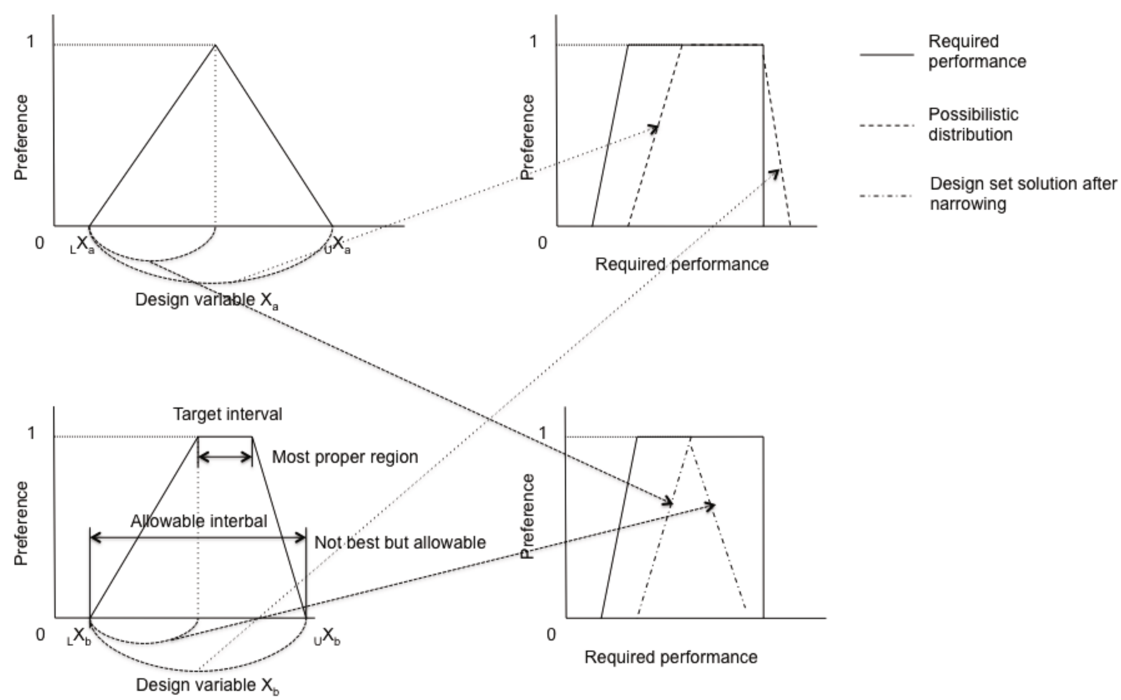

Fig. 1: Procedure of set-based design method.

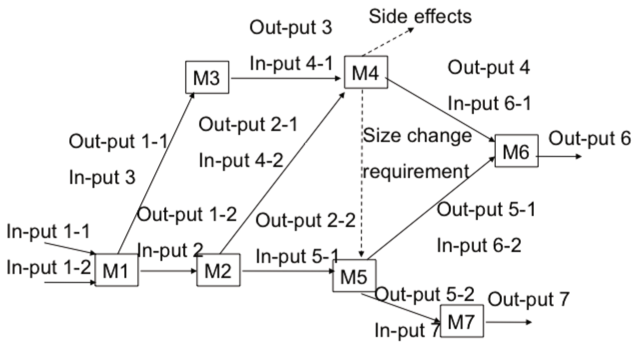

Fig. 2: Functional structure diagram.

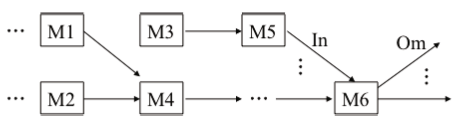

Fig. 3: Functional structure diagram with simple relationships.

of each module, that is, functional relationships among modules including upgrade target and non-target modules.

The diagram allows us to understand qualitatively the upgrade effect for non-target modules. Usually, a product may have complicated functional relationships, shown in Fig. 2. In the present study, to show the concept of the proposed methodology, we apply our upgrade method to the product with simple relationships, shown in Fig. 3.The symbols, M, In and Om, in Fig. 3 mean module, input and output of each module, respectively.

Generally speaking, upgrade design is related to the factors of functional performance, geometry, layout, cost, environmental load, over-specification, durability life, value life, and so on. This means the multi-objective evaluation of upgrade design. The purpose of the present study is to show that PSD method is very effective for upgrade design solution. Fig. 4 shows the process to solve the upgrade design problem by PSD method. We explain each process in 3.1 to 3.4 and chapter 4.

In the present paper, the followings are considered as the first step of the study.

(a) Range of upgrade performance of upgrade target module.

(b) Effects of upgrade on performances of upgrade non-target modules.

(c) Environmental load of product or modules by upgrade.

(d) Over-specification of non-upgrade product in performance and environmental load.

(e) Total comparison of upgrade and non-upgrade products, based on PSD method.

Generally, product design strategy differs depending on each product itself, designer or manufacturing company. So, the upgrade design result obtained by the present method is placed to show the possibility of upgrade design for designers. Namely, it depends on the design strategy whether the result is referred or not.

3.1 Considerations of Upgrade Performance

Target module and upgrade performance are determined by evaluating value deterioration of performance by customers or by development strategy of product by manufacturer. One of the methods to determine the upgrade target module is proposed to use the concept of Quality Functional Development (QFD) [3]. Ranged set of upgrade performance is predicted by customer's purchasing trends for the past product or prediction of future technical development at upgrade time. In the present study, ranged set of upgrade performance is introduced as the change from the original (non-upgraded) performance to upgrade performance.

Upgrade-time can be also determined by the prediction of product life. The upgrade-time has uncertainty that is similar to that of upgrade performance. In order to treat upgrade-time as the ranged set, we can use waste data of the past product, total performance analysis [4], evaluations of deterioration of the product's value or the other product waste prediction results to estimate product life.

For example, Fig. 5 shows a schematic graph of value deterioration of a product through the relation of value life and durability life of product. This graph is generally made for a product with a longer durability life than value life. The product can be used until the end of its durability life (T_2), but the actual product will be disposed at the end of product value life. So, real service time of product by customers is T_0 to T_1 of Fig. 5. If product disposal is for replacing a past product to a new one, according to product's value life, the time around T_1 is set to upgrade time by the designer. If the product will be upgraded at T_1 in a range of upgrade-time, product value will increase as shown in Fig. 6. This means the extension of product value life from T_1 to T_3 and the decrease of product disposal. However, in the present paper, the treatment idea for upgrade time mentioned above is just shown, and then is not introduced in the calculation of an example problem shown later.

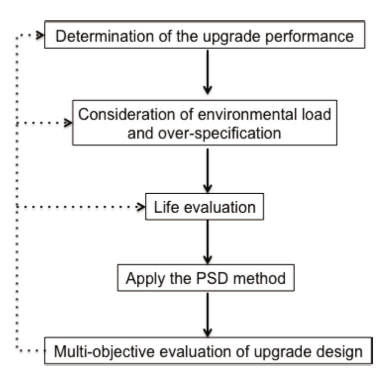

Fig. 4: Procedure of upgrade design method.

3.2 Consideration of Environmental Load and Over-Specification

Upgrade product might be in the state of over-specification to non-upgrade product at the time of design for original manufacturing. In this paper, in addition to product performance, we treat environmental load as performance requirement. These requirements are also expressed in terms of ranged set for target and non-target modules according to the result of the upgrade.

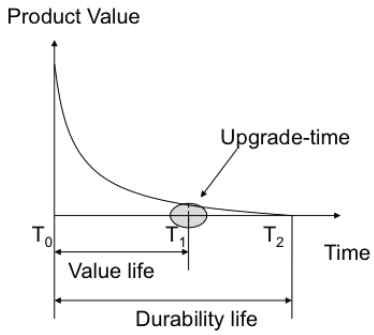

Fig. 5: Product's value graph

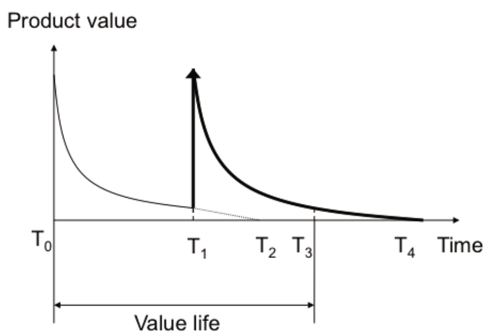

Fig. 6: Upgraded product's value

Then, there is a possibility that the introduction of a concept of ranged set for upgrade product design will save environmental load more than replacing a product and will avoid upgrade design of a product with too much over-specification.

Environmental load is determined by product function, performance, manufacturing facility, material, shipping and so on. In this paper, we calculate the amount of carbon dioxide output in terms of environmental load units and volume of product materials as evaluation of environmental load.

3.3 Life evaluation for Non-Target Module

The target module will be replaced at upgrade-time. But, non-target modules will continue to be used even after upgrade time. So, non-target modules need an evaluation of durability life of the product. That's why non-target modules, at least, need a durability life until T_4 in Fig. 6.

Product life or module life is evaluated in terms of water resistance, abrasion resistance or rupture strength. Non-target modules will have a much longer life than target modules. So non-target modules of upgrade product are more over-specified than non-upgrade product's modules at the time of original manufacturing. However, since non-target modules have longer durability life, it can be components of a reusable product with or without upgrade and have the potential for reduced environmental load.

3.4 Apply the PSD Method

In this paper, we obtain ranged sets of upgrade performance and design variable that affect the upgrade by PSD method, following the functional structure diagram. Fig. 7 shows functional structure diagram that is made for 2 modules, that is, module 1(M1) is target module and module 2(M2) is non-target module. In the case that out-put 1-2 (upgrade performance) changes at upgrade-time, ranged sets of out-puts 2-1 and 2-2 are calculated by PSD method.

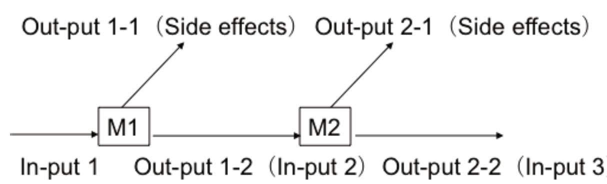

Fig. 7: Input-output relationship between modules M1 and M2.

For example, X_1 and X_2 are assumed to be design variables of target module M1 and non-target module M2, respectively. Fig. 8 shows ranged sets for design variables, required performance of upgrade product, possibilistic distribution and design set solution after narrowing. Possibilistic distribution calculated by the original entire ranged sets of X_1 and X_2 does not satisfy range set of required performance. Fig. 8 shows that the ranged set of design variable X_2 is divided and that a combination of a divided set (1) of design variable X_2 and the original set of variable X_1 satisfies range set of required performance.

4 EXAMPLE PROBLEM

In this paper, we apply our upgrade method to transfer robot arm. Functional structure diagram of this robot arm is shown in Fig. 9. And we evaluate upgrade design of robot arm by upgrade performance, non-target module's performances and environmental load.

4.1 Design Problem

Robot arm is required for transfer performance such as how much weight it can transfer. The upgrade scenario in

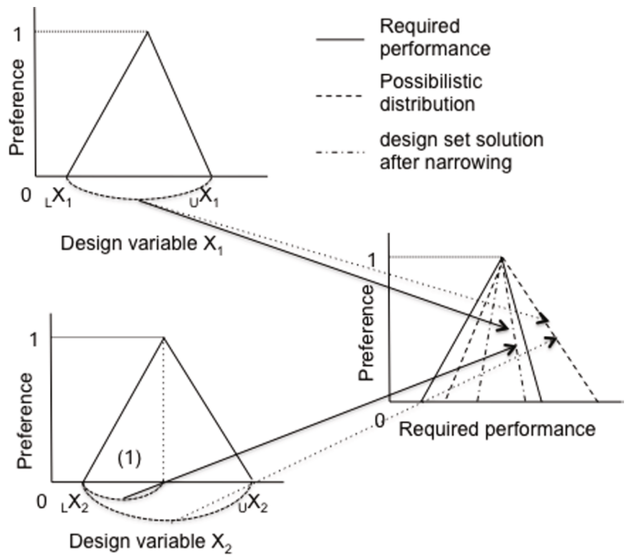

Fig. 8: Ranged sets of Design variables of X_1 and X_2, required performance, possibilistic distribution and design set solution after narrowing.

the present paper is as follows. The decided upgrade plan is about the increase of transfer performance twice. So, if original robot arm has transfer performance of 4 kg, a scenario is to upgrade this performance to 8 kg by replacing a part of motor. Because motor is closely involved in transfer performance. We consider uncertainties caused by future industrial situation and treat upgrade performance as a range, this is set to [7, 9] in kg. The performance is related to designs of arm and power shaft, transmission of power from motor to arm and material (assumption of aluminum). Actually, strength design is carried out to meet changes of load by upgrade. So, required performances are shear stress of power shaft and bending stress of arm, and then design variables are outside diameters of arm and power shaft are introduced. Ranged sets of design variables of non-target modules that satisfy ranged sets of upgrade performance, required performance and environmental load are obtained by PSD method. Environmental load is evaluated by the volume of structural components and environmental load unit for aluminum material.

Environmental load of upgrade product is smaller than that for replacement product and is evaluated for carbon-dioxide emission for this example problem. When non-target upgrade product is manufactured, the amount of carbon-dioxide emission yields 45 kg. When a product is replaced to that with target module, another 45 kg of CO_2 is emitted. So if less than 45 kg of carbon dioxide is emitted by upgrade, we avoid over-specification of non-target modules. If less than 90kg of carbon dioxide is emitted, we have reduced environmental load more than replacing a product. That's why the preference number 0 is set for CO_2 emission of 90 kg and the number 1 is set for 45 kg, shown in Fig. 10.

4.2 Results and Discussions

Fig. 10 shows each ranged set of the design variables, upgrade performance, required performances including environmental load and design set solutions after narrowing step of PSD process. This result shows if arm diameter and power shaft diameter are designed by combining ranged sets of the design variables that are the results of PSD calculation, as shown in Fig. 10 (Power Shaft Diameter: [0.04, 0.05] in m and Arm Diameter: [0.052, 0.055] in m), they can be prepared for upgrade effect.

Also, this combination enables us to decrease bending stress of the arm and shear stress of the power shaft to the range of required performances.

Calculating result of the amount of carbon dioxide shows that the upgrade product saves environmental load more than replacing the product to a new non-upgrade product. If we calculate the amount of carbon dioxide output not only for manufacturing process and shipping process but also for different material usage, we can expect it make much more difference in environmental load between the productions of upgrade product and non-upgrade product. This result also shows the upgrade product yields the amount of carbon dioxide output that is more than 45 kg. Also, it is said this non-target modules of upgrade product have over-specification at manufacturing more than non-upgrade product.

Thus, the proposed method can provide a kind of upgrade design method, considering the changes in environmental load, required performances and design variables. Then the designer can evaluate upgrade design at the original design phase.

5 CONCLUDING REMARKS AND FUTURE WORK

In this paper, upgrade design method based on PSD is proposed. In order to show the availability of the method, an example problem to upgrade the performances of robot arm, including environmental load, is designed. In the design, some kinds of uncertainties caused by the future industrial situation are evaluated. In the future, in addition to the issues considered in the present paper, the other uncertainty factors of the cost, life and reusability of product and so on will also be investigated.

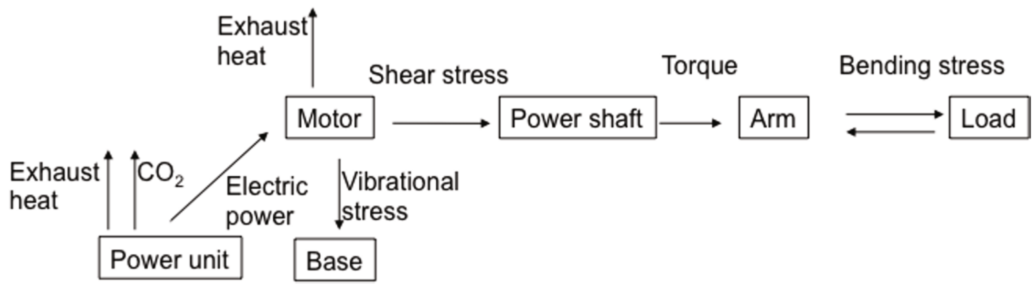

Fig. 9: Functional structure diagram of this robot arm

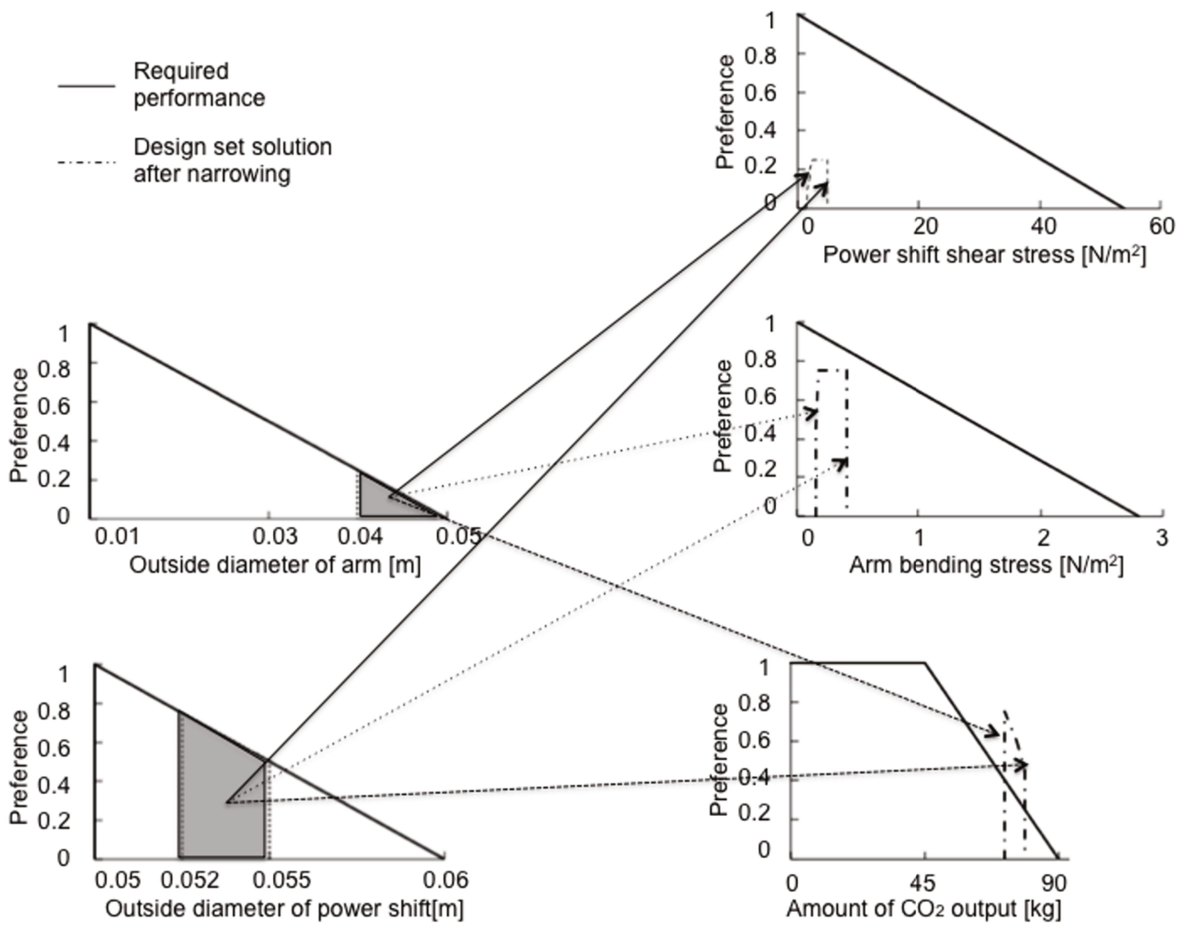

Fig. 10: Required performances and design variables, possibilistic distribution and design

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Recycling Valuable Metals via Hydrometallurgical Routes

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Abstract

The hydrometallurgical method is one of the key technologies in metal recycling, because it enables the fine separation between chemically-similar metals and a small-scale operation. In this paper, the recent results of our hydrometallurgical recycling studies are outlined. The topics include (i) noble extractants for precious metal separation, (ii) recovery of rare-earth elements from neodymium magnet scrap, (iii) nickel recovery from spent electroless nickel plating baths, and (iv) an energy-saving copper recycling process. In (i), new amide-type solvent extraction reagents have been developed for precious metals, one of which, thiodiglycolamide, rapidly and selectively extracts palladium from platinum and has a high durability against oxidation. In (ii), a process consisting of oxidative roasting – selective acid leaching followed by solvent extraction separation of dysprosium from neodymium has been proposed. In (iii), solvent extraction using a chelating reagent is used to extract nickel ions from spent electroless nickel plating baths, and the nickel ions are recovered as a nickel sulfate solution which can be reused in the plating process. In (iv), a copper recycling process utilizing monovalent copper in an ammoniacal alkaline solution is described, which would significantly reduce the energy requirement for copper electrowinning.

Keywords:

recycling, hydrometallurgy, solvent extraction, electrowinning, platinum, rare earth, nickel, copper

1 INTRODUCTION

Metal recycling is becoming increasingly important, particularly in countries with limited natural metal resources and limited landfill areas like Japan. The hydrometallurgical method is one of the key technologies in metal recycling, because it enables the fine separation between chemically-similar metals and a small-scale operation. In this article, our recent results regarding metal recycling using the hydrometallurgical method are outlined. The topics are (i) noble extractants for precious metal separation, (ii) recovery of rare earth elements (REEs) from neodymium magnet scrap, (iii) nickel recovery from spent electroless nickel plating baths, and (iv) energy-saving copper recycling process.

2 NOBLE EXTRACTANTS FOR PRECIOUS METAL SEPARATION

Precious metals such as gold, silver, platinum, palladium, and rhodium are widely used in the advanced industry fields. Because of their limited resources, however, their supply is fragile. Therefore, in order to stably supply such precious metals, the promotion of their domestic recycling is very important.

Solvent extraction is mainly employed as a separation method for precious metals. In a typical commercial process, after dissolving the precious metal wastes with hydrochloric acid containing chlorine, silver is first removed as a residue (silver chloride), then the gold, palladium and platinum are extracted using dibutylcarbitol (DBC), dialkylsulfide (DAS) and tri-*n*-butylphosphate (TBP), respectively, and rhodium remains in the raffinate [1, 2]. Although these extractants have already been established typical reagents, they have some problems; i.e., low hydrophobicity(DBC), low stability against acid (DAS), slow extraction (DAS), and low extraction (TBP).

Our major interest in this study is the application of *N*,*N*-disubstituted amide compounds as the extractants for precious metals, because their hydrophobicities can be enhanced by introducing long-chain alkyl groups into their side chains, and their extraction properties and selectivities can be customized by changing the number of amide groups or introducing another donor atom into the molecular structure. Therefore, we synthesized several amide compounds and investigated their extraction properties for precious and common metals, and have developed effective amide extractants for the separation of precious metals; monoamides for gold [3, 4], thiodiglycolamides for palladium [5, 6], diglycolamides for platinum [7] and amide-containing tertiary amines for rhodium [8]. The extractants for palladium and rhodium are now described.

Palladium(II) and platinum(IV) are similar in chemical properties and belong to soft acids based on the HSAB rule; thus, their mutual separation is not easy. The current extractant, DAS, tends to be oxidized and its extraction rate of palladium is very low. In order to solve these problems, we have developed thiodiglycolamide (TDGA)

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shown in Fig. 1, in which a sulfur (soft base) is introduced between two amide groups. By the batch shaking-out study using hydrochloric acid solutions, the fast kinetics for palladium(II) extraction and high selectivity for palladium(II) from platimum(IV) were found for TDGA [5]. Also, the long-term contact of TDGA with the mixture of nitric acid (0.75 mol/L) and hydrochloric acid (2.25 mol/L) revealed the high durability of TDGA against oxidation. Therefore, it is expected that TDGA can be used as a selective extractant for palladium(II).

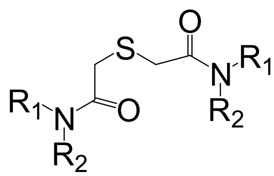

Fig. 1: Chemical structure of TDGA.

Because rhodium is difficult to extract, there is no effective industrial extractant for this metal. However, we have recently developed an effective reagent for rhodium, *N*-*n*-hexyl-bis(*N*-methyl-*N*-*n*-octyl-ethylamide)amine (HBMOEAA) [8], by introducing two amides into the tertiary amine (Fig. 2). This is done by considering the size-recognition effect of the outer-sphere of the target complex [9]. The extraction of rhodium, palladium, and platinum from hydrochloric acid solutions was investigated. HBMOEAA was found to extract 80% rhodium (100% palladium and platinum) from 0.5 – 2 mol/L hydrochloric acid solutions. This is a very high efficiency as the rhodium extraction from a relatively higher concentration of hydrochloric acid. After extraction of palladium, platinum, and rhodium from 0.5 – 2 mol/L hydrochloric acid solutions, only the extracted rhodium was stripped with 10 mol/L hydrochloric acid. This means that rhodium can be recovered before industrial palladium and platinum. In this sense, HBMOEAA has high potential to become an effective rhodium extractant.

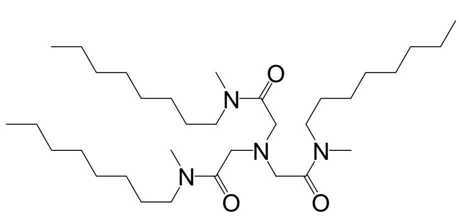

Fig. 2: Chemical structure of HBMOEAA.

3 RECOVERY OF RARE EARTH ELEMENTS FROM NEODYMIUM MAGNET SCRAP

Neodymium-iron-boron magnets (neodymium magnet) are widely used in automobiles, hard disk drives, and electric appliances, and now indispensible for our daily life. The neodymium magnet contains several percent dysprosium, which is a heavy REE and of high value. The establishment of a recycling technology from magnet scrap is an urgent issue.

A large amount of cutting and polishing wastes of the magnets are being generated [10]. This in-plant scrap is recycled by the manufacturers, while the magnets placed in the products and commercially sold are not recovered after disposal.

As for the magnet waste in the disposed products, a large amount of impurities will be present in the recovered magnet. Thus, it is necessary to establish a process to remove these impurities and also mutually separate the rare earth elements.

The neodymium magnet contains 60 -70% iron. Thus, it will be uneconomic to totally dissolve the magnet by acid. Instead, selective leaching is required, which dissolves only the REEs and leave the iron in the residue. From this viewpoint, we are studying an REE separation process in which the oxidative roasting is applied to the demagnetized magnet in order to transform iron to hematite, Fe_2O_3. Because hematite is insoluble in the dilute acid, selective leaching of the REE is possible. After the selective leaching, dysprosium is separated from neodymium and other impurities by solvent extraction.

Table 1 shows the effect of roasting on the leaching efficiency of each metal in the neodymium magnet [11]. Although the leaching efficiencies of the REE with and without roasting are both high, it is shown that roasting depresses the iron leaching and thus enhances the for REE selectivity. The XRD analysis identified that the leaching residue of the roasted magnet was Fe_2O_3.

Table 1 : Effect of roasting on the leaching efficiency of each metal in the neodymium magnet

	Fe	Nd	Dy	Pr
With Roasting (1173K, 21.6 ks)	0.48	>99	>99	>99
Without Roasting	56	>99	>99	>99

(HCl:0.02 mol/L, Leaching temperature: 453K, Leaching time: 7.2 ks)

Solvent extraction is generally applied to the separation and purification of the REE. The extractant, 2-ethylhexylphosphonic acid mono-2-ethylhexyl ester (EHPNA), is usually used for this purpose. Fig. 3 shows the relationship between the equilibrium pH and the extraction percentage of dysprosium(III) and neodymium(III) with EHPNA. It is shown that dysprosium(III) is selectively extracted in the lower pH region. The extracted REE can be stripped (back-extracted) with a higher concentration of acid. Neodymium can also be extracted with EHPNA at a higher pH leaving the impurities, such as nickel and boron, and easily stripped with acid [12]. The REEs in the solutions obtained by the acid stripping can be precipitated by adding oxalic acid in order to form RE oxalates which are calcined to obtain RE oxides.

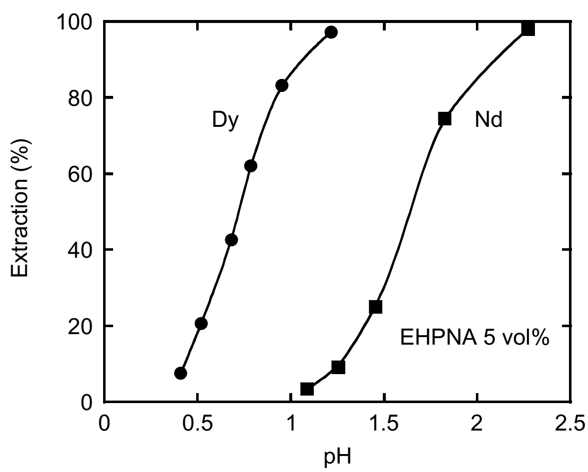

Fig. 3 : Effect of the equilibrium pH on the percentage extraction of Dy and Nd. Aqueous phase: 1 mol/m^3 $Dy(NO_3)_3$ or $Nd(NO_3)_3$ in 1 kmol/m^3 (Na, H)NO_3 (single RE solution) . Diluent: Shellsol D70. Temp.: 298K. Volume ratio: 1.

4 NICKEL RECOVERY FROM SPENT ELECTROLESS NICKEL PLATING BATHS

With the increasing importance of the electroless nickel plating technology in many fields, such as the electronic and automobile industries, the treatment of the spent baths is becoming a serious problem. The spent baths are currently treated by a conventional precipitation method, and nickel in these baths is not recovered. Thus, it is necessary to recover and reuse nickel in the spent bath from the standpoints of environmental protection and economy of the plating plants. Here we summarize our studies related to the nickel recycling process from the spent baths using solvent extraction.

In our proposed process (Fig. 4), the impurity metals of zinc and iron are initially removed by acidic organophosphorous reagents, such as EHPNA, without adjusting the pH. This is based on the fact that EHPNA selectively extracts zinc and iron from weakly acidic solutions leaving nickel in the aqueous raffinate [13]. The aqueous raffinate is sent to the nickel extraction stage using a β-hydroxyoxime, such as 2-hydroxynonylacetophenone oxime (HNAPO), which is a chelating reagent, as the extractant. It is necessary to increase the pH to 6-7 by adding sodium hydroxide in order to achieve the equilibrium extraction of 99% or higher. Nickel stripping is easy with sulfuric acid at the equilibrium pH of less than 3; thus, a concentrated nickel sulfate solution can be obtained [14]. However, the extraction and stripping rates of nickel with LIX84I are so low that high efficiencies cannot be obtained during a continuous operation. This difficulty was solved by adding a small amount of an acidic organophosphorous reagent to the organic phase as an accelerator. For example, by adding 2 vol% EHPNA, the time to attain equilibrium during the vigorous mixing is reduced from 60 to 10 min for extraction and from 60 to 20 min for stripping [13]. Because (i) the equilibrium extraction percentage was only slightly affected after adding the acidic organophosphorous reagent [13], (ii) the extracted complex was found to be the same as that with the single LIX84I based on the XAFS measurements [15], and (iii) the dominant species adsorbed at the aqueous/organic interface at the pH greater than 5 seems to be the EHPNA anion [16], the acidic organophosphorous reagent plays the role of a phase transfer catalyst between the aqueous/organic interface and the bulk organic phase. A detailed kinetic study is now being carried out by us [17].

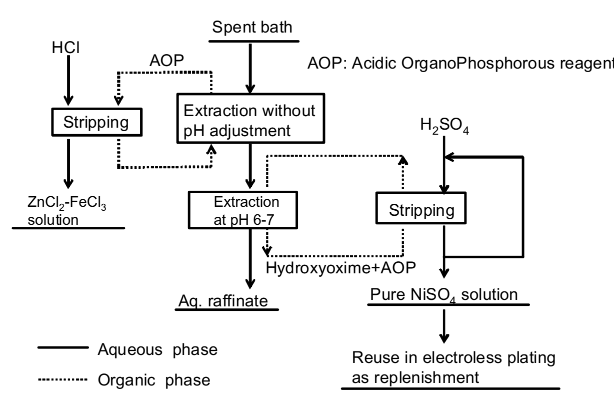

Fig. 4 : Process flowsheet for the nickel recovery from the spent electroless nickel plating baths using solvent extraction.

According to the continuous test using a mixer-settler extractor, a 99.9 % nickel extraction was obtained for three countercurrent stages, while a 98.4% nickel stripping was achieved with 1 mol/L sulfuric acid using two countercurrent stages [18].

The recovered nickel sulfate solution can then be reused for the electroless nickel plating process. The plating test employing the baths containing 20-100% of the recovered nickel revealed that the use of the recycled nickel caused no change in the plating rate [19].

As for the extraction behavior of nickel using the mixer settler, a chemical engineering model considering the extraction equilibrium and kinetics, fluid dynamic property in the mixer, and material balance between each stage was found to semi-quatintitatively reproduce the extraction data [20].

This process was installed in a plating plant of an electroless nickel plating company in Japan and successfully operated for more than one year [21]. At present, in order to enhance the efficiency, the improvement of the extractor is under investigation by the Japan Atomic Energy Agency in collaboration with us [22].

5 ENERGY-SAVING COPPER RECYCLING PROCESS

A significant amount of copper (10 - 30 mass%) is present in waste printed circuit boards (PCB). Currently a part of this copper is recovered via a pyrometallurgical route in copper smelters; however, the process cannot be operated without sulfide ore. As a technological option in the future, a compact and flexible process operated without sulfide ore should be developed. Hydrometallurgical processes have often been proposed in order to recover copper from such wastes. In these processes, copper is electrowon from cupric ions in a sulfuric acid solution. Because the power consumption of this electrowinning is high (2000 – 2500 kWh/ton), the economic feasibilities of these processes are questionable. We have developed a new hydrometallurgical process with electrowinning from cuprous ions as the core technology. The recent summary by Wang et al. [23] about the dissolution method of metallic copper shows that our method is unique.

Figure 5 shows the flow sheet of the energy-saving copper recycling process from electronic scrap. This process uses an ammonia-ammonium salt solution containing cuprous ammine complexes (Cu(I)) and cupric ammine complexes (Cu(II)), and consists of the three stages of leaching, purification and electrowinning [24]. In this process, copper is recovered in the following way: (i) copper in the waste is oxidized by Cu(II) and dissolved as Cu(I) in the solution during the leaching stage, in which iron and aluminum will not be dissolved, (ii) impurities in the solution are removed by solvent extraction, etc., (iii) the pure Cu(I) solution is introduced into the cathode compartment of an electrolytic cell, and half of the fed Cu(I) is reduced to metallic copper on the cathode, (iv) the remaining Cu(I) is transferred to the anode compartment and is oxidized to Cu(II) on the anode, and (v) the formed Cu(II) is reused as the oxidizing reagent in the leaching stage. One of the advantages of this process is the low power consumption requirement during the electrowinning stage. The cathode and anode reactions during the electrowinning are as follows:

$$\mathrm{Cu(I)} + e^- = \mathrm{Cu} \qquad E_0 = -0.10 \text{ V vs. SHE} \qquad (1)$$

$$\mathrm{Cu(II)} + e^- = \mathrm{Cu(I)} \qquad E_0 = 0.10 \text{ V vs. SHE} \qquad (2)$$

The theoretical cell voltage of this process is 0.20 V, which is much lower than that of the conventional copper electrowinning process using a sulfuric acid and cupric sulfate solution, i.e., 0.89 V. In addition, the copper electrowinning from the monovalent state essentially requires half the amount of electricity that is required for the conventional electrowinning from the divalent state. Based on these two facts, the theoretical power consumption requirement of this electrowinning is about 9 times lower than that of the conventional one.

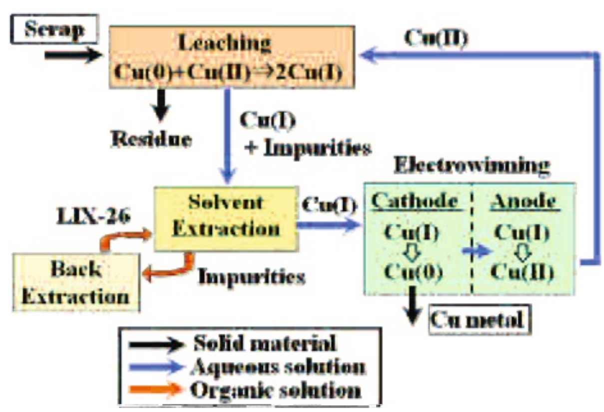

Fig. 5 : Flowsheet for the energy-saving copper recycling process.

Up to now, we have obtained the following results : (i) Cu(I) is formed by dissolving metallic copper with Cu(II) in an ammoniacal alkaline solution [24], (ii) both the cathode and anode reactions of the electrowinning took place at high current efficiencies [25, 26], (iii) the impurities like zinc and lead are removed by solvent extraction [27], (iv) high purity copper is recovered even from a real PCB waste [28], and (v) the lead content lead as a major impurity in the electrowon copper is decreased using a phosphate ion [29].

6 CONCLUSIONS

Our results for the four hydrometallurgical recycling projects have been summarized. Recently, the recycling of valuable metals is receiving more attention because of the significant increase in their prices. Hydrometallurgy is believed to be a useful method in order to specifically achieve a fine separation, while we have to recognize its drawbacks such as slow kinetics and requirement of the water treatment facility. The combination of pyro- and hydrometallurgies is essential for the optimum solution.

ACKNOWLEDGEMENTS

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Development of Eco-Friendly Thermoelectric Materials as Alternatives to Rare-Metal Alloy

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Abstract

Thermoelectric devices have recently attracted renewed interest for their potential application in waste-heat recovery systems. For the widespread use of the devise, thermoelectric material consisting of abundant and cheap elements is required. From this point of view, a Heusler Fe_2VAl alloy was investigated. Thermoelectric performance of this alloy was improved by the microstructure control and element substitution. In addition, we fabricated a thermoelectric module using this alloy and evaluated power generation ability. The power output density of the module was 0.2 W/cm^2 on the heat source of 573 K. Although this value is still lower than the state-of-the-art Bi-Te module, we expect that the abundance and the low-cost of constituent elements provide advantages in the practical application.

1 INTRODUCTION

In the process of converting primary energy into a usable form such as electricity, more than 60% of the original energy is released into the atmosphere as waste heat. Effective use of this waste heat is being sought against the recent social background, such as concerns over the future supply of energy and the emergence of environmental issues.

However, it is difficult to effectively utilize the waste heat by means of conventional energy conversion techniques because the sources of waste heat is small and widerly scatterd, such as each power plants, factories, and automobiles, and moreover the majority of the waste heat is at low temperatures of less than 200°C. In order to effectively utilize this scattered, small-scale, and low-temperature waste heat, thermoelectric generation, which has a conversion efficiency independent of the energy scale and is capable of generating electricity from thermal energy of any temperature, may provide a solution.

Thermoelectric effects in materials enable direct energy conversion from thermal energy to electric power and vice versa without any harmful emissions. Therefore, thermoelectric devices have recently attracted renewed interest for their potential application in clean energy-conversion systems. Especially, vast amounts of waste heat are targeted for thermoelectric power generation in order to promote effective utilization of energy resources (Fig 1).

The conversion efficiency of a thermoelectric device depends mainly on the material's thermoelectric properties, which are evaluated using the thermoelectric figure of merit Z (= $S^2\sigma/\kappa$, where S is the Seebeck coefficient, σ is the electrical conductivity, and κ is the thermal conductivity). The high performance thermoelectric material is therefore indispensable for the construction of high efficiency thermoelectric devices.

However, conventional thermoelectric materials, such as Bi-Te and Pb-Te, are mainly composed of rare metals. Then, the use of these materials as the basic elements in thermoelectric power generation devices will be problematic, because large quantities of materials are required for the large number of waste heat sources.

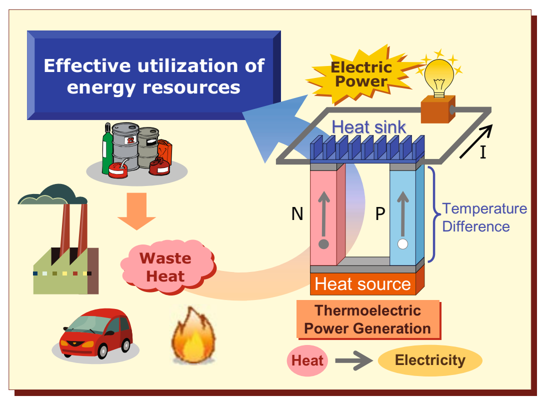

Fig. 1 Concept of waste heat recovery using thermoelectric power generation device.

In this study, an iron-based thermoelectric material is investigated as a replacement for the Bi-Te alloy. A Heusler alloy, Fe_2VAl, is a promising candidate for thermoelectric power generation near room temperature because of its high thermoelectric power factor PF (= $S^2\sigma$, which is used to estimate the power generation ability of a material) [1-3], which is comparable to Bi-Te alloy. Furthermore, because of its high mechanical strength and excellent resistance to oxidation and corrosion, a durable thermoelectric devices can be fabricated using this alloy [4-5]. However, the Z value of this alloy is poor because of its high κ. Consequently, its thermoelectric energy conversion efficiency is less than that of Bi-Te alloy.

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Reduction of κ is therefore necessary for practical applications.

For the reduction of κ in Fe_2Val alloy, we fabricated microstructured material using powder metallurgy process in order to increase the number of grain boundaries, which can scatter phonons. For the further reduction of κ, we doped a heavy element into the Heusler Fe_2VAl structure to achieve κ reduction effect within grains by the mass-difference scattering in the crystal lattice. In addition, we fabricated a thermoelectric module using this alloy and evaluated power generation ability.

2 RESULTS AND DISCUSSIONS

2.1 Microstructure refinement

Microstructured Fe_2VAl material has been synthesized by a powder metallurgy technique [6]. First, Fe_2VAl powder was prepared by using a mechanical alloying method. By optimizing the alloying conditions that allow stable repeated mechanical pulverizing and mixing, the alloyed powder consisting of the nanometer-sized internal structure was obtained as shown in Fig. 2. The crystallite size evaluated by the peak width of X-ray diffraction pattern with Scherrer equation was about 10 nm. Next, the mechanically alloyed powder was sintered rapidly using a pulse-current sintering technique to suppress grain growth during heat treatment. Then a sintered Fe_2VAl alloy made of nanometer-order crystal grains were obtained as shown in Fig. 2.

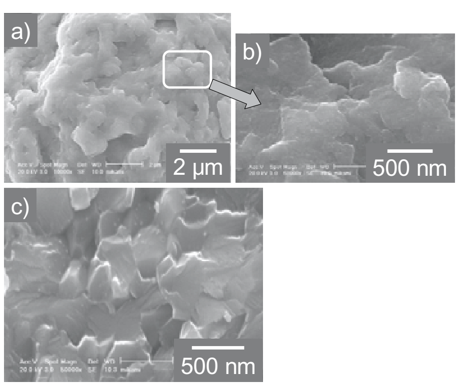

Fig. 2 a) b) Microstructure of Fe_2VAl powder prepared by mechanical alloying. c) A fracture cross-section of Fe_2VAl alloy synthesized by pulse-current sintering.

In the microstructured sintered alloy we succeeded in lowering the κ value through a scattering effect at the grain boundaries. The κ value of the sintered Fe_2VAl alloy evaluated by the laser flash method was 16 W/mK. This κ value was much lower than that in the arc-melted Fe_2VAl sample of 28 W/mK. In addition, the microstructural refinement also improved the durability of the material by dramatically increasing its mechanical strength. For instance, the bending fracture strength of the sintered Fe_2VAl alloy was 800 MPa. This value is almost 10 times higher than that of Bi-Te alloy.

2.2 Heavy element doping

Heavy element doping effect on κ of the Fe_2VAl alloy was investigated [7]. Al site was partially substituted by Sb. κ of the sintered alloy was significantly reduced from 16 W/mK to 9.5 W/mK by the Sb substitution for only 3 at% of Al site as shown in Fig. 3. This large κ reduction effect is attributable to the large difference in atomic mass between Sb and the constituent elements of Fe_2VAl alloy.

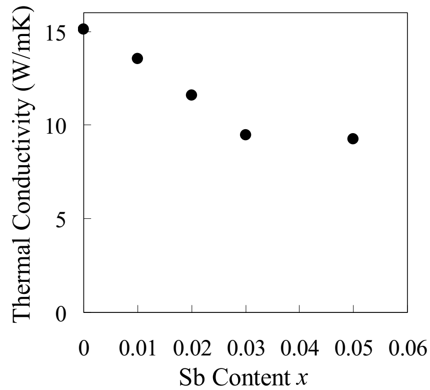

Fig. 3 Thermal conductivity of $Fe_2VAl_{1-x}Sb_x$ alloy at room temperature.

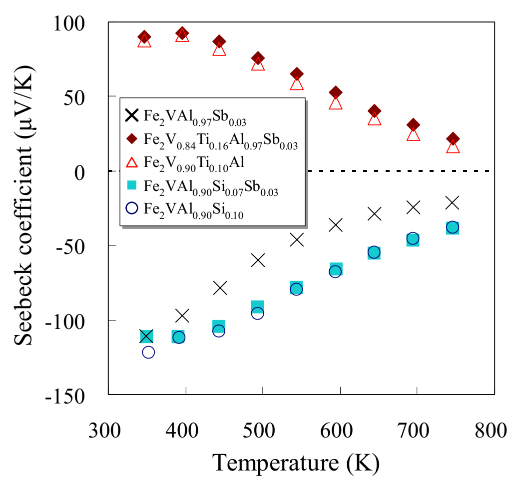

Fig. 4 Temperature dependence of Seebeck coefficient in Sb-doped Fe_2VAl alloys

To optimize the thermoelectric performance of the Sb-doped Fe_2VAl sintered alloy, the valence electron density was adjusted by additional element substitutions. For the n-type material, electron doping by the additional Si substitution was examined. As shown in Fig. 4, the S value in the sample with the double substitution of Sb and Si is as high as that in the $Fe_2VAl_{0.9}Si_{0.1}$, which was reported as a high-performance n-type Heusler alloy [1].

On the other hand, for the p-type material, additional Ti substitution was conducted. For the additionally Ti-substituted sample, the valence electron density is reduced and the Fermi level can be shifted from a conduction-band to a valence-band, because the number of valence electrons of Ti is lower than that of V. As a result, S value was changed to a positive value. As shown in Fig. 4, the S value in the sample with the double substitution of Sb and Ti is as high as that in the $Fe_2V_{0.9}Ti_{0.1}Al$, which was reported as a high-performance p-type Heusler alloy [2]. From these results, sintered alloys having sufficiently large absolute S value can be prepared by the element substitutions for both n- and p-type material. In addition, these additional element substitutions can also enhance σ. The electronic part of thermoelectric property in the Sb-doped Fe_2VAl Heusler alloy is therefore sufficiently optimized. Moreover, since the κ value was less affected by these additional element substitutions, total thermoelectric performance was improved.

2.3 Development of a Fe_2VAl thermoelectric module and Power generation test

Electrode connection is one of the most important factors for the development of thermoelectric modules. For the construction of conventional thermoelectric devices, jointing materials, such as solder, were used for the connections between electrode and thermoelectric material. However, this technique spoils the high mechanical strength characteristic of Fe_2VAl alloy, because jointing materials usually have a low melting point and low mechanical strength. In order to develop a high strength thermoelectric module, a direct joining of Fe_2VAl sintered alloy and copper electrode was examined [4-5]. The direct joining was achieved by a solid-phase diffusion bonding. The estimated bonding strength is about 100 MPa. Sintered alloys having a high mechanical strength were connected with a high bonding strength, thereby producing a durable thermoelectric device. Moreover, the electrical resistance at the connection is negligible, resulting in minimal power loss at the connection.

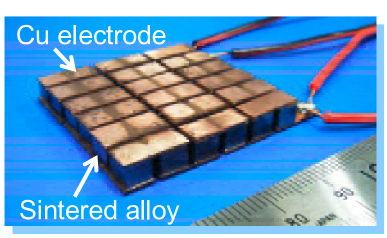

Fig. 5 The Fe_2VAl thermoelectric module.

Power generation capacity of the thermoelectric module consisting of the Sb-doped Heusler Fe_2VAl alloys was evaluated [8]. The power generation test was performed using the thermoelectric module consisting of 18 pairs of p-n junction (Fig. 5). One side of the module was heated by a hot plate and the other side was cooled by a copper heat sink with circulating water of 293 K. As shown in Fig. 6, open-circuit voltage (V_{oc}) and maximum output power (P_{max}) value increase with the increasing the hot plate temperature (T_h). The P_{max} value at T_h=573 K reaches 2.5 W. Since the heat receiving area of this module is about 35×35 mm^2, the output power density is estimated to be 0.2 W/cm^2.

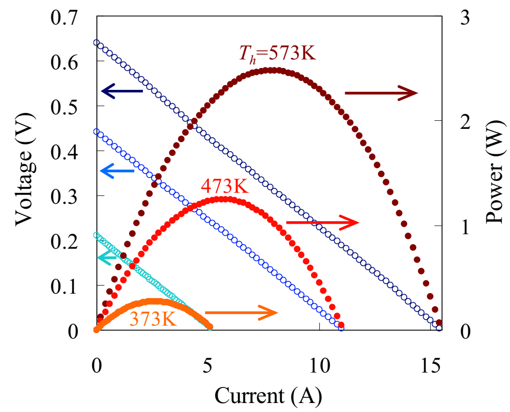

Fig. 6 Output voltage and power of thermoelectric module consisting of 18 pairs of p-n junctions. T_h is the hot plate temperature, and the module was cooled by circulating water with a temperature of 293 K.

This output power density value is twice as high as that of the thermoelectric module consisting of the Heusler Fe_2VAl sintered alloys without Sb doping such as p-$Fe_2V_{0.9}Ti_{0.1}Al$ and n-$Fe_2VAl_{0.9}Si_{0.1}$ measured in the same heating and cooling condition [4]. As mentioned above, since the electronic part of thermoelectric properties of Sb-doped Heusler sintered alloys were optimized and is almost the same as the conventional p- and n-type materials, V_{oc} and P_{max} from these two modules should also be the same assuming the equivalent ΔT was achieved for both modules. However, in practice, it is difficult to apply the same ΔT to the modules having the different thermal conductance because the heat supplying and absorbing capacity of our experimental setup is finite and small compared to an ideal infinite heating-cooling source. Therefore, the lager V_{oc} and P_{max} value from the module consisting of Sb-doped Heusler alloy arise from the larger ΔT at the thermoelectric element resulting from the reduction of κ. Actually, the ΔT in the Sb-doped Heusler module at Th=573 K calculated from V_{oc} and S of sintered alloys is about 180 K, which is much larger than that in the module consisting of the Heusler sintered alloys without Sb doping such as 120 K [4]. This result indirectly indicates the enhancement of energy conversion efficiency of thermoelectric module.

3 SUMMARY

Thermoelectric performance of Heusler Fe_2VAl alloy was improved by the microstructure refinement and element substitution. The reduction of κ maintaining superior electronic part of thermoelectric property enhances total thermoelectric performance of the alloy. As a result, obtained P_{max} from the module consisting of Sb-doped Heusler alloy is twice as high as that from the module consisting of Heusler alloy without Sb-doping.

Although output power density of 0.2 W/cm^2 on the heat source of 573 K is still lower than the state-of-the-art thermoelectric module, such as 1 W/cm^2 of a Bi-Te module [9], we expect that the module provide an advantage in practical application. For instance, with its comparably higher mechanical strength, the Fe_2VAl thermoelectric device can potentially be used in harsh environments such as the internal combustion engines of cars, which are subjected to vibration and extreme heat cycles. In addition, the device is economical and suitable for mass production because the Fe_2VAl thermoelectric material consists of elements that are cheaper and have a more reliable supply compared with conventional thermoelectric materials. To demonstrate the advantages of the Fe_2VAl thermoelectric device, we actively promote the development of the practical thermoelectric power generation system through the collaboration with industries and universities.

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Material Flow Analysis for Sustainable Resource Management

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Abstract

Material flow analysis is one of assessment tools for exploring resource sustainability. To examine the role of material flow analysis in resource management, this paper introduced two case studies. One is about environmental emissions from informal recycling sectors in global lead cycle. Another is about resource losses in E-wastes exported from Japan. Both case studies indicate that material flow analysis can identify criticalities for recycling technology but need more progress for proposing recycling systems.

Keywords:

lead, E-wastes, informal sectors, international trade, environmental emissions

1 INTRODUCTION

Resource management needs not only to develop 3R technologies but also to assess resource life cycle from mining to waste management through production and use quantitatively. Such a quantitative assessment is known as a material flow analysis [1]. Material flow analysis quantifies a generic resource life cycles, as shown in Fig.1, to explore resource sustainability. Quantification includes not only inputs/outputs between life stages but also interactions with environment and imports/exports. Each flow is estimated based on mass balance approach, using government statistics, research investigations, company reports, and economic/engineering models. Material flow analyses are now available for a number of metals on country, regional, and global levels [1]. This paper examined the role of material flow analysis in resource management by case study for lead and E-wastes.

2 CASE STUDAY FOR LEAD

Material flow analysis was conducted for lead with one of toxic metals, targeting for 160 countries in 2007 [2]. The advanced point of this analysis over previous work [3] is to take account into informal sectors at recycling stage. As the parts of material flow analysis for lead, the estimation results for environmental emissions at life stages on global level in 2007 are summarized in Table 1. Global lead emissions to air, water, and soil in 2007 were 150 Gg, 16 Gg, and 2,500 Gg respectively. Especially, air emissions from informal sector dominate about 90% of total air emissions due to their rudimentary recycling. Air emissions from informal sectors are mapped on Fig. 2. This map provides that Informal sector's emissions concentrate mainly on developing countries. For example, 60% in total air emission was from only China and India.

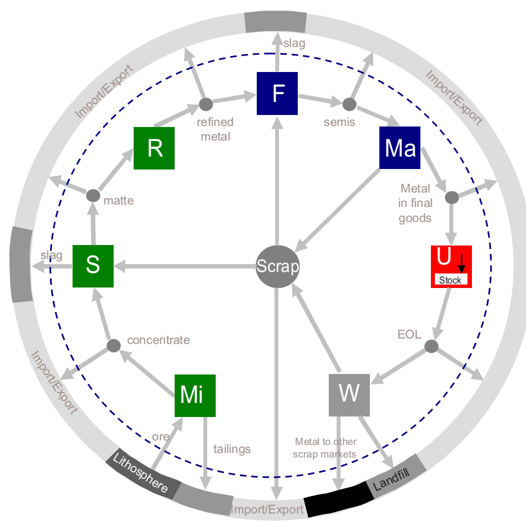

Fig. 1: A generic resource life cycle.

(Mi: mining, S: smelting, R: refining, F: fabrication, Ma: manufacturing, U: use, W: waste management, Circles indicate markets for commodity transfer)

Table 1: Estimation results for environmental emissions at life stages on global level in 2007. (Unit: Gg-Pb/yr)

Life stages	To air	To water	To soil
Mi	4	1	930
S&R			
Formal	3	0.5	150
Informal	130	2	220
F&Ma	12	12	150
U	0.4	0.4	
W			1,000
Total	150	16	2,500

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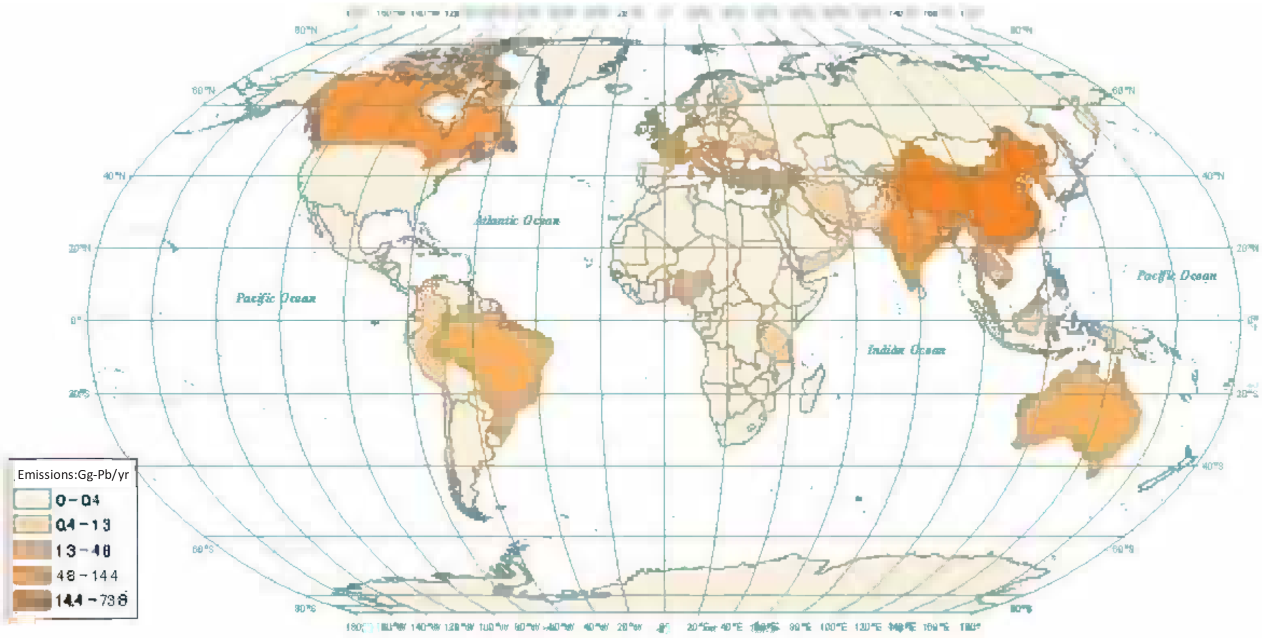

Fig. 2: Mapping of air emissions from informal sectors in 2007.

3 CASE STUDAY FOR E-WASETS

As for material flow analysis of E-wastes, Japanese resource outflows in the form of exported used electronics in 2007 were estimated, using Japanese trade statistics within Bayesian model approach [4]. In this estimation, electronics are characterized through eight product groups: cathode ray tube television sets (CRTs), liquid-crystal display television sets (LCDs), plasma display panel television sets (PDPs), air conditioners, refrigerators, washing machines, microwave ovens, and vacuum cleaners. Table 2 shows the exports of selected metals contained in used electronics in 2007. The results indicates that more than half of the indium (In) and 20-30% of the barium (Ba), lead (Pb), antimony (Sb), strontium (Sr), zirconium (Zr), silver (Ag), gold (Au), and tin (Sn) in domestically discarded products were not recycled in Japan, but rather were exported in electronics to be used elsewhere. The destinations of these metals were mainly Asian countries with rudimentary recycling systems [4].

4 SUMMARY

The example of informal sector in material flow analysis for lead demonstrates that recycling technology level affects environment pollutions largely. The case study for E-wastes, furthermore, finds that technology level gap between developing and developed countries leads to the transfer of risk for resource losses and pollutions. From both case studies, material flow analysis can provide critical points for current recycling technology. Material flow analysis is an appropriate tool for assessing "current" resource cycles but need more progress in its model development for proposing "future" recycling system.

Table 2: Estimation results for metal outflows from Japan through exported used electronics in 2007. (Unit: Mg/yr)

Metals	Exports: a	Domestic[1]: b	a×100/b
Ag	5.8	29	20
Au	0.28	1.2	23
Ba	1,700	5,900	29
Cr	300	5,100	5.9
In	1.1	1.9	58
Ni	130	2,200	5.9
Pb	3,200	11,000	29
Sb	140	490	29
Sn	250	1,300	19
Sr	2,600	9,300	28
Zn	55	510	11
Zr	620	2,100	30

[1]Metal stocks calculated from E-wastes generated domestically.

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Construction of integrated management system of material and energy using an information technology.
-Invitation to the Smart Recycle-

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Abstract

Recovery of useful metal from e-waste was carried out by using liquefaction in biomass derived tar or steam gasification in the presence of eutectic carbonate. These two technologies were feasible and fitting for a small distributed process, because plastic parts of e-waste can be removed under relatively mild condition without dismantlement required high cost. In the smart recycle society supported by information technology, we can expect that targeted materials are recovered selectively from the e-waste and the hydrogen derived from waste plastics is used as energy of complementary electrical source of unstable renewable energy.

Keywords:

Recycle, Waste plastics, Liquefaction, Gasification, Smart recycle

1 INTRODUCTION

In order to construct sustainable society, recovery of useful resources from the end-of-life industrial products is important to use limited resources effectively. For instance, a lot of useful metal such as gold or copper is used in electronic devices. It is very important to recover these metal from the e-waste not only for reducing environmental load but also for securing indispensable strategy materials to electronic industry. However, only a few electric devices such as cell-phones containing many precious metals or some household appliances on which recovery duty is imposed have been disposed, because recovering of metal from the end-of-life electronic devices require high cost. Moreover, plastics recovered from the e-waste cannot be used as a feedstock or a fuel, because they contain a lot of toxic halogen compounds or heavy metals. Recently we developed new two technologies using either liquefaction or gasification [1] to recover useful metal and plastics from the e-waste. By using these new technologies, we can expect to reduce the cost significantly which is required to recover useful metal, and to use the plastics of electronic devices as energy resources or material resources effectively.

Research development of each recycling technology, such as our works, is important. However most of these works have focused on only the development of recovery technology from the existing waste-products passively. It was not enough to optimize whole social system or whole supply chain. In later part of my presentation, I would like to introduce a new concept of integrated management system for material and energy, named "Smart Recycle", by using information technology.

2 EXPERIMENTAL RESULT AND DISCUSSION

2.1 Recovery of useful metal from epoxy printed circuit board by liquefaction in biomass derived tar.

Liquefaction of epoxy circuit boards was carried out in a tar at 200-350 ˚C for 60-120 minutes under atmospheric pressure. In some experiments, a small amount of sodium hydroxide or sulfuric acid was used as a catalyst. The tar was derived from liquefaction of Japanese cedar in cresol or from thermal decomposition of the epoxy board.

In our study, the epoxy board was liquefied almost completely in the both tar at 250-300°C for 60 min (Fig.1) as well as liquefaction in cresol solvent, because the two tar contain a lot of cresol derivatives. On the thermal decomposition of the once liquefied epoxy board, liquid product containing a lot of cresol derivatives was formed. Therefore the liquid product can be used as a solvent of liquefaction again or feedstock for chemical industry (Fig.2). Our process is more feasible than previous methods using super critical solvents or hydrogen donor solvents, because it does not need high pressure vessels or expensive solvents.

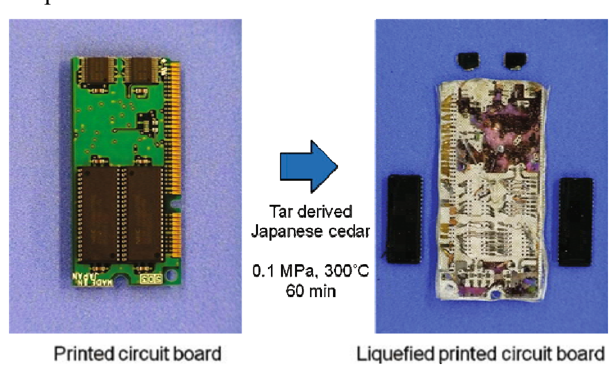

Fig.1 Liquefied printed circuit board

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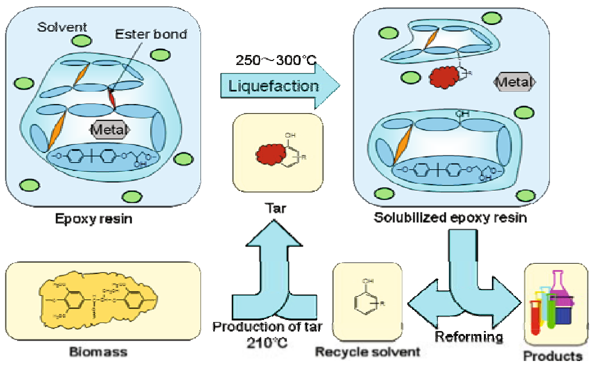

Fig.2 Recovery of metal from epoxy circuit board by using liquefaction in biomass derived tar

2.2 Conversion of plastics to clean energy gas by steam gasification in the presence of molten carbonate

Thermal decomposition or gasification of e-waste was already carried out by numerous people. However, they could not use products as energy resources effectively, because products were contaminated by toxic halogen compounds. On the steam gasification of the e-waste in the presence of eutectic carbonate, toxic halogenated compounds hardly remained in products, because most of the bromine or chlorine was converted to safe and stable inorganic salt. Plastics were converted to hydrogen and carbon dioxide almost completely at 600 – 700 °C by steam gasification in the presence of eutectic carbonate, and yield of tar decreased significantly. The gasification of epoxy board was accelerated by eutectic carbonate, and plastics in the e-waste could be removed easily without dismantlement or pulverization (Fig3).

Use of excess amount of the eutectic carbonates (Li_2CO_3, Na_2CO_3, K_2CO_3) was effective to remove plastics from the e-waste. However, a lot of carbonate was consumed by a reaction of inorganic materials such as glass fiber. Consumption of carbonate could be ignored when a small amount of eutectic carbonate or pure potassium carbonate was used, and the plastics were removed enough by gasification.

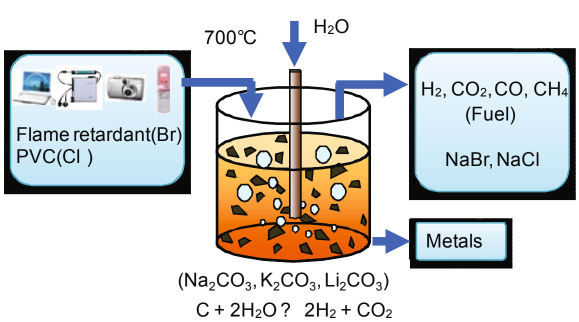

Fig.3 Steam gasification of e-waste by steam gasification in the presence of eutectic carbonate

2.3 Integrated resources management system using information technology (Smart Recycle)

Although a lot of materials are used in industrial products, it is almost impossible to know these material's species, amount, and location. However, we can recover the targeted materials effectively and accurately by using design information for manufacture. Digital identification tag, for example bar code, QRC code, and RF-ID, has already been used in many supply chains to manage production, delivery, and sales. By adding the address information to the tag, consumers or recyclers can obtain their necessary data respectively from the address in which design information is stored (Fig.4).

Renewable energy such as wind power is one of the most important energy resources in future. However, we have to construct a new power control system to maintain stable power supply, because the renewable energy is unstable. In the new control system, large electric power storage or small power station is controled through internet quickly. Hydrogen derived from the small distributed gasification plant of plastics is fitting for a energy source of the power station in the new system.

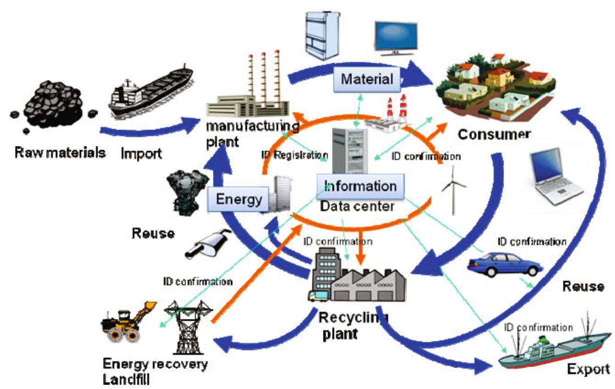

Fig.4 Overview of Smart Recycle

3 SUMMARY

Liquefaction or gasification is effective to recover useful resources from the end-of-life industrial products. Design information for manufacture is very important to recover targeted resources effectively from electronic devices. Hydrogen derived from gasification of plastics is suitable for use in a small power station that is complementary electrical power source of unstable renewable energy. We would like to construct the smart recycle society where environment friendly recycling is promoted by using information technology.

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End-of-Life Strategy - From Weight to Value

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Abstract
Regulatory targets for collection and recycling are set to reduce the amount of waste ending up in landfills and to incineration. These targets are mainly weight based, which easily leads to recycling of the heaviest compounds of the products, or rather the materials and compounds most substantially represented in the products

Waste electrical and electronic equipment (WEEE) is one of the fastest growing waste streams in the whole world. In addition, the material composition of WEEE is very heterogenous and it is changing rapidly. Typical to these changes are e.g. increasing number of substances and materials in each product, decreasing weight of valuable substances and materials per product, and increasing use of composites and nanomaterials. Each of these changes has increased the challenges and complexity of recycling and of returning the substances and materials to reuse.

Using weight based recycling targets for WEEE leads to inefficient recycling from environmental and value point of view and most of the valuable substances end up to the waste streams. Technologies to extract even small amounts of valuable substances exist but the problem is more on the systems level because the present recycling goals are not supporting the guidance of present material flows to these processes. Moreover, the existing regulation doesn't encourage the development of better separating systems for these substances. This article describes an analysis made of computer scrap composition and recycling value in Europe. The results show clearly the problems in weight based recycling regulation.

The WEEE directive of the EU is under revision (early summer 2011) and the new targets for recycling are still weight based. Weight based targets for WEEE lead to increased environmental burden, loss of material value, and send wrong messages to product development. More innovative recycling targets should be developed. The regulation needs targets where the value of substances and materials, and environmental effects are taken into account, so that most of the substances can be returned to the product cycle in an economically and environmentally sound way.

Keywords:
WEEE, recycling, value development, value distribution

1 INTRODUCTION

In the past few years the generation of waste electrical and electronic equipment, WEEE, has grown vastly, and the rate of generation is expected to continue growing. EU legislation has set recycling targets in order to favour reuse and recycling instead of landfilling and incineration. These targets are still in the revised legislation set by mass, which may result in larger recycled volumes, but with value still being lost, although the set targets are met. [1]

Over the world consumer electronics have become increasingly popular. Though many of the items are smaller, lighter, thinner, faster and more effective, their material composition has become more complex. [2]

In WEEE the bulk usually consists of the cheaper materials, plastic covers and possibly cast iron for structure. Especially in IT products the value lies in the valuable metals of the circuit boards. In this paper our case examples are on computer product waste.

2 VALUE CHAIN APPROACH

2.1 Value development

The value of a discarded product changes during the treatment process. A typical value development trend is shown in figure 1.

The discarded product mostly has a value entering the value chain i.e. reuse value could be the case. During the treatment process the value will change, common is that the value decreases. Ideally the intention is to achieve an increase in value by the end of the treatment process. In the best case of recycling the value will increase during the process, if it decreases, downcycling has occurred or it ends up as waste.

Changes in any part of the chain, will affect the value development. Different treatment methods or sorting and collection schemes may give different outcomes of the value development.

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Fig1: Development of value of a discarded product in the value chain

Ideally the information of the development of value in and between different processes and sub processes will help to recognise the sore spots in the treatment methods used, and give insight for development. This may also be a tool to help design products to enable an adequate and improved recycling in the future.

2.2 Value chain of WEEE

Waste electrical and electronic equipment includes a vast variety of different items. They are divided into 10 categories, with several products in each category. [3]

Whereas the value chain for a product begins in acquiring raw materials, the value chain of a WEEE device begins once the product becomes waste and is discarded as shown in figure 2.[4]

To achieve a detailed value chain description we need to view different product categories and even subcategories or product types separately. [4]

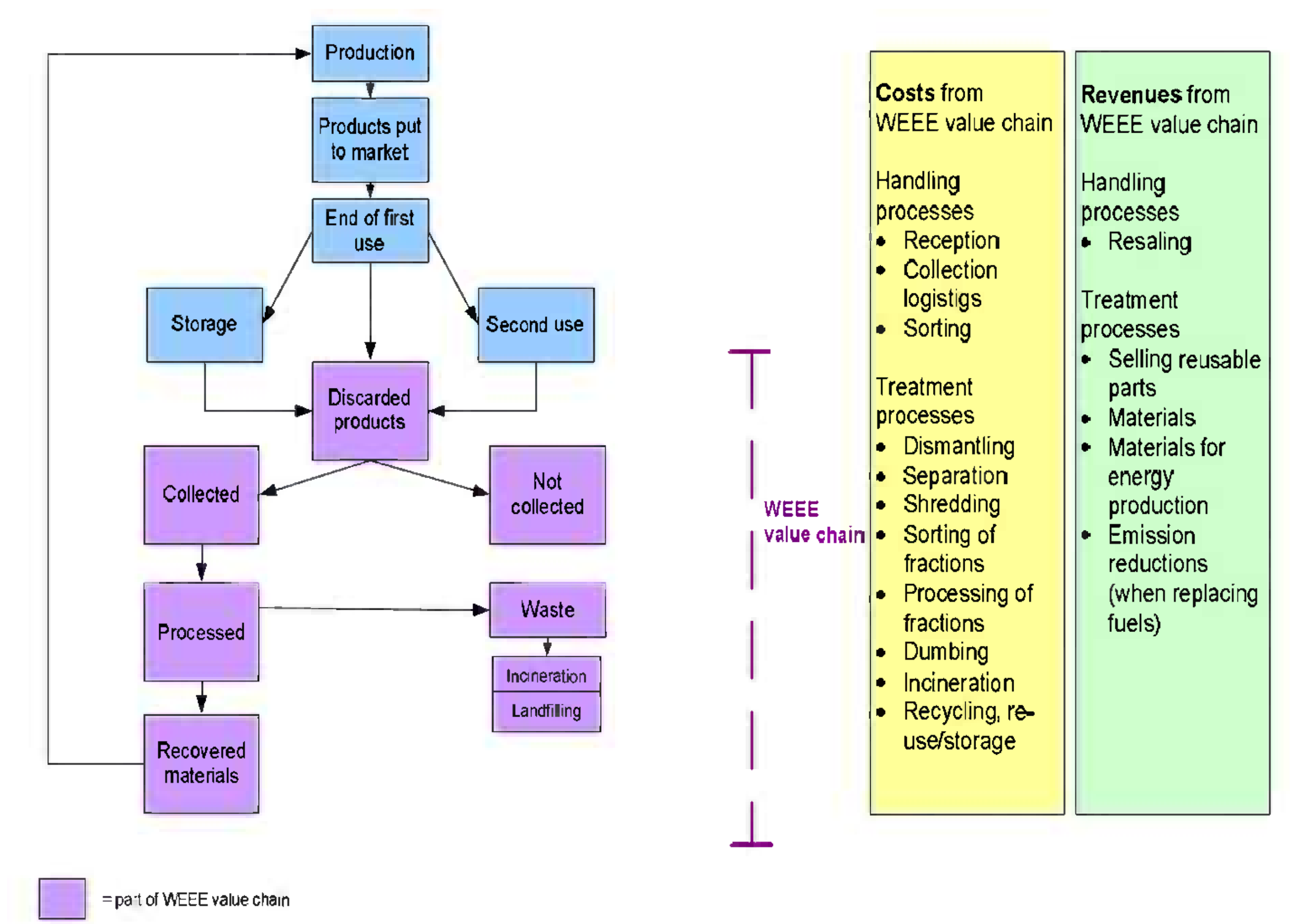

Figure 2. WEEE value chain

Although WEEE consists of a very wide range of materials, the materials are in most studies divided into five groups: ferrous metals, non-ferrous metals, glass, plastics and other materials. [5] Costs of the chain such as treatment costs or logistics, and revenues sale of reusable parts or recycled materials, or even energy production or substitution in the chain will affect the value generated.

Ferrous metals are mostly dominating by mass-%. Still, depending on the equipment, the value often lies in the valuable metals, although the quantities may be small. For example for computer scrap between 65% and 80% of the value is in the precious metals. [4, 6]

3 MATERIAL DISTRIBUTION AND VALUE IN WEEE

3.1 Material distribution in WEEE

Most WEEE products consist of a wide variety of materials. Simpler low value products consist of fewer materials, whereas i.e. computer products have a very complex composition. When studying the value distribution products that have valuable materials are of special interest.

A representative group of WEEE to examine, when looking into the material values, are computer products. In the calculations for this paper we concentrate more specifically on the materials found in PC desktops, CRT monitors, LCD screens and laptops (excluding keyboards, printers, hard disc peripherals and mice). In figure 3 the development of the distribution of the main metals in computer products in EU25 from 2002 to 2013 can be viewed. [4, 6]

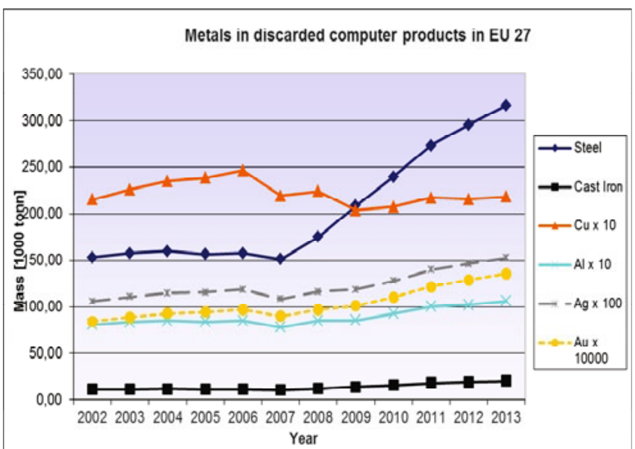

Fig 3. Estimation of metals in discarded computer products in EU 25 between 2002 and 2013. [4, 7]

It is obvious that the concentration of precious metals is quite small the scale being different.

3.2 Value distribution

Even though the concentrations of precious metals in WEEE are small, they represent a substantial part of the value content. In figure 4 the value distribution in order of decreasing mass representation can be viewed.

Figure 4 shows clearly, that the materials with the most weight are in fact not very valuable, whereas the small gold and silver amounts add up to the greatest value. In fact the value distribution is almost reverse to the weight distribution.

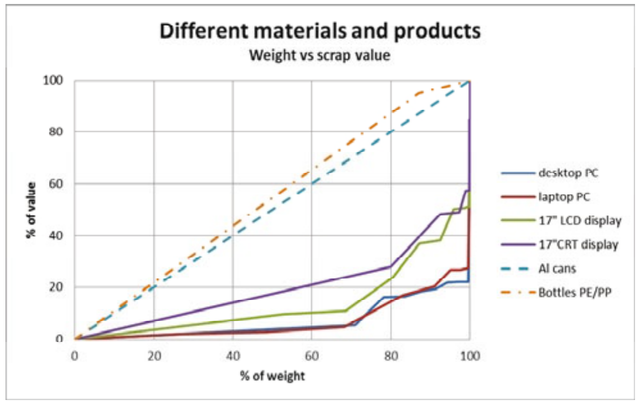

Fig 4: Value distribution in computer products starting on the left with materials with the largest mass% going toward materials of smaller concentrations (simple products like Al cans and PE bottles as reference)

By recovering steel, glass, and plastics, roughly in order of appearance in a weight based system, the recovery rate would sum up to about 90% if all could be recovered, the value would barely come up to a 20% level. This way the targeted recovery and recycling rates are reached, but most of the value is lost, since the bulk material is not especially valuable.

Taking look at the value distribution, it would be financially more rewarding to focus on the valuable metals. For computer the value of gold and silver add up to over 70% of the value, but will hardly show on the weight distribution in Fig. 4. This way the collection targets cannot be met.

The technology exists for recycling most of the valuable substances, but is only implemented by a few actors. In computer products most of the valuable and rare substances are concentrated to the printed circuit boards of the computers, which means that by manual or mechanical separation the precious materials can be concentrated substantially. This way the concentrations of the precious metals to be mined in WEEE are usually much higher than the ones in ore. [8]

4 SUMMARY

When recycling waste electrical and electronic equipment, there are many challenges, but also opportunities.

The material composition of WEEE is complex and very heterogenous. It is also changing rapidly. An increasing number of substances and materials as well as composites and nanomaterials is being used. The amount of valuable substances and materials is being minimised the bulk being fairly inexpensive.

With high tech metallurgical processes it is possible to recover most precious metals from WEEE.[2] Still there are only a few high tech recyclers.

With weight based recycling targets the common interest does not seem to lie in retrieving the value in the waste but to meet the demanded targets. At present legislation does not support a value based recycling, but economic or legal incentives would clearly be required, to achieve better overall recycling results as well as value.

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Application of Economical Evaluation Method of Rare Earth Magnets Recycling to Compressors

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Abstract

The risk of procurement failure for rare-earth metals, such as neodymium and dysprosium, is rising. Consequently, Hitachi has embarked on developing technology to recover rare earths from end-of-life products. The efforts of developing disassembly machine and studying rare-earth extraction technology have targeted the rare-earth magnets used in the compressors of home air-conditioners and in the hard disk drives of personal computers. With a focus on the compressors removed from air-conditioners, this report describes the cost evaluation for the transport process to the disassembly location and for the rare-earth magnet recovery process using the compressor disassembly machine under development. First, the collection tonnage of compressors, which would have a large impact on the cost, was estimated. In the next step, processing costs were derived by aggregating the cost factors calculated on the basis of the estimation results, and the recycling economy was evaluated. These results will be used to clarify the cost-share percentages per factor to identify measures for improving the economics.

Keywords:

Rare earth, recycling, cost evaluation, rare metals

1 INTRODUCTION

Rare-earth metals have become indispensable in the manufacture of electronic products. For example, because of their strong magnetic flux density, neodymium (Nd) and dysprosium (Dy) are used as materials for magnets. Rare-earth magnets are used in the motors of air-conditioner compressors and the hard disk drives of personal computers, where compactness and high performance are required. Currently, 97% of these rare-earth metals are mined in China, whose reinforcement of export regulations has increased risks in procurement. To sustain the manufacturing of products, countermeasures to this procurement risk must be instituted. One countermeasure gathering interest is recycling, in which base material stock is recovered from end-of-life products and reused. In fact, the tonnage of metals accumulated in Japan is said to be comparable to any major, resource-rich country in the world [1]. As a new procurement route for metal resources, recycling of rare-earth metals contained in end-of-life products is considered to be valid. Thus, the Hitachi Group embarked in 2009 on the development of rare-earth recycling technology for high-performance magnetic motors with a contracted subsidy from the Ministry of Economy, Trade, and Industry. The outline of the project is shown in Fig. 1.

The project entailed (1) the development of an automatic disassembly machines to remove rare-earth magnets from compressors in air-conditioners and from 3.5-inch hard disk drives in personal computers; (2) the study of the technology to extract rare-earth alloys (Nd, Dy) from removed magnets; and (3) an economic evaluation of these recycling processes. Among the project topics, the research in this report concerns item (3). Using the technologies developed under this project, the Hitachi Group targets commercialization of rare-earth recycling by 2013. In examining commercialization, economic evaluation of the business is extremely important in determining the engagement policy. For the purpose of assessing rare-earth recycling process costs by the developed technologies and recommending improvements toward improved profitability, this report provides estimates on future emissions of compressors within Japan. Based on the resulting estimates, the methodology for economic evaluation of rare-earth recycling is examined for the collection of disposed products through magnet recovery.

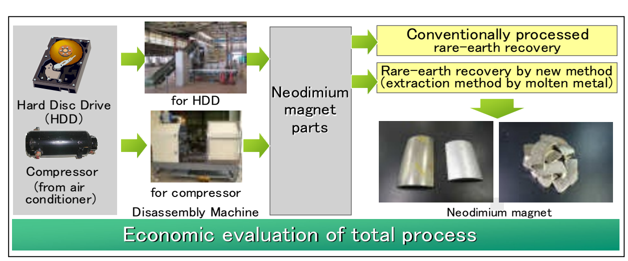

Fig. 1: Outline of the rare-earth recycling

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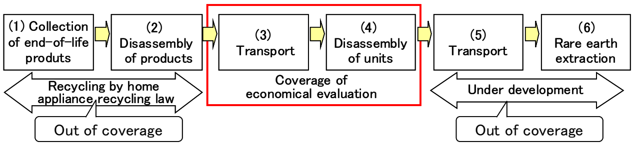

Fig. 2: Coverage of economic evaluation

2 METHODS

2.1 Approach to evaluation methodology

The scope of economic evaluation in this research is mapped out in Fig. 2. As shown in the figure, rare-earth recycling from end-of-life products comprises (1) the collection process of disposed, end-of-life products; (2) the product dismantling process to remove units containing rare-earth magnets from collected products; (3) the process for transporting removed units to the disassembly location, where magnets are removed from the units containing rare-earth magnets; (4) the unit disassembly process for removing the components containing rare-earth magnets from the units; (5) the process for transporting rare-earth components to the rare-earth extraction location; and (6) the process for extracting rare earths (Nd, Dy) from rare-earth components.

Among the products of the project targeted for evaluation, this report targeted the compressors contained in air-conditioners. Hard disk drives and air-conditioner compressors are targeted products in this project because these products currently use the greatest amounts of rare-earth magnets. Air-conditioners containing compressors subject to this evaluation are collected and recycled under the Home Appliance Recycling Law in Japan and the compressors have already removed. For this reason, costs accrued in processes (1) and (2) are already implemented, and costs accrued in processes (5) and (6) are under development and so excluded from this evaluation. Costs accrued in processes (3) and (4) are therefore subject to evaluation.

2.2 Recovery tonnage estimates for rare-earth magnets

Processing tonnage is an important factor in the appraisal of recycling costs. Thus, we first estimate tonnages of rare-earth magnets obtained from the compressors for recycling, and then calculated the costs based on the estimated tonnages. The years subject to appraisal are set from 2013 to 2020, the eight years during which commercialization is expected to start, since a new business must be profitable within three or four years after launch and a trend assessment for several years thereafter can be obtained.

The research refers to the estimation methodology released by the National Institute for Environmental

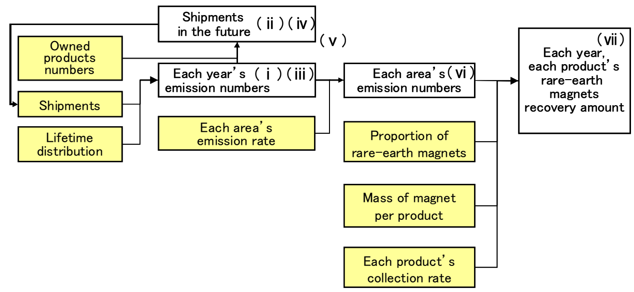

Fig. 3: Methodology of estimation of rare-earth magnets recovery amount

Studies (Japan) and others [2] for the tonnage of disposed end-of-life products in order to estimate collection tonnages of end-of-life products, as shown in Fig. 3. The procedure for estimating collection tonnages is as follows:

(i) The Weibull distribution function can describe the distribution of lifetimes for a variety of products. Assuming that the Weibull distribution can approximate the proportions of product disposal, the following Equation 1 represents those figures (assuming disposal tonnage is 0 for the year of shipment). Then, by employing Equation 1, Equation 2 is derived to represent the number of disposed units in any year under evaluation for products shipped in the respective year of manufacture. By totaling the number of disposed units of products shipped for each respective year of manufacture, as obtained by Equation 2, the total number of disposed units in a year under evaluation is calculated by Equation 3.

$$Wt(i) = 1 - \exp\left[-\left(\frac{i}{y_t}\right)^{\alpha} \cdot \left\{\Gamma\left(1+\frac{1}{\alpha}\right)\right\}^{\alpha}\right]$$

Equation 1

Wt(i): the proportion of disposed products by the end of the year t among those shipped in year $t-i$, i years previous;

y_t: average years used;

α: parameter for the distribution of years used.

$$G_{t,t-i} = P_{t-i} \times \left(Wt(t-i) - Wt(t-(i-1))\right)$$

Equation 2

$G_{t,t-i}$: number of products manufactured in the year $t-i$ and disposed in the year under evaluation t;

P_{t-i}: product units shipped in year $t-i$.

$$G_t = \sum_{i=1} G_{t,t-i} \quad \text{Equation 3}$$

G_t: number of product units disposed in the year t.

(ii) Shipment units were calculated with the following Equation 4:

$$P_t = N_t - N_{t-1} + G_t \qquad \text{Equation 4}$$

P_t: shipped product units for year under evaluation t;
N_t: number of product units owned for the year under evaluation t;

The number of owned units *Nt* employs statistics released by the Cabinet Office, but future numbers are estimated when no statistics are available. As an added note about owned units (future numbers), because the number of owned units of air-conditioners has remained nearly constant in recent years, this number is assumed to remain constant in the future at the 2009 level.

(iii) G_{t+1}, the number of disposed units in year $t + 1$ is calculated with Equations 2 and 3 by using the shipment units calculated in (ii).

(iv) The number of shipment units in year $t + 1$ is calculated with Equation 4 by using the number of disposed units obtained in (iii).

(v) The numbers of shipment units and disposed units are calculated by repeating (iii) and (iv).

(vi) Obtained disposal unit counts are multiplied by the proportion of product disposal by region to calculate the number of disposed units by region.

(vii) To the number of disposed units by region, the proportion of rare-earth magnet product, magnet mass per product, and rate of product collection are multiplied to calculate tonnages of recovered rare-earth magnets by year and by region.

Figures for the various parameters are established by using publicly released statistical data.

Tonnages of recovered rare-earth magnets obtained by the above procedure are first subject to validation. Under the Home Appliance Recycling Law, the actual counts of collected units are disclosed for air-conditioners. Thus, for air-conditioners, the number of collected products, obtained by multiplying the calculated number of annually disposed products with the rate of collection by products, can be validated against the actual counts. After this validation, the tonnages of rare-earth magnets recovered from compressors are calculated.

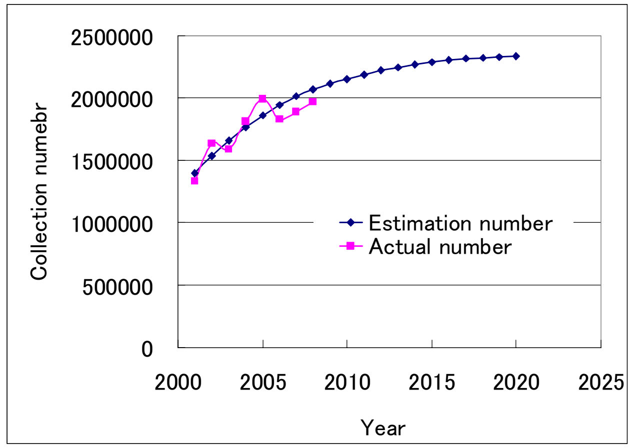

Fig. 4: Comparison of estimation and actual number

3 RESULTS

3.1 Validity confirmation results for collection tonnage estimation

The actual number of collected air-conditioners and the estimated collection counts are shown in Fig. 4. Actual counts represent the air-conditioners collected in Japan under the Home Appliance Recycling Law, and are shown for the years 2001 to 2008. The average difference between actual and estimated counts is 5% or less, and so the result confirmed that the calculated counts obtained under the collection tonnage estimation methodology are valid.

3.2 Results of recovery tonnage estimation

The calculated results of recovery tonnages of rare-earth magnets from compressors are shown by prefecture in Fig. 5, and the total figure for Japan is shown in Fig. 6. Recovery tonnages have large regional differences, as shown in Fig. 5.

Recovery tonnages are on an increasing trend. Although total air-conditioner shipments have remained constant in recent years, their proportion of rare-earth magnet usage is on an increasing trend. The proportion of rare-earth magnets by 2020 is expected to be approximately 90%,

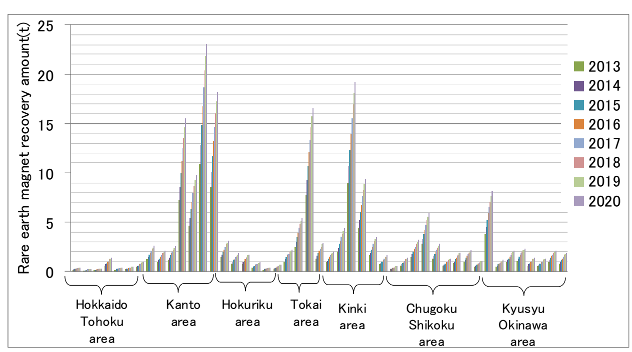

Fig. 5: Estimation of each area's recovery amount

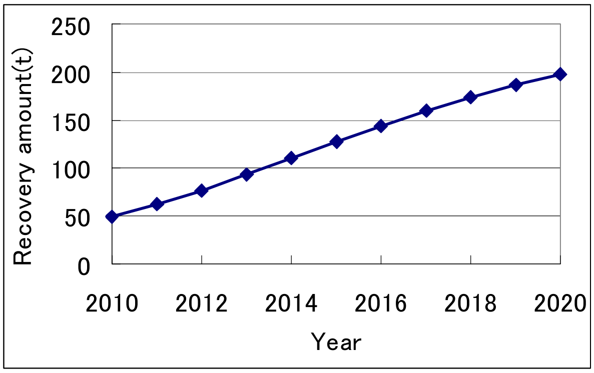

Fig. 6: Estimation of each year's magnet recovery amount

and so the potential recovery tonnages will continue to increase until 2030, and thereafter remain constant.

3.3 ECONOMIC EVALUATION

Evaluated Items

An economic evaluation based on the obtained collection tonnage estimation results is examined. Table 1 shows the items noted as appraised cost items. The respective cost items are calculated according to the following methods.

• Transport Costs

Transported tonnage for each occurrence is calculated on the basis of the transport frequency of once a month, and so the annual transported tonnage by region is divided by 12. Under the assumptions of a truck size corresponding to the transport tonnage and the use of sea vessels from Hokkaido, transport costs are calculated from truck tonnage, sea vessel tonnage, transportation distance, and transport counts. The upper limit for truck tonnage is set at 15 t, and if the transported tonnage for one time exceeded this figure, the transport count is increased. Internally investigated figures are used to determine the unit transport cost from truck tonnage, sea vessel tonnage, and transported distance.

• Labor Costs

Based on unit costs obtained from interviews with recycling facilities, labor costs are calculated by multiplying the annual operating hours to disassemble the compressors and the necessary head counts. Annual operating hours are calculated from annual collection tonnages and the processing tonnage per unit hour of the processing apparatus.

Table 1: Costs of recycling

Process	Costs
Carriage	Shipping cost
Unit disassembly	Labor cost
	Utility cost
	Purchases cost
	Gain on sale of materials

• Utility Costs, Input Product Purchase Costs

Amount of utilities consumed, input product tonnages, and recovered product tonnages per unit hour at each process are calculated by multiplying the annual operating hours, utility unit costs, and unit costs for input products obtained from interviews with recycling facilities (all fixed figures).

• Selling Profits of Recovered Products

The selling profit is calculated by multiplying the tonnage of recovered product per unit hour at each process, the yield, the annual operating hours, and the unit price of recovered product (fixed figure) obtained from interviews with recycling facilities. Recovery included not just the rare earths, as intended, but also other materials recovered through rare-earth recovery.

Evaluation Methodology

The cost required for recycling is calculated by totaling the figures for the cost items above, from the transport freight costs to the extraction processing costs, and then subtracting from the total the selling profit of recovered products, including recovered products other than the rare earths. An economic evaluation of recycling is considered possible by calculating the cost per kilogram of rare-earth alloys by dividing this figure by the annual collection volume.

As the results provided in Section 3.2 show, the recovered tonnages of rare-earth magnets from compressors vary by prefecture. In some areas, cases are observed where the collection tonnage remains far below the processing tonnage of a single compressor disassembly device for rare-earth magnets. Thus, a cost appraisal is considered necessary under an assumed scenario where collection and dismantling of air-conditioners are conducted more or less at one location in each prefecture, while compressor disassembly locations are consolidated such that compressors are transported for recycling processing. Going forward, we plan to devise measures that reduce costs and to recommend cost reduction proposals based on the evaluations obtained.

This report is a part of result of "The development of technology for recycling rare earth metals from urban mines" with a support of Japan's Ministry of Economy, Trade and Industry.

4 SUMMARY

The Hitachi Group is engaged in developing recycling technologies for rare-earth magnets and conducting economic evaluations of recycling for the purpose of recommending measures toward commercialization. Thus, we first worked on estimating recovery tonnages of rare-earth magnets from compressors and calculated the estimation figures by confirming the validity of the methodology. Going forward, we will conduct economic evaluations of the recycling process by aggregating the calculations of the various costs (transport, labor, utilities, etc.) accrued in the recycling process by using the obtained estimation figures.

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Identifying the End of Life Decision Making Factors

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Abstract
The early stages of design are the optimum stages to determine a product's End of Life strategy. There are two problems surrounding current EoL decision making approaches. Firstly, the type of criteria used is fairly limited to design-centred perspectives, neglecting important factors such as legislation or return infrastructure. Secondly, there is confusion regarding the optimum End of Life decision making approach. Designers are not fully aware of the best steps needed to determine the most suitable EoL strategy for a product. The aim of this paper is to determine factors needed to assist successful Design for End of Life (DfEoL). This paper presents a qualitative, multi-case study approach, collecting data from three companies. Case studies, in the UK, were used to understand and record current understanding, as well as unearthing more EoL decision-making factors. By evaluating the list of factors from literature and case studies, key factors will be highlighted as crucial issues to consider during DfEoL

Keywords:
End of life, decision making, product design, remanufacturing, reuse and recycling

1 INTRODUCTION

End of Life management can by defined as "a process of converting end of life products into remarketable products, components or materials", creating a closed loop design [1]. EoL strategies include reuse, repair, recondition, remanufacture, recycle, disposal and incineration [2]. Reuse can be defined as a recovered product sold with minimum interference [3]. Repair is a correction of a specified point, and reconditioning is a returning the product to a satisfactory working condition [4, 5]. Remanufacturing is the process of returning a product to OEM performance specification, with a warranty to match [4, 5]. There are many benefits of creating a closed loop lifecycle. Primarily, in many instances, it diverts waste material from landfills and incineration, thus promoting ecological sustainability. Economically, closed loop design, in some instances, allows OEMs to reuse their original products, using less virgin material. However, not all products are suited to all EoL strategies. Each strategy depends on different (and at time, conflicting) design characteristics, legislation, and business models and market perceptions.

The majority of EoL research focuses on management aspects and determining the EoL of a product once it has been manufactured, used and returned. However, literature suggests that the EoL strategy of a product must be determined in the early stages of the design process [6, 7]. EoL decision making in product design is poorly addressed in literature. There are two problems surrounding current EoL decision making. Firstly, the type of criteria used is fairly limited to technical aspects e.g. product characteristics, as the designer has control over these issues in the design stage. The implication of only analysing product characteristics is that it does not take into consideration other equally influential aspects such as environmental impacts, social trends and also legislative pressures, which have can affect the overall EoL decision. The second problem associated with current EoL decision making is confusion regarding the optimum End of Life decision making approach. It is the author's opinion that designers are not fully aware of the best steps needed to determine the most suitable EoL strategy for a product. Furthermore, case study findings suggest that the current EoL decision making tools are not widely used in industry.

The aim of this paper is to determine the external factors which should be integrated into the EoL decision making during the design stage. The originality of this work stems from the fact it is the first instance where internal (internal to the design stage e.g. product characteristics) and external factors (external to the design stage e.g. legislation, or social trends) have been identified to determine the EoL strategy of a product. Furthermore, factors from the internal and external categories will be evaluated and the most important factors will be amalgamated into EoL decision-making criteria. The synergy, between the two sets of criteria, help to create an inclusive list of issues which should be analysed when making EoL decisions during the design stage.

2 END OF LIFE DECISION MAKING

2.1 EoL approaches in literature

Research argues that EOL considerations must be integrated into the design process [8-10]. Furthermore, it has been indicated that all environmental considerations must be decided upon in the early stages of design [11-14].

There a several benefits of determining the EoL route during the design stage. Firstly, design engineers can help

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facilitate productive and effective product retirement by selecting the optimum route, to reap the most environmental and economical gains. Secondly, the advantage of knowing a product's EoL strategy is that the designer can evaluate the product concepts against the selected EoL characteristics and therefore make improvements to the design. Thirdly, determining the EOL of a product allows specified design guidelines to be used, e.g. design for remanufacture.

2.2 Type of Approaches

Predominately, the two major types of EoL decision making models used in design are (i) mathematical models and (ii) product design focused models. Mathematical models are usually used when time and costs are the most important factors, in regards to selecting the appropriate EoL strategy. Furthermore, due to the complexity of mathematical models, they are rarely used in early stages of design. Based on product portfolios, rather than single products Mangun and Thurston's [15] mathematical approach aims to determine the EOL strategy of each component based on cost, reliability and environmental impacts. The model can also determine the optimal take back period through servicing.

On the other hand, product design focused models [6, 7, 16, 17] are interested in design characteristics and their effect on the desired EoL strategy.

2.3 Criteria

A systematic, comprehensive literature search was undertaken to appreciate the state-of-the-art in DfEoL and to identify gaps in knowledge. As a result of the analysis of literature, 32 general EoL decision-making factors were identified (see Table 1). The factors can be categorized as either internal or external.

2.4 Lack of External Inputs

Literature suggests that external factors are not considered adequately during decisions made at the design stage.

Findings from literature shows that current approaches are neglecting to look at crucial areas- in particular complying with legislation and addressing customer demand. External factors are essential in the decision making process, especially in the case of remanufacture. For example remanufacture is reliant on high return of cores, customer demand for remanufactured products and a viable business profit. Additionally, with the growth of EPR legislation, particularly in the EU, it is essential that these external legislative factors are integrated into the recovery determination process.

Another crucial element concerning criteria is a lack of analyzing different types of factors. For example ELDA focuses only on design attributes [6] and Kwak's approach is concerned with disassembly [18]. Limited number of approaches adopts a holistic methodology by examining design, economical, environmental, legislative and customer's needs simultaneously.

Table 1 Categorization of EoL Decision Making Factors

	Classification of factor	Factors
Internal	Design	wear out life, level of integration, technology cycle, number of parts, design cycle, reason for redesign, life span, assembly direction, disassembly time, material, joining methods, purity of material, mass of material, hazardous content, part function, component layout, manufacturing processes, estimated mass, relationship between components,
External	Eco	Disassembly costs, resell prices, product value, recycling costs, transportation costs, labour costs
	Environ	LCA score, eco indicator,
	Business	Returns processes, degree of damage, core return volume, reconditioning processes, return rate, facility costs
	Legislation	None
	Customer Demands	None

2.5 ELDA Approach

The ELDA approach (End of Life Design Advisor) bases its decision making criteria solely on product characteristics, as this is the only aspect the designer has control over during the early stages of design[6]. The EoL strategy is determined by six inputs; Wear out life, technology cycle, and level of integration, number of parts, design cycle and reason for redesign. The suggested EoL is compared to company's current EoL strategy and then any necessary improvements to either design or strategies are made (see Figure 1).

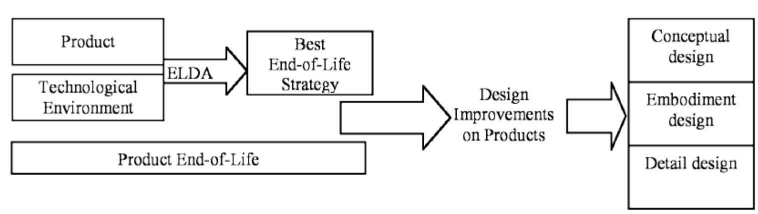

Figure 1 ELDA Approach (from Brissaud et al [17])

ELDA is a sound approach for integrating end of life thinking into the design process, as it relies on the information available during the design stage. However, the main limitation of this approach is the fact it only analyses internal factors. The implication of this leads to a comparison of the designer's suggested strategy to the company's actual business strategy or capabilities. This approach needs to be expanded upon by integrating external factors which will help to accurately differentiate between EoL strategies.

2.6 Problems with Approaches in Literature

To conclude the problems surrounding existing approaches is the lack of a holistic approach between analysing internal and external factors. External factors are essential for distinguishing between EoL routes when dealing with product design features which satisfy a number of EoL routes. External factors are ineffectively dealt with in decision making, for example further research is needed to determine exactly which external factors should be including in the analysis and how can they be and answered during the design stage. These factors will be added to the six internal factors outlined in the ELDA approach. Finally, there are various reasons for the poor integration of external factors into the decision making process at the design stage:

- Information to satisfy external factors is not available during the early stages of design.
- It is the author's perspective that designers' knowledge, regarding external factors, is low
- It is the author's perspective that there is confusion concerning the 'right' external factors to analyse.

3 RESEARCH METHODOLOGY

3.1 Case Study Companies

This paper presents a qualitative, multi-case study approach, collecting data from three companies. Case studies, in the UK, were used to understand and record current understanding, as well as unearthing more EoL decision-making factors. By evaluating the list of factors from literature and case studies, key factors will be highlighted as crucial issues to consider during DfEoL.

Among the studied companies are an OEM engine manufacturer and remanufacturer (Company A), an OEM photocopier manufacturer and remanufacturer (Company B) and an OEM luxury hi-fi manufacturer (Company C). Although Company C is not a remanufacturer, the design of their products is suited to this route and it undertakes in recycling. In additional, there is a substantial demand for Company C's second hand products. For an overview of the companies refer to Table 2.

3.2 Data Collection

The data was collected via semi-structured interviews, either face to face or through telephone calls regarding the following issues:

- Which factors should be used to make decisions?
- Which point in time are decisions made?
- Who is involved in the decision making process?
- Which tools, if any, are involved?

In all cases, there was a site visit, highlighting the manufacturing and remanufacturing (Companies A & B) processes. In additional, a focus group, with academia and industrial experts, was set up to determine the needs of EoL decision making tools.

Table 2 Overview of Case Studies

	Type of Company	**Main Products**
Company A	OEM manufacturer, remanufacturer & contract reman to others	Car engines, heavy vehicle engines
Company B	OEM manufacturer, remanufacturer	Printing and publishing equipment, photocopiers
Company C	OEM manufacturer	Hi-fi systems

4 RESULTS

4.1 Which factors should be analysed?

Table 3 external factors which the case studies found critical in the EoL decision making process. In all cases external factors were highlighted as playing an essential role in the determination of a product's EoL route. The factors highlighted in bold represent factors that from this research finding appear not to be addressed in EoL decision making literature. However, from the case studies conducted in this research it is apparent that industry relies on external factors immensely to make EoL decisions. This is contrary to the approaches which feature in literature

Table 3 External Factors collected from Case Studies

Company	Factors
Company A	(i)Recovery Time (ii)**remanufacturing process costs** (iii)**customer demand**
Company B	(i)**Compliance with new legislation** (ii)**Consumption model – buy or lease product** (iii)Design lifetime – how long will this particular design be in circulation before a new model is introduced. (iv) **feedback from service on similar models on design aspects**
Company C	(i)**compliance with WEEE directive**

Another case study visit is proposed for the future, and it is expected that further external factors will be added to the above list. From the research conducted at the moment it is apparent that the sheer volume of external factors cannot all be evaluated during the design stage. It is then essential to further assess which options are feasible to answer and to include them with ELDA's six internal factors. However, the challenge in creating this list is to ensure that the factors can be answered (see 4.2).

4.2 Challenges for Answering External Factors

Although external factors are influential in decision making, case study research proposes that it is difficult to answer them at the early stages of design. Case study findings indicate that the reason behind this is that designers do not have the information, knowledge or time to think about external factors. Furthermore findings also suggested that external factors are sometimes carried out by managerial staff therefore are usually outside the realm of the designer's responsibility.

This can be illustrated by the findings from Company A and B. When Company A's product are returned at their EoL, with some products, are not entirely designed for remanufacture. This is because the designer has not considered external factors leading to the selection of remanufacture, and consequently design for remanufacture. The servicing department must rectify these changes, to make it possible to perform remanufacturing as the EoL strategy.

4.3 Challenges: Who should be involved

Company B ensures that the EoL route is decided using a multidisciplinary team, consisting of engineers, designers, procurement specialists and service engineers. This procedure takes place during the design phase of product development. The purpose of this team is to ensure that there are people with the right information and knowledge to analyse the EoL route requirements of the product, especially regarding external factors. The inclusion of procurement and service specialists ensures that the decisions are analysed from an external view point by taking into account their knowledge regarding returns infrastructure, storing and sourcing of spare parts and the ease of remanufacturing of the product.

4.4 Tools – how effective are they?

The outcome of the specialist focus group criticised the usability of EoL determination tools. The drawbacks for the tools can be summarised as:

- Require too much information at the early stages of design
- Take too long to determine the EoL route
- No training/poor understanding of current approaches

They suggested some guidelines to improve the uptake of new tools under the following themes; how to enable the designer to use tools properly, ways to make EoL tools produce results relevant for the company/sector and ways to drive businesses to optimise EoL thinking. The guidelines are listed below:

How to enable the designer to use tools properly

- Set a clear strategy and specific goals for the design team. If it´s a requirement, they will do it
- Need the right information at the right time to enable quick and easy application
- Right tools for the rights stage of the design development
- Tools for different levels of knowledge
- Sustainability agenda across the organization

Ways to make EoL tools produce results relevant for the company/sector

- Develop methods / tools that fit with the requirements of the user (development in collaboration with industry and users)
- Link with other requirements designer has (cost and performance)
- Tools suitable for early design phase and fit into workflow (not a separate activity)

Approaches to drive businesses to optimising EoL thinking

- Business should take full responsibility of the product lifecycle, including the depth of the product
- The information gap between company and customer must be filled – maybe through standardization.
- It has to be more profitable to be green than to wash green.

5 CONCLUSION AND FUTURE RESEARCH

This paper addresses the complexity of selecting product recovery strategies during the design stage. It acknowledges the gap in literature concerning a lack of external inputs integrated into the decision making process at the design stage. The originality of this work identifies external key factors which should be used in the determination of an EoL strategy for a product. The external factors will be integrated along with ELDA six internal factors to create an inclusive list of issues which should be analysed when making EoL decisions during the design stage.

The literature review presents approaches which lack analyzing aspects outside the design process. These external factors which are essential indicators for many EoL routes, are inadequately addressed due to low levels of knowledge and availability of information.

Findings from case studies suggest that industry is much more adapted to integrating external factors, due to the demand of making profits. External factors, which are not included in literature's approaches include:

- Complying with EU legislation
- Considering the consumption model-buy or lease
- Design feedback/improvements from the service department
- Design model expected life time.

There was little evidence that the approaches presented in literature are being used by industry. Academic and industrial experts expressed the need for new tools' inputs to reflect the level of information available at that point in time of tool integration. Furthermore the tools and methods need to be developed in collaboration with the expected users, in order to create a useful, easy to use tool.

Future research should aim to establish the exact level of knowledge which is available at the early stages of design. It should also try to ascertain the optimum solution in incorporating external factors and its related information into the design process in order to determine the most suitable EoL route of a product.

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Active Disassembly for the End-of-Life Treatment of Flat Screen Televisions: Challenges and Opportunities

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Abstract

The principle of Active Disassembly (AD), in which innovative reversible fasteners can be simultaneously activated by an external trigger signal, enables a promising End-of-Life (EoL) treatment for electric and electronic products. Therefore, the economic and environmental constraints for implementing AD are discussed, as well as the information requirements for AD. Furthermore, the potential benefits of properly implementing active fasteners in a Liquid Cristal Display (LCD) and a Plasma Display Panel television are presented based on a case study.

Keywords: Active Disassembly, Flat Screen Televisions, Recycling, WEEE

1 INTRODUCTION

There are three key motives for manufacturing and recycling companies to improve the end-of-life (EoL) treatment of Waste Electric and Electronic Equipment (WEEE). Firstly, customer environmental awareness is creating opportunities for "green marketing". According to Loannou et al., market trends and brand image reputation are two of the most dominant drivers for sustainable product design and manufacturing [1]. Accordingly, manufacturing companies can gain competitive advantage by incorporating Ecodesign in their product development. Secondly, the development of alternative EoL treatment strategies for WEEE is required to reduce the involved processing costs. The currently adopted EoL treatment strategies for WEEE are often characterized by a low to negative profitability [2]. According to Huisman et al., the main reasons for this low return are the high collection, transportation and treatment costs which cannot be covered by the revenues from the recovered components and materials [2]. Finally, the third key motive to improve the EoL treatment of WEEE are the European WEEE directive [3] and the upcoming recast of this directive [4]. The quotas of this recast will range from 50 to 70% with respect to recycling and a recovery rate of 70 to 80% depending on the product category is expected [4]. According to the current WEEE directive recycling means the reprocessing of a waste material for the original or other purposes, and recovery means the use of combustible waste as a means of generating energy through direct incineration [3], which currently is a common treatment for plastics. Furthermore, the European directives do not only affect recyclers but also manufacturers, since they increasingly require manufacturers to take full responsibility for the EoL treatment of their products.

The conventional EoL treatment strategies for electronic products, which are based on product shredding or smashing, only permit to recycle a limited amount of precious metals and plastics. Due to the considerable environmental impact when not reclaimed and the high economic value of these materials, improvements in the conventional EoL treatment of WEEE are required. Furthermore, some categories of electronic products contain a considerable amount of plastics, such as Liquid Cristal Display (LCD) flat screen televisions (FTVs) which contain about 30% plastics on a mass basis. For these product categories, it is crucial to develop EoL treatment strategies which include recycling of plastics to achieve the recycling rates of the upcoming recast of the WEEE directive and to recycle precious metals to lower the environmental impact of the EoL treatment [5, 6].

2 ALTERNATIVE EOL STRATEGIES

Different strategies to improve the EoL treatment of electrical and electronic equipment have been studied in prior research, such as:

- Manual disassembly strategy, for which the treatment cost is mainly related to the amount of time required to disassemble a product and the labor wages. Due to high labor costs in Europe, manual disassembly of WEEE is under the current circumstances generally characterized by a low to negative profitability [7].
- Automated disassembly, for which prior research has proven the technical feasibility of fully automating a non-destructive disassembly process for, among others, , personal computers [8] and mobile phones [9]. However, automating the disassembly process in an EoL treatment is currently limited by the variation of returned products, which requires a great capacity of recognition and intelligence [10, 11].

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- Advanced post-shredder separation strategy, for which different technologies have recently been developed to separate shredder residue based on (optical) material properties. However, prior projects demonstrate that the main challenges for implementing such a strategy are the high investment costs and the low separation efficiency of optical separation processes for WEEE [12, 13].
- Design For Disassembly (DFD), for which many efforts have been made in prior research, since the efficiency of disassembly operations can be significantly influenced by an optimization of the product structure [14]. However, the time to localize and identify connectors covers approximately 30% of the total disassembly time [15]. Furthermore, prior studies have shown that the economic feasibility of disassembly can only be guaranteed if the disassembly time and cost are reduced by at least 75% for electronic products [16]. Therefore, DFD strategies which require a localization and identification step have only a limited potential to make systematic disassembly a preferred EoL treatment [17].

To accomplish a decrease in disassembly time of more than 75%, the development of fasteners with a lower technical disassembly complexity is required. Within prior research fasteners with an Active Disassembly (AD) functionality have been proposed [7, 18]. Active fasteners are connections for which a specific external trigger or a combination of triggers can initiate a simultaneous (one-to-many) unfastening process. Since AD allows simultaneously releasing fasteners within different products, AD is assumed to allow a productivity increase by a factor 5 to 10, and to reduce the disassembly costs with up to 70% [16]. Therefore, active disassembly, when properly implemented, has the potential to shift an EoL treatment with systematic disassembly from a cost factor to a profit generating activity [15, 17].

3 ACTIVE DISASSEMBLY

3.1 Trends to consider for Active Disassembly

When developing components for future electronic products, different trends in the evolution of these products have to be taken into account. TRIZ, a problem-solving, analysis and forecasting tool derived from the study of patterns of inventions in the global patent literature, contains different interesting trends which can be related to the evolution of fasteners and electronic products, such as [19]:

- Smart materials: from passive to fully adaptive fasteners, e.g. made out of shape memory materials. The most advanced research on active disassembly yet is based on materials which are able to return to an initial shape when heated above the trigger temperature [20-25].
- Object segmentation: from monolithic solid fasteners to a segmented solid up to a vacuum to hold an assembly together. Some examples of AD fasteners which are in line with this trend are: Velcro made of shape memory materials [18, 26] and the use of a vacuum instead of glue to assemble photovoltaic cells [27].
- Evolution macro to nano scale: miniaturization is a clear trend for electronic products and accordingly for the fasteners used in these products. Unfortunately, this impedes the implementation of some prior developed active fasteners in today's products. For example fasteners which make use of the extension of water when freezing or pneumatic expansion are difficult to implement in the current generation of FTVs, which continuously decrease in thickness [28, 29] .

3.2 Ecologic and economic constraints

To allow an industrial implementation of AD both ecological and economic constrains should be considered. Therefore, it is important to select a working principle for AD which requires only a limited amount of trigger energy. For that reason, working principles for AD, such as the chemical reaction proposed by Suga et al. [30, 31], where a hydrogen storage alloy is pulverized in a hydrogen atmosphere under a pressure of 4MPa and a temperature of 100 °C, are less interesting for an industrial implementation. Also, thermally triggered active fasteners require a substantial amount of energy for heating up or cooling down electronic products above or below the broad temperature range of the use phase. Furthermore, the amount of scarce materials in active fasteners should be limited or a significant percentage of the connectors should be recycled to reduce both the ecological impact and cost of implementing an AD strategy.

Besides these constraints, one of the main challenges for implementing AD in an industrial setting is the required investment for the application of releasable joints. The integration of these joints in the product design at the outset of a product's lifecycle represents only minor benefits for the producer, for e.g. during maintenance under warranty obligations. The main returns of this investment are only obtained at the end of the lifecycle, when the product is typically no longer owned by the producer. For this reason, a holistic life cycle approach is desired for most electronic consumer products, in which all different actors in the lifecycle are involved. Nevertheless, producers or companies who offer their products in a Product Service System (PSS) can significantly benefit from an EoL strategy with AD, since these companies may also be responsible for the EoL treatment of their products.

4 INFORMATION REQUIREMENTS

Nowadays, information associated with products is gradually lost after the point of sale, which is one of the major obstacles for efficient recovery of value from EoL products [32]. As long as no standard active fasteners are commonly implemented, an efficient identification of products with active fasteners and information about the corresponding trigger are essential. Furthermore, information about the product composition and structure is required to allow a correct sorting for further treatment of components once a product is disassembled regardless of the adopted EoL treatment strategy.

The desirable properties of product information can be described by three dimensions: the level of detail of the product information, the ability of product identification and the product information location. Firstly, the required level of detail of the product information depends on the envisaged EoL treatment, for e.g. with manual or automated sorting. However, potential improvements in the current EoL treatment strategies need to be taken into account. Therefore, highly detailed product information should be accessible for the envisaged EoL treatments. Secondly, the product identification can be facilitated by implementing product identification technologies in products. For example, bar code labels, which are commonly placed on FTVs for logistic reasons, can sometimes still be used to identify the product model at the EoL of the product. The product model can then be used to look up detailed product information. However, often more than one barcode is attached to every product and barcode labels are sometimes damaged during the use phase [32]. For these reasons, the reliability and efficiency of the identification can be improved by applying modern identification technologies, such as Radio Frequency Identification (RFID), which allows a fast and remote identification of products using radio waves [32]. Finally, if product identification is possible, it does not necessarily means that the information needs to be located at the product. Two extreme scenarios can be identified here: information access through a data network or information integrated in the product [33]. A system which enables to integrate fundamental information to a product and access more detailed product information through a data network seems most appropriate for this application. In this way manufacturers will be able to better protect their Intellectual Property (IP) and can choose when to share which product information, e.g. to only share detailed information when products reach their EoL. Furthermore, such a system can support a business model in which the product manufacturer is able to add detailed product information in a database in later stage and sell this product information in accordance to the surplus value it comports to the recycler [34].

5 CASE STUDY OF FLAT SCREEN TELEVISION

5.1 Differences in LCD LED, LCD CCFL and PDP

Three Philips FTVs with different and commonly used flat screen technologies are analyzed and compared within this case study. The technology adopted in the first FTV is a Plasma Display Panel (PDP), the second FTV uses a Liquid Cristal Display (LCD) with a backlight consisting of Cold Cathode Fluorescent Lamps (CCFL) and the third is a LCD FTV with backlights consisting of Light Emitting Diodes (LEDs), which are located at the side of the television.

The current market is expected to reach about 150 million TV sets in 2010 in Europe [2]. The European market is mainly dominated by LCD televisions (>90%) and there is an ongoing change from CCFL (44%) to LED (56%) back lights [35]. PDP televisions are also analyzed within this case study, since they are expected to represent a significant share of EoL FTVs in the coming years, as PDP televisions were mainly sold before 2005 [2].

As shown in Table 1, the material content strongly depends on the adopted FTV technology. PDP FTVs are significantly heavier and have a significantly higher amount of PCBs and floated glass. On the other hand, LCD FTVs contain more plastics, since plastics are, besides the housing, also used in these FTVs to diffuse and polarize the light of the CCFL or LED backlights. From a recycling point of view, an important difference between LCD FTVs with CCFL and LED backlights is that CCFLs contain mercury. Therefore, when these backlight lamps are broken an additional process for the removal of toxic mercury vapors is required. The in this study analyzed, Phillips LCD television with LED backlights is the winner of the Green Awards 2011 and, according to the EISA Green Award jury, for the first time a truly Ecodesign product [36]. This television is perceived as an Ecodesign product due to its innovative reduction in energy consumption, improvement in product architecture and more efficient packaging. This FTV is significantly lighter and has, besides the difference in backlight, an unconventional material composition. The major difference with common LCD FTVs is that mainly aluminum is used in the product housing and structure.

5.2 Material values and separation efficiencies

In the case study presented in this paper, the potential revenues of recovered materials and the potential recycling rate in accordance with the European WEEE directive are calculated for two EoL treatment strategies, as shown in Table 1. A comparison is made between an EoL strategy where the FTVs are directly shredded and an EoL treatment strategy where all fasteners in the FTVs are assumed to be reversible by AD.

The material recovery rates for the ferrous metals and the aluminum, used in the calculations, are based on the estimated efficiency of magnetic and eddy current separation processes for shredded material from FTVs [12]. For the direct shredder strategy no polymer recycling is assumed, since all the housing plastics of the analyzed FTVs contain phosphor based Flame Retardants (FR) and plastics with FR are rarely recycled [5]. Nevertheless all polymers with phosphor FR are authorized for re-use by European legislation [3]. The reason why these polymers are often not recycled is that they risk to be polluted in the shredding process with polymers with banned brominated FR and that further separation of these polymers from shredded residue based on their flame retardants is

Table 1: Value of recovered materials and recycling rates according to the WEEE directive for Philips PDP, LCD with CCFL and LCD with LED FTVs for a direct shredder EoL treatment strategy and an EoL treatment strategy with AD

Material Custom Name	Weight / TV			Value of recovered material	Direct shedder strategy	AD strategy
	PDP	LCD + CCFL	LCD + LED			
	(%)	(%)	(%)	(€)	(%)	(%)
PCBs	14%	6%	5%	900	0%	95%
Cables	1%	1%	-	700	0%	100%
Plastics (total % and % send to incineration)	11%	34%	24%	-160	100%	1-15%
Thermoplastics	2%	1%	-	400	0%	0%
PET	-	4%	6%	660	0%	100%
PMMA	-	4%	15%	2920	0%	100%
ABS + PC + FR 40	8%	16%	1%	1370	0%	100%
PC + FR 40	-	7%	-	1370	0%	100%
PC + GF10	1%	2%	1%	300	0%	100%
Glass	37%	-	-	-55	0%	100%
Glass LCD	-	9%	12%	50	0%	100%
Metals: Ferro based	26%	47%	5%	220	75%	100%
Metals: Aluminum based	11%	3%	54%	2060	88%	100%
Value of recovered materials / Tonne of televisions (€)	**296**	**57**	**505**			
Recycling rate according to the WEEE directive	**30%**	**38%**	**51%**			
Value of recovered materials / Tonne of televisions (€)	**862**	**694**	**914**			
Recycling rate according to the WEEE directive	**98%**	**92%**	**95%**			

currently not feasible at high material throughputs [5]. Also, Polymethylmethacrylate (PMMA), Polyethylene Terephtalate (PET) and all PCBs are assumed to be sent to incineration, since the (optical) separation of these materials is not yet proven to be economically viable. For the AD strategy the recovery rates are calculated assuming that all large components are disassembled and separated based on detailed product information. Furthermore, the same separation efficiency is used for the PCBs as presented by Meskers et al. for the manual disassembly of PCBs from Personal Computers [37].

All values of recovered materials used for this case study are based on estimates from prior studies. The values of some recovered materials differ significantly between sources, since they are generally incinerated with energy recovery and not recycled [2, 12, 13, 38]. For this case study, rather optimistic values of recovered materials in Europe, as proposed by Huisman et al., are used [2]. However, to receive these values for recovered material a steady supply of polymers with an assured quality should be achieved. For plastics sent to incineration with energy recovery a cost of 160 euro per tonne is taken into account and for the recovered cables a value of 700 euro per tonne is used, based on data from Salhofer et al. [38]. Both for the LCD, which contains mainly glass, and for the glass of the plasma television the values of the recovered materials are based on data from Cryan et al. [12]. The values of the PCBs are based on the average material content of FTVs, as described by Huisman et al. [2], and values of recovered PCBs, as used by Keller [2, 39].

5.3 Conventional EoL treatment versus AD

The case study shows that for an EoL treatment strategy with direct shredding and commonly used separation processes, such as magnetic separation and eddy current separation, a considerable value can be recovered from PDP FTVs, since these TVs contain a high percentage of aluminum and ferrous metals. However, from LCD FTVs with CCFLs only a low value can be recovered. Nonetheless, an additional process for the removal of toxic mercury vapors is only required for these FTVs with CCFLs. For the LCD FTV with LED backlights a considerably higher value can be recovered compared to the other FTVs analyzed in this case study. The main reason here for, is the exceptionally high amount of aluminum that this Ecodesign product contains, which can easily be recovered with a direct shredder strategy. Therefore, this LCD FTV with LED can be described as a product which is successfully designed to improve the amount of materials which can be recovered with a conventional EoL treatment with direct shredding.

When comparing both EoL treatment strategies, there is a clear improvement in value of recovered materials possible by implementing an EoL treatment strategy with AD. Mostly for the LCD FTV with CCFL a significant improvement in the value of recovered materials of about 600 euro per ton can be achieved, since an EoL treatment strategy with AD allows to recycle most plastics and PCBs. Accordingly, these calculations also determine that, neglecting the time value of money, about 18 euro per LCD FTV with CCFL is the total maximum investment for the implementation of active fasteners and additional process in the EoL treatment, which can make AD an economically preferable EoL treatment strategy.

The recycling rates calculated for the direct shredding strategy for the in this case study analyzed LCD FTVs are below the quotas required by the current European WEEE directive. Consequently, improvements in the recycling rate will be required when the volume of EoL LCD FTVs increases. However, the recycling rate is calculated for a combined treatment of consumer products, of which FTVs currently constitute only a small share. Based on these results, it can be expected that recycling plastics glass will be compulsory to achieve the recycling rates of the upcoming recast of the WEEE directive. A significant increase in the percentage of recycled materials can be achieved by implementing an EoL treatment strategy with AD, as demonstrates by the case study. However, to permit recycling of all materials from different components after active disassembling a product, detailed product information, such as the used type of flame retardant, is required. If all this information is available the EoL, active disassembly has the potential to shift an EoL treatment with systematic disassembly from a cost factor to a profit generating activity.

6 CONCLUSION

Based on the presented case study it can be concluded that, compared to the conventional EoL treatment with direct product shredding, there is a high increase in recycling rate and value of recovered materials possible by implementing active fasteners in flat screen televisions. However, further developments in the field of AD are essential to make the implementation of active fasteners technically feasible for the current generation of flat screen televisions and to overcome the economic and ecologic constraints mentioned in this paper. Furthermore, detailed product information is required for an EoL treatment with AD to allow the identification of the required trigger for AD and an accurate sorting of disassembled components for further treatment. To facilitate the product identification at the EoL robust technologies, such as Radio Frequency Identification, should be implemented in products with active fasteners.

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Increasing energy efficiency by remanufacturing and reengineering

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Abstract

Traditionally, manufacturing companies are mainly optimising their process efficiency with lean management approaches like reducing the seven wastes. In times of rising energy and material costs due to limited primary energy and raw material availability, small and medium-sized companies (SMEs) in particular are facing the challenge to increase their energy efficiency. Analyzing the manufacturing costs of SMEs during the European research project "Methods for Efficiency" (M4E) clearly revealed that a reduction of energy costs is possible as soon as the machinery and the factory infrastructure of these companies are specifically set-up or reengineered for the purpose of energy efficiency. Hence, to enable SMEs to gain transparency in terms of the energy consumption of both their machinery and auxiliary production equipment, a proceeding was developed for assessing their energy efficiency in detail. First component-wise power measurements of the pneumatic systems, lighting and various machinery in different operation modes such as ramp-up, idle or production mode were conducted. Based on these gathered data guidelines are developed to increase the energy efficiency of manufacturing processes which use yet existing machinery and systems. This affects the energy-efficient operation as well as reengineering and remanufacturing of equipment.

Keywords:

Sustainable manufacturing, industrial ecology, energy saving, energy efficient production

1 INTRODUCTION

1.1 The project "Methods for Efficiency"

On the one hand the project's acronym M4E stands for the project title "Methods for Efficiency". On the other hand it is a shortcut describing the five dimensions man, machine, management, material and energy, which are assessed by the three institutes involved together with nine manufacturing companies [1].

This project consortium consists of the Department of Production Engineering of the KTH Royal Institute of Technology Stockholm in Sweden, the Chair of Manufacturing and Remanufacturing Technology and the Fraunhofer Project Group Process Innovation; the latter two are located at the University of Bayreuth in Germany.

This actual project is funded by the EraSME research program of the European Union and started in January 2010. The following contribution contains both evaluated and conceptual project results.

1.2 Resource and energy efficiency

Resource efficiency is a key-driver for technology and innovation management of products both new and already in use, since industrial customers are aware of the ecological impact of their machinery in the utilization phase of the product life cycle [2]. Concerning the resources man, machine and management lean production methods still offers huge opportunities, since they are not yet fully implemented in SMEs. Today's missing link to increase the material- and energy efficiency is the availability of suitable approaches [3] relying on an affordable database.

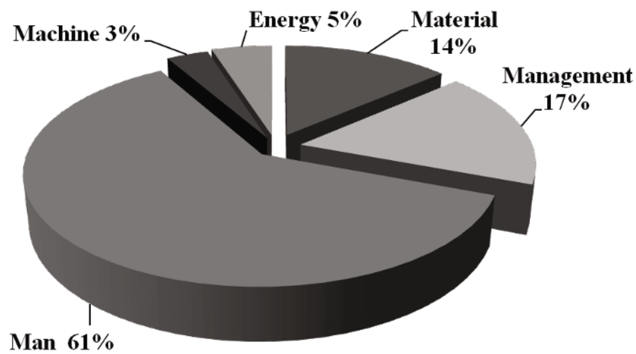

Figure 1: Resource specific saving potentials in SME identified in the research project "Methods for efficiency" (intermediate result)

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Looking at the cost structure of SMEs, the share of energy costs of currently 1.8 percent [4] today is relatively low due to the current energy prices. Nevertheless considering all realizable saving potentials the intermediate result shows that a share of 8% of all identified savings during this project was related to energy saving measures.

2 ANALYSIS AND CONCEPT DEVELOPMENT

2.1 Proceeding

Focusing on electrical energy consumption the machinery and the auxiliary plant equipment were analyzed in the participating companies.

First, in order to get a brief overview of the consumption on plant level, data from the power supply company was used to quantify the ratio between costs for power peaks and for the base load. This was followed by measurements on infrastructure and machinery. The latter was investigated on process, machine and component level [5]. The interpretation of the measurement results revealed the main dissipation drivers which are described in chapter 3. For each of these a possible optimization measure was considered and checked for technical and financial feasibility.

Finally, selected project results were implemented in the companies. A selection of these is discussed in chapter 3.

2.2 Allocation of electric energy consumption

Due to the lack of automated energy monitoring in SMEs today [6], the availability of consumption data on process level is often limited on the energy bills. Therefore temporary electric power measurements on process level in a first step help to create transparency, especially when it comes to the identification of energy spikes [7]. Regarding the production process and facility management, the main energy intensive technologies in use were accessed concerning their electric energy consumption. As shown in figure 3 this approach clearly revealed that the main electric consumers are machinery (62%), pneumatic power supply (13%) and lighting (16%).

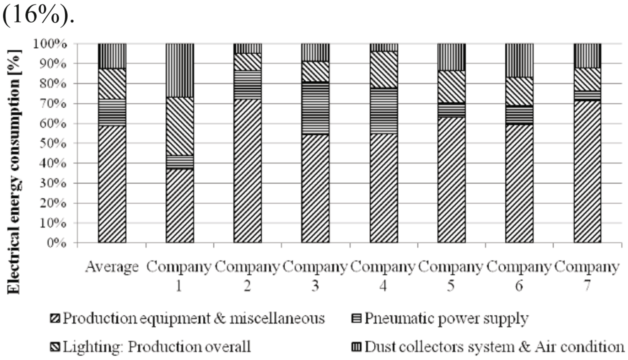

Figure 2: Allocation of electrical energy consumption on plant level

These main consumers were examined in a further detailed approach, including the measurement on machine level measuring the electric energy consumption of each machine component [8] in different operation modes (see chapter 3.1).

2.3 Optimization measures

It is important to distinguish between energy savings that require technical modifications (e.g. implementing heat recovery) and those that can be achieved by motivating employees and addressing their sense of responsibility [9]. Employees largely influence the energy consumptions of equipment in idle mode. This could be lighting in temporarily abandoned areas (see chapter 3.3) or unused production machines (see chapter 3.1). In addition for processes that go along with an undefined material input like painting or cleaning the behavior of the worker is crucial for both the resource input and the achieved quality. Figure 3 shows that the behavior depends on knowledge and motivation as well as alertness. Despite improvements are often incalculable visualization [10] is a widespread practice [11].

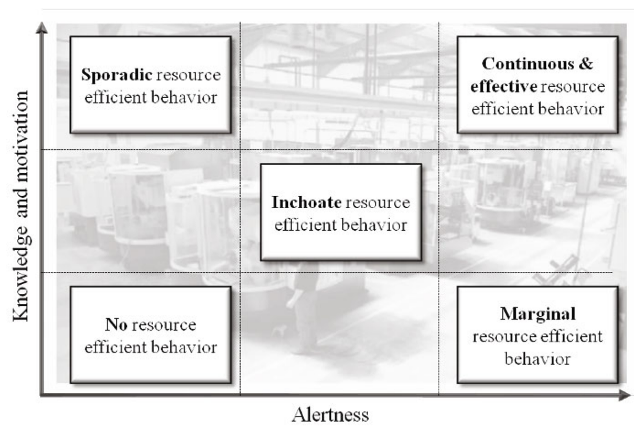

Figure 3: Degree of employees' involvement in efficient usage with material and energy resources

Based on measurement results that characterize the energy consumption of a given production machine, energy savings can be realized by the following measures. First, in case of an anyway necessary replacement, a new efficient system or machine should be chosen to fit the requirements of the user, concerning both operation mode (notably the control system) as well as performance. The second option gets along without mayor investments by involving the worker himself and saving energy resources in consequence of attentive behavior (like manually switching off not needed components) [12]. When there are no technical restrictions this is often a feasible and cost-effective approach. Third, reprogramming the machine control can save a notable amount of energy by automatically switching off auxiliary components in idle mode. In the fourth place the existing production equipment should be re-dimensioned based on the findings during the power measurements with appropriate smaller or more efficient drives [5].

These approaches require detailed investigations of consumers like explained in chapter 3. This includes parameters like the required torque, rotation speed or load case, which affect the configuration of the machine control.

2.4 Critical success factors for implementations

The main critical success factors of reengineering the existing or conventional machinery e. g. with new energy-efficient drive components are economic hurdles, especially the payback periods which are not often below the established allowance of two years. Due to the rising energy costs, this fact will, however, change in the near future, and this is why the developed proceeding supports manufacturers, who begin to integrate energy-efficient technology management into their maintenance and procurement processes. SMEs which adapt their yet existing production facility and machinery to the changing requirements by steadily improving energy efficiency by reengineering and remanufacturing ensure to strengthen their own market position and stay competitive in ecological and economical ways.

3 SELECTED PROJECT RESULTS

Based on the measurement actions [13] saving potentials were identified, of which some are related to technical solutions [14] others could be realized by the employees with attentive behavior.

3.1 Machinery

The measurement started with the ramp up of the machine tool (Gildemeister CTX 310). This mode typically comes along with an energy consumption peak as certain thermal and hydraulic conditions are aimed at. In the following idle mode the machine is ready for production and auxiliary components like the hydraulic pump, the fan drive and the machine control keep working. As soon as production starts additional energy is needed for the coolant pump and the main drives. The main drives stop between each manufactured part while the coolant pump does not. In the end the measurement of the ramp-down mode shows the cascade-like switch-off of the different components.

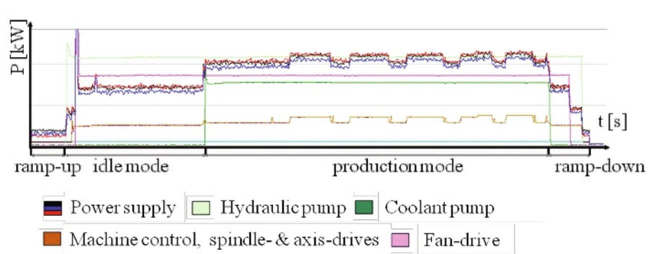

Figure 4: Load curve of a machine tool

The dissipation of energy in idle mode is pointed out in figure 5. The reason is that about 75% of energy is needed to power auxiliary equipment (chiller, extraction system, coolant pump, hydraulic pump) and only 25% is used for direct value adding [15] processing (machine control and spindle and axis drives). In idle mode the power consumption drops only to 73% of the power needed in production mode. Because of unspecified control not needed auxiliary equipment keeps on working resulting in high energy losses. As workers have only unsuitable options like switching off the whole machine, eco design of the system control is an effective way to save energy.

Baseline energy consumption should be minimized by turning-off components not needed in the idle mode [16]. A cost-effective way for realization is reengineering [17] (see chapter 3.4).

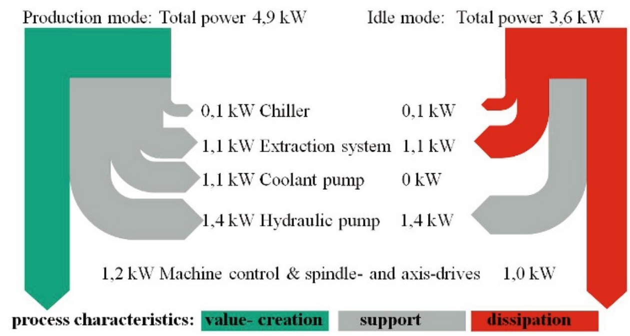

Figure 5: Interpretation of measurement results

Another major driver for energy costs are power peaks which cause the energy supply company to run its facilities in less efficient modes. Such peaks occur for instance when the ramp-up of production machines overlaps. Figure 4 shows such a peak of a turning machine as soon as the machine is turned-on.

Attentive behavior of the workers can reduce energy costs in multiple ways. A company in the automotive supply industry uses a screen as a lean energy management solution (see Figure 6) to show workers in which intervals to ramp-up the die molding machines. Thereby peak load costs were reduced by a four-figure euro sum.

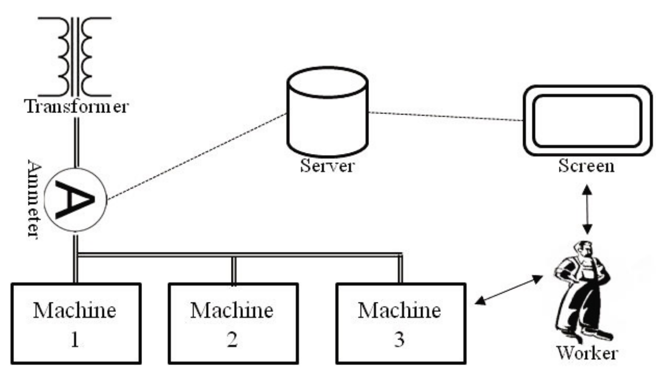

Figure 6: Ramp-Up Management, Addressing employee's behavior with visual assistance technology in order to save costs for power peaks

3.2 Compressed air supply

Compressed air supply is a major driver for energy costs in most plants (see Figure 2). Although compressed air is the most expensive energy carrier, both supply system and pneumatic components lack efficiency [18]. Therefore an optimization-tool was developed to redesign parts related to energy losses. This affects compressors, connecting elements, pneumatic components as well as system controls. As optimization of these systems should concentrate on the main issues right from the beginning, the tool starts with a pre-selection of worthwhile investigations. After a guided data collection an interactive checklist shows, which investigations such as long time electric power and temperature measurement of compressors, ultrasonic detection of leakages, determination of air contaminations, volume flow rate and flow pressure at pneumatic components, are for the given company essential.

In the following a list of optimization measures is created automatically. This list is joined by a calculation of saving potentials and pay-back periods for each of these measures. These optimization measures involve short time improvements regarding compressor controls and leaking connecting elements as well as laborious actions like heat recovery and reengineering pneumatic components.

The applied pneumatic components are the main drivers for the needed air pressure in the whole compressed air system. Undersized pneumatic components require an increased pressure level causing the compressed air system of the whole plant to lose efficiency. Reengineering such components allow to lower the needed air pressure from high levels like 9 bar or more to a moderate level like 6 bar or less. Keeping in mind that reducing the air pressure by 1 bar reduces the cost for pneumatic supply by as much as 10% such improvements are rather worthwhile.

In some cases it might turn out as beneficial to replace pneumatic components with electric ones – or in special applications even the other way round.

As a result of the investigations during the research project “Methods for Efficiency” the cooperating companies realized average energy savings concerning compressed air supply of 15%.

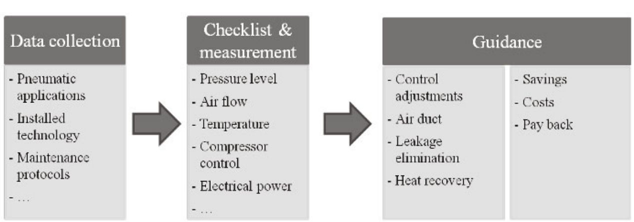

Figure 7: Structure of optimization-tool for compressed air supply

3.3 Lighting

Since lighting affects not only the employees’ productivity [19], but also consumes about 16% of the whole energy consumption of a plant (see Figure 2), a closer look is worthwhile. There are two possibilities for optimization measures:

The first is to shorten the switch-on time of the lighting systems. Lighting was activated in the production area of the companies that were engaged in the project “Methods for efficiency” all day even in summer time. Especially when working in different shifts at neighboring work stations the lighting of the whole area stayed in use notwithstanding that most work stations were not occupied (see figure 8). Encouraging workers to dampen the light of working areas in idle mode promises savings as much as 17% of the energy consumption of lighting.

The second possibility to cut energy costs for lighting is to improve the lighting technology in use. T5 fluorescent lamps together with appropriate reflectors are yet superior to LED lighting and compared to the T8 standard 15% energy savings are achievable.

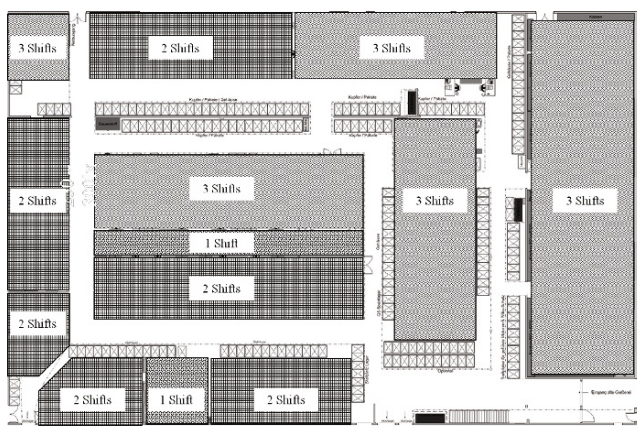

Figure 8: Lighting need in the production area of a SME

A worthwhile technology for reengineering production sites with large roof windows like in shed roofs is to take advantage of the incoming sunlight. By continuously measuring the light intensity with an illumination sensor and installing adequate regulation technique modern fluorescent lamps can be damped. Under sunny conditions power input drops temporary to 66%, whereby energy savings go up to 12% over a whole two shift working day.

3.4 Development of Guidelines

Saving energy in a production plant requires different proceedings for different energy consumers. As mentioned in chapter 2.4 energy efficient solutions have to fit financial criteria. Figure 9 shows that on one hand modernization of production equipment and lighting bear large energy savings, but is accompanied by major investments. On the other hand strengthening resource saving behavior of the employees and improving the condition of the pneumatic system (e.g. by eliminating leakages) will save less energy but requires more organizational effort than financial means [18].

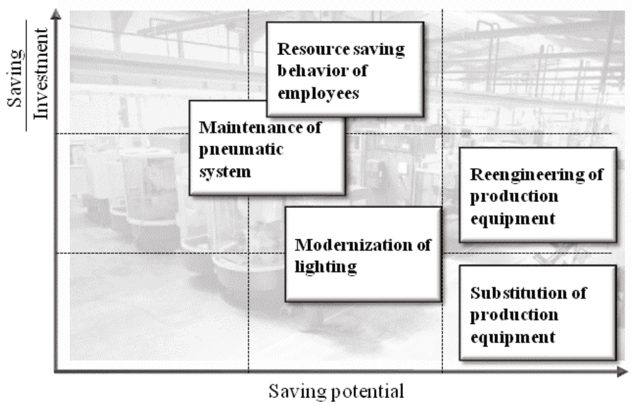

Figure 9: Classification of main starting points for resource saving in production plants

The following focuses on efficiency improvements that require financial means. Because of financial hurdles these improvements will take place when a major overhaul is needed (e.g. when old equipment loses function).

As one option to reduce financial strains remanufacturing allows reaching good value with little money. Thus approaches to combine remanufacturing with efficiency improvements seem promising.

Actual studies [20] imply that remanufacturing does not save energy for every product. Especially for complex machine systems like production equipment a remanufactured product competes with newly manufactured goods with the next generation of product features [21]. Due to use phase efficiency improvements and design trends keeping up with new developments is challenging for these remanufactured products. Therefore a qualitative decision support model is needed to combine remanufacturing with enhancing the energy efficiency by reengineering in order to handle technology leaps. As shown before there are several options to improve energy efficiency of complex machines. Firstly, certain electric drives can be replaced by solutions with a higher efficiency class or upgraded with frequency converters. In some cases even downsizing in agreement with customers is profitable. Second, redesigning pneumatic components that can work at low air pressure, allow integrating the machine in a low pressure system. Third, specific changes in the equipment control, like automatically switching off electric components in idle time lead to a minimized baseline consumption.

To sum up the three main drivers of energy consumption in a plant, there are different opportunities for improvements. Like figure 10 shows, equipment like lighting consumes most of its energy in the use phase. Therefore when it comes to a major overhaul the equipment should be replaced by a new technology. On the other hand equipment which energy consumption is dominated by its production (e.g. cranes because of the use of large amounts of material and the limit of its daily operating time) should be remanufactured, when a overhaul is necessary. In between these two cases overhauling entire production machines requires a combination of reengineering and remanufacturing. In this way advantages like minimized baseline consumption and the ability of working with a low pressurized air supply can come together with the classical benefits of remanufacturing like reusing heavy casting parts and attached components like hydraulic pumps.

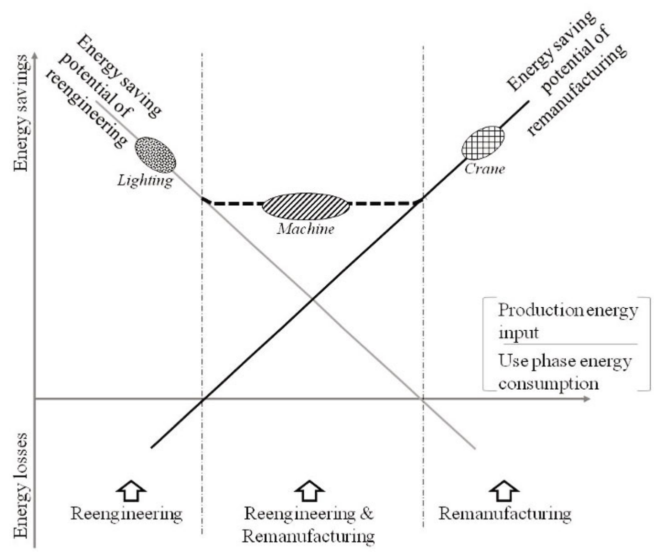

Figure 10: Allocation of investment related saving options in relation to energy input into equipment production and equipment use phase

Thereby this decision support model helps machine operators as well as the machine developer to adapt the machine setup according to the concrete requirements, which are determined by the equipment's character.

4 SUMMARY

In this paper, energy consumers in typical manufacturing plants were measured and structured in order to determine the order of priority for improvements. Mainly, the reduction of baseline energy consumption and the improvement of employees' engagement offer opportunities with small investments. Case studies across a broad range of industrial segments revealed different optimization approaches for machine design in contrast to operational efforts depending on whether the predominant energy need occurs in use phase or as production energy input. Furthermore, the paper shows the need to emphasize and to combine reengineering with remanufacturing of existing production equipment since these machines are the biggest consumers of electrical energy in a plant. A system pattern of how to effectively include workers into an energy saving policy and a classification to master reengineering costs will be detailed in future research projects.

5 ACKNOWLEDGMENTS

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Improving the Efficiency of the Remanufacture of Complex Mechanical Assemblies with Robust Inspection of Core Units

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Abstract
This paper presents the findings of experimental research carried out at a Caterpillar Remanufacturing facility in the UK into core inspection at the initial stage of remanufacture – Receive Core. The results show an increase in productivity in line with an increase of inspection but that this increase is finite and over-inspection leads to an overall decrease of productivity and an increase in costs. The amount of inspection that produces an economic benefit is related to the complexity of the assembly in terms of number and type of component parts. Similar benefits can be seen when complex assemblies are reduced to smaller assemblies in order that an appropriate level of inspection can be carried out. The results also show that the amount of viable inspection can be closely linked to the cost of the component rather than the facility operating costs. This is important because remanufacturers traditionally base their pricing and product recovery on their operating costs. The new knowledge concerning the factors affecting the efficacy of core inspection is being used to develop a generic decision-making methodology for core inspection at component level to improve the overall efficiency of the remanufacturing operation.

Keywords:
remanufacturing, inspection, productivity, operations

1 INTRODUCTION

Remanufacture, a process to return used product to an "as-new" condition with an equal warranty [1] is typically carried out on complex mechanical assemblies as the remaining value in the used product is high. Remanufacturing is often a more efficient reuse strategy than recycling as, in addition to the reduction in landfill and the use of virgin material, it also reduces the amount of energy used in production by removing the need for raw material production and the subsequent shaping and machining processes thus slowing or reducing the production of greenhouse gas emissions such as CO_2. Sutherland et al [2] found that at component level, the energy savings could reach 90%. These finding echo Lund [3] who suggested that up to 85% by weight of a remanufactured product may come from reclaimed components, and that remanufactured components have a comparable quality to new whilst requiring between 50% and 80% less energy to produce. Taken as a whole, this can produce manufacturing savings of between 20% and 80%. Remanufacturers look to either decreasing work content or the included quantity of new material is the main route to increase profitability.

There remain barriers to remanufacturing particularly around the paucity of research into the field. The development of a robust definition has helped to clarify the confusion with repair and reconditioning, however Guide [4] identified that remanufacturers perceive the scarcity of effective remanufacturing tools and techniques as a key threat to the industry. Ijomah [1] quantified these key characteristics on a five-point scale ranging from "Not Significant through to "Critical". The characteristic deemed to be most important to remanufacturers was component inspection – the only one rated as critical. Personal industrial experience and observation of the remanufacturing process has shown that this remanufacturing sub-activity, although it can have significant bearing on overall productivity, is often undertaken in a hap-hazard manner based almost purely on experience and guesswork and lacks proper methodologies and tools. However, it is known that efficiency and effectiveness are key requirements for enhancing profitability and productivity in a business environment.

2 RESEARCH BACKGROUND

It is usual practice in remanufacturing to inspect at all stages through the process, often functionally and in all cases visually. The result of this is a high quality product for customers but lowered profitability for the remanufacturer through either too little initial inspection leading to unnecessary processing and further inspection later through the process, or through core being unnecessarily rejected early in the process and leading to a poor recovery rate. Subramoniam et al [5] proposed that a lack of reman-specific cost-benefit analysis tools has led to poor decision making for remanufacturers and this can be observed in remanufacturing companies. An in-depth literature survey undertaken as part of this research has proven that little research has been

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undertaken in the "Receive Core" remanufacturing sub-activity. This research will identify new knowledge about the factors that affect the inspection process and consequently provide a quantifiable approach to inspection at the critical "Receive Core" sub-activity potentially leading to improvements in the productivity of remanufacturing both at that stage and further through the process. This new knowledge is also intended to be accessible to operational managers as much of the research found during the literature review involved complex mathematics and, as discovered during preliminary interviews, is rarely adopted by industry. The automotive industry was selected because of its long history of remanufacturing.

Lund [3] defined three basic types of remanufacturer:

- OEM remanufacturers – often a process alongside their manufacturing operations;
- Third-party remanufacturers – remanufacturing under licence for the OEM and often, but not always with their technical support; and
- Independent remanufacturers – remanufacturing other people's goods without licence or support for direct sales into the aftermarket.

The key difference between independent remanufacturers and OEM and contract remanufacturers in terms of core is that in almost all cases the customers are responsible for return of core units with the remanufacturer having little control over the quantity, mix or quality of returns. This can have a significant impact on ability to supply customers particularly where the mix of core units cannot be guaranteed to match the mix of remanufactured units required by the customer. In addition, contract remanufacturers operate with fixed cost contracts that allow for no additional charge to be made for badly damaged or incorrect core.

This research builds on the research of Errington [6] who looked at core and inspection strategy in independent remanufacturers. The key difference here is that this research will augment that work by looking at both OEM and contract remanufacturing processes to identify the specific component characteristics that determine the appropriate level of inspection.

Caterpillar Remanufacturing Services is both an OEM remanufacturer and contract remanufacturer for a variety of automotive and industrial customers with four facilities across Europe. The facility at Rushden, where this research is being conducted, is primarily focused on remanufacturing petrol and diesel internal combustion engines with a capacity up to approximately 6 litres and their ancillary components (starter motors, fuel injection equipment, turbochargers etc.). Initial interviews with key staff at the facility suggested that the majority felt that any process other than a cursory inspection was a waste of time.

3 EXPERIMENTAL DESIGN – STAGE 1

The aim of the experiment was to establish whether inspection of core made a material difference to the speed of remanufacture and hence productivity. Engines of varying types would be inspected against differing criteria to measure what the effect of inspection was on the remanufacturing process.

Four engine types were selected to ensure a representative sample of engine types, sizes, applications, supplied dress level and customers. They were:

Engine A: Four cylinder, automotive petrol engine, supplied at long engine level*.
Engine B: Six cylinder, automotive diesel engine, supplied at long engine level*.
Engine C: Four cylinder, specialist application diesel engine supplied at full dress level**.
Engine D: Six cylinder, industrial application diesel engine supplied at full dress level**.

* Long engine level: Cylinder block, crankshaft, con-rods, camshafts and head, sump and covers, oil pump and water pump.
** Full dress level: Long engine level plus starter motor, alternator, compressor, fuel injection equipment, flywheel and turbocharger as applicable.

Four inspection protocols were developed to test the effect of different levels of inspection on the whole remanufacturing process. The extent of the inspection was limited by the available technology.

Protocol 1 - no inspection, decant, establish part number and reuse. This protocol was to test whether inspection of core made any material difference.

Protocol 2 – decant, establish part number, visual, external inspection and grading; either use, close to new – bypass the usual process or severely damaged – use as a parts donor. This is the usual process and acted as the baseline.

Protocol 3 – Protocol 2 plus manual rotation of moving parts, visual and scent inspection of rotating electrics and close inspection of open ports and oilways.

Protocol 4 – Protocol 3 plus inspection using a fibre optic endoscope to investigate the internal condition of cylinder bores, turbochargers, alternators etc.

Written standard work was provided for each inspection protocol, as were quality acceptance standards for decision-making.

Used core arrives at the facility from the OE manufacturer or their appointed core collector on a frequent but not regular basis and is often batched under a generic part number or type. As a consequence of this, core was essentially randomised at receipt. However, to ensure no inadvertent bias a protocol was assigned, 1 – 4 in turn, to each core prior to decanting. Processing times for each stage of remanufacture as well as any in-process scrap was recorded. Each engine through the remanufacturing facility is assigned a unique tracking number and this was used to ensure all measured times were correctly recorded. Core units of all four selected types were measured over a period of 5 months with a total of 2196 engines studied.

4 RESULTS – STAGE 1

It was anticipated from literature [7, 8,9,10 etc.] that there would be a productivity benefit from increased inspection but that this would lessen as inspection content increased. This was seen in engines C and D but the effect was less obvious on engines A and B (see figure 1).

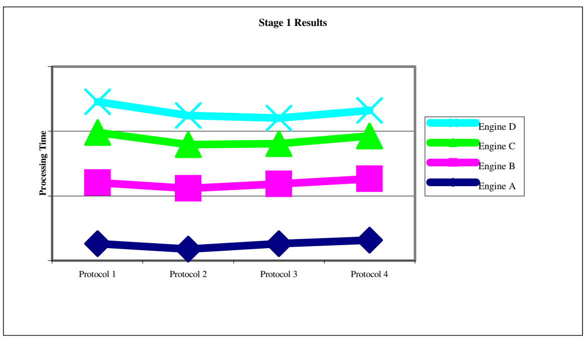

Figure 1: Stage 1 Results

Table 1 (below) shows change in overall processing time and component scrap rate for each engine and protocol. Summary results are shown here for clarity as the complete data comprised over 43,000 individual entries. The in-process scrap figures were used to calculate the time spent processing components that were later disposed of and this time added to the processing time for each engine. The difference (positive or negative) between the baseline and each protocol time together with the available processing time in the factory (calculated from the standard working week and the operators dedicated to that particular engine) was then used to calculate the increase or reduction in weekly capacity arising from the individual protocol.

Initially the following was observed from the results:

- No inspection (Protocol 1) increased the overall processing time for all engines, with the majority of this increase being experienced in the disassembly phase;
- Engines supplied to the customer at long engine level showed little or no benefit from increased inspection;
- Protocols 3 and 4 produced a decrease in overall processing times for engines C and D;
- Protocol 3 produced the greatest decrease in overall processing times for engines C and D;
- Increasing the level of inspection generally decreased the amount of in-process scrap; and
- Individual complex components (turbochargers, starter motors etc.) showed a greater decrease in both in-process scrap and processing time as the level of inspection increased.

Engine	Protocol	% Change in processing time from baseline	In-process scrap %	Additional Capacity Units/week
A	1	+0.30	12.20	-0.81
A	2	Baseline	10.16	Baseline
A	3	+0.21	9.78	+0.03
A	4	+1.75	9.67	-0.17
B	1	+0.23	13.86	-0.89
B	2	Baseline	10.18	Baseline
B	3	-0.82	10.02	+0.63
B	4	+0.25	10.11	+0.50
C	1	+2.81	14.24	-3.75
C	2	Baseline	11.71	Baseline
C	3	-7.32	8.67	+10.58
C	4	-6.13	8.59	+8.71
D	1	+0.57	9.81	-6.64
D	2	Baseline	8.42	Baseline
D	3	-6.93	8.04	+10.37
D	4	-6.37	7.94	+9.29

Table 1 Results for Each Engine/Protocol

Further examination showed that the largest impact on processing time, other than for disassembly, was seen in the ancillary components – turbochargers, starter motors, alternators etc. Preliminary examination of this indicates a two-fold benefit: firstly in earlier identification of required replacement parts and secondly in reduced processing times. Table 2 (below) illustrates this showing the improvement in processing times for the turbocharger of engine D.

Turbo (D)	% Change in processing time from baseline	In-process scrap %	Additional Capacity units/week
P 1	+7.99	16.13	-2.97
P 2	Baseline	14.58	Baseline
P 3	-12	11.82	+5.2
P 4	-14.98	11.07	+5.81

Table 2 Results for Engine D Turbocharger for each Protocol

5 EXPERIMENTAL METHOD – STAGE 2

A second, much smaller, experiment to validate the findings was then developed where 20 each of engines C and D were used.

Every engine had the following parts removed prior to any work being carried out: starter motor, turbocharger, alternator, compressor and external fuel injection equipment. These parts were inspected to protocol 4.

The remaining part of each core was then randomly assigned either protocol 2 or 3 and inspected to that level. Once again processing times for each stage of remanufacture as well as any in-process scrap was recorded. These engines were also assigned a unique tracking number and this was used to ensure all measured times were correctly recorded

6 RESULTS – STAGE 2

The stage 2 experiment, although carried out over a much smaller sample owing to time limitations, confirmed the results seen in stage 1. As expected from the initial experiment, increasing the level of inspection of complex assemblies decreased the processing times as illustrated in table 3. There were also benefits in increasing the level of inspection of the remainder of the core units even after the figures were adjusted to account for the removal of ancillary items. This can also be seen in table 3.

	% Change in processing time from baseline	In-process scrap *	Additional Capacity units/week
P2 EC	-0.32	11.45	+ 0.33
P2 ED	-0.96	12.26	+0.47
P3 EC	-7.51	10.18	+9.62
P3 ED	-6.77	9.98	+9.11
P4 EC parts	14.39	10.63	+5.42
P4 ED parts	13.87	9.71	+5.17

Table 3 Stage 2 results

7 DISCUSSION

Protocol 1 (no inspection) impacted clearly on the overall processing times. This was expected both from the local knowledge within the subject facility (Protocol 2 being the default inspection protocol) and from literature. The simple act of visually sorting core (Protocol 2) to ensure that pieces in the worst condition are either de-prioritised or used only as donors for replacement parts at need, ensures that time is not needlessly wasted disassembling parts that will be scrapped very quickly in the process. There was also an increase in in-process scrap that can be largely attributed to defect parts not being identified earlier in the process. This also was reduced by implementing protocol 2. Protocols 3 and 4 showed a benefit by reducing processing times although this did not outweigh the additional inspection time where the engine dress level was limited to long engine (engines A and B), particularly for protocol 4. Individual process results link this to the lack of ancillary items supplied as part of the dress for long engine. Examination of the individual results strongly indicate that for simple components such as cylinder blocks, crankshafts, connecting rods, sumps etc. increasing the level of inspection past a visual inspection at the receive core stage gives little or no benefit in terms of reducing the overall processing times. There is a small benefit in terms of reducing in-process scrap but this is also outweighed by the increased inspection time. Components that are more complex, in terms of the number, function and type of constituent parts, such as cylinder heads, have their processing times reduced when the level of inspection is increased. The information gained from the increase in inspection enables targeted remanufacturing operations – eliminating unnecessary steps and a more timely purchase of replacement parts. The largest processing reduction can be seen in complex components. Those with the largest diversity of constituent parts (number, function and type, a starter motor typically has mechanical, electrical and electronic components) demonstrate the largest reduction in processing times as the variation in potential operations required to remanufacture the assembly is the widest. The results indicate, validated in the stage 2 experiment, demonstrate that inspecting component parts of a complex assembly to different levels increases capacity in remanufacturing operations.

8 SUMMARY

Inspection of core prior to use produces a benefit in terms of reducing the overall processing time. Experimental results show an increase in productivity from increased inspection. However, for relatively simple components that benefit is finite whereas the benefits increase dramatically as the complexity of the component increases. This has cost implications for remanufacturers. Typically a turbocharger, starter motor or other such part constitutes a large proportion of the value of an engine. Treating these components to a level of inspection greater than that typically given to the whole engine, brings a greater benefit. If the level of inspection considered viable for those components is judged as being proportional to their value in the overall engine rather than the typical current model of total time taken against the cost of the process, more inspection time can be justified, particularly if less time is allocated to simpler component parts. The increase in productivity, resulting in part from a decrease in in-process scrap as well as the lower processing time, and the cost benefits accrued from the reduction in processing time mean that the overall process efficiency is improved with greater inspection.

9 CURRENT WORK

A methodology to assess the complexity of components and assemblies either by themselves or as part of a larger assembly and assign an appropriate inspection protocol is being developed to ensure the benefits observed during the experimental phase can be leveraged. In addition, work to quantify the benefits of such a methodology continues.

The inspection protocols developed for the experimental phase of the research were limited by the available technology at the remanufacturing facility. Investment in new non-destructive testing methods and technologies would allow further experimentation to investigate whether the benefits of further inspection using these methods at the Receive Core stage of remanufacturing could result in decreased processing times further through the process.

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In what way is remanufacturing good for the environment?

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Abstract
Remanufacturing is often considered as a environmental preferable choice of end-of-life option in comparison to material recycling or manufacturing new products. However, there is not a standardised process of making these environmental calculations. This paper explores the environmental performance of remanufacturing in comparison to material recycling and manufacturing of new products. The method was mainly through literature study but also own investigations. The results show that remanufacturing is in general a preferable option due to environmental gains of: alleviation of depletion of resources, reduction of global warming potential and chances to close the loop for safer handling of toxic materials.

Keywords:
Remanufacturing, environmental calculations, system boundary, LCA

1 INTRODUCTION

Manufacturers are seeking ways of working towards a more sustainable development and one way of doing this is to have resource efficient approaches to satisfy their customers' needs. This could partly be conducted through product remanufacturing. Started out as a common model in the automotive, large machinery and printing industry, many other industries are also starting out to look at remanufacturing as a business model to reduce cost and reduce environmental footprints. In particularly, there is a substantial amount of embodied energy saved by remanufacturing the parts instead of making new parts from scratch. It is reported that 28 million tonnes of CO_2 is being saved every year from remanufacturing activities [1]. Remanufacturing is positioned one level up from recycling in the end-of-life hierarchy, see Figure 1.

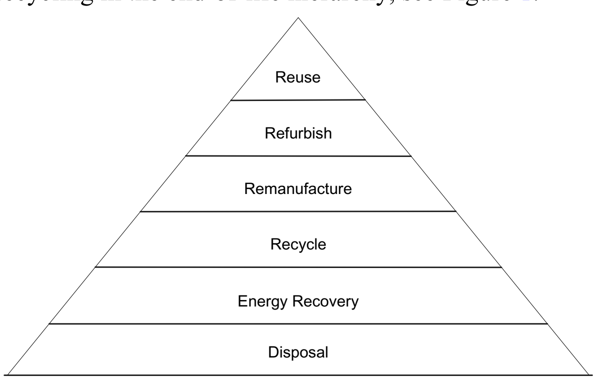

Fig. 1 End-of-life hierarchy.

The end-of-life hierarchy is arranged according to the environmental impacts of the various end-of-life options and in general, it is always more preferred to choose the option on the top before moving down the hierarchy.

In this paper remanufacturing is referred to as 'an industrial process of putting the non-functional or retired products back to like-new conditions. It is the generic term that describes the process in which a recovered good, or core, is transformed through disassembly, cleaning, testing, and other operations into a product that is tested and certified to meet technical and/or safety specifications and has a warranty similar to that of a new product', as defined by the World Trade Organization (WTO)[2].

Remanufacturing has been practicing in the industry for over 20 years but there is limited reports and study of the environmental benefits that is brought by remanufacturing. In general, the environmental benefits of remanufacturing are embedded in the delay of disposal, the alleviation in resources depleting and the savings in embodied energy to make new products. It is only generalised as remanufacturing save about 85% of the energy used. There is limited papers discussing the actual environmental quantified benefits of remanufacturing as compared to that of recycling and also most remanufacturing works are focusing on the economic benefits [3]. With this background, studies relating to environmental credential of remanufacturing were initially done in the area of energy intensities analysis.

1.1 Comparison with recycling and manufacturing

In many previous conducted environmental calculations on remanufacturing comparisons with material recycling have been found. Material recycling then builds on technologies that shred the products and components into smaller parts which then can be separated through various manual and automatic processes see e.g. [4, 5]. In the material recycling case the materials used in manufacturing are salvaged but not the embodiment energy used for making the parts and assembling them together which also is salvaged when performing remanufacturing. In addition, comparisons are quite often made with the manufacturing of new components and products. End-of-life options and manufacturing is illustrated in a product life cycle in Fig. 2.

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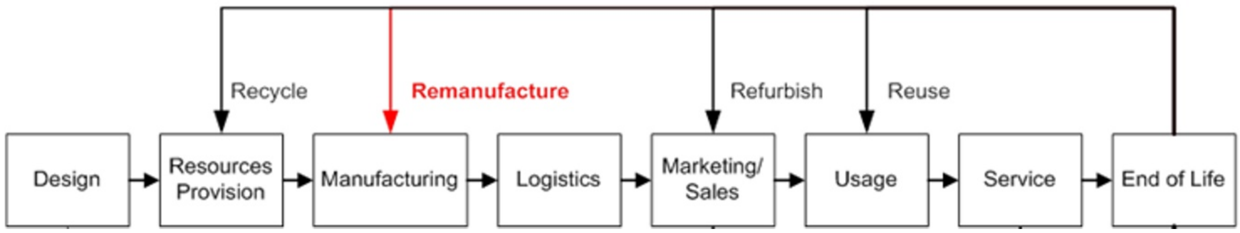

Fig. 2 Product life cycle [6].

2 AIM

The aim of this paper is to explore the environmental performance of remanufacturing in comparison to material recycling and manufacturing of new products. The different kinds of studies in quantifying the environmental impacts of remanufacturing were reviewed. Investigations made were relating to the kinds of products, the system boundaries and the measurements taken.

3 METHODOLOGY

The methodology for this research is mainly through a literature study but also data from interviewing researchers and industry partners in remanufacturing research projects. During the literature search, keywords including “remanufacturing”, “ecological benefits”, “environmental impact assessment” and “environment” were searched in journal databases such as Science Direct and IEEE Xplore. Some studies have been published at international conferences as the authors have been visiting during our remanufacturing research since year 2000. These are sometimes hard to find and there are likely some missed that are not always accessible on the internet. In addition, the environmental issues of remanufacturing were discussed at the first international conference on remanufacturing (ICOR) in Glasgow this summer. The special session was chaired by the authors and had around 40 participants from both academia and industry. The findings of the special session discussion are also added into this paper.

4 ENVIRONMENTAL STUDIES OF REMANUFACTURING

The following paragraphs will describe the results of our literature study and specifically focus on which ***products***, ***system boundaries*** and ***measurement methods*** that have been used along with the ***results of the environmental calculations***. To start with, the calculations found in research are summarized in Table 1.

Table 1: Summary of the environmental 12 studies found in literature (in chronological order).

Study	**Products**	**System Boundary**	**Measurement Method**	**Preferable Option**
A) Kerr & Ryan (2001) [7]	Photocopier	Reman Processes **vs** New Production excluding usage and transport	Material Consumption, Energy Consumption, Water Consumption, Landfilled waste, CO_2 equivalent	Remanufacturing sees at least a 19% savings in all the indicators.
B) Sundin & Tyskeng (2003) [8]	Washing Machine and Refrigerator	Reman (Rem): transport, reman until packaging Recycling (Rec): service, collection, material recycling New production (NP): production	Material resources (MR), Energy resources (ER), Greenhouse gases (GG), Acidifying gases (AG), Ground level ozone gases (GoG), Eutrophication compounds (EC), Hazardous waste (HW), General waste (GW)	**Washing Machine**: MR = Rec, ER = Rec, GG = Rec, AG = Rem, GoG = Rem, EC = Rec, HW = Rem, GW = Rec **Refrigerator**: MR = Rec, ER = Rec, GG = Rem, AG = Rem, GoG = Rem, EC = Rec, HW = Rem, GW = Rem
C) Lindahl et al. (2006) [9]	Toner cartridge, Forklift truck and Brake caliper	Reman and Recycling Processes **vs** New Production excluding usage and transport	LCA with following impact assessment methods: EPS, ECO S, ET long S, ET norm S	**All three products**: EPS = Rem, ECO S = Rem, ET long S = Rem, ET norm S = Rem

D) Four Elements Consulting (2008) [10]	Cartridges	Entire life cycle with Reman processes **vs** entire life cycle with New Production, both with a usage of 100 usable page	Global Warming Potential	New Production has lower carbon footprints
E) Sutherland et al. (2008) [11]	Diesel Engine	Reman processes with transport **vs** New Production	Energy consumption	Reman uses ~ 10 % of what new production need.
F) Kim et al. (2008) [12]	Alternator	Reman processes excluding transport **vs** New Production:	Material Consumption, Energy Consumption, Waste Generation, GHG Emissions	Reman reported a lower number in all 4 categories
G) Gell (2008) [13]	Different types of toner cartridges	First life cycle + reman over a few life cycles with take back stage but excluding usage **vs** New Production excluding usage	Carbon Footprints	Reman has 25-60% savings depending on their life span per usage and number of reman times.
H) Kara (2009) [14]	Gear Box	Reman processes including transport, recycling and disposal phase **vs** New Production with Recycling and Disposal phase	Carbon Dioxide Equivalent	Reman has 34% less carbon impact.
I) Kara (2010) [15]	Inkjet Cartridge	Reman processes including transport, recycling and disposal phase **vs** New Production with recycling and disposal phase	Carbon Dioxide Equivalent	Reman saves 33% of the carbon footprints
J) Baustani et al. (2010) [16]	Dishwasher, Washing machines, Refrigerators	Entire life cycle with reman, usage and without take back stage **vs** New Production including usage	Energy Consumption	Reman saves 44% for washing machines, 32% for refrigerators and 14% for dishwashers.
K) Amaya et al. (2010) [17]	Truck injector	Entire life cycle with reman processes **vs** entire life cycle with recycling processes VS entire life cycle of New Production	Carcinogens, Respiratory organics, Respiratory Inorganics, Climate change, Radiation, Ozone layer, Ecotoxicity, Acidification/Eutrophication, Land Use, Minerals and Fossil Fuels	Reman can save up from 8% to 46% of environmental impacts.
L) Goldey et al. (2010) [18]	Wireless Switch and wireless base station	First life cycle + Second remanufactured life cycle **vs** Two life cycles of New Production	Acidification Potential, Eutrophication Potential Freshwater Aquatic Ecotoxicity Potential , Human Toxicity Potential, Marine Aquatic Ecotoxicity Potential , Ozone Layer Depletion Potential	Both products: Remanufacturing

4.1 Studied Products

Firstly, there are not many products that are being remanufactured at the moment yet. The list of products that are being studied for their environmental savings from remanufacturing includes photocopiers, printer cartridges, washing machines, refrigerators, diesel engines, fuel injectors, wireless switches, office furniture, single use cameras, alternators, gear boxes and cellular phones. Most of the products being studied so far are industrial products as it is probably easier for these products to be remanufactured due to the easier take back implementations and warranty issues. One of the characteristics of these products is that some of them are on a leasing model or product service system (PSS), see also [19]. In addition, these are largely mechanical component remanufacturing as they are more durable that suffer lesser wear and tear. Add to the fact that they often do not function as critical components that have very strict requirements. This is similar to current literature that concluded remanufacturing is more prevalent in high technology sectors as well as PSS modeled and not fashion or status related markets [20].

4.2 System Boundary

System boundary is one of the most critical issues in any assessment study. It can be determined if the study is positive or negative environmental impact. Depending on the purpose of the study, the system boundary must be adjusted to represent and reflect the practical and realistic situation of the subject of study appropriately.

From the studies, it can be seen that there are many ways of conducting the environmental assessment of remanufacturing especially when it comes to comparisons. The system boundaries are defined in several ways to suit the purpose of the study concerned. These are generally classified in the following five categories:

1) Comparing 1 manufacturing cycle with 1 remanufacturing cycle. The focus here is to compare strictly the difference in employing remanufacturing instead of manufacturing at the stage level. It does not include the life cycle perspectives, see Study A, E and F in Table 1.
2) Comparing the entire life cycle with remanufacturing or recycling replacing the manufacturing stage but including the take back stage. This is a comparison between 2 full life cycles- one as the normal product life cycle and the other with manufacturing stage being replaced with remanufacturing or recycling with the inclusion of take back stage, see Study C, D, H, I, J and K in Table 1.
3) Comparing 1 manufacturing cycle with 1 remanufacturing cycle and 1 recycling cycle. Here 2 end-of-life strategies are being considered with 1 manufacturing cycle to see if remanufacturing is indeed more environmentally preferable, see Study B in Table 1.
4) Comparing 1 life cycle with manufacturing + 1 life cycle with remanufacturing with 2 life cycles with manufacturing as you need at least 1 new cycle of manufacturing before a remanufacturing cycle is possible, see Study L in Table 1.
5) Comparing the different number of times the products is being remanufactured, see Study G in Table 1.

There are many issues and assumptions that need to be taken into considerations and decide on the system boundary. An example of this is the two different studies (Study D and I) where in the results the authors of study I states:

"Carbon impact of a remanufactured inkjet cartridge is 0.81 kgCO2eq compared to 1.212 kgCO2eq for new manufacturing" … "Remanufactured inkjet cartridges have around 33% less carbon impact than the new ones when excluding the use phase".

..while the authors of study D states:

"Original HP cartridges are a better overall choice for the environment when compared with remanufactured cartridges e.g. 7% better in global warming potential" … "Environmental impact doesn't end with production e.g. more than 94% of a cartridge's environmental impact can occur after production - primarily during use".

This shows that which parts of the product life cycle is included within the system boundaries can affect the overall environmental results.

4.3 Measurement Method

The measurement method used for the studies can be broadly categorized into ***direct*** and ***indirect*** measurement methods.

Direct - Measuring consumption of materials, energy and waste generated and translate this directly to resources savings. This is a straight forward process that provides the first cut assessment of the environmental benefits. However, it can be argued that it does not provide enough justifications as the weight and volume of the materials are not representative of the effects on environmental directly. Some materials are more precious than others and require more efforts to mine them out. Some small and lightweight materials can also be more harmful to the environment than their bigger and heavier counterparts. Some studies in the recent years started to convert these measurements into carbon dioxide equivalent according to the IPCC standards for a common indicator to be used in communication and comparisons.

Indirect - Applying Life Cycle Assessment methods and calculate the eco-points to assess the environmental impact on the respective impact categories to get the long term potential environmental impact. A whole list of data inventory is being created for the assessment. This method is by the generic guidelines of LCA in ISO14020-24. It provides more insights and accuracy of the environmental impacts. It is however can be too tedious for all the data to be of good quality to give a true representation.

4.4 Environmental Preferable Option

Most environmental calculations show that remanufacturing is a preferable option in comparison to new manufacturing and other end-of-life options. In the literature surveyed, all studies except one concluded that from a life cycle perspective, the gains from the avoidance of environmental impact are positive at the same time delivering the same functions.

Based on the principles of LCA, there are three main categories namely depletion to resources, harm to human health and global warming potential. However as this paper is focusing on environment benefits only, the categories on human health is not included.

Alleviation of depletion of resources

Remanufacturing involves the reusing of parts in new products after some additional cleaning, testing and certifying are carried out. In this way, the parts do not need to be disposed of and hence saving resources in handling the disposal. At the same time, from a life cycle perspective, it has eliminated the need to make new parts for the new products from raw materials. This reduces the demand on raw resources which has to be taken out from the earth and at the same time improves resource productivity as the same amount of resources can be used for long time. With this, when an assessment of material intensity is being carried out, it is likely that the new products with remanufactured parts will score better as less resources are being put in to produce the new products.

Reduction of Global Warming Potential

To extract raw material from the earth and process it into parts that can be used in new products generally require a lot of energy. Remanufacturing keeps the embodied energy of the parts which otherwise would have to be spent in making new parts. The avoidance of this reduces the amount of emissions to the atmosphere and thus reducing the impact on global warming potential. Take for example, to remanufacture 1 office workstation in US can save up the amount of power needed for powering 10 American households for the whole day [21].

Chances to close the loop for safer handling of toxic materials

With remanufacturing, the products are being taken back at the end of life. This will also bring back any toxic materials that are embedded with the products and enable a recycling process to be set up for these materials. Caterpillar had successfully established such practices in their many years in remanufacturing of the engine cylinders [22].

5 DISCUSSIONS AND CONCLUSIONS

Here the results are discussed and finally concluded.

5.1 What should be measured?

There are various types of environmental indicators for quantifying environmental factors, from the earlier days of MIPS to the recent carbon footprints assessment. The three main categories in environmental impact assessment are resource depletion, global warming potential and harm to human health. From a purely environmental perspective, material intensity, energy intensity and greenhouse gases should be measured.

In the area of remanufacturing, there has been a lack of environmental assessment studies [3, 23]. From the literature, the more dominant work in the earlier days was to study how remanufacturing has improved energy intensity largely due to the savings in embodied energy. In the recent years, there is a rise in translating and assessing the environmental impacts of remanufacturing in terms of CO_2 equivalent or carbon footprints.

5.2 How to get data?

One of the biggest drawbacks of LCA is the lack of good quality data and this applies to assessing remanufacturing activities also. Often there is a need to acquire life cycle data from the different part of the supply chain and this can be too much of a hassle to collect. Furthermore, to assess the life cycle environmental benefits is an emerging area and there are many companies who are not ready to keep and/or share data yet.

Previous works in the area of assessing the environmental benefits of the remanufacturing has been surveyed. From the existing works, it is largely agreed that remanufacturing has brought about better sustainability in terms of reducing the environmental impacts through the avoidance of certain processes. The saving from keep the embodied energy of the parts by remanufacturing is positive and crucial to the increasing demand for natural resources as well as rising crude oil price. However when comparing remanufacturing with other end-of-life options e.g. material recycling it is not always preferable from different environmental perspectives to remanufacture, see e.g. Study B in Table 1.

In addition, it is also evident that there is no established method that is widely accepted by many to quantify the environmental benefits of remanufacturing. Most of the studies conducted were based on LCA guidelines which are somewhat general. The paper has also discussed that the scenarios on how system boundary can be defined and it is found that in order for remanufacturing to take place at a rate where the environmental impacts can be maximized, there is a need to promote life cycle thinking during the design stage to incorporate more design for remanufacturing concept.

In order to get an environmental (and economic) sound end-of-life strategy the options should be monitored and changed according to ambient conditions. Therefore, modeling the end-of-life options should be possible for several iterations. These environmental measurements can also be used for setting the targets/goals for a company's environmental performance according to environmental standards e.g. ISO14001 and EMAS.

6 FUTURE RESEARCH

With the wide range of products being remanufactured, there is a need to classify the kind of application of the assessment method. There is no one single method that can be easily applied without the assessor spending a substantial amount of time looking at it.

Hence, further research is needed to come up with a simple way of determining what is to be included for an estimated environmental assessment method for remanufactured goods. This means to meet the needs and challenges of developing a methodology for everyone to assess the environmental footprints so that it can be communicated and compared.

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Building a holistic understanding of Reverse Logistics for SME Automotive Remanufacturers

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Abstract
Within global economies, there is a growing concern with regards to the excessive production and consumption habits of the manufacturing industry. Due to the scarcity of raw materials, the environment's inability to absorb residues and emissions, and the consumption needs of a growing population, present manufacture and waste patterns are not sustainable. This research is concerned with the development of an emergent product recovery strategy called Remanufacturing, where used/failed/obsolete products are returned to an as good as new condition through the reclamation and recovery of used parts.
Through investigations with Remanufacturers in the UK, this research is concerned with how a Reverse supply chain infrastructure can be set up and controlled to ensure that used products can be collected from a customer site, transported to a remanufacturing facility for recovery, and consequently redistributed back onto the market. This paper presents the findings from the first stage of investigations where key operations, activities and processes have been identified, together with the management systems and strategic factors that underpin and control the overall Reverse Logistics process

Keywords:
Reverse Logistics, Reverse supply chain Remanufacture, Decision-making

1 INTRODUCTION

The process of Recovering value from used/failed/obsolete products at the end of their life through an emergent product recovery strategy called 'Remanufacturing' has received an increasing amount of attention from both academia and industry in recent years. This is down to a number of reasons: The emergence of Extended Producer Responsibility (EPR) legislation; the recognition of the environmental benefits that can be achieved through redirecting waste destined for landfill back into the manufacturing loop; a growing awareness of the societal benefits that product recovery can bring to local communities; and the realisation that Remanufacture offers a potentially lucrative alternative to long established disposition practices (e.g. scrapping, incineration and even recycling). In sum, Remanufacture can be regarded as a key strategy for sustainable development.

Remanufacturing is an industrial process where used products (called cores) are brought back to a 'like-new' functional state by rebuilding and replacing component parts. The process begins with the reclamation of products that have reached the end of their life (i.e. are worn-out, have failed, or have become technically obsolete). These cores are then taken to a remanufacturing facility where they are disassembled, cleaned, inspected, re-machined, reassembled and tested to ensure they meet particular quality standards.

At the heart of Remanufacture is the Reverse Logistics process, which is concerned with the collection and transportation of old products from a point of use, to a point of recovery or proper disposal. According to Srivistava [1], designing effective and efficient Reverse Logistics networks is a pre-requisite for remanufacturing and a key driver for providing the economic benefits necessary to initiate and sustain Green supply chain management. More and more businesses are starting to realise that Reverse Logistics is not merely just a 'costly side-show', but a necessary requirement in building and sustaining competitive advantage in today's modern business environment [2]

However, Remanufacture and Reverse Logistics are together riddled with uncertainty, a result from the fact that once a product is out in the customer's possession, the manufacturer/remanufacturer has very little control over how the product is used, how well it is maintained and when it will be returned. As a result, Remanufacturing managers have expressed that they struggle to design, plan and control the reverse supply chains that collect and recover value from used products [3]. Genchev [4] has found that Remanufacturing managers have a limited understanding as to what is involved in the handling of returns, including the major processes and accompanying activities. Moreover, much of the existing research into Reverse Logistics has been criticised as being too focused on optimizing an isolated part of the problem without

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considering the level of integration necessary in order to help practitioners in the design of Reverse supply chains [5].

The aim of this research is to address these issues through the development of a holistic, formalised Reverse Logistics framework to facilitate effective Remanufacture. The research follows a multiple case study approach, consisting of four SME automotive Remanufacturers in the UK. The investigations are being carried out in two phases: firstly, to build up a holistic understanding of what the Reverse Logistics process actually entails and secondly, to determine the key considerations, decisions and steps involved in the set up and control of a Reverse Logistics process. This paper presents the findings from the first stage of investigations where key operations, activities and processes have been identified, together with the management systems and strategic factors that underpin and control the overall process. Challenges previously reported in literature are also confirmed and further challenges distinct to SME's are identified.

2 REMANUFACTURE & REVERSE LOGISTICS

2.1 Remanufacture

Remanufacturing can be defined as, *"The process of returning a used product to at least original equipment manufacturer (OEM) performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent*" [6]. The popularity of remanufacture as an end of life strategy has grown significantly over the last 20 years. This is mainly due to businesses realising both the economic and environmental benefits that can be achieved through successful remanufacturing. It can be considered as a potential 'win-win-win' situation: The customer benefits from getting a quality product at a lower price, the manufacturer profits from achieving a reduction in manufacturing costs and the environment gains from the result of a lower environmental impact.

The remanufacture industry is often referred to as the 'hidden giant', due to its surprisingly large size. In the UK, the industry is worth £5billion and $53billion in the U.S [7], which is on par with the Steel Industry. As a result, top global companies such as BMW, Rolls Royce, IBM and Xerox are starting to recognise this industry as being both economically and environmentally lucrative, and have subsequently started to implement Remanufacturing and recovery programmes as a strategy for both business and sustainable development.

2.2 Reverse Logistics

Essential to the success of Remanufacturing is the Reverse Logistics process. The most widely accepted definition of Reverse Logistics comes from The European Working group on Reverse Logistics, REVLOG. They define it as: "*The process of planning, implementing and controlling flows of raw materials, in process inventory, and finished goods, from a manufacturing, distribution or point of use, to a point of recovery or point of proper disposal.*" [8]. In simple terms, Reverse Logistics can be thought of as the process of collecting and transporting used or unwanted products from a customer or retailer site to an appropriate facility where the remaining product value can be recovered. The types of returns involved in Reverse Logistics vary from customer returns such as end-of-life, end-of-use and warranty returns, to Distribution returns such as product recalls and commercial returns [9]. Whereas, when a more holistic view of Reverse Logistics is taken, the backwards flow of manufacturing returns during production, such as scrap parts, production leftovers and material surplus can also be included. Key activities in the process include transportation, warehousing, distribution and inventory management, but can be stretched to include inspection, separation and disassembly activities. Looking at the bigger picture (Figure 1), Reverse Logistics can be considered as an integral part of the wider Closed-Loop Supply-chains of reuse companies, providing the vital link between the traditional forward supply chain and the recovery activities involved in restoring value in end-of-life products.

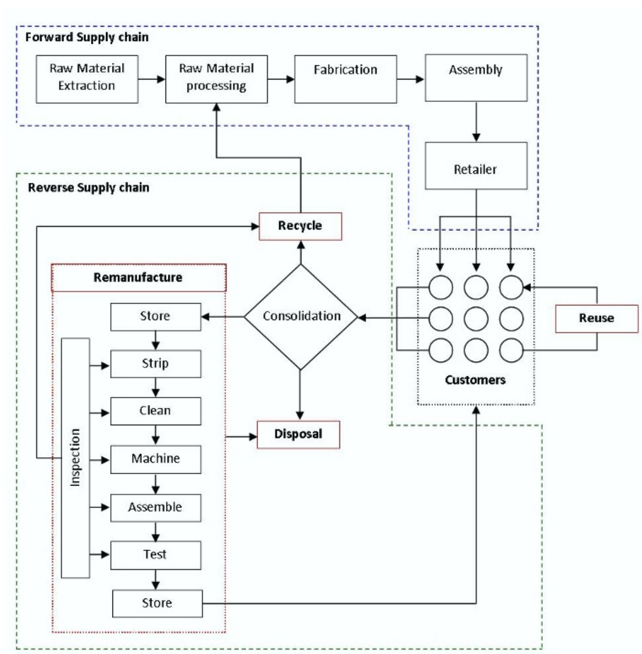

Figure 1: Closed loop supply chain with Remanufacturing

2.3 Uncertainty & complexities

According to Blackburn et al. [3] 'managers struggle to design, plan and control the reverse supply chains that process returned products from the customer, recover their value and use or sell them again'. Reverse Logistics is a complex process that suffers from being inherently uncertain in nature. This uncertainty is brought about through the lack of product specific information that can be gathered throughout a product's lifecycle. There already exists a plethora of research that acknowledges the importance of Uncertainty in Reverse Supply chains, so much so that it has indeed become a key characteristic of the research field. Guide [10] has identified seven key complicating characteristics of the product recovery process, "(1) the uncertain timing and quantity of returns, (2) the need to balance returns with demands, (3) the disassembly of returned products, (4) the uncertainty of materials recovered from remanufactured items, (5) the requirement for a reverse logistics network, (6) the complication of material matching restrictions, and (7) the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times. Moreover, the quality of the returned core, the location of the core, the cost of the reverse logistics process, and decisions over product recovery options (e.g. refurbish, recycle, incineration, etc.) are further complicating characteristics of Reverse Logistics and Product Recovery management [11].

It is therefore important that Remanufacturing practitioners are given as much help in the design management and control of Reverse supply chains to accommodate this level of uncertainty and complexity. In the next section, a literature review is presented on the relevant work that has been carried out in Reverse Logistics design

3 REVERSE LOGISTICS DESIGN

In today's modern business environment, it is becoming increasingly more critical that companies implement a reverse supply chain infrastructure to deal with the growing rate of product returns that businesses are now being faced with. Extended producer responsibility legislation (such as the ELV and WEEE directives) demands that companies are made responsible for the collection and proper disposal of their products at the end of their life. Due to the rising cost of landfilling, together with the obvious environmental, societal and legislative implications, more and more businesses are adopting product recovery strategies (such as remanufacturing, reconditioning and repairing) as an attractive alternative to the dominant product disposition practices (scrapping and landfilling). Moreover, businesses are starting to realise that they can capitalise on the 'green image' attached to product recovery operations, and are thus harnessing it as a powerful marketing strategy to appeal to an emergent demographic of eco-conscious customers.

These driving forces have subsequently led to an increasing number of contributions being published towards developing the field of Reverse Logistics knowledge and theory, specifically in understanding how a reverse Logistics process can be designed, managed and optimised.

One of the most important tasks when setting up a Reverse Logistics system is to identify and examine the decisions involved in the design process. According to Fleischmann et al. [12], the most crucial decisions are in choosing: how to collect the cores from their former users, where to inspect and separate the cores to determine their recoverability, where to rework the used products into a remarketable condition, and finally how to distribute the resultant products back on to the market.

Following this, the majority of research into Reverse Logistics decision making has been focused on the development of conceptual models that address: Location and allocation of recovery facilities problems; the determination of optimal inflows and outflows of materials in the Reverse supply chain; what method of recovery or disposition to use; and the development of models that assess the most suitable 3rd party logistics provider to choose from.

These models have been instrumental in the development of the field, however there still remains much to be developed, especially with regards to strategic management and decision making in Reverse Logistics. Reverse Logistics and Remanufacturing are still relatively new and underdeveloped research areas, and as such, lack the holistic treatment needed in order to establish a comprehensive Reverse Logistics framework that would allow Remanufacturing managers to effectively design their Reverse supply chains. Through a systematic literature review, a number of aspects in need of development towards creating a more holistic overall perspective of Reverse Logistics have been identified. They are as follows:

- **The need for multiple business perspectives of Reverse Logistics operations in the Remanufacture industry.** The majority of existing work is focused on the Original Equipment Manufacturer (OEM) situation. There is a need for further investigation into the business practices of Independent and contract remanufacturers. It is the smaller, independent businesses that make up the majority of the Remanufacturing and Reuse industry, but surprisingly, it's the OEM's that have received the majority of attention from researchers and academics. In a study conducted by Hauser & Lund [7], consisting of 2000 remanufacturers in the U.S. it was found that only 6% were OEM's. The remaining remanufacturers were found to be 3rd party, Small to medium sized enterprises (SME's). It is important to understand that these companies are not just smaller versions of larger OEM firms. Their needs and often their decision making processes differ significantly from those of larger firms.
- **The need for a comprehensive treatment of design decisions.** The literature available on the types of decisions that Remanufacturing managers need to make when designing (and redesigning) the Reverse

Logistics process is both relatively sparse and narrowly focused on a set of specific decisions (location, number, transport routes, logistics company selection, etc.). There is a need to further investigate the full extent of the decisions and considerations involved in setting up a Reverse supply chain.

- **A need for more empirical research to tie existing models with the reality of the industry**. Much of the existing Reverse Logistics research can be characterized as mostly quantitative and operational in nature [12], [13]. It has only been until much more recently that a more strategic approach has been taken towards Reverse Logistics Management. For a research field with its roots in Operations Research, this is no great surprise. However, many of these models have been criticised as being too distant from the reality of actual Remanufacturing practices and fail to assess industry relevant issues under realistic conditions [5]. Moreover, much of what is based on actual Remanufacture and Reverse Logistics practice is from theory that is between 10 and 15 years old. Hence, there is a need for more empirical research in the investigation of the current industry practices of remanufacturing companies.

Based on these constructs, an agenda for research has been formulated which is described in the next section.

4 METHODOLOGY

The aim of this research is to empirically investigate the Reverse Logistics practices of SME Remanufacturers, with the overall objective of creating a formalised framework to facilitate the design, management and control of a Reverse Logistics system. In order to reach this goal, the research has been split into two stages: firstly to identify the day to day activities, operations and management systems that govern the RL process for SME remanufacturers; and secondly, to understand why and how the RL system has been setup in such a way. This involves the determination of the key decisions, considerations and steps involved in the inception and design of the RL system.

4.1 Multiple case study

Due to the subjective nature of the problem, a qualitative approach to data collection has been taken. This research aims to capture the attitudes, perceptions and experiences of managers in the remanufacturing industry and thus requires an appropriate methodological framework to ensure a rich and holistic picture is attained. Accordingly, a multiple case study methodology has been chosen to guide the research, following Eisenhardt's approach to theory development [14]. Case studies are required when there is a need to understand complex social phenomena, allowing for the holistic and meaningful characteristics of real life events to be retained throughout the investigation. Moreover, we are investigating an area that has received little attention in existing research and thus requires a suitable approach to building theory.

Under investigation are four SME Independent and Contract Automotive Parts Remanufacturers based in the UK. The decision to focus solely on the Automotive sector was based on the fact that the Automotive sector is the largest industry engaged in remanufacturing [7], and thus makes this research applicable to a wider range of companies. It is also an industry that is under severe environmental and legislative pressure. In the European Union, Automotive manufacturers are required to reach a recovery rate in excess of 95% of the weight per end-of-life vehicles by the year 2015. Furthermore, by focusing on one particular industry, a greater level of generalisability and rigour can be achieved in establishing what is truly representative of that industry and not misinterpreted by another industry sector.

Prior to entering the field, a case study protocol was crafted. Each case has been investigated with the same protocol, but treated on an individual basis. Data has been collected through conducting semi structured interviews, in person and over the phone (the respondents consisting of CEO's, logistics managers, purchasing managers, operations managers, and shop floor workers); through observing the Remanufacture and reverse Logistics activities, and through reviewing company specific documents. The results have been analysed using within case analysis and through searching for cross case patterns with the aid of NVivo, a software tool that specialises in consolidating and managing qualitative data.

5 FINDINGS

The case companies under study are Mackie Transmissions, a transmission remanufacturer based in Glasgow; Ivor Searle, the UK's largest independent engine remanufacturer; Caterpillar who remanufacture their own engines and for major automotive manufacturers; and MCT ReMan, leading a transmission remanufacturer. See table 1. (below)

Table 1. Case companies

Case	**Business type**	**Remanufacture service**	**Location**
Mackie Tranmsissions	Independent & Contract	Transmissions	Glasgow, UK
Ivor Searle	Independent	Engines	Soham, UK
Caterpillar Reman	OEM & Contract	Engines	Rushden, UK
MCT ReMan	Contract	Transmissions	North Somerset, UK

5.1 Strategic factors and drivers

First of all we determine the strategic factors and drivers that underpin the Remanufacture and Reverse Logistics processes of SME Remanufacturers. The primary focus and priorities of the businesses under investigation were found to be in:

(1) Making a profit. For Independent and Contract Remanufacturers, making a profit from Remanufacturing is absolutely fundamental in order for the company to survive. Research suggests that many OEM's do not usually adopt remanufacturing as a profitable business endeavor; instead they will often engage in remanufacturing to deter independent remanufacturers from reusing their products; or as part of long-term corporate strategies, such as moral and ethical responsibility; or in securing the spare parts supply market [15]. Contrary to this, the core businesses of Independent and contract companies lie solely in remanufacturing, and accordingly must be a profitable venture. In order to compete with OEM's over the attainment of used cores, SME remanufacturers will offer prices that are significantly cheaper than that of OEM's. As an example, Mackie Transmissions are able to supply a remanufactured equivalent that is generally 60% of the price of a new version. In some cases this is even higher, for example, recently the company dealt with a customer who had been quoted £7,500 by his local OEM dealership for a replacement transmission. Mackie transmissions were able to supply a remanufactured equivalent (as good as new) for £2,300. Moreover, to ensure its quality, the resultant transmission was given a warranty of 3 years that outperformed the OEM's own 1 year warranty.

(2) Fulfilling customer's needs and demands. In each company, it was stressed that the customer's voice is carried through the whole process, from collection, remanufacture and through to redistribution. The focus here is on doing whatever is easiest and most convenient for the customer. Requests from customers over how the core should be collected, the time frame for it to be recovered, and the level of machining to be done during the remanufacturing process are just some of the demands that the remanufacturers have to be flexible around in order to fulfil. Much of a Remanufacturers reputation is built on customer satisfaction. The companies' ability to attain a wider customer base is done largely through creating awareness about their services through general word of mouth and previous customers making recommendations to people they know. Customer satisfaction is therefore of paramount importance.

(3) Commitment to quality. In an industry with an unavoidable 'used/failed/old product' stigma attached to it, it is essential that the resultant remanufactured units are made to the highest standard and are indeed as 'good as new'. This is done through strict inspection, the implementation of quality standards, the use of high precision machining equipment and through training up employees to a highly skilled level.

Other strategic factors that were identified as important to the development of the business include: cutting costs, time efficiency, research and development, and Environmentalism and Sustainable development. These factors not only drive the business models and strategies of SME Remanufacturers, but provide the foundations for the management and operation of the Reverse Logistics and Remanufacture processes.

5.2 The Reverse Logistics process

The Reverse Logistics systems for each company under study were all found to have in common, three primary constructs that make up the whole system, comprising of:

- A distribution network, responsible for the physical flows of parts and materials between entities within the supply chain
- A formalized Reverse logistics program, responsible for the management of acquisition policies and contracts.
- An I.T system responsible for the flow of information between key actors within the supply chain.

The distribution network can essentially be thought of as the infrastructure that binds the whole process together. It consists of distribution channels, transport routes, and the supply chain partners involved in transporting a used core from a customer, to a remanufacturing facility where the core is recovered, and subsequently distributed back to the customer again. The primary activities involved in such a distribution network include Collection, Consolidation, Logistics, Recovery/Remanufacture, Parts procurement and Redistribution. During the collection stage, cores are acquired by a local garage or car dealership through the customers initiating the return. Initial diagnostics are run on the part to identify faults and a remanufactured equivalent is ordered. The faulty unit is then sent to a regional consolidation centre where it is grouped together with similar units and is scheduled for collection by a logistics carrier to take it to a remanufacturing facility. Caterpillar was the only remanufacturer in this study who was found to use their own in-house logistics for transportation; the rest primarily outsourced to 3rd party providers. On arrival at the remanufacturing facility, the unit is disassembled, sorted, cleaned, re-machined, reassembled and finally tested to make sure the remanufactured product meets certain quality standards. The resultant remanufactured item is then redistributed back to the customer, usually via the same route it came.

Essential to the success of the Distribution network is the Reverse Logistics program. It is what ties the Reverse Logistics process with the overall business model. Its responsibilities lie in setting what products are to be collected, where they are collected from, what type of acquisition policy to use, how to entice customers to initiate returns, the determination of lead-time targets, who the strategic partners are and the management of contracts. It is essentially, the control centre for managing the whole Reverse Logistics process

Thirdly, an I.T system is needed in order to capture data and facilitate information sharing between players in the reverse supply chain. The main benefit of doing this lies in limiting uncertainty by providing up to date information on a product from its whole lifecycle. Information relating to quality (its condition, its fault history, its age and intensities that it has been used at) and its time of arrival (at what point it is sent from collector, where it is in delivery process) can be used to better predict the timing, quantity and quality of incoming cores. In order to attain, distribute and share this information, an appropriate I.T system needs to be in place across the reverse supply chain. A formalised I.T system that is shared between entities within the supply chain can help not only in reducing uncertainty, but also in improving the quality of decision making and overall supply chain performance.

6 CONCLUSIONS

For the SME Independent and contract (third party) remanufacturers that we dealt with, Reverse logistics was regarded as an absolute necessity to the success of the business, though hadn't quite been realised yet as an area of optimisation. As such, there was no Performance measurement or key performance indicators specified by the remanufacturers under investigation. The businesses that we dealt with were primarily focused on developing and enhancing the business through two main areas: maintaining quality through the remanufacture process and increasing customer satisfaction through fulfilling their needs. Reverse Logistics is simply viewed as a facilitator to these two processes. To conclude, we confirm the findings of [16] that Reverse Logistics remains one of the largest and most overlooked opportunities to facilitate return profits to a company.

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The needs of meso level research for sustainability research and agenda of research and education of CEIDS

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Abstract

Sustainability science is an emerging academic discipline that aims to point pathways toward a sustainable society by understanding the complex and dynamic interactions among the earth, social, and human systems and making the interactions sustainable. Sustainability science has two key features traditional science does not have. One is to understand the complex and dynamic object systems as it is. The other is sustainability science inherently includes action not just analyzing something. Osaka University is establishing a new institute for sustainability research named "Center of Environmental Innovation Design for Sustainability (CEIDS)." This paper introduces agenda of research and education of this institute. Especially, we focus on meso level in three-layered model; vision level (*e.g.*, visions for the low carbon society), meso level, and seeds level (enabling seeds such as new photo-voltaic material). We are planning to systematize such vision-meso-seeds model and to develop methodologies and technologies inherent to the meso level sustainability research. Since meso level sustainability research inherently includes action, the research activity should be accompanied with experiments in the context of the meso level, *i.e.*, the real world. We embed social experiments into each research project in CEIDS. We believe that CEIDS is the first research center focusing on the meso level sustainability research.

Keywords:

sustainability science, meso level, sustainability research, research agenda, innovation

1 INTRODUCTION

Sustainability science is an emerging academic discipline that aims to point pathways toward a sustainable society by understanding the complex and dynamic interactions among the earth, social, and human systems and making the interactions sustainable [1]. The main cause of threating the sustainability is the explosion of the social and human systems and, as a result, the size of the social and human systems has become equivalent to the size of the natural system of the earth. This causes the global warming problem, the resource depletion problem, the North-South problem and so on. Yoshikawa [2] pointed out this problem as "hypothesis of finiteness."

Because of this feature of the sustainability issue, the traditional science and engineering cannot solve the sustainability issue and sustainability science should take approaches different from those of the traditional science and engineering.

Osaka University is establishing a new institute for sustainability research named "Center of Environmental Innovation Design for Sustainability (CEIDS)." This is a university–wide platform for carrying out research on environmental innovation design and providing education programs while developing regional and international collaboration networks. CIEDS is setting up a new research agenda for the sustainability science based on three key concepts; meso level, transdisciplinary, and social experiments.

This paper introduces agenda of research and education of this institute.

2 FEATURES OF SUSTANINABILTY SCIENCE

Sustainability science has two key features traditional science does not have. One is to understand complex and dynamic interactions among the earth, social, and human systems as it is. Traditional science tends to decompose a complex object into simplified models that is more easily solvable in order to increase its purity. However, this tendency created a lot of territorial sciences none of which can solve the sustainability issue. As discussed in Section 1, the core cause of the sustainability issue is the explosion of the social and human systems and the complex and dynamic interactions between the earth, social, and human systems. The traditional territorial sciences, therefore,

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cannot solve this problem in size, complexity, and diversity. Negative influences of the traditional territorial sciences include ignorance of interactions between territories and lack of imagination what happens when a result of science is deployed into the real world where there are no such artificial scientific territories. For example, counter measures for fossil fuel depletion, such as diffusion of electric vehicles, windmills, and smart grids, may accelerate depletion of cupper and some scarce resources. And, some scientists say that if we grow algae in the sea around Japan, the biotechnology can produce enough amount of energy from the algae. But this may not happen.

The other is sustainability science inherently includes action not just analyzing something, which is a typical attitude of the traditional sciences. This may be understood as the difference in missions between the sustainability science and the traditional science. For example, medical science inherently includes actions (*i.e.*, medical treatment), while physics does not (besides actions for experiments). The mission of the sustainability science has some commonality with that of medical science. In the above examples, how to control diffusion of electric vehicles and how to diffuse farms of the algae are the issues out of the scope of the traditional analytical science. Therefore, the sustainability science should incorporate actions that are treated in engineering, marketing, sales, and other non-traditional scientific domains.

3 THREE KEY CONCEPTS OF SUSTAINABILITY RESEARCH IN CEIDS

As discussed in the previous section, the sustainability science should have the discipline to understand complex and dynamic systems in a holistic manner and should include actions. Komiyama [1] used "transdisciplinary" for indicating these aspects of the sustainability science. We also seek for "transdisciplinary" sustainability science, but the word "science" is too narrow since it sounds as if it does not include engineering or other no-traditional scientific domains. This paper, therefore, use "sustainability research," rather than "sustainability science" from now on.

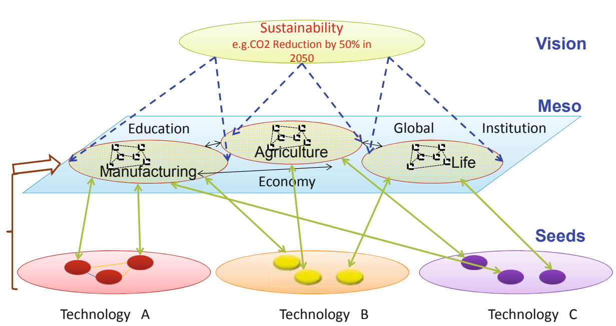

Fig. 1: Vision-Meso-Seeds three layered model

The question here is how to execute the sustainability research that satisfies the above two prerequisites. CEIDS takes an approach for setting up agenda for sustainability research and education based on three key concepts; that is, meso level, transdisciplinary, and social experiments.

3.1 Meso level

As the first key concept, we focus on meso level research in three-layered model (see Fig. 1); vision level (*e.g.*, visions for the low carbon society), meso level, and seeds level (*e.g.,* enabling technologies such as new photo-voltaic material and institutions such as automotive recycling law). Although sustainability science tends to be vision-oriented, action (*i.e.*, realizing the vision) often requires some enabling seeds such as advanced technologies and new institutions. On the other hand, although the territorial science is very efficient in advancing itself, new findings invented in such territorial science do not directly result in realizing the vision, because researchers in the territorial science do not want to see outside of the territory (in other words, it decreases the efficiency of the progress of the territorial science).

Moreover, we consider that it is impossible to relate various enabling seeds to visions directly. Seeds cannot be effective for realizing the vision unless they are implemented as products and/or systems by combining existing and advanced various seeds. Such implementation requires design and engineering perspectives, which are different disciplines of the seeds. Another issue is that there exist alternatives of each product and system. Such alternatives are chosen by, *e.g.*, the market mechanism and customers' choice. This implies that advanced seeds contributing to sustainability do not always survive in the market.

In short, although various advanced seeds have been developed in the territorial science and engineering, they do not result in "green innovation," since these seeds are not well implemented in the real world. And, meso level is the catalyst that encourages the implementation of the seeds, which will results in realizing the visions. In other words, there needs some technologies, systems, and/or institutions in order to deploy new seeds into the real word and to prevent some side effects of such deployment (*e.g.*, so-called rebound effect when introducing a fuel-efficient automobile). An important research issue in meso level is to develop methodologies for designing such a package of new seeds with supporting technologies, systems, international standards and/or institutions and implementing it in the real world.

Therefore, we aim to systematize such vision-meso-seeds model for clarifying sustainability visions and, at the same time, to develop design methodologies of the meso level. This is our meso level sustainability research.

Please refer other papers in this session (*e.g.*, [3][4][5]) for detailed discussions on the meso level. For instance, Kobayashi *et al.* [4] propose SDT (Scope, Domain, and Time) framework for representing the meso level.

3.2 Transdisciplinary research

We believe there exist research topics and methodologies inherent to the meso level. The mission of CEIDS is to develop such methodologies and technologies for the meso level sustainability research. This section describes research agenda of the meso level sustainability research at CEIDS. As discussed in Section 3.1, the mission of the meso level research is to construct the VMS model shown in Fig. 1 in the real world in order to realize the sustainable society. Such meso level research has essential two features; that is, it should include actions rather than just analyses and it is transdisciplinary rather than the territorial science.

The meso level research covers the whole VMS model in Fig. 1 and, then, research topics are classified as follows:

(a) Construction of VMS model

Theoretical and practical research for developing the VMS model.

(b) Vision level

In our research agenda, we do not focus on the vision level (*i.e.*, proposal of new visions), since there exist too many visions.

(c) Synthesis (design and action) of vision-meso relationship

This topic includes detailing a vision into the meso level and clarifying requirements for industry, lifestyle, social infrastructure, *etc.* by, *e.g.*, scenario analysis [8], and theories and methodologies for them such as scenario design methodology [6] and institutional design methodology.

Another important aspect is communication and consensus making on the sustainable society and deployment of new seeds, including science and technology communication and consensus making. Ignorance of this aspect can be found in genetic recombination food, nuclear power plants and their accidents, and environmental pollution by industry.

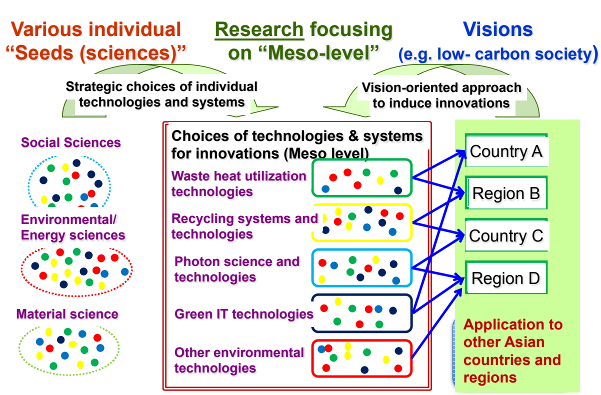

Fig. 2: Seeds oriented meso level research (left arrow) and vision oriented meso level research (right arrow)

(d) Analysis of vision-meso relationship

E.g., development of sustainability evaluation methods and systems and various simulation techniques and models.

(e) Meso level

E.g., definition and theoretical framework of meso level.

(f) Synthesis (design and action) of meso-seeds relationship

E.g., development of design methodologies for a package of new seeds with supporting technologies, systems, international standards and/or institutions, as discussed in Section 3.1.

(g) Analysis of meso-seeds relationship

An important aspect in this level includes multidimensional evaluation of products, services, systems, societies, *etc.* by using, *e.g.*, life cycle assessment and life cycle simulation [10] and development of various simulation techniques and models for finding out social conflicts and side effects when deploying a package of seeds (*e.g.*, [7][9]).

The other important aspect is systematizing seeds from the viewpoints of meso level and vision level. Such topic includes technology mapping [5], technological strategy roadmap, and knowledge systematization [11].

(h) Seeds level

As a university wide research center, CEIDS does not focus on development of specific seeds. Rather, we collect seeds throughout the university, clarify their needs from the viewpoint of sustainability meso level, and organize them into packages.

Practically, we run two kinds of research projects; that is, seeds oriented meso level research (mainly related to (f) and (g)) and vision oriented meso level research (mainly related to (c) and (d)). In Fig. 2, seeds oriented meso level research and vision oriented one correspond to left rounded arrow and right rounded arrow, respectively. And, we organize four research units at the initial stage, as shown in Fig. 3. In this figure, "sustainable society research unit" executes the vision oriented meso level research and other three units execute the seeds oriented research.

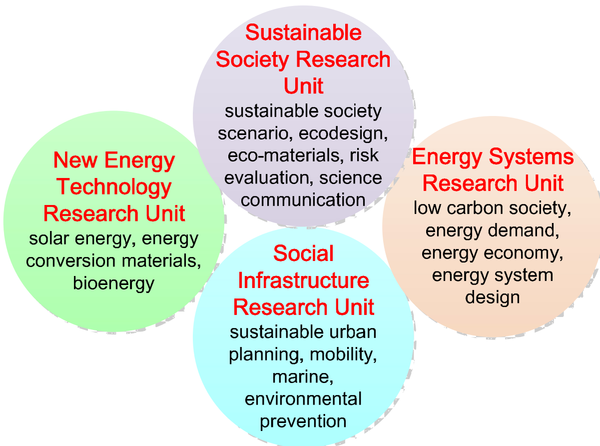

Fig. 3: Research Units

3.3 Social experiments

Since meso level sustainability research inherently includes actions, the research activity should be accompanied with experiments in the context of meso level, besides simulations we intensively employ. We feel that many efforts on sustainability research has reached a sort of barrier that cannot be broken without implementing the research results in the real world; examples include design of new eco business, institutional design for collection of discarded products, deployment of smart grids, and so on. Then, initiatives of sustainability research should embed experiments.

While experiments in the territorial science can be done in laboratories, experiments in the meso level research should be done in the real world by definition. We call such experiments 'social experiments.' In CEIDS, we encourage social experiments and prepare three kinds of their fields:

- Campus: the university campus with students and staffs is a good field for social experiments. As the first step, we realize energy saving campus by employing various advanced seeds developed in the university and outside of the university.
- Local community: we are going to run various collaborative projects with local community and industry.
- International: we are also going to run international collaborative projects. One of main targets is collaboration with Asian countries. We are expecting to design new packages of advanced seeds with Asian colleagues and to implement them.

Through such social experiments, we establish the following research cycle for each topic of the meso level research:

1. Basic research for generating and advancing seeds (done throughout the university)
2. Research for constructing the meso level packages
3. Social experiments
4. Feed back from the experiments and finding out issues
5. Going back to 1.

4 KEY ACTIVITIES OF CEIDS

Activities of CIEDS consist of four units of meso level research integrating various research territories, development of education mechanism and system for fostering connoisseurs who has meso level thinking, and social experiments in the campus and under local and international collaborations, as shown in Fig. 4.

The main activity besides research is education. We provide a variety of courses ranging from general education for the first year students to specialized subjects on sustainability research for graduate students. We believe that all scientists and engineers should think about the meso level for sustainability; for example, it is indispensable for them to think about potential positive and negative effects and conflicts with others when his or her seeds are deployed in the real world and to prepare safe guards against them.

Moreover, we are planning to prepare a graduate school program for educating experts in sustainability science who can plan and design the meso level toward the sustainable society.

5 CONCLUSIONS

This paper introduced the research and education agenda of CEIDS (Center of Environmental Innovation Design for Sustainability) for sustainability science. CEIDS serves as a university–wide platform for sharing knowledge and people. It carries out research on environmental innovation design and provides education programs while developing regional and international networks. It also promotes on-campus activities dedicated to energy saving campuses and sustainability.

In this paper, after discussing features of sustainability science, we proposed three key concepts of sustainability research, which is a wider concept including engineering and other disciplines than science, in CEIDS; that it, meso level, transdisciplinary research, and social experiments. We believe that meso level, which relates global sustainability visions and technological and non-

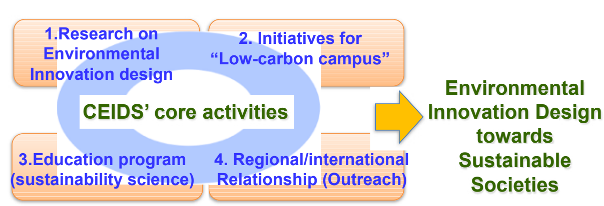

Fig. 4: Key activities of CEIDS, Osaka University

technological seeds, is the core for realizing the sustainable society by deploying such seeds into the real world with systematizing such seeds with supporting technologies, systems, international standards and/or institutions. We also believe there exist research topics and methodologies inherent to the meso level. The mission of CEIDS is to develop such methodologies and technologies for the meso level research and CEIDS is the first research center focusing on the meso level sustainability research.

Future works include comparison and collaboration with similar integrated sustainability research projects (e.g., [12]).

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Sustainability Research: From Science to Engineering

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Abstract

Challenge of sustainability research is repeatedly emphasized as practices contributing to issues we face and we will face, although such an expertise is still rare. To meet the demand from society to sustainability research, it should not only explore credible knowledge for each stage but also develop powerful tools for grasping diverse and credible knowledge, conducting deep and comprehensive analysis, designing salient and legitimate solution, and implementing it in an efficient and effective way. Current status and obstacles for that goal are discussed

Keywords:

Sustainability, interdiscipline, transdiscipline

1 INTRODUCTION

Sustainability research aims to solve social issues, which means that research does not only feed credible knowledge to society but also engage in problem solving processes. Komiyama and Takeuchi adovocated that a challenge unique to sustainability science is the process of shifting from the stage of phenomena identification and analysis to that of problem solving [1]. It requires scholar further exploration and expertise in society. Knowledge, science has advanced to seek, definitely plays a critical role for that purpose. But we must note that a sustainable society can be achieved only when knowledge is accompanied by action. Although action without knowledge leads to uncertain results, knowledge without action cannot change a situation. Therefore, academia must be proactive to solve social issues when they take their mission seriously.

This normative statement might be similar to principle of engineering research. But engineering research has more limited scope as their client. For example, mechanical enginerring studies mechanical properties of objects for mechanical engineers, chemical engineering explores chemical processes for chemical engineers. On the contrary, scope of sustainability science is so broad to include enviromental, social, and human perspectives on a certain issues.

In this contribution, I propose fundamental components of sustainability research including knowledge, analysis, design, and implementation. These components correspond to different stages of process for solving issues. Sustainability research should explore credible knowledge for each stage and develop powerful tools for grasping diverse and credible knowledge, conducting deep and comprehensive analysis, designing salient and legitimate solution, and implementing it in an efficient and effective way.

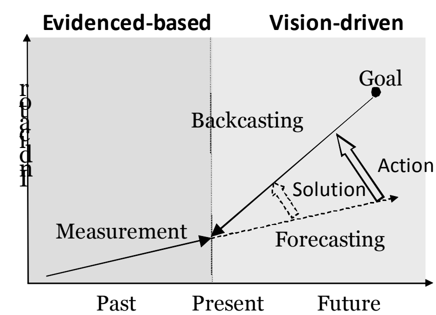

Fig. 1: Framework of sustainability research

2 KNOWLEDGE FRAMEWORK

In the previous review [2], current knowledge framework in research relating sustainability was summarized as Fig. 1. In that framework, goals are broad, qualitative statements about objectives and visions. Examples of goals are reducing hunger, stabilizing climate, and improving health. Indicators are quantitative measures selected to assess progress toward or away from a stated goal, and target values are quantitative values of indicators for attaining the goal at a specific time or within a certain timeframe. The historical trend of the value of an indicator is measured by a variety of methods, and is extrapolated to project the future. Trends are changes in the values of indicators over time, and driving forces are the processes that influence trends and our ability to meet agreed-upon targets that work as the principal drivers toward or away from sustainability goals and targets.

However, more important feature of that framework is the points that it includes a step of backcasting, providing solution, and taking initiative in action. For sustainability science, this step necessarily differs from the conventional transition from basic to applied research, because solutions to problems may have to be sought before those problems have been sufficiently analyzed or even

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identified. Global warming is the prime example of this dilemma. Plausible solutions are dependent on the temporal and spatial scale. In this situation, academia is asked to present their solution for society even when they cannot convince root cause of that issues and feasibility of a solution. Therefore, intense dialogue and feedback among academia and stakeholders are necessary to elucidate essential structure of issues and increase feasibility of a proposed solution. Sustainability science must co-produce knowledge with society in order to strengthen the linkages between knowledge and action.

3 FROM SCIENCE TO ENGINEERING

As discussed above, researchers not only try to understand certain phenomena through observation of a certain phenomena and analysis of causal chain analysis behind that but also to propose solutions through problem-solution chain analysis. Moreover, these solutions are not limited to technological ones, but include—indeed, emphasize—the social and political aspects of solutions. It requires us to turn scientific investigation to engineering expertise. This effort must combine engineering, psychology, economics, institutional design, legal studies, political science, and other social sciences.

It is not a rudimentary task to conduct such an interdisciplinary research, because there are a number of obstacles for researchers to do, because incentive, culture, norm, priority, expectation are different among a variety of academic disciplines. Some programs are launched to overcome the limitations by establishing boundary organizations bridging mutually distant disciplines. An example is Integrated Research System for Sustainability Science (IR3S), and there are other similar projects and organizations. But they have limited size and continuity in funding. And it is difficult to recruit young talents because there is less recognition, visibility, publication channels, employment and carrier opportunities.

Network of networks (NNs) is proposed as a key factor to integrate diverse knowledge and action. NNs is a network among existing networks. The NNs facilitates communication among universities, research institutes, and other actors by spanning the boundaries of existing networks. We all know that no single institution is capable of tackling the complex and intertwining issues we face, and we have therefore established a number of research networks to integrate our efforts in a synergetic manner. Building and operating a network of such networks is the key to promoting collective action. A network is expected to serve as a conduit of knowledge and a platform for collaboration. However, as we are all aware, even through networking it is not always easy to secure sufficiently broad capabilities to achieve our objectives because the members of a network are often limited to those who are already in the same circle. Therefore, we need to go a step further: connect these networks and create a NNs to link otherwise mutually isolated research institutes and sectors, thereby promoting a higher level of integration and securing a broader base of capabilities.

Collective action requires networks and flows of information between individuals and groups to oil the wheels of decision-making. These sets of networks are usefully described as an asset of an individual or a society and are increasingly termed social capital. At its core, social capital theory provides an explanation for how individuals use their relationships to other actors in societies for their own and for the collective good. There are several efforts underway to build networks of networks among leading universities, governments, industries, and society. But the existence of a NNs does not guarantee that it will work well. What factors, then, are involved in the successful functioning of a NNs?

We do not have enough knowledge about the conditions where NNs can work well. Although it will be clarified through case examples and future action research, there are some factors which might be necessary conditions like epistemic community, collective mind, dynamic tension and shared leadership among participants, mutual learning and respect, diffused interface among organizations.

As already stated, a sustainable society can be achieved only when knowledge is accompanied by action. Action is essential and indispensable. But in order to attain our goals, we must also have a credible, salient, and legitimate solution, which, I believe, be designed by a good combination of scientific research elucidating fundamental understanding on issues and engineering research feeding knowledge to be utilized in design of a solution and in testing feasibility of it.

4 CONCLUDING REMARKS

It is now clear that interdisciplinary effort and transdisciplinary expertise are essential and that we should address it as a part of sustainability science and research, even if this still happens all too rarely. Engineering research is clearly needed to provide plausible solutions, but has yet to play a prominent role in sustainability science. Research on research is also needed to collect and structure the problem-solution chains reported in fragmentary fashion in different research papers from different disciplines. It is also necessary to elucidate factors which promote collective action for collaborative efforts to solve issues that we face and we will face.

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A Framework for Comprehensive Sustainability Research Focusing on the Meso-level

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Abstract

Sustainability has become the most important research field for policy makers, corporate executives, scientist, and engineers. Yet, most of the topics addressing sustainability have tended to exclusively focus on details in a specific domain or to lack comprehensiveness in their scope and approaches. The objective of this paper is to propose a comprehensive framework to foster sustainability research by bridging related elements, in which engineering and managerial approaches are integrated into scientific approaches. The framework consists of three components: scope, domain and time. We focus on modeling at the meso-level as a key to bridging system elements from the perspectives of the three components. Through case studies, this paper demonstrates how the framework functions in terms of pursuing sustainability research. We attempt to identify research agenda concerning sustainability based on the framework by analyzing examples of research topics. The proposed framework and research agenda are found to be useful for providing a perspective for promotion of sustainability research in various fields.

Keywords:

Sustainability research, granularity of scope, meso-level, inter-domain, consistency

1 INTRODUCTION

Sustainability has become more and more important research fields not only for scientists and engineers but also policy makers and corporative managers. Yet, much of the research addressing sustainability tends to be specialized in a specific research area with having no holistic views. To overcome this challenge, scenario and visioning studies that deal with long-term sustainability has been proposed [1]; however, even this type of research often ignores social and economic feasibility. Therefore, the importance of visioning, the integration of different views in terms of technology, cost and time constraints, has been addressed [2]. In line with this, sustainability science emerged as a new academic discipline to understand interactions between socioeconomic and ecological systems, aiming at the achievement of peace and sustainable society [3, 4]. In this paper, we use the term "sustainability research" instead of "sustainability science" when referring to integrated research for sustainability, following Hadson et al. [5]. Hadson et al. suggest using "sustainability research" which better captures the essence of how research in the sustainability field should be: "science" generally has a close link to the paradigm in natural sciences while research for sustainability requires transdisciplinarity in which various stakeholders including scholars in natural and social sciences and engineers are involved.

The authors raise three challenges that ought to be overcome. First is that proper link hardly exists between elements of micro-level research and those of macro-level research. For example, how to reflect the global target of greenhouse gas emissions reduction to the industry's research and development (R&D) scheme is one of the most difficult tasks. Second is a lack of link among different systems that sustainability research deals with. Although climate change, natural resource conservation, biological diversity, and social economies respectively comprise an important field as systems, attempts to connect those systems within a research scheme are insufficient. The third challenge lies in the fact that undesirable time inconsistency often emerges among technological development, institutional design and its implementation, and products diffusion. For example, without an appropriate institutional arrangement, renewable energy technologies that are costly in general cannot come in a wide use rapidly enough to meet a set-up goal.

The objective of this paper is to propose a comprehensive framework to foster sustainability research by bridging related elements, in which engineering and managerial viewpoints are incorporated. In what follows, Chapter 2 proposes the integrated framework and Chapter 3

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demonstrates the case study. Chapter 4 proposes agenda for sustainability research constructed based on the framework, and then compares the proposed framework with existing literature. Chapter 5 concludes the paper.

2 FRAMEWORK

Our research framework consists of three components; scope, domain, and time (Fig. 1). This framework is to facilitate research activity through research categorization, including finding of new research topics, and to direct a future research project.

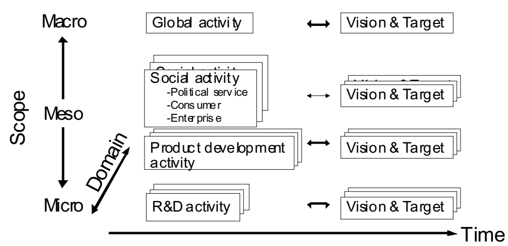

Fig. 1: A framework consisting of three components

- Scope: The scope component has three levels; macro, meso (intermediate) and micro. In each level, related activities are identified in accordance with research objectives. Specifically, the micro level activities comprise technological R&D. The macro level activities comprise international agreements in the sustainability arena. Finally, the meso level activities are such as products development, corporative and industrial management, consumer behavior, administrative services, among others (Fig.1). This item selection is not necessarily a fixed one but is relatively made in the whole scope. In order to achieve the macro target, connecting the information in macro and micro levels is necessary. In particular, we address the importance of an appropriate model in the meso level. With this comprehensive framework, research types are grouped based on whether it takes into account the link among multi-level activities.
- Domain: Traditionally, any academic discipline has advanced its domain with development of applicable theories by limiting its views. Because of this historical background, connecting different domains is not an easy task. Sometime, evolution of a new domain science can be found in between domains. But in the sustainability field, it is often the case that decisions are made for practical reasons without robust scientific foundations. In this framework, we categorize research types based on whether it binds different domains to another.
- Time: In sustainability research, it is important to understand temporal dynamics and/or to achieve goals within a certain period of time through planning and management. This framework divides research types based on whether it regards time as an important concept.

3 CASE STUDY

3.1 Montreal Protocol

According to the comprehensive framework, the Montreal Protocol on substances that deplete the ozone layer is regarded as a successful case in which institutional level goals become consistent with the macro level target. The process from macro-target setting to its achievement is as follows; a) adopted in 1987 and effective in 1989, b) R&D on component technologies such as heat insulators, refrigerant and freezer systems, c) products development, e) business model establishment for replacing obsolete products, and e) first achievement of the target in 1996 (Fig. 2). The successful factors can be summarized as follows:

- All the countries and regions of the United Nations successfully ratified the treaty.
- Among the decision makers at the micro (technological development), meso (product development and business operation) and macro (social target), the criterion that bans the use of regulated substances was clearly shared and no other options were available.
- It only deals with a single domain of air conditioning or thermal cycling equipment.

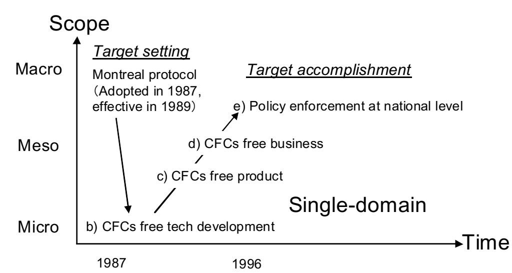

Fig. 2: An analysis example of Montreal Protocol using the proposed framework

3.2 Kyoto Protocol

The Kyoto Protocol adopted in 1997 on Greenhouse Gasses (GHGs) reduction is on the other hand regarded as an unsuccessful case in which inconsistency emerges in target settings and time scheduling among different levels and domains.

In the case of Kyoto Protocol, the following components are not necessarily linked together: a) national reduction targets domestically agreed, b) establishment of effective policies for the global target, c) development of technologies for GHGs' emission reduction, d) corporative strategies, and e) consumers' behavior (purchase and use).

Status of accomplishment of each country is various [6], and several reasons for the failure are as follows (Fig. 3).

- The Protocol merely covers a small fraction. It covers no more than 63.7 percent of the world GHG emissions as of 2011. This means that no global consensus over the macro target has been made.
- It fails time management. That is, situations each of the participated countries faced substantially differed during the third Convention of the Parties (1997) and the year in which the Protocol became effective (2005).
- Too many measurements/options were available in the macro, meso, and micro scale levels. Moreover, responsibility was not clearly specified to each of the stakeholders.
  - At national level, central governments can possibly comply with the target by utilizing emissions trading.
  - The private sectors including industry that faces severe competition under the global market have generally no incentive to GHGs reduction; hence, the magnitude of their efforts is subject to large uncertainty.
  - Even with energy efficient products, total GHG emissions can increase if operation/using time becomes much longer (i.e., rebound effects). At the present moment, no guideline principles exist as to how to systemize micro-level component technologies and how fast a society should disseminate the technological system.
- Energy-related technologies currently under development and energy infrastructure such as smart grid require institutional arrangements. Institutions affect the diffusion of renewable and energy-saving technologies and the creation of a market for new technologies and products. For example, some countries have expanded the markets for wind/photovoltaic power generation by introducing Feed-in-Tariff (FIT) systems.

Those reasons why the global GHGs emission reduction effort is unable to function under the Kyoto Protocol can be summarized as follows. It is involved by a large number of actors across multiple domains, those actors have numerous options as countermeasures, and some of the actors such as consumers are not readily controlled.

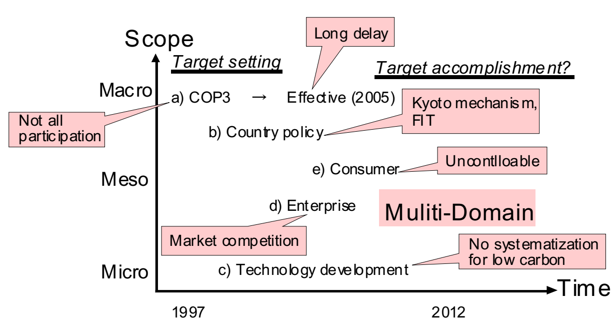

Fig. 3: An analysis example of Kyoto protocol using the proposed framework

Systematic integration of different actors is an imperative task in the meso level research in order to achieve a macro target.

3.3 Environmental infrastructure - Sewage System

Sewer system is an indispensable environmental infrastructure to maintain sound environmental and aquatic conditions. However it is, in principle, a very energy intensive system. In fact, the whole sewer system that includes wastewater treatment, pumping and sludge treatment processes in Japan is estimated to consume approximately 0.7 % of the yearly electricity consumption in Japan (Ministry of Land, Infrastructure, Transport and Tourism in Japan, 2007), making it a big part of GHG emission source. Given the pressing global agenda to achieve low-carbon societies, it is increasingly important to set in and construct less energy consuming sewer system. Hence the goal is to pursue a system in which energy consumption is less or even carbon neutral energy is generated from organic waste (i.e. sewage sludge) collected from the households through the sewer networks, while maintaining the primary function to treat waste water. Although laying the new sewer system (infrastructure) is carried out at city or region level, it shall make a difference for the challenge to combat the climate change at the global level.

Simultaneously, transferring the new type of sewer system to economically developing countries is of great importance, because these countries are now just in the stage of laying a variety of new environmental infrastructures particularly in the urban and peri-urban areas and there is a huge potential for adopting the new type of infrastructure which is less energy consuming and serves to maintain sound environment. When it comes to facilitating the exportation of such new systems born in Japan, then it may require efforts to carry out smooth deals and business practices in the targeted countries, which is a challenge for Japanese business communities.

Indeed, it requires multilateral approach to configure less energy consuming sewer system and transferring such concept to economically developing countries. At micro level, it is indispensable to apply relevant technologies which allow sewage sludge to be fermented, producing bio-energy in the most effective manner. It is also important to identify the most suitable technologies that best serve to optimizing both bio-energy production and wastewater treatment, and to re-design the sewer system on the whole which allows the efficient recovery of generated bio-energy. Such methods as life cycle assessment should be carried out to examine total environmental loads associated with introducing the new system.

From the proposed sustainability research framework, we classified these research elements into the categories of Scope, Domain and Time as follows:

a) Scope

- Micro level: Advancement of relevant technology and research seeds, such as high-temperature fermentation, fermentation technologies with meta-genome application.
- Meso level: Assessment systems and city planning - packaging the most suited technologies, life cycle assessment of environmental loads associated with new systems, re-design of sewage plant for optimized efficiency, etc.
- Macro level: Transferring the new system to urban areas in developing countries with surveys of socio-economic conditions in the targeted regions.

b) Domain

- The agenda necessitates interdisciplinary approach. Academic disciplines that cover include, but are not limited to, environmental (civil) engineering, environmental system analyses, environmental economics and city planning, business models.

c) Time frame

- In case of Japan, the existing system (infrastructure) should be replaced by the new one after some time (10 to 15 years), depending on the physical conditions of existing systems. A strong political will at municipality level, backed by scientific evidences about the merits of new system from environmental and economic viewpoints, is of vital importance to accelerate the replacement. If this system is to be introduced in other developing countries, then there is a possibility of smooth introduction in short time period, especially at a time when such countries are now keen to develop urban systems with sound infrastructures.

4 DISCUSSION

4.1 Deriving research agenda for sustainability from the sustainability research framework

In this section, we identify research agenda for sustainability as an application of the comprehensive framework. We first define research types using the three framework components (scope, domain, and time) as a criterion. Specifically, we refer to research that connects activities at the macro, meso, and micro levels as the multi-level-linking research. Likewise, we define research that joints multiple domains as the domain-linking research. Finally, research that values on the time concept (e.g., future studies and project management) is referred to as the time-constraint research. Having defined these three research types, we now configure seven research categories. This configuration provides us with insights into sustainability research, which will help us find new research themes. Table 1 reports the comprehensive categories of sustainability research. In this table, existing sustainability studies are grouped into the seven categories according to the configuration.

1. Multi-level-linking: Consensus building, leading design and system of systems (SoS) belong to this category. In consensus building studies, how to hold responsibility (for a sustainability challenge) in common among the participants/stake holders is of significance [7-8]. Leading design demonstrates a virtual design for meeting the products goal regardless of its feasibility [9]. Applying the leading design approach can possibly identify the theme of R&D that is vital for the establishment of a sustainable society. This enables us to concentrate R&D resources including government's funding on the particular theme and to accelerate development of new

Table 1: A classification of related researches

Research Category	Elements of research agenda	Focussing components			Focussing level and direction	Reference
		Scope	Domain	Time		
1	Consensus building	X			Meso → Macro; Bottom-up	Susskind [7], Matsuura [8]
1	Leading design	X			Meso → Micro; Top-down	Nakajima [9]
1	System of systems (SoS) for policymaking	X			Micro ⇔ Meso ← Macro; Interaction	Agusdinata [10]
2	Seeds-driven eco-innovation pakaging	X	X		Micro ⇔ Meso ← Macro; Interaction	Hara [11]
3	Dynamics of consensus making	X		X	Meso → Macro; Bottom-up	
3	Demand estimation based on technology diffusion	X		X	Micro → Meso → Macro; Bottom-up	Matsumoto [12]
3	Transition management of environemntal policies	X		X	Micro → Meso; Bottom-up	Rotmans [13]
4	Linkage of senario simulation systems	X	X	X	Micro ⇔ Meso ← Macro; Interaction	Umeda [14]
4	R&D management of eco-technology	X	X	X	Micro ⇔ Meso ← Macro; Interaction	Kobayashi [15]
5	Knowledge structuring for sustainability		X		Integration at Micro leval	Graedel[16], Kumazawa [17]
5	Static estimation of rebound effect		X		Meso	Herring [18]
6	Dynamic modelling of industrial ecology		X	X	Meso	Matsumoto [19]
6	Dynamic estimation of rebound effect		X	X	Meso	
7	Demand estimation of natural resources			X	Macro	Harada [20]
7	Business model transition			X	Meso	Kobayashi [21]
7	Eco-technology evolution analysis			X	Micro	Vooght [22]

technologies. SoS is a key concept when we consider multi-level-linking research. For example, the application of SoS for energy policy has been reported [10].

2. Multi-level-linking + domain-linking: Synthesizing research and technology seeds based on mapping toward systematic visioning has been attempted at Osaka University [11]. Management work such as a product development project is unnecessary for this approach. However, to systematically direct each of the research seeds towards a macro vision while keeping discretion for each of the researchers is a challenge.
3. Multi-level-linking + time-constraint: Forecasting implementation and dissemination of new technologies is in this research category. Predicting the processes of how eco-technology and low-carbon energies are disseminating into societies is an example [12]. Rotmans et al. has proposed a "transition management" approach, which attempts to manage the diffusion process of niche environmental technologies through legal and administrative supports [13]. Moreover, dynamics of consensus building and process modeling are into this category.
4. Multi-level-linking + domain-linking + time-constraint: In an attempt to compare scenarios that have different assumptions, the simulator for sustainable society that links different levels and domains has been developed [14]. Also, more practical cases have been reported, in which integration of R&D and environmental management is demonstrated through the synthesis of societal forecasting with respect to sustainability and development of eco-technologies [15].
5. Domain-linking: Research that links scientific knowledge in different fields has been increasing [16]. Further, knowledge structuring research has been conducted to understand the causal relations among sustainability components [17]. This category includes studies that deal with rebound effects of energy efficient technologies as well [18].
6. Domain-linking + time-constraint: Predicting industrial structure change is in this category. A study of how information and communication technology impacts on a society is an example [19].
7. Time-constraint: Forecasting research that deals with a single domain is in this category, including macro forecasting for natural resources [20], firm level methodology on transition to reuse business [21], and analysis of technological progress [22].

4.2 Comparison with existing literature

This section compares our framework with existing literature to clarify the meaning of our study. Kates et al. [3] argues that the important research questions in sustainability science are to understand 1) the inter-linkages between different spatial scales (e.g., the impacts of the establishment of resource circulating society in Asia on global sustainability), 2) the complexities of functioning of a system (e.g., assessment of eco-system services), and 3) temporal trends and urgency (e.g., forecasting and understanding of trends and thresholds).

Jerneck et al. proposed a research platform to facilitate the structuring of research themes in sustainability science [23]. Their platform consists of the following three components. The first component is the research challenges regarding the four fields; climate change, biodiversity, land-use change, stable supply of water resources. The second is composed of three research types dealing with; provision of scientific foundation, target setting for sustainability, and implementation of a strategy to achieve the set-up goal. The third determines a research approach depending on whether it is problem solving oriented or of critical research.

Kajikawa, through sustainability science literature review, demonstrates that goal setting, indicator setting, indicator measurements, causal analysis, forecasting, problem solving analysis necessarily constitutes a sustainability science framework [24]. According to Kajikawa, what distinct sustainability science from other sciences is in the fact that sustainability science is problem solving oriented. In the sense, he also addresses the significance of engineering approach in sustainability research.

As far as the role of research framework is concerned, the authors hold the same purposes in common with those in sustainability science [23, 24]. Our framework contains the spheres and fields that are covered by sustainability science literature [3, 23-24]. The advantage of our framework is however that it helps us construct research agendas in a comprehensive manner.

Engineering and management studies are different from sciences in that engineering and management studies aim at achieving a given goal within a limited time period while sciences purpose the pursuit of truth with no time limitation. Because of this, engineering and management have advanced by limiting its scope and domain on purpose. For example, the objective of engineering design is to find a design solution within a time limit. For this purpose, to identify and structure the issues is of vital importance, for which empirical knowledge (i.e., know-how) is useful. In sustainability research, which by

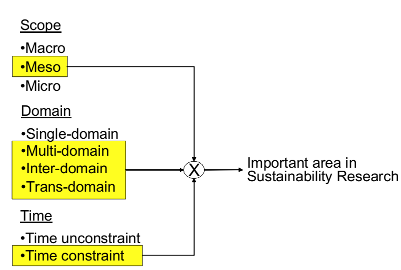

Fig. 4: Important areas in sustainability research

definition focuses on how to achieve sustainability, it is of significance to link different research components with having limited scope and domain areas. The authors consider that meso-level research taking into account time constraints and multi-inter-trans domains [24-25] will become more important for real integrated sustainability researches (Fig. 4). For such meso-level researches, the proposed framework will be useful to structure a research problem.

5 CONCLUDING REMARKS

This paper proposed a comprehensive framework that categorizes sustainability research by the scope, domain, and time components. We argued that advancement of meso-level research that connects macro visions and element technologies at micro level is a key. Through case studies as applications of the framework we identified specific challenges that should be solved at meso-level. Finally, we constructed a comprehensive list of research agenda using the proposed framework and shed light on the role of research framework, highlighting the advantages of our own. Our future research seeks a strategic application of the comprehensive framework; including the establishment of specific research themes and refinement of the research agendas.

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Synthesis of Research and Technology Seeds at Osaka University – a Discussion for Advancing Sustainability Research

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Abstract

In this paper we first propose a new concept of "meso level" research which aims to provide the linkages between science and technology seeds (micro) and societal visions (macro) with an aim to achieve sustainable societies and then highlight essential components of the meso level. We argue that synthesizing the seeds of science and technology constitutes a core part of meso level research, which has hardly been practiced at university level. We carry out a case study in an attempt to map out and synthesize all the relevant research and technology seeds associated with environmental issues and sustainability, which are currently studied at laboratory level within Osaka University. We collected 138 potential seeds from all the relevant institutes and departments affiliated with the university and sorted the seeds according to Japan's three sustainability visions at policy level. We show that universities possess a variety of science and technology seeds and could potentially provide collective knowledge that would help facilitate societal transformation towards sustainability, if these seeds are well synthesized for specific purposes. We discuss that it is of importance for universities to be capable of synthesizing research seeds with the view to contributing to achieving sustainable societies.

Keywords:

Meso level, Osaka University, sustainability research, synthesis of research seeds

1 INTRODUCTION

Science and technology (S&T) plays essential roles in the quest for a transition toward sustainability [1]. Traditionally, the scientific activities started with an objective of understanding things and thus analysis was the primary focus of studies. Accordingly, scientific disciplines tend to become increasingly narrow and specialized as analyses become more detailed in their focuses [2]. On the other hand, Sustainability Science recently emerged with an aim to grapple with complex and dynamic interaction among the global system (e.g. climate, resources, ecosystems), social system (e.g. politics, economy, technologies) and human system (e.g. life style, health, values and norms) and to explore such complex relationships between the systems [3]. Indeed, Sustainability Science differentiates itself from the traditional type of science in various aspects.

Kajikawa [4] summarizes basic components of Sustainability Science, including; goal setting, forecasting, backcasting, indicator measurements and causal chain analyses. In fact, an increasing number of studies on the promising tools such as visioning and future scenario approach, multilateral (sustainability) indicator systems and knowledge structuring, have recently been conducted [5, 6]. Above all, vision and scenario making is most important field to which Sustainability Science should contribute. However, authors argue that practical approaches to realize proposed visions and scenarios are still insufficient. In fact, we find it hard to promote actual transformation to societal visions, such as a sound material-cycle and low-carbon society.

In this paper, we first propose the concept of "meso level" research that aims at filling conceivable gaps between the individual science and technology seeds (micro level) and societal visions (macro level). By explaining why the concept matters to advance sustainability research, we discuss some essential functions of meso level research. We hereby use the term sustainability research, by which we mean practical research with an aim to transforming society towards desirable visions, effectively applying the theory and framework of Sustainability Science.

Among others, we highlight that synthesizing promising but usually scattered seeds (or knowledge) of science and technology constitutes the core of meso level research. In fact, structuring and synthesizing relevant research seeds have hardly been conducted at university level, while universities play major roles in advancing individual science and technology. As an exercise, we carry out a case study to examine promising research seeds within Osaka University. We explored research seeds that potentially contribute to dealing with sustainability and environmental problems, and then sort the collected seeds

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in a matrix as the first step of synthesis. We successfully collected 138 potential seeds from all the relevant institutes and departments affiliated with Osaka University and sorted them in a matrix. We show that a university has a potential for tackling environmental problems and sustainability and could possibly provide a collective knowledge that enables societal transformation towards sustainability, once these promising seeds are synthesized for specific purposes.

2 PROPOSAL OF MESO LEVEL RESEARCH

2.1 Why meso level research matters?

In an effort to pursue sustainable society, sharing visions for desirable societies is indispensable to direct society towards sustainability. Scenario study, among others, is thus considered as a distinctive field in Sustainability Science. Actually, its unique roles have been recognized in such policy discussions as climate changes [7].

However, we suggest that a new research framework be still required to actually induce societal transformations. We argue that there are thinkable gaps between knowledge (i.e. available science and technology) and visions which are usually far distant from where we are now. By taking an example of building sound material-cycle society (hereinafter, SMS), an important pillar for Japan's strategic vision for sustainability [8], we tentatively raise the following items as challenges, which provide insights into why meso level research matters:

1) Spatiotemporal boundaries
2) Difficulties in mapping out and synthesizing available science and technology seeds
3) Trade-off and synergies among applied technologies
4) Time lags in technology saturation in markets
5) Time lags in efficacy of technology applications in society
6) Uncertainty in the institutional design and responsive behavior of consumers
7) Uncertainty in learning and adaptation capacity of consumers
8) Lack in verification/assessment systems in society

The first item is about physical boundaries and time scales for building SMS. *The Fundamental Plan for Establishing a Sound Material-Cycle Society* enacted by the government of Japan in 2003 introduced the quantitative and comprehensive indicators based on material flow accounts at the nation level [9]. "Recycling ratio" - one of such indicators - addresses recycling level (total recycled amount/direct material input). The plan proposes the target for its improvement from approximately 10% to 14% between 2000 and 2010. However, it is not easy to identify which technologies should best work out toward the national goal at what spatial boundaries. Nor will it be easy to find out the optimized spatial level of recycling practices (industry plants, cities, regions level), and best combinations of such practices at different levels.

The second through fifth items have to do with science and technology seeds. The second one, in particular, addresses the necessity of overviewing and synthesizing promising, but usually scattered and unstructured seeds. This aspect is the main discussion point of this paper and will be discussed in the case study at Osaka University in section 3. As noted in the introduction part, scientific disciplines became increasingly narrow and specialized to deepen the analytical capabilities [2] and it has not necessarily been the priority for universities to synthesize knowledge developed at universities beyond boundaries of disciplines. Conversely, sustainability research requires enhancement of such synthesizing capability.

The third item is about the possible trade-off or synergy that might surface among available science and technology in their applications. While there are a variety of available technologies to be applied for achieving SMS, simple combinations of available technologies shall not ensure the realization of societal goals, mainly due to likely synergies and trade-offs. Nonetheless, research aiming to look into this aspect has been rather scant in the context of sustainability research.

The fourth and fifth items are about "time-lags" in relations to application of technologies. Assumingly, there will be time-lags between application time of technologies and their saturations in markets. It is also possible that the time lag exists between applications of technologies in the markets and the time when the efficacy of their applications become visible. Thus, it is crucial to take into consideration the thinkable time lags when applications of science and technologies are initially planned.

The sixth and seventh items have to do with a variety of thinkable "uncertainties." Among others, we highlight uncertainties particularly with regard to consumers' behavior in markets and consumers' adaptation capability to changing environment. When policy measures are applied to induce consumer's behavioral changes, uncertainty is to be assumed particularly in terms of how consumers will react and to what extent consumers will be capable of adjusting to such changing environment. This makes it harder for us to identify specific policy measures that best work out.

Finally, the eighth item highlights the lack in verification or appraisal systems in society. Verification in this context means an evaluation scheme embedded in society for testing whether implemented policies and applied technologies were appropriate or not in dealing with specific problems or meeting societal needs. Such verification or appraisal system is essential to rightly direct the societies towards envisioned sustainable society. For instance, "technology assessment" with stakeholders' participation is now increasingly recognized as important to enhance public involvement in mobilizing science and technologies used to sustain our society where benefits and risks are shared by stakeholders. Similarly, building sustainable societies necessitates persistent and reflexive verification scheme over time, with various stakeholders' participation.

These examples show that producing cutting-edge technologies only will not warrant the achievement of the societal goals. Nor will the simple combination of available seeds lead to shared goals. Fujimoto et al [10] discuss that mismatch exists between technology-driven (bottom-up) approach and vision-driven (top-down) approach in the context of combating climate change. While a number of technologies and measures are now accessible in tackling climate changes, combinations of these measures will not ensure the achievement of societal goals, such as 70 % CO_2 emission reduction by 2050. This indicates that "technology-push" only is not hopeful approach. Backcasting approach, on the other hand, is also vigorously studied, which is used to identify tangible measures to achieve such concrete targets as 70 % CO_2 emission reduction. However, measures derived from this top-down approach shall not necessarily verify whether the measures will turn out to be actually feasible and practical enough to attain the goals, due mainly to the listed challenges above. In short, filling the mismatches between bottom-up and top-down approaches constitutes a core challenge that ought to be overcome. This indeed gives a rationale as to why the "meso" level perspective is indispensable, which aims to bridge the conceivable gap between element seeds (micro) and societal goals (macro).

2.2 Concept and essence of meso level research

In order to overcome the stated challenges, we propose a new concept－the meso level research. The meso level research primarily aims at exploring the middle part between the science and technology seeds (micro) and societal visions (macro), and then filling the gaps between them. More specifically, we hypothetically propose some essential functions that the meso leve research should be concerned about, as follows :

【Main functions and interests of meso level research】

- Bottom-up approach: Synthesis of available science and technologies; Analyses of relationships among available science and technologies (e.g., linkages, trade-offs, synergies); Identifying appropriate technologies and their best mixure
- Top-down approach: Applying scenarios (backcasting) approaches to envision future images of desirable societies; Identifying possible measures (including technologies, policies and institutional designs) and roadmaps with time framework towards visions ; Recognizing appropriate directions for R & D (i.e. vision-driven technology development)
- Design and management of societal transition/transformation: Institutional designs with in-depth analyses on human's reactive behaviors; Management of technologies with analyses on their saturations in markets, etc.
- Reflexive appraisal systems with stakeholder participation: Multi-lateral (sustainability) assessment for applied technologies, roadmaps and future scenarios with a variety of stakeholders participation; Accountability and consensus building among stakeholders

Above all, it is one of the most important roles for meso level research to examine the mismatches (gaps) between these bottom-up and top-down approaches. Matching of available technologies found from bottom-up approach and promissing measures identified through top-down approach shall more likely accelerate innovations especially in terms of societal transformation.

3 SYNTHESIS OF RESEARCH SEEDS AT OSAKA UNIVERSITY

3.1 Methods for data collection

As noted earlier, synthesizing element seeds of science and technology is one big challenge for sustainability research. As yet, comprehensive understanding and overviewing of such element sciences and technologies have hardly been conducted at university level. We thus carry out a case study aiming to collect and sort relevant research and technology seeds within Osaka University for the synthesis purpose.

As of 2010, Osaka University consists of 11 departments, 16 graduate schools and five research institutes, with about 3,100 faculty members (full-time only). Top-level researches are being carried out within each department and cutting-edge technologies in various environmental fields, such as solar energy utilization, have been developed through their research activities at laboratory level.

We tried to collect as many relevant research seeds as possible, following the procedures described in Fig 1[11]. In the fiscal year of 2010, we attempted to cover all the organizational departments, schools/graduate schools and research institutes affiliated with the university in conducting this survey. Based on the organizational map created, we searched the websites (homepages) and other information sources of all the associated laboratories whose research scopes aim to deal with environmental issue and sustainability at any levels. After identifying relevant laboratories and their research seeds, we communicated with all the laboratories to obtain their permissions for disclosing their research information for our study purpose. We then studied further details of the research scopes and contents in each selected laboratory not only through the information available on the websites, but also research papers and documents. We eventually confirmed 138 laboratories in total and their affiliation (school/institute/department) within the university as follows.

- Graduate School of/School of Engineering (52 labs)
- Graduate School of /School of Engineering Sciences (17 labs)
- Graduate School of /School of Science (13 labs)
- Graduate School of Information Science and Technology (1 lab)
- Research Center for Environmental Preservation (1 lab)
- Center for Advanced Science and Innovation (2 labs)
- Joining and Welding Research Institute (3 labs)
- Institute of Scientific and Industrial Research (7 labs)
- Research Center for Solar Energy and Chemistry (2 labs)
- Center for Quantum Science and Technology under Extreme Conditions (1 lab)
- The Museum of Osaka University (1 lab)
- Graduate School of / School of Pharmaceutical Sciences (6 labs)
- Graduate School of / School of Human Sciences (10 labs)
- Graduate School of / School of Economics (4 labs)
- Institute for Social and Economic Research (1 lab)
- Graduate School of Law and Politics / School of Law (3 labs)
- Graduate School of Law (Law School) (2 labs)
- Osaka School of International Public Policy (4 labs)
- Graduate School of / School of Letters (4 labs)
- Institute of Protein Research （2 labs）
- Center for the Study of Communication-Design (1 lab)
- Institute for Higher Education Research and Practice (1 lab)

Note that the information shown here does not necessarily mean that there exist no other potential research seeds at the university. Though our effort was focused upon getting information on as many research seeds as possible, we claim that there can be other promising research activities which deserve our attention. Screening of such uncovered seeds will be carried out in next stage in the second screening (Fig. 1).

3.2 Sorting of collected seeds

Based on the collected information, we attempted to sort the seeds in a matrix for the purpose of overviewing and synthesizing research seeds at Osaka University. Table 1 illustrates the matrix with the collected seeds.

We first classified the seeds into three domains according to three pillars of Japan's strategic visions towards a sustainable society [8]: 1) Low-carbon society (and new energy development), 2) Sound material-cycle society (SMS) and 3) society in harmonization with nature (e.g. air, soil, water). These domains are listed in the row of the matrix. These domains, then, are further divided into sub-domains for details. Low-carbon society (1) domain is classified into: i) energy systems and ⅱ) materials and elementary research for new energy development, such as solar photovoltaic, solar cell, fuel cell, thermoelectric conversion, device and combustion technologies. Sound material-cycle society (2) domain is further classified into: ⅰ) materials, ⅱ) recycling technologies and processing, and ⅲ) other basic research such as those focusing on molecular level for material development. The third domain (i.e., society in harmonization with nature) basically addresses other environmental issues, such as water, soil, biology and air, along with some research fields related to city/urban planning. The domain is further divided into three sub-domains of ⅰ) biotechnology, pollution prevention and purification technologies and relevant material development, and ⅱ) other basic research which primarily focuses on biology cells, molecular, catalyst, etc. Note that the sub-domain of（2）- ⅱ）includes so-called end-of-pipe technologies.

In terms of the columns of matrix, we included methods: (A) development of science and technologies, (B)

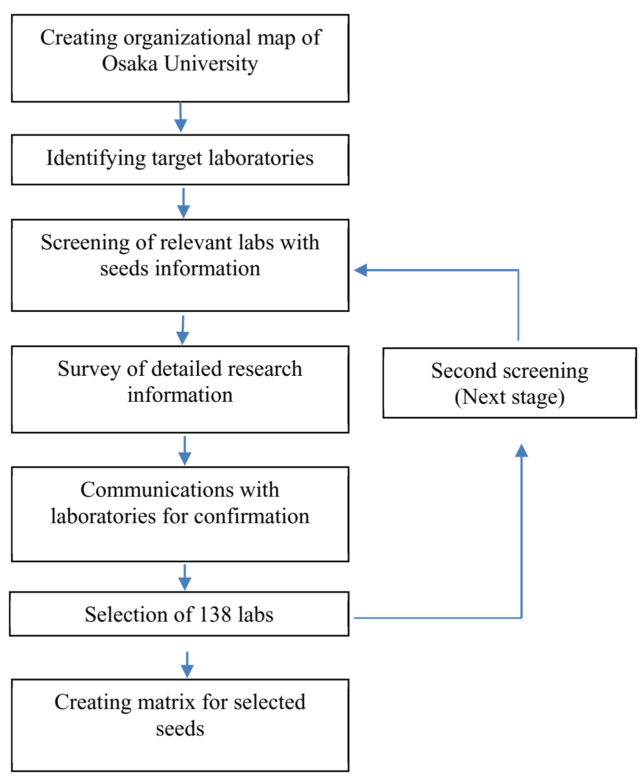

Fig. 1: Procedure to create research seeds matrix

assessments, simulations, system analyses and (C) governance, institutional design, policy and human systems. The research fields in the column (C) are usually not restricted to one single issue or problem like low-carbon society. Rather, they tend to cover many issues in a cross-cutting manner. We therefore did not classify the column (C) by resarch domains of 1), 2) and 3).

Table 1 shows the number of laboratories (138 in total) and affiliate information individually allocated in each row-column box of the matrix. Note that allocation of laboratories was subjectively made by the authors, taking into account the research scopes and themes in each laboratory. Indeed, some laboratories should cover more than one particular row-column box. However, for simplification purpose, we tentatively allocated all the laboratories into each row-column matrix individually.

3.3 Discussion

From the table, it is understood that research seeds at Osaka University cover a variety of topics (domains 1-3) , and research methods (column A-C), while the relative strength lies in the technology development (column A). In terms of SMS policy, for example, strong potential exists in the basic research and technologies development in such fields as material sciences and recycling processes, though some laboratories are also devoted to such fields as management and policy.

We also highlight that there are cases in which laboratories share commonalities or similarities in their

Table 1: Matrix of research seeds at Osaka University - Numbers of laboratories and affiliate information

<table>
<tr><th colspan="2"></th><th>Development of Science and element technologies (A)</th><th>Assessments, simulations, system analyses (B)</th><th>Governance, institutional design, policy, human systems (C)</th></tr>
<tr><td rowspan="2">Low-carbon society/new energy (1)</td><td>Energy system (i)</td><td>Engineering [4]
Engineering science [2]</td><td rowspan="2">Engineering [5]</td><td rowspan="7">Engineering [2]
Human Sciences [8]
Economics [4]
ISER [1]
Law and Politics [3]
Law school [2]
OSIPP [4]
Letter [4]
CSCD [1]
IHERP [1]</td></tr>
<tr><td>Materials for new energy (ii)</td><td>Engineering [5]
Engineering science [6]
ISIR [3]
JWRI [1]
RCSEC [2]
CQSTEC [1]</td></tr>
<tr><td rowspan="3">Sound material - cycle society (2)</td><td>Material (i)</td><td>Engineering [7]
Engineering science [4]
JWRI [1]</td><td rowspan="3">Engineering [2]
Information Science [1]
ISIR [1]
Pharmaceutical Sciences [1]</td></tr>
<tr><td>Recycling technology, processing (ii)</td><td>Engineering [5]
CASI [2]
JWRI [1]</td></tr>
<tr><td>Others, basic (element) research (iii)</td><td>Engineering [1]
Engineering science [2]
Science [2]
RCEP [1]
Museum [1]</td></tr>
<tr><td rowspan="2">Harmonization/symbiosis with nature (water, soil, air, etc)

(3)</td><td>Biotechnology, pollution prevention & purifications, (i)</td><td>Engineering [3]
ISIR [1]
Pharmaceutical Sciences [3]</td><td rowspan="2">Engineering [10]
Science [1]
Pharmaceutical Sciences [1]
Human Sciences [2]</td></tr>
<tr><td>Others, basic (element) research (ii)</td><td>Engineering [8]
Engineering science [3]
Science [10]
ISIR [2]
IPR [2]
Pharmaceutical Sciences [1]</td></tr>
</table>

Note: Abbreviation is used to describe the name of affiliate (department). The parenthesis attached to the affiliates represents the number of associated laboratories.

scopes of research, while they are affiliated in different departments. Though detailed analyses are awaited on whether these laboratories are actually cooperating each other at any level, perhaps facilitating mutual interactions should further promote various innovations. Presumably, such cooperation could enhance the efficiency of technological advancement. Institutional designs that help further facilitate such cooperation beyond departmental boundary shall be increasingly important at university level, as well.

It is also worth noting that some seeds can be applied to not only one domain like SMS, but to other domains, such as low-carbon societies. Technologies that advance bioenergy utilization would be a good example. Energy using biomass, such as organic wastes in urban areas, indeed contributes in promoting SMS, but it can also be effective in combating climate change as carbon neutral energy. In this regard, there is a possibility of co-benefit coming from one single technology. Overviewing of research seeds from the "vision" perspective is also a partial function of meso level research.

At a glance, the themes of basic research listed in the domain of (2-ⅲ) and (3-ⅱ) appear far distant from the visions, such as SMS. However, the breakthrough in the fundamental research shall eventually help advance sustainable society, if properly applied in real world. The questions here is how best to select the most appropriate seeds produced in such basic research and to combine them with other research seeds in accordance with societal visions. This is exactly a role which meso level research should play, as we discussed in former section.

We showed collective information of research seeds at Osaka University in the form of matrix as the first step of synthesis exercise. A more detailed synthesis should be made in the context of meso level research, especially to further look into how best we can mobilize such a variety of potential seeds under specific scenarios. The next step would be to discuss concrete examples in which appropriate science and technology seeds based on the matrix are matched with required seeds identified from such scenarios, taking into account, for instance, time framework (e.g. roadmaps), multi-lateral evaluation of technologies and efficacy in case of seeds' application.

4 CONCLUSIONS

In this paper, we first discussed the importance of meso level research which focuses upon linking individual science and technologies and societal visions with an objective of realizing sustainable society. We tentatively proposed essences for meso level research and highlighted that synthesizing research seeds comprise a core of meso level research.

We indicated that universities can potentially provide collective knowledge that helps facilitate societal transformation towards sustainability, if research seeds are synthesized in line with visions. Accumulation of case studies would be of importance to deepen knowledge about synthesis of science and technology in the context of meso level research.

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Integrated Scenario Design for Sustainability Research – Concept, Framework and Challenges

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Abstract

Sustainability research (SR) is an emerging academic research field that aims to point pathways toward a sustainable society. This paper takes designing scenarios as a means of knowledge structuring so that researchers from various disciplines are able to systematically share various expertise regarding sustainability issues. In this paper, we propose the concept of integrated scenario design (ISD) that reflects the scientific and social knowledge into scenarios in a comprehensive and dynamic manner. The ISD concept also intends to give feedback to the real world from what is described in the scenarios in order to help to bring about innovations necessary for transitions from existing social systems to a sustainable society. Based on the ISD concept, we clarify research issues that should be addressed in terms of designing and deploying scenarios in SR.

Keywords:

sustainability research, scenario research, integrated scenario design, knowledge structuring, sustainable society

1 INTRODUCTION

There is a strong need of establishing a sustainable society by solving a wide range of problems, such as climate change, resource depletion, energy security, and deterioration of biodiversity [1]. With a particular focus on the coexistence of human beings and the environment, sustainability research (SR) is an emerging academic research field that aims not only to untangle the complex and dynamic interactions between these three systems but also to identify pathways toward a sustainable society [2]. Since SR inherently encompasses multi-faceted aspects in terms of both targeted problems and targeted systems, SR should span a wide variety of disciplines. Above all, the concept of knowledge structuring is of particular importance in an effort to acquire a comprehensive view of the multi-faceted and complex problems [3].

Aiming to develop a conceptual framework for knowledge structuring, this paper takes designing scenarios as an approach to describing visions and transitions toward a sustainable society. Scenario is not merely a prediction but we refer to scenarios as a set of plural futures that might unfold possible pathways to a sustainable society [4]. The activities of designing scenarios are helpful for, at least, linking fragmented expertise provided by researchers in different disciplines in the process of discussing and sharing multiple future images. The objectives of this paper are: (1) to grasp the trends of current scenario research by surveying exiting studies related to scenarios, (2) to propose the concept of integrated scenario design (ISD) as an ideal framework of designing scenarios, and (3) to suggest research needs and prospects on designing scenarios in the field of SR. In this paper, we propose the concept of ISD that reflects scientific and social knowledge into scenarios in a comprehensive and dynamic manner. The ISD concept aims to give feedback to the real world from what is described in the scenarios in order to help to bring about innovations necessary for transitions from existing social systems to a sustainable society. Based on the ISD concept, we clarify research issues that should be addressed for designing scenarios in SR.

2 SCENARIO APPROACH TO SUSTAINABILITY RESEARCH

2.1 Necessity of scenarios for sustainability research

According to Jerneck, *et al.* [3], sustainability research (SR) can be organized as an integral of (1) scientific understanding, (2) sustainability goals, (3) sustainability pathways and strategies, and (4) implementation. Fundamental challenges of SR encompass the following two aspects [5].

1. Action-oriented: As SR aims to provide knowledge for action for sustainability [6], it should involve multiple stakeholders (including non-academics) in the framing and conduct of research.
2. Undertaking integrated assessments: To deepen an

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understanding of complex science, SR must undertake integrated assessment, which possesses a reflective and iterative participatory process to link knowledge (science) and action (policy) [7]. In this assessment, SR must bring disciplines together in order to allow for the integration of results in an interdisciplinary manner and then achieve consistency among them [7].

Firstly, SR is by definition action-oriented aiming at achieving sustainability [7]. Since sustainability is a normative concept, SR must seek outcomes (*i.e.*, solutions) through discussions on what is sustainability made by various stakeholders. This is a main feature of SR when compared with traditional sciences, which tend to pursue the truth from analytic viewpoints (*e.g.*, simulating thermal deformation of materials using a finite element method). The second challenge implies the necessity of interactions between society and science for consensus building within an SR framework. It even requires the embracement of diverse disciplines.

Given these challenges of SR, existing studies emphasized the importance of (i) knowledge-structuring [3] and (ii) the concept of a network of networks where researchers from various disciplines bring together various pieces of expertise regarding sustainability issues [8]. Specifically, we believe scenarios are possibly capable of tackling with the two challenges of SR. Designing scenarios must be, at least, a strong catalyst for:

- Allowing diverse participants to explore alternative pathways to sustainability and to formulate options that might be taken at various times [9] and
- Interweaving a wide variety of fragmented knowledge regarding sustainability as a set of stories that are described in the scenarios.

Scenario does not mean merely a prediction; rather it is an imaginative explication of possible states of a society [10].

Within the field of SR, a large number of scenarios for sustainability have been proposed. Scenario examples include climate change by Intergovernmental Panel on Climate Change (IPCC) [11], impacts of biodiversity loss on human well-being by Raskin, *et al.* [12], and energy technology perspectives by International Energy Agency (IEA) [13]. The problem is, however, that their implications are effective only in a limited field or domain in sustainability. For example, the IPCC report does not deal with dynamic interactions between energy security, biodiversity losses, and poverty issues in the scenarios. We thus need further efforts to envisage a holistic view of sustainability in an interdisciplinary way.

2.2 Scenario development methods and techniques

When it comes to scenario development methods, the scenario planning approach is best known in the business arena. Having originated in the military strategic planning in the 1940s, the scenario approach turned to be considered as a promising corporate decision-making method after Shell successfully overcame the oil crisis in the 1970s using the scenario [14]. In scenario planning, Schwartz [4] popularized a method of composing scenario. In his method, key factors are first identified by using a matrix and then multiple futures are specified based on different states of highly uncertain factors. The scenario planning method has been applied to sustainability studies (*e.g.*, [11]).

Existing scenario studies include literature that deals with scenario development techniques as well [15][16]. We surveyed more than 100 related papers and categorized scenario techniques into four categories; presentation, development, assessment, and use/implementation. Likewise, van Notten, *et al.* [17] distinguished scenarios into two groups by the taken approach. The forecasting approach defines the present states as a starting point toward envisioning futures, whereas the backcasting approach explores pathways backward from a predetermined future state to the present to discuss what policy measures are required to realize the envisioned future. Examples of classifying sustainability scenarios are summarized in [18].

2.3 Problems

The scenario approach is regarded as a prevalent and practical tool in exploring future strategies and, in fact, many specific scenario techniques are available as explained in Section 2.2. However, how to design and implement scenarios has not been well established from an academic perspective, especially in the context of SR. That is, the current scenario research exclusively focuses on how to describe scenarios for a specific field/domain such as climate change, biosphere, energy, and land use. However, in reality more integrated approach through consensus building among stakeholders from different fields/domains is essential to take specific actions related to SR. For example, policy makers may face a situation to make a balance between ensuring the local ecosystem and employment. These arguments imply that holistic as well as theoretic frameworks and guidelines are required to accelerate SR. In what follows, we propose the concept of integrated scenario design as a systematic and scientific way to design scenarios in an attempt to demonstrate knowledge structuring for SR.

3 CONCEPT OF INTEGRATED SCENARIO DESIGN (ISD)

3.1 Prerequisites for scenario research in SR

Responding to the challenges of SR, we claim that a participatory approach is needed. In particular, designing scenarios should serve as a means of dialog among a number of participants, whereby helping to link a variety of knowledge over multiple disciplines. When we convene a session of designing scenarios in an attempt to undertake both of the two challenges of SR (see Section 2.1), we are faced with at least the following prerequisites for the scenario design:

(i) Framing the problem for understanding what is targeted and solved in the scenario;

(ii) Performing integrative analyses and assessments regarding sustainability issues;

(iii) Facilitating communications among the participants through the scenario;

(iv) Executing strategic planning based on the scenario as an action-oriented approach;

(v) Ensuring reflexivity of the scenario so that people can reflect and adapt their behavior [19].

Regarding (ii) and (iii), Kishita, *et al*. [20] emphasized the importance of clarifying logical structure of scenarios for enabling a systematic dialog, a transparent review, and assessment among stakeholders involved. With respect to (v), scenarios should be updated in a dynamic manner in accordance with changes of the real world. Since transitions of the real world will not always be consistent with the scenario, we should manage transitions toward a sustainable society through "Plan, Do, Check, and Action" (PDCA) cycles. In the cycles, proposed scenarios are to be regularly monitored and analyzed, and action plans should be modified if necessary [21].

The essential outcome of scenario design is not a scenario itself, but systematic understandings and new perspectives of the future [9] and facilitating communication [10]. In this sense, we should pay more attention to scenario design methodologies (including scenario design processes) that satisfy the aforementioned prerequisites, rather than the contents of scenarios.

3.2 Conceptual framework of ISD

We propose the concept of integrated scenario design (ISD) as a blueprint of scenario design methodologies. The paper argues that ISD intends to meet the prerequisites (i)-(v). The concept of ISD refers not only to scenario descriptions but also to iterative processes of different activities; *i.e.*, problem identification, scenario development using assumptions and data, and review and evaluation of the scenario. Moreover, we point out the importance of viability of scenarios in ISD in terms of policy and strategy making, stakeholders' participation, and scenario updating. In other words, scenario design activities should not end at the point of writing a scenario document; it involves iterative processes in that the scenario should be implemented in the real world as a way of decision-making, *e.g.*, making policies and strategies in municipalities, and then be updated or modified.

Fig. 1 illustrates the concept of ISD. The vertical axis means the functions of scenarios that presumably determine how effectively design and implementation of the scenario influence on the society and stakeholders from a sustainability viewpoint. In our concept, scenario functions are evaluated depending on not only the scenarios themselves but also the capability of the associated individual stakeholders, organizations, or society with the scenario design and scenario implementation. On the other hand, the horizontal axis denotes time; a new generation scenario is created when old scenarios are updated in response to changes in the real world. The ISD concept consists of a scenario design

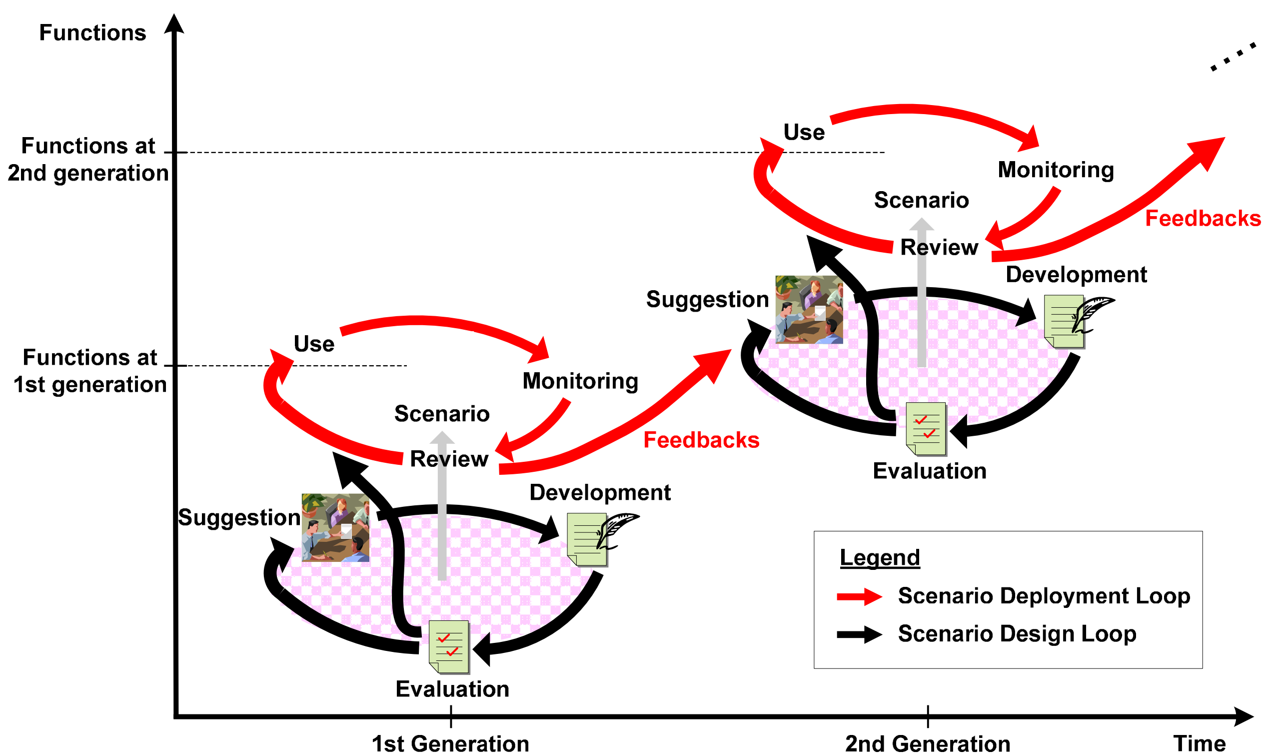

Fig. 1: Concept of Integrated Scenario Design (ISD)

loop and scenario deployment loop. The scenario design loop aims to envision future images in terms of sustainability and analyze or assess the envisioned futures. The scenario deployment loop aims to make actions based on action plans or strategies in the designed scenario. Chermack [22] emphasized that assessing the outcomes of scenario design is desirable for giving feedbacks to the projects after scenarios have been developed. Thus, the ISD intends to cover even this feedback loop for ensuring a comprehensive support (see Fig. 1). Details of each type of the loops are given below.

Scenario Design Loop

According to van der Heijden [9], scenarios should be developed in an iterative manner where new insights are gradually articulated by raising questions among participants involved in the scenario design. In this paper, we define a scenario design loop as iterative processes of (a) identifying or suggesting problems, (b) scenario development or adding scenario descriptions using assumptions and data, and (c) review and evaluation of the scenario (see Fig. 1). Accordingly, recurrent undertaking of a small loop (unit loop) consisting of steps (a) - (c) is proposed, as indicated with black arrows in Fig. 1, in order to detail scenario descriptions until development of the scenario is completed. The gray upward line in Fig. 1 describes the detailing process of the scenario with a recurrent undertaking of unit loops, representing a transitional path from a scenario design loop to a scenario deployment loop.

Scenario Deployment Loop

Taking into account reflexivity of the scenario as shown in the prerequisite (v), we define a scenario deployment loop as iterative processes of (d) using the scenario in the real world, (e) monitoring both the scenario and the real world to detect inconsistency between them, and (f) reviewing the scenario and checking whether the scenario is effective enough by the scenario design team (participants) based on the results of the monitoring. If the scenario design team considers the scenario as being unacceptable or outdated in view of the real world, the team is supposed to update it by reflecting the circumstances of the real world and changes of peoples' behaviors in an appropriate manner.

4 CASE STUDY: ANALYZING EXISTING SCENARIOS BASED ON THE ISD CONCEPT

4.1 Case study and prospects for ISD

In this section we discuss the prospects and challenges for ISD by looking into two examples of Shiga prefecture's project in Japan [23] and Sustainable Seattle in the United States [24]. These two cases highlight communities' attempt to develop scenarios and visions for sustainable societies. The two cases are different from each other in terms of main theme, organizational structures, and process for their activities, as discussed later on. The comparative analysis of two different cases shall provide useful insights into our current discussion on ISD. Specifically, we compare the two cases from the viewpoints of scenario development processes, exploring such aspects as main theme of the activities, organizational bodies, main actors involved, and appraisal mechanism to review or verify the visions and envisioned scenarios, and derive lessons and implications to ISD. We then discuss the prospects and challenges that we should address for ISD.

4.2 Profiles of two cases

Shiga's case aimed at developing visions for sustainable Shiga in 2030 and to identify the roadmaps toward the visions. In fact, very few cases have been reported in Japan, in which future visions and scenarios are developed at the community or municipality level, making the Shiga's case unique. By referring to socio-economic and environmental conditions and their future prospects, the Shiga scenario set targets for 2030, such as reducing GHG emissions by half (from the 1990 level) and recovering water quality in Lake Biwa to the level in the decade from 1965. The committee set up by the local government (*i.e.*, Shiga prefecture) presented these targets in 2007. It then reported concrete roadmaps to achieve the set targets in 2009, after passively incorporating comments from local citizens at a few public meetings organized by the local government.

Sustainable Seattle, on the other hand, attempted to select indicators to assess the sustainability status of Seattle city. Community members consisting of local citizens selected 40 comprehensive indicators under five large categories of environment, population and resources, economy, youth and education, and health and community. Each individual indicator was analyzed over a period and interpretation of the assessment was made by investigating whether such indicators showed better performances over the period. Assessment report, which has been issued since 1993, provides a timely review of sustainability trends in the Seattle/King County region.

4.3 Comparative analysis

In the case of Shiga, the local government (Shiga prefecture) served as the secretariat and set up the committee. The committee members were, in principle, selected by the secretariat. The member consisted of about 10 people, representing from the experts, local municipality, business community and woman's community. The committee member, in collaboration with the secretariat and other working groups, clarified visions and roadmaps by holding a series of meetings. The final version of visions and roadmaps were officially reported after holding a few meeting open to public. It is, however, unclear how and to what extent the public comments and reviews have been incorporated in the final version. Since only a short time period has passed since the initial publication of the visions and roadmaps in Shiga, it is too early to judge whether reflexive appraisal system for such

Table 1: Comparison of the two cases

Factor	Scenario	
	Shiga	Seattle
Political influence/ Administrative capability	Strong	Weak/ Moderate
Persistency of activity	Moderate	Moderate
Validation process	Weak	Strong
Reflexivity	Weak/ Moderate	Strong

visions is to be conducted in Shiga's case. We discuss this point in Section 5.

In the case of Seattle, the main theme of the activities is to assess the sustainability status of the city based on selected indicators. Nonetheless, this case is very relevant to the present discussion on ISD, in that the indicators were selected on the basis of local people's ideas for visions and future scenarios for sustainable Seattle. The 40 indicators represented were selected from a list of 99 recommended by a "Civic Panel" of 150 citizens convened in 1992. This activity has long tried to reflect the viewpoints of local citizens as much as possible. In comparison with Shiga's case where only a small number of selected representative were involved, participation of local citizens is a very strong point in Seattle's case. It is also important that, the indicators represented have been modified (added or deleted) in response to new information or valuable criticism [24]. This clearly shows a practice of reflexive appraisal system for the indicator systems, which should directly or indirectly impact activities to formulate future visions and select indicators in Seattle.

5 PROSPECTS AND CHALLENGES FOR ISD

In this section we attempt to derive some implications on prospects and challenges for ISD from the case study.

Before discussion, we clarify the following four factors as key for the ISD concepts to effectively work. The first two factors deal with the possibility of target achievement. The capability of main actors matters in the ISD concept as the target/goal is to be accomplished through long-term and iterative processes. The two capability factors include; 1) political influences and administrative capability; and 2) persistency of activity. Third is the validity of the set-up targets; *i.e.*, the long-term goal should be widely accepted by communities and societies. In other words, various stakeholders' participation in the ISD process is essential. Fourth is whether the activity contains a reflexivity process. Sustainability by nature involves a long-term process with a variety of uncertainties. The ISD approach requires iterative review and verification process regarding the visions and its approaches.

Table 1 reports the weakness and advantages of the two cases in the four key factors for the ISD concepts. Shiga's case is a new attempt as local initiatives in Japan led by the local government. The positive aspect for this scheme is that the legitimacy of created visions shall be stronger with back–up of local government. However, this type of initiatives in Japan is often subject to uncertainty. Change in administration could possibly alter the past initiatives. Furthermore, the organizational structure possibly shall reduce motivations for continuous and reflexive appraisal processes to the initial scenarios and visions. It is, in principle, the local government that decides the objectives of making visions/scenarios, procedures for making visions, and the member. This scheme is frequently adopted for various policy making processes in local and national government in Japan. The problem, however, is that this scheme might hinder motivations to review the scenario's process in a flexible manner. Once the main objective (*i.e.*, making the visions/scenarios/roadmaps for Shiga in 2030) is completed, then the mission is supposed to be over at that point. In addition, the representation of local citizens is limited relative to the total number of stakeholders selected in the committee.

On the other hand, Seattle case generally shows the opposite results to Shiga's case. Its nature of bottom-up approach has an advantage in the validation process as many stakeholders participate in the goal-setting process. The case also has a unique feature in the persistency of the activity. Sustainable Seattle, which is the main actor of this initiative, has had persistent support from the city of Seattle as well as private sectors including individual donors. This strong support makes it possible to last its activities for more than two decades and hence to contain the review process in the appraisal system. The political influence and administrative capability is usually a weak point in the bottom-up approach. Yet, Sustainable Seattle has a scheme to carry out specific projects and programs as an effort to improve the situations after the regular indicator assessment. This kind of scheme is perhaps made possible by building a good relationship with the authority and private sectors.

From these observations, scheme and governances of scenario making processes are very important. Balanced and sufficient representation of local citizens (stakeholder participation) and organizational settings should be of particular importance, impacting the conditions to ensure the reflexive reviewing processes. At least, a variety of similar initiatives and social experiments need to be further promoted and lessons/knowledge coming from such societal experiences should be accumulated.

6 DISCUSSION AND CONCLUSION

In this paper, we proposed the ISD concepts to shed light on the roles of scenarios in SR by providing specific tasks in the scenario designing loop and scenario deployment loop. We then demonstrated a case study to show that main actors and decision-making structure along with social backgrounds in the scenario design indeed affect the capacity to execute each of the tasks in the ISD framework. Particularly the comparative study of the Seattle and Shiga cases revealed the following three items as important research questions; (i) how to formalize processes in the ISD framework, (ii) how to execute these processes, and (iii) to identify conditions under which ISD can be executed.

To challenge these three questions, the ISD framework should incorporate expertise from communication studies on such fields as interactive communication, scenario management, facilitation techniques, and governance. Our comparative study suggests the importance to develop an appropriate platform for enabling the scenario design team to carry out ISD. Supporting tools for scenario development could help construct a well-structured platform for ISD.

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Meso-Level Research towards Low Carbon Society

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Abstract
To achieve the Low Carbon Society, not only the technological progress but also change of the society is required. It includes land use planning, life style, institutional design, consumer's behavior, and so on.
For example, consumer's choice of energy efficient technology is not always agreed with economical optimum in household economy. In Japan, preference to photovoltaic is very high and there is large amount of willingness to pay for photovoltaic technology. On the other hand, preference to solar water heater is low and total number of installation has been decreasing. The authors propose several types of "eco-design of low carbon society" in residential and commercial sector. Examples are as follows: 1) Design of energy efficient land use. 2) Industrial and institutional design of building integrated solar energy systems.

Keywords:
low carbon society, meso level research, land use, consumer's behavior

1 INTRODUCTION

In the strong demand for accomplishing low-carbon society, huge kinds of researches have been implemented on science and technology fields related to global warming mitigation measures such as energy efficiency, renewable energy, and so on. This trend has been spreading to various kinds of basic science and technology fields. It is believed that low-carbon society in about 2050, where amount of GHG emission becomes half of present value, must be supported by fruits of these researches.

However, it is not guaranteed that accomplishment of these researches and developments conforms to the purpose of low carbon society automatically even these researches would intend to do. At the present time, these basic science and technology fields are too segmentalized and there is long distance from these research fields and vision of low-carbon society. To develop and disseminate the technologies that the low-carbon society truly demanding, the new research field which intends the management and synthesis these researches and technologies for bridging this gap is required. Fujimoto et. al. [1] calls these fields as "Meso-level research".

In this paper, several kinds of "design" issues to accomplish low-carbon society are introduced and discussed as an example of "Meso-level research".

2 DESIGN OF ENERGY EFFICIENT LAND USE

In the situation that large portion of energy consumption is occupied by residential and non-residential sector, dissemination of low-carbon technologies to building is one of the most important issues. In addition, whole concept of building and city is very important element of sustainability. In Japanese cities, there are many kinds of barrier to sustainability as follows:

1) Difficulty for renovation of residential and non-residential buildings in inner city.
2) Declination of residential area in the outskirts under depopulating society.
3) Deficit of greenery area.

These issues are strongly related to land use planning. "Compact city" is one of important concepts for sustainable city planning. In addition, in the context of energy efficient city planning, following two points must be discussed.

4) Density control of the district

There are two kinds of models for energy efficient district. [2]

The one is low density building area, which utilize solar thermal, photovoltaic, passive solar design, natural ventilation. Since density of these natural energy sources is low, enough open space is required to adopt them. Most of low-carbon residential area projects consist of low-rise terrace houses.

The other model is high density building area, which utilize high-efficiency urban infrastructure such as district heating and cooling system which utilizes waste heat from CHP (Combined heat and power) and garbage incinerator. To avoid large installation cost for heat pipeline network and energy loss for heat conveyance, heat demand density

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should be as high as possible. Therefore this kind of infrastructure is suitable for high density building area.

5) Scale of non-residential buildings

Physically, unit of energy consumption of building per floor area has a tendency to become larger as the scale of building become smaller due to the larger ratio of perimeter. In addition small- and mid- scale building has a difficulty to designing energy efficient building due to the cost and time constraint.

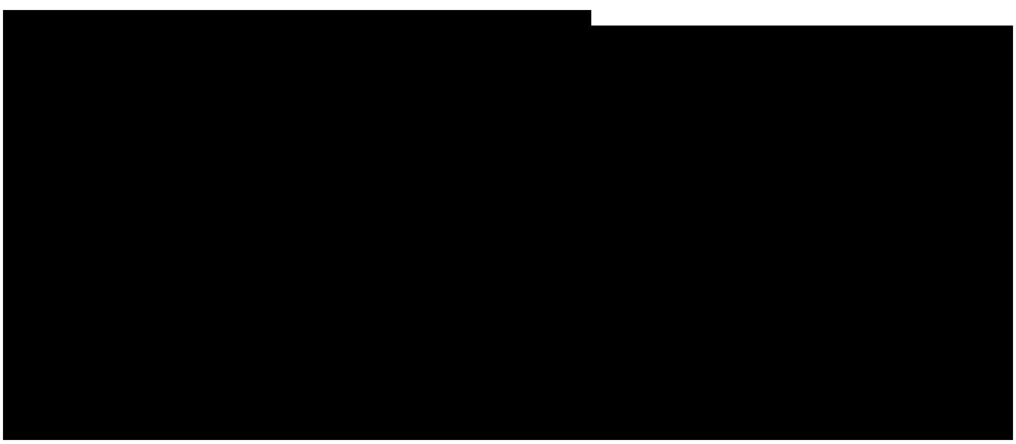
However, in most of Japanese areas have medium density between abovementioned two types of energy efficient districts. In addition, the share of small- and mid- scale building which is less than 5000 m^2 is about 70% of total floor area and 95% of number of buildings in Japanese non-residential building stock as shown in figure 1. This also means the difficulty of energy management of these building stocks.

The authors [3] shows the spatial building stock pattern management which means transition of land use from medium density commercial area to high density commercial area and open space is important factor in the long term transition scenario towards low carbon cities as well as advancement in technologies, dissemination of energy saving measures in buildings and optimization of local energy generation and distribution systems.

3 EFFECT OF ENERGY DEMOGRAPHICAL PARAMETER ON ENERGY CONSUMPTION

As well as land use, demographical parameters such as the age structure of a region, number of family member and so on. The authors [4] estimated per capita energy consumption of residential, commercial, and passenger transportation sectors of Keihanshin Metropolitan Region, Japan. Keihanshin Metropolitan Region consists of 6 prefectures including Osaka and Kyoto. Its population size is approximately 20 million. Carbon dioxide emission is approximately 50 million ton-CO_2/year from the residential, commercial and passenger transportation sectors of the entire region. The total energy consumption for the three sectors can be seen as energy used for living, work, transport and other social activities. A bottom-up model was developed for each sector and the estimated energy consumption was allotted to persons who initiate energy consumption in their house and commercial buildings and for transport in order to analyze the structure determining per capita energy consumption.

Figure 2 shows the estimated energy consumption of demographic classification by gender, age group and occupation. Working male and female are further divided into singles and those in a multiples family. Energy consumption of single male and single female is larger



(a) Floor area. (b) Number of buildings.

Fig. 1 : Distribution of the scale in Japanese non-residential building stock.

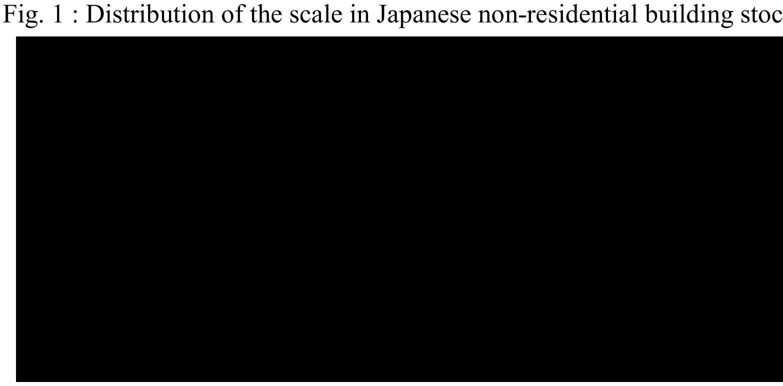


Fig.2 Per capita energy consumption of three sectors.

Table 1 Factors influencing per capita energy consumption and influence of the factors

Sector	Factor	Rising or falling of per capita energy by the factor: Rural	Urban
Residential	Meteorological condition	Depends on the location	
	Size and form of house (small in urban and higher ratio of apartment)	Rise ⟷	Fall
	Average number of family member (high in rural while low in urban)	Fall ⟷	Rise
Commercial	Floor area of commercial buildings per trip (higher in urban)	Rise ⟷	Fall
	Number of trip (frequency of access; higher in urban)	Fall ⟷	Rise
Passenger transport	Dependency on vehicle transport (higher in rural)	Rise ⟷	Fall
	Total number of trip (higher in urban) and distance to destination (longer in urban)	Fall ⟷	Rise
Total	Demographic structure:		
	Ratio of elderly people (higher in rural, lower in urban)	Fall ⟷	Rise
	Ratio of workers engaged in tertiary industries (lower in rural, higher in urban)	Fall ⟷	Rise

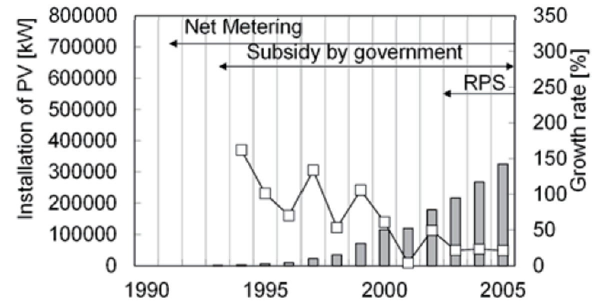
than those who in a multiple family. This is due to the difference in energy consumption of residential sector. The per capita energy consumption of residential sector is larger in small families because energy consumption for most end-uses (such as electricity consumption for refrigerator and water heating for bathing) are shared by family members and not simply proportional to the number of family member.

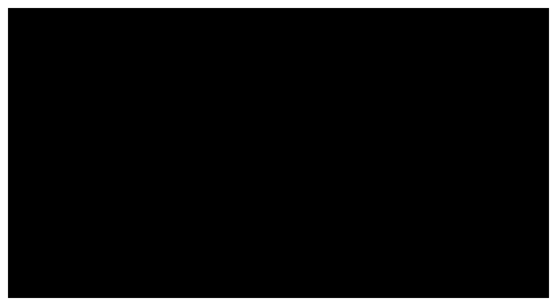
Working male and female have larger consumption of commercial and passenger transportation sectors compared other demographic categories. The difference can be mainly attributed to the consumption for working and work trip. In addition to this, working male and female have a larger number of trips, meaning that they use commercial buildings more frequently than unemployed persons. Housewives and people aged 70 and over have a relatively small energy consumption of commercial and passenger transportation sectors. By contrast, they have a relatively large consumption of residential sector due to longer hours during which they spend time in house. Children have a smaller total energy consumption compared to other categories.

The variety in regions must be considered too. Based on the result estimated by the authors, per capita energy consumption for the three sectors in the cities in Keihanshin Metropolitan region varies from 28 to 38 GJ/year•person. In previous researches, it has been reported that per capita energy consumption of passenger transport is larger in rural area than urban area. However, the structure determining per capita energy consumption is more complicated, as factors increasing or decreasing energy consumption co-exist. Table 1 briefly summarizes key factors and the influence.

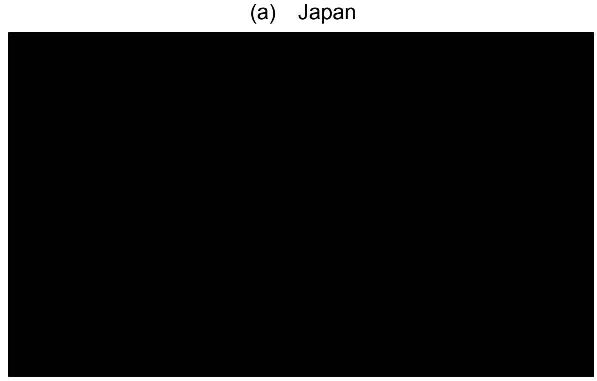
4 INDUSTRIAL AND INSTITUTIONAL DESIGN OF BUILDING INTEGRATED SOLAR ENERGY SYSTEMS.

In the national scale energy-economic model to predict energy supply and demand in the future usually use general equilibrium model which seeks economically reasonable solution. However, in the Japanese household sector, consumers sometime behave economically "unreasonable" selection. Consumers usually do not





(a) Japan



(b) Germany

Fig. 3 : Relationship between amount of installation of PV panels and total balance of payment.

Table 2 The results of choice experiment for PV and SWH.

Attributes	Coefficient	Significance	WTP	
Installation of 3 kW of PV	1.97	***	1.23	Million yen/installation
Installation of SWH	−0.41	*	−0.26	Million yen/installation
Initial installation cost increase [thousand yen]	−0.016	***	1.00	yen/yen
Subsidy for installation [thousand yen]	0.029	**	1.80	yen/yen
Purchase rate of surplus electricity [yen/kWh]	0.011	**	6.9	Thousand yen/(yen/kWh of purchase rate)
Annual reduction of energy cost [thousand yen/year]	0.159	***	10	Yen/yen
Annual CO_2 emission reduction [t-CO_2/year]	−0.065	*	40.7	Thousand yen/t-CO_2
Number of installed units [thousand units]	−0.001		0.3	Thousand yen/%

*** 1% of significance, ** 5%, and * 10%.

consider investment recovery exactly when purchasing energy efficient appliances or renewable energy systems.

Figure 3 shows the relationship between amount of installation of PV panels to residential building and total balance of payment in 20 years from installation for Japan and Germany respectively. In Japan, PV installation had been growing even total balance is deficit more than one million yen. On the other hand, PV installation in Germany had grown when total balance became surplus in 2000. This fact shows that Japanese consumer had considerable amount of “willingness to pay” (WTP) for PV panels.

On the other hand, solar water heater (SWH) has very low consumer’s preference. Table 2 shows the results of a choice experiment to investigate the consumer’s preference on PV and SWH by authors [5]. Even in the same category of solar energy utilization system, consumer’s preference is quite different. This result shows the consumer’s preference as follows:

1) PV has high WTP (1.23 Million yen) but SWH has negative WTP (-0.26 Million yen).
2) Consumers evaluate the subsidy at 1.8 times larger than actual value.
3) In feed-in-tariff, consumers evaluate the revenue by electricity purchase rate for about seven years.

For the reason of negative evaluation on SWH, Kimura [6] analyzed that this fact is based on convenience of SWH is inferior to conventional water heaters. Therefore, not only the low carbon performance but also the industrial design, system design for convenience and institutional design are inevitable to disseminate renewable energy technologies.

5 SUMMARY

This paper shows the examples of Meso-level research on low-carbon society such as land use design, influence on demographic parameter, and industrial and institutional design of building integrated PV systems. There are many other examples such as management of research development on low-carbon technology to adapt energy transition scenario, design of house and appliance purchase plan to adapt progress of energy technology and so on. These design issue is critical part to realize low carbon society.

ACKNOWLEDGEMENT

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Scenario analysis of cement production in China: the role of policy and technology in the pathway to sustainable society

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Abstract.

China's annual cement production is by far the largest in the world. Although it is a necessity for economic development, its production requires huge amount of energy inputs, adversely affecting sustainable development. In this paper, we identify the determination of cement demand in China and demonstrate scenario analysis toward 2015. We demonstrate that while technological development in the cement industry in China is important in terms of reducing energy input, the most critical factor is to achieve balanced economic growth. In particular, our results suggest the importance of the achievement of the economic growth target in the 12th Five-Years-Initiative of China, addressing the effective urban planning and financial mechanism for technological development and diffusion.

Keywords:

China, Cement, Economic growth, Urbanization, Scenario Analysis, Technology, Energy Consumption

1 INTRODUCTION

Cement is a necessary material for economic development used in infrastructures and buildings. Yet cement production is an energy intensive industry being the major source of multiple pollutants including CO_2 among others. In fact, CO_2 emissions from the cement industry accounts for 5% of the total world emissions. Meanwhile, the world cement production has been rapidly increasing because of the economic growth in the emerging economies such as China, India, and Brazil. Among them, China is by far the largest cement producer country accounting for more than 40% of the world cement production in recent years while its technology level for cement production is way behind that of industrialized countries. In this paper, we demonstrate scenario analysis of cement production for China to present pathways of future cement demand based on different scenarios addressing policy implications and institutional design.

Specifically, we first analyze world data and confirm that per capita demand for cement is converging to some point after countries reach some income level, but the convergence points may substantially vary across regions. Particularly, we find that per capita cement production in China is much higher than that in other regions even after controlling for income effects. Having these observations in hand, we then investigate Chinese cement production and regional characteristics related to cement demand and energy use, such as urbanization, industrial structure, income and technology.

Regarding cement production, we show that even though urbanization and economic growth trends are different across the regions and areas, overall cement demand is expected to increase if these trends continue their increasing pattern. As for technology, we present that cement industry in China has very low energy efficiency compared to that of other industrial countries while the technology level varies across regions. These observations obviously imply that if current situations continue, energy consumption and corresponding carbon emissions attributed to cement production will become a major constraint to achieve sustainable development for China.

We then carry out scenario analysis to shed light on how GDP growth, urbanization and technology diffusion affect cement demand and energy consumption by discussing the role of policy and urban planning. The results show that substantial potentials exist to reduce cement demand and energy used in the industry, depending on future urbanization, urban design and technology diffusion across areas. We address the significance of urban planning, capacity building, and finance mechanisms to specify the pathways of desirable scenarios. Particularly, this paper investigates the situations and perspectives of the market and regulations in the cement industry including mergers and acquisitions through foreign investment and some regulations and their implementation in the cement industry.

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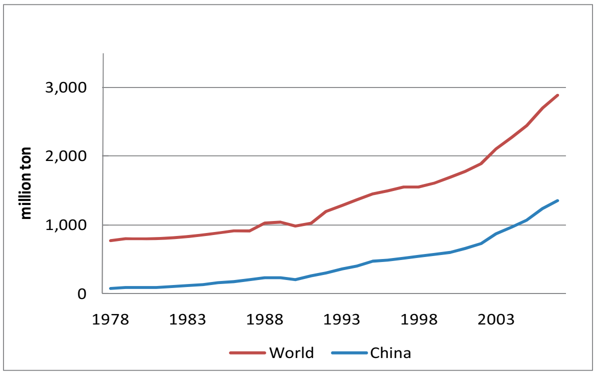

Fig. 1: World and China's cement production

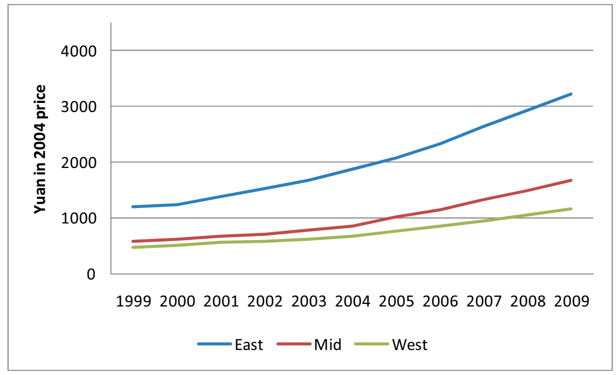

Fig. 3: Per capita GDP in China by region

2 WORLD TRENDS IN CEMENT PRODUCTION

World cement production has been rapidly increased in the last decades. The world production in the late 80's was 1 billion metric ton a year, and now it approaches 3 billion metric tons (Fig.1). This rapid increase is probably attributed to GDP expansion in the emerging economies. Particularly, China has accounted for more than forty percent of the world's cement production for years. (Fig. 1) and this trend will continue given the current trends in economic growth.

Overviewing the world cement production at the country level reveals interesting trends. First, the cement production in absolute amounts and in per capita level varies spatiotemporally. Per capita cement of production is; 100 to 300 kilograms in many of the less developing countries rages; around 1,000 kilograms in some emerging economies including China and middle eastern countries; and 300~500 kilograms in the western countries. These observations in turn imply that there is a certain pattern of cement production of countries. Considering the purposes of cement products, countries that experience rapid economic growth show growing cement production pattern.

Uwasu et al. [*1*] analyzed more than 100 countries cement production data from U.S. Geological Survey [*2*] to confirmed if country's cement production per capita converges using cement macroeconomics and financial engineering techniques (i.e., beta-convergence and unit-root tests [*3*]) They further statistically showed that China's cement production is considered to be higher even after controlling for the development stage and population effects. Fig. 2 summarized the cross section and time series analysis results from Uwasu et al. [*1*]. Here we posit that this pattern plausibly applies to China. Moreover, it is important to figure out at which path China or Chinese provinces will follow. Next section exclusively examines China's cement production. Section 4 then demonstrates scenario analysis is useful to examine the pathways China will possibly take.

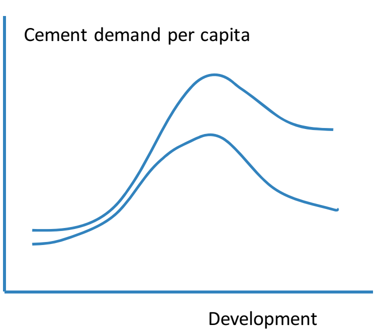

Fig. 2: Country's cement demand and development

3 CHINESE CEMENT PRODUCTION

3.1 Regional distribution of GDP, population and cement production

China is a vast country (9.6 million km^2) with the world largest population (1.3 billion). It is useful to see the country's profile in terms of manufacturing products by region or areas because there is a large disparity in economic development level between geological regions (i.e., the east, mid and west regions) and that cement products are locally produced and consumed because of its weight (i.e., too heavy to transport a long distance.)

For now, we look at regional distribution of GDP, population and cement production in three regions : the East consisting of 11 cosatal privinces (Beijing, Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Shandong, Fujian, Guangdong), the Mid of 8 provinces (Shanxi, Inner Mongolia, Anhui, Jiangxi,

Table 1: Population & urban population rate by region

Population (Urban ratio)	2005	2006	2007	2008	2009
East	56,317 (0.53)	56,887 (0.55)	57,483 (0.55)	57,984 (0.56)	58,463 (0.57)
Mid	52,318 (0.37)	52,360 (0.38)	52,389 (0.40)	52,618 (0.41)	52,841 (0.43)
West	19,688 (0.32)	19,884 (0.33)	20,047 (0.34)	20,223 (0.35)	20,355 (0.36)

Note: Population in 10 thousand. Numbers in parentheses are ratio of urban population to total population.

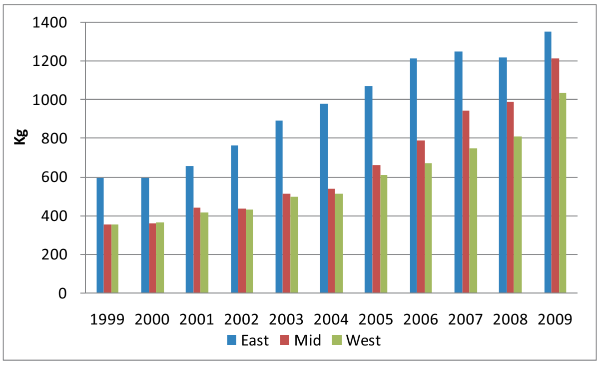

Fig. 4: Per capita cement production trend by region

Henan, Hubei, Hunan, Chongqing), and the West of 10 inland provinces (Shaanxi, Guangxi, Hainan, Guizhou, Yunnan, Tibet, Gansu, Qinghai, Ningxia, Xinjiang). It is well known that the East region is most developed and the west region is least developed. As Fig. 3 shows, although these three regions have experienced rapid economic growth in the last decades, per capita GDP in the East in fact more than twice larger than that of the West.

Table 1 summarizes population information between 2005 and 2009.The population of the East, Mid, and West regions are respectively 584 million, 524 million, and 203 million in 2009. Moreover, population growth rate and urbanization rate are different in the three regions: the East has the highest population growth rate as well as urbanization rate while the West has the least. The table shows also an increasing trend of urbanization rate in all the three regions.

The economic activities and geographical distribution of population affect cement production in the three regions. Fig. 4 shows cement production trends in the three regions from 1999 to 2009. First, the East region has the largest production level in all the time. Second, both total and per capita cement production were increasing during the period. These observations suggest that GDP and poplation distribution are closely associated with cement production and demand. Next subsection confirms that GDP and poplation distribution in addition to some area characheristics affects cement demand.

Table 2: Definition of seven areas

1	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia
2	Liaoning, Jilin, Heilongjiang
3	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong
4	Fujian, Guangdong, Guangxi, Hainan
5	Henan, Hubei, Hunan
6	Chongqing, Sichuan, Guizhou, Yunnan, Tibet
7	Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang

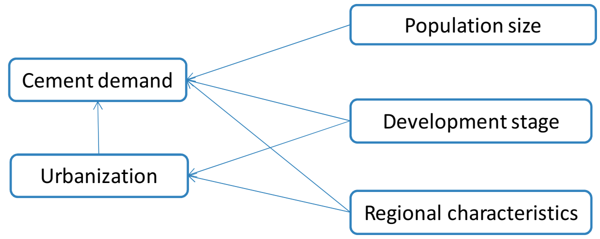

Fig. 5: Structure of how cement demand is determined

3.2 Determination of cement production level

This subsection demonstrates that regional cement production level in China is determined by economic, population and location factors using statistical techniques. For this purpose, we introduce a new definition of provincial areas. Table 2 provides the definition of the seven areas in China. Provinces that are adjacently located constitute one area, possibly building an economic network. Given the fact that cement products are too heavy to be transported in a long distance, we assume that production in one area is nearly equal to the cement consumption (demand) in the area. The new area definition considers this cement products' attribution.

Fig. 5 illustrates the structure of how area's cement production/demand is determined. Four key factors include; GDP per capita, population, urbanization and area's characteristics. Population captures the demand size of cement products. Also, existing literature has shown that there is a positive association between urbanization and economic development [5]; urbanization and GDP per capita affects cement demand per unit of person or area size. Moreover, we hypothesize that there is a location feature as determination for cement demand. The area's characteristic is assumed to influence cement production/demand (i.e., location effects). First is a direct factor: vast land induces more demand for cement for large scale of infrastructures. Second is an indirect one: it affects the form of urbanization regardless of economic

Table 3: Urbanization rate and GDP per capita

	Coefficient	Standard error
Log of GDP per capita	0.092	0.005***
Area 1	0.064	0.005***
Area 2	0.128	0.005***
Area 3	0.046	0.005***
Area 4	0.092	0.005***
Area 5	-0.012	0.003***
Area 6	-0.019	0.003***
Constant	0.368	0.002***

N=35, Adjusted R squared=0.99
Note: ***, **, and * denote statistical significant at the 1 %.
The dummy variable for Region 7 is omitted as base.

Table 4: Determinants of cement production

	Coefficient	Standard error
GDP per capita	3867.21	2,167.15*
Population	-1.02	2.39
Urbanization	112,038.40	32,974.15***
Area 1	-2,473.50	12,707.31
Area 2	-22,298.44	4,771.26***
Area 3	47,321.78	57,043.07
Area 4	256.47	20,083.83
Area 5	22,819.78	27,966.49
Area 6	21,254.10	24,023.24
Constant	-29,500.58	22,809.51

N=35, Adjusted R squared=0.98
Note: ***, **, and * denote statistical significant at the 1 % , 5%, and 10% levels, respectively. The dummy variable for Region 7 is omitted as base.

development level. We constructed the database of cement production, population, GDP per capita, and urbanization for the seven areas through 2005 to 2009 (5 years), based on the seven regions, so that the number of observation is 7×5=35. All data are obtained from a series of Chinese official statistics [*4*]. Finally, we attempt to capture the location effect using area dummy variables.

First, we show urbanization is influenced by development stage and area characteristics. Table 3 reports the regression results of ordinary least squares in which we regress income and areas' dummy variables are regarded as determination of urbanization. We used a logarithm of GDP per capita as we expected that urbanization rate increases with GDP per capita rise at a decreasing rate. All of the explanatory variables are statistically significant. Given the estimated coefficients of area dummies, the results indicate that urbanization rate in the area 1-4 are higher and that rate in areas 5 and 6 is lower than that in Area 7, GDP per capita being equal.

Having observed this, we now demonstrate the determination of cement production/demand. Table 4 reports the regression results of cement production determination. First, GDP per capita is statistically significant with a positive sign. This is consistent with the result in the literature [*5*]: as an economy grows, urbanization proceeds. Secondly, population is not statistically significant, which suggests that the demand size of cement is not affected by population itself when economic factors among others are considered. Third, urbanization is statistically significant with an expected sign, suggesting urbanization increases the demand for cement even after controlling for the development level. Finally, we see that most areas have no particular area effects except for Area 2 (the north east provinces). Its

Table 5: Four scenarios and assumptions

BAU	Current trend of rapid economic growth, urbanization & technology improvement
BAU+ innovation	BAU plus innovation in the cement industry
5YI	7% GDP growth rate with focus on balanced policy and corresponding urbanization
5YI+ innovation	Economic growth based on the 5YI plus innovation in the cement industry

coefficient is negative and statistically significant, meaning cement demand or production in this area is smaller than other areas, other factors being equal.

4 SCENARIO ANALYSIS OF CEMENT PRODUCTION IN CHINA

Those analyses indicate that two factors, economic growth and urbanization, are dominantly important for future cement demand. Moreover, cement production is accompanied by large energy inputs. Hence, not only cement demand but also production technologies determine energy consumption with respect to cement production.

We set up four scenarios based on two cases in terms of economic activity levels that affect cement demand size and technological development patterns which affect energy use for cement production in the future (Table 5). Our target year period is 2015, which deals with relatively a short period in the typical scenario studies. But for cement, our analysis proves to be meaningful in the sense that there is a huge difference in the consequences for sustainable development depending on which paths China will take even in this time period.

Economic activity level is captured by annual GDP growth rate. We set a 7% rate as the low case, which refers to the target number proposed by the 12th Five-

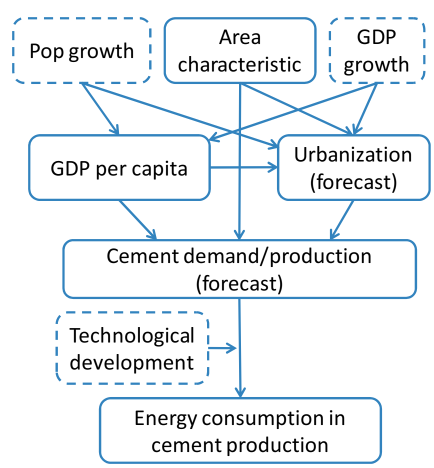

Fig. 6 : How indicators are projected

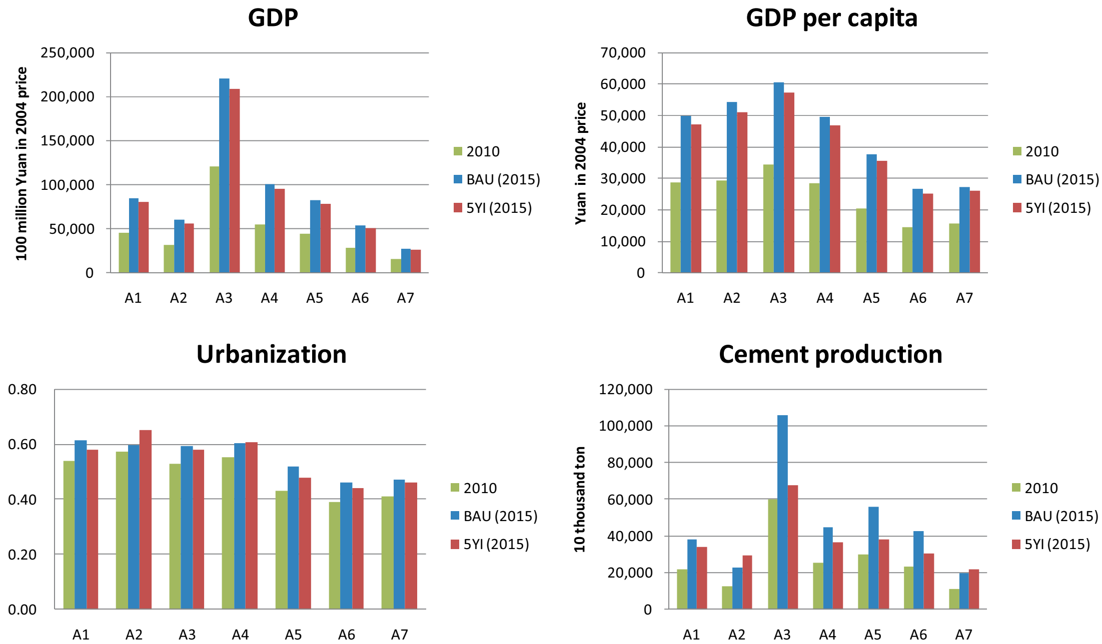

Fig. 7: Projection of economic indicators, urbanization and cement production in 2015 by area based on two scenarios

Year-Initiatives of China. On the other hand, the high case assumes 12~13 percent growth per annum based on the past 5 years' performance in each area. Regarding technological development, average energy intensity for cement production (energy in mega joule (MJ) used to produce one ton of cement) in China is around 4,500 MJ, which is much higher than that in Japan which performs one of the best energy efficiency in cement production practices (about 3,000 MJ) [*6*]. Moreover, there is a large disparity in energy intensity: the best area achieves around 3,600 MJ/ton while the worst area has as much as 5,000 MJ/ton [*7*]. Finally, the intensity in all the areas has been improving in the last 4 years. So, in this scenario analysis, we assume two cases in terms of technological development in the cement industry. The high case (i.e., innovation) assumes all the areas have the currently available best technologies in China, i.e., 3500 MJ/ton in 2015 assuming that innovation evolves. The lower case assumes the current improvement trends (i.e., BAU).

Fig. 6 illustrates the way of calculation for the projection regarding urbanization, cement demand, and corresponding energy input for production. In the figure, the factors with dotted line indicate the ones that are pre-determined by the scenario assumptions in Table 6. First, population and GDP in 2015 are calculated for the seven areas based on the two scenarios. Second, corresponding GDP per capita is computed. Third, using the estimated coefficients in the regression equation in Table 4, urbanization rate for the seven areas are estimated. Likewise, using the regression estimates in Table 5 and indicator values of population, GDP per capita and urbanization with consideration of the areas' effects, cement production in 2015 is projected. Finally, energy input for cement production corresponding to each of the demand cases is respectively calculated for the two technology development patterns.

Fig. 7 shows the calculation results, projected indicators in 2015 in the two GDP growth cases (i.e., BAU and 5YI) and those in 2010 as references. First, the results show that GDP will rapidly expand particularly in the BAU case: GDP in most areas will get twice in five years. Second, this economic expansion generates large impacts on cement demand in 2015 through per capita GDP growth and urbanization. Compared the low case and high case in GDP growth, this effects are substantial. Per capita GDP in the high case are higher than those in the low case by five to ten percent. As well, urbanization rates in the high case are higher by two percent than in the low case (except for Area 2). These differences hence influence on cement demand. On average, cement demand in the high case is 26 percent higher than in the low case: in Area 3, the increase rate reaches 60 percent.

Table 6 presents the projection of energy consumption for cement production/demand corresponding to the high and low GDP growth cases. Among the four cases, the BAU scenario (i.e., high GDP growth and BAU technological improvements) has by far the largest energy consumption for cement production while the 5YI+I scenario (low GDP growth plus technological innovation) has the least. Further, comparing each of the four cases with another reveals the magnitude of energy saving potentials due to increase in cement demand and technological development. On the one hand, technological innovation alone improves energy efficiency by 12 percent compared to the BAU cases. On the other hand, the 12~13 percent of annual GDP growth (high growth case) brings 27 percent

Table 6: Projection of energy consumption (inputs) for cement production in 2015 (in Giga Joule)

	BAU	BAU+I	5YI	5YI+I
A1	120,141	120,135	107,143	107,137
A2	100,788	80,591	129,739	103,740
A3	383,295	370,567	245,118	236,978
A4	178,989	156,282	145,735	127,247
A5	185,533	175,807	127,456	120,774
A6	193,359	149,466	137,036	105,928
A7	88,998	68,891	98,459	76,215
Total	1,251,103	1,121,739	990,686	878,020

Note: In Chinese official statistics, energy data is reported by using the standard carbon equivalent (SCE) unit. We converted the SCE unit into joule according to the National Academy of Sciences [*7*].

larger cement demand than that with the case of low economic growth. In sum, as far as total energy input for cement production is concerned, the results clearly indicate the importance of controlling total demand along with technological development and diffusion.

5 DISCUSSION

We have shown that even though urbanization and economic growth trends are different among the seven areas, overall cement demand is expected to increase if the current trends continue their increasing pattern. Consequently, the energy inputs to meet the demand for cement will be extremely large. In fact, energy consumption for cement production alone in 2015 in the BAU scenario (i.e., high growth without prominent technological progress) could account for 24 percent of total energy consumption in 2009 [*4*].

We identified two important factors. First is the neccessity of efficiency improvements in the cement industry through technological development and diffusion. In the present cement industry in China, most cement kilns (around 90%) are of shaft type rather than rotary type in China resulting in very low energy efficiency compared to that of other industrial countries [*9*]. We also showed that there is a large variation in technology level across the areas. Together with the scenario analysis results, these observations imply that substantial potentials exist to decrease cement energy used in the industry. However, in the Chinese cement industry state-owned and small-scale plants are dominant, which causes both institutionally and financially difficulty in technological diffusion. As Price and Galitsky reported, the issue is not the lack of feasible technology, but the lack of institutions to finance it [*9*]. On the other hand, foreign direct investment in the cement industry in China has been recently increasing [*10*]. Not only for the introduction of advanced technologies and practices, but also scale enlargement of specific cement plants through mergers and acquisitions could contribute to the improvement of energy efficiency.

Second is the most critical one as our scenario results show: how to achieve balanced economic growth in the coming years. In fact, the unpresedented rapid economic growth in China for the last decades has caused socioeconomic and environmental issues including income inequality and heavy pollution. Ou results suggest China will have to follow the economic projection initiated by the 12th Five-Years-Initiative while sufficient investments in environmental technologies are made even if they are costly in the short term. Given the results that urbanization significantly increases cement demand, we also address the role of urban planning as well as capacity building through appropriate policies, both of which lead to reduction of environmental load associated with industrial production and transportation as well as to the creation of better instituions including finance mechanisms. Altough some of the challenges raised here are perherps of long term challenges, immediate introduction of specific measurements is essential for Chinese sustainable development.

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Scenario Analysis on the Impact of Diffusion of Next Generation Vehicles on Material Consumption and GHG Emissions

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Abstract

In this study, we developed an automobile cohort model to evaluate the effect of the diffusion of next generation vehicles such as hybrid electric vehicles and electric vehicles on material consumption and GHG emissions. This model comprises three submodels: the cohort survival submodel, the GHG emissions estimation submodel, and the material consumption estimation submodel. Comparison of three diffusion scenarios (baseline, optimistic, and pessimistic) using this model showed that more diffusion of next generation vehicles induces large material consumption while low diffusion encourages more GHG emissions.

Keywords:
next generation vehicles, cohort model, rare metals, total material requirement, LC-GHG emissions

1 INTRODUCTION

Diffusion of next generation vehicles (NGVs) having high environmental performance is one of the top priorities for achieving the target of halving GHG emissions by 2050. In Japan, the Ministry of the Environment (MOE) and the Ministry of Economy, Trade and Industry (METI) have implemented several policies to promote the diffusion of NGVs and stimulate further technological innovations such as hybrid electric vehicles (HEVs) and electric vehicles (EVs). Although these technological replacements are expected to contribute to a reduction in the total environmental load, their disadvantage is that powerful batteries and motors used in HEVs and EVs require a wide variety of rare metals. Furthermore, research regarding the risks of global material consumption is inadequate. In this research, we first clarify the profiles of life cycle GHG emissions and materials consumption, and then discuss the wider impact of diffusion of NGVs on the environment by considering risk-risk trade-offs.

2 METHODOLOGY

2.1 Model building

In order to analyze the impact of the future diffusion of NGVs, we developed an automobile cohort model that estimates the number of NGVs and evaluated the environmental impacts based on three diffusion scenarios. This model is composed of three submodels: the cohort survival submodel, the material consumption estimation submodel, and the GHG emissions estimation submodel.

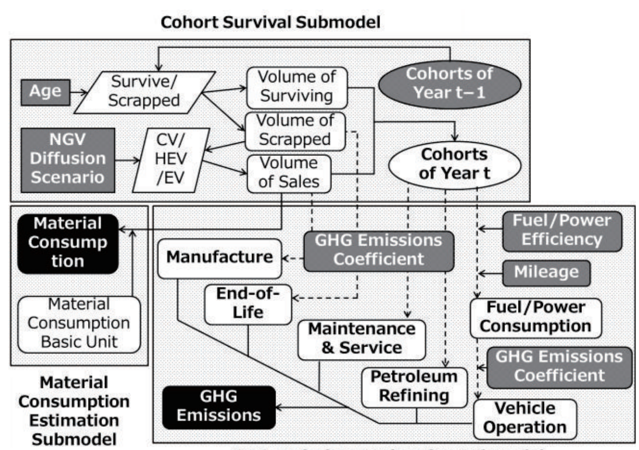

Fig. 1: Outline of automobile cohort model

Fig. 1 shows the outline of the model.

In this study, we focused on private vehicles. These vehicles are expected to be the major cause of the increase in CO_2 emissions during the next decade; in 2008, they contributed 48.9% of CO_2 emissions from the transport sector in Japan [1]. As NGVs, HEVs and EVs were considered.

Cohort survival submodel

In the cohort survival submodel, the volume of the vehicle cohorts was estimated on the basis of that in the previous year. Vehicles in circulation are scrapped following the

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Age a / Year	0	1	2	3	…	Volume of Vehicles Surviving
2000	$C_{0,00}$	$C_{1,00}$	$C_{2,00}$	$C_{3,00}$	…	$\Sigma_a C_{a,00}$
2001	$C_{0,01}$	$C_{1,01}$	$C_{2,01}$	$C_{3,01}$	…	$\Sigma_a C_{a,01}$
2002	$C_{0,02}$	$C_{1,02}$	$C_{2,02}$	$C_{3,02}$	…	$\Sigma_a C_{a,02}$
2003	$C_{0,03}$	$C_{1,03}$	$C_{2,03}$	$C_{3,03}$	…	$\Sigma_a C_{a,03}$
2004	$C_{0,04}$	$C_{1,04}$	$C_{2,04}$	$C_{3,04}$	…	$\Sigma_a C_{a,04}$
2005	$C_{0,05}$	$C_{1,05}$	$C_{2,05}$	$C_{3,05}$	…	$\Sigma_a C_{a,05}$
⋮	⋮	⋮	⋮	⋮		⋮

Fig. 2: Concept of vehicle age cohort

scrappage function. For simplicity, we assumed that the entire cohort is scrapped when the age reaches the average lifetime of 12 years [2]. The vehicle market is assumed to be saturated, indicating that the number of vehicles purchased each year is equal to that scrapped.

Eq. 1 represents the survival of vehicles and Fig. 2 shows the concept of vehicle age cohort.

$$C_{a,t} = L_{a,t} C_{(a-1),(t-1)} \quad \text{(Eq. 1)}$$

$C_{a,t}$ is the volume of vehicles at age a in year t and $L_{a,t}$ is the survival function for the vehicle cohort at age $a-1$ in year $t-1$.

Table 1 shows the share of sales and diffusion of NGVs in each diffusion scenario. Three scenarios (baseline, optimistic, and pessimistic) were used, based on Next Generation Vehicle Strategy 2010 announced by METI [3]. The baseline scenario assumes a moderate diffusion rate, the pessimistic scenario assumes a suppressed diffusion rate, and the optimistic scenario assumes an augmented diffusion rate.

Sales data from 2000 to 2009 was acquired from the Japanese Automobile Manufacturers Association [4][5] and the Automobile Inspection & Registration Information Association [6].

Table 1: NGV diffusion scenarios

(a) Share of sales

	2009	Pessimistic Scenario		Baseline Scenario		Optimistic Scenario	
		2020	2030	2020	2030	2020	2030
CV	89%	81%	58%	61%	38%	41%	16%
HEV	11%	9%	33%	19%	43%	29%	54%
EV	0%	10%	10%	20%	20%	30%	31%

(b) Share of diffusion

	2009	Pessimistic Scenario		Baseline Scenario		Optimistic Scenario	
		2020	2030	2020	2030	2020	2030
CV	98%	85%	70%	75%	50%	65%	30%
HEV	2%	10%	20%	15%	30%	20%	40%
EV	0%	5%	10%	10%	20%	15%	30%

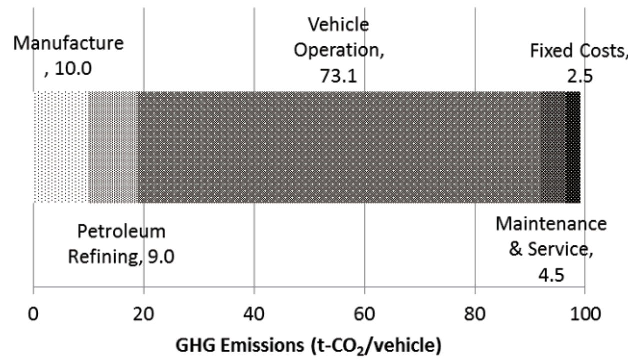


Fig. 3 GHG emissions by vehicle life stages

GHG emissions estimation submodel

The GHG emissions estimation submodel calculates life cycle GHG emissions (LC-GHG) using the volume of sales, scrappage, and cohort information. As we focused on the environmental impact of diffusion of NGVs, we calculated overall GHG emissions per year related to the vehicles. Fig. 3 shows the volume of GHG emissions from each life stage of a vehicle.

The boundary of the LCA was based on the EIO-LCA model, which was developed in MacLean and Lave [7]. In the model, automobile life cycle was divided into five stages in which GHG are emitted: manufacturing, petroleum refining, operation, maintenance and service, and fixed costs (end-of-life is not included in the EIO-LCA model, because analyses show that energy use, emissions, and economic impacts because of this LC stage are small). Because CO_2 constitutes the majority of GHG emissions, the emissions were assumed to be equal to CO_2 emissions in this submodel. We used Eqs. 3–8 to calculate GHG emissions during the entire life cycle of vehicles. Table 2 shows the definition of each parameter.

$$GHG_M = V_{Sales} \times C_{GHG(M)} \quad \text{(Eq. 3)}$$

$$GHG_P = V_{Stock(CVs/HEVs)} \times C_{GHG(P)} \quad \text{(Eq. 4)}$$

$$GHG_S = V_{Stock} \times C_{GHG(S)} \quad \text{(Eq. 5)}$$

$$GHG_F = V_{Stock} \times C_{GHG(F)} \quad \text{(Eq. 6)}$$

$$GHG_{O(CVs/HEVs)} = C_{Fuel} \times C_{GHG(Gas)} \times V_{Stock(CVs/HEVs)} = \frac{M}{E_{Fuel}} \times C_{GHG(Gas)} \times V_{Stock(CVs/HEVs)} \quad \text{(Eq. 7)}$$

$$GHG_{O(EVs)} = C_{Electric} \times C_{GHG(Electric)} \times V_{Stock(EVs)} = M \times E_{Electric} \times C_{GHG(Electric)} \times V_{Stock(EVs)} \quad \text{(Eq. 8)}$$

Table 2 : Parameters and definitions for GHG emissions estimation

Parameter	Definition
GHG_M	GHG emissions from manufacture
V_{Sales}	vehicle sales [4][5]
$C_{GHG(M)}$	GHG emissions coefficient of manufacture [7]
GHG_P	GHG emissions from petroleum refining
$V_{Stock(CVs/HEVs/EVs)}$	vehicle stock of CVs/HEVs/EVs [4][5][6]
$C_{GHG(P)}$	GHG emissions coefficient of petroleum refining [7]
GHG_S	GHG emissions from maintenance and service
$C_{GHG(S)}$	GHG emissions coefficient of maintenance and service [7]
GHG_F	GHG emissions from fixed costs
$C_{GHG(F)}$	GHG emissions coefficient of fixed costs [7]
$GHG_{O(CVs/HEVs/Evs)}$	GHG emissions from operation of CVs/HEVs/EVs
C_{Fuel}	annual fuel consumption per vehicle
$C_{GHG(Gas)}$	GHG emission coefficient of gas [8]
M	annual mileage per vehicle [9]
E_{Fuel}	fuel efficiency by vehicle type [10]
$C_{Electric}$	annual electric consumption per vehicle [11]
$C_{GHG(Electric)}$	electric coefficient for GHG emissions [9]
$C_{Material}$	material consumption
$U_{Material}$	material consumption basic unit [12][13]
V_{Sales}	volume of sales [4][5]

Material consumption estimation submodel

In the material consumption estimation submodel, we evaluated the annual consumption of four base metals and 25 rare metals in the automobile industry on the basis of automobile sales by vehicle type. Material consumption was estimated as shown in Eq. 9. Table 2 shows the definition of each parameter.

$$C_{Material} = U_{Material} \times V_{Sales} \qquad \text{(Eq. 9)}$$

Table 3 shows the unit material consumption of each type of vehicle. This data was acquired from the Life Cycle Assessment Society of Japan [12] (base metals) and Yano Research Institute [13] (rare metals).

2.2 Evaluation Indices

Consumption of exhaustible resources is one of the central issues examined in this study. However, the definition of the depletion of resources is unclear. Therefore, several indices to evaluate it have been proposed, each reflecting physical, economic, and technological aspects of resources. Caneghem et al. [14] compared several indices using integrated indicators that focus on the impact of resource depletions. These indicators include CML, CexD, Eco-indicator99, and EPS. In addition, the method based on mass and energy is used. Considering these indicators as a primary analysis, we analyzed resource consumption using indices on the basis of the amount of reserves of the respective resources.

We applied four methodologies to weigh different resources consumptions: TMR index, reserves, mine production, and reserves-to-production ratio Table 4 shows the evaluation indices used for the metals**.** These data were acquired by Harada [15] (TMR index) and the U.S. Geological Survey [16] (reserves, mine production, and reserves-to-production ratio).

Table 3: Material composition of vehicles

	Material Consumption Basic Unit (g)		
	CV	HEV	EV
Ni	5,690	14,652	14,652
Cr	14,746	0	0
W	205	0	0
Co	3	1,238	1,238
Mo	1,173	123	123
Mn	12,095	0	42,204
V	309	0	0
Mg	5,161	0	0
Nb	265	0	0
Sr	24	0	0
Ti	1,058	0	0
Zr	59	0	0
S	512	0	0
B	17	0	0
Pt	5	0	0
Rh	1	0	0
Pd	6	0	0
Ir	0	0	0
La	5	0	0
Y	2	0	0
Li	0	0	8,851
Mm	0	2,922	0
Nd	0	495	495
Dy	0	116	116
Ga	0	3	3
Fe	721,839	721,839	721,839
Al	76,967	76,967	76,967
Cu	11,099	11,099	11,099
Pb	7,660	7,660	7,660

3 RESULTS

3.1 GHG emissions

In the baseline scenario, the amount of GHG emissions from vehicles gradually decrease till 2030 as HEVs and EVs diffuse (Fig. 4), primarily because of their high energy efficiency in the operation stage (Fig. 5). In 2030, GHG emissions are 23% less than the emissions in 2009,

Table 4: Evaluation indices of metals

	Chemical Symbol	TMR Index	Reserves (t)	Mine Poduction (t)	Reserves-to-Production Ratio (year)
Nickel	Ni	260	7.6×10^{7}	1.6×10^{6}	49
Chromium	Cr	26	3.5×10^{8}	2.2×10^{7}	16
Tungsten	W	190	2.9×10^{6}	6.1×10^{4}	48
Cobalt	Co	600	7.3×10^{6}	8.8×10^{4}	83
Molybdenum	Mo	750	9.8×10^{6}	2.3×10^{5}	42
Manganese	Mn	14	6.3×10^{8}	1.3×10^{7}	48
Vanadium	V	1,500	1.36×10^{7}	5.6×10^{4}	243
Magnesium compounds	Mg	70	2.4×10^{9}	5.6×10^{6}	430
Niobium	Nb	640	2.9×10^{6}	6.3×10^{4}	46
Strontium	Sr	500	6.8×10^{6}	4.2×10^{5}	16
Titanium mineral concentrates	Ti	36	6.9×10^{8}	6.3×10^{6}	110
Zirconium and hafnium	Zr	560	5.6×10^{5}	1,190	47
Sulfur	S	-	-	6.8×10^{7}	-
Boron	B	140	2.1×10^{8}	3.5×10^{6}	60
Platinum	Pt[1)]	5.2×10^{5}	6.6×10^{4}	183	361
Rhodium	Rh[1)]	2.3×10^{6}	6.6×10^{4}	-	-
Palladium	Pd[1)]	8.1×10^{5}	6.6×10^{4}	197	335
Iridium	Ir[1)]	4.0×10^{4}	6.6×10^{4}	-	-
Lanthanum	La[2)]	3,100	-	-	-
Yttrium	Y	2,700	5.4×10^{5}	8,900	61
Lithium	Li	1,500	1.3×10^{7}	25,300	514
Neodymium	Nd[2)]	3,000	-	-	-
Dysprosium	Dy[2)]	9,000	-	-	-
Gallium	Ga[3)]	1.4×10^{5}	-	106	-
Iron ore	Fe[4)]	8	8.7×10^{10}	2.4×10^{9}	36
Aluminum	Al	48	-	4.1×10^{7}	-
Copper	Cu	360	6.3×10^{8}	1.6×10^{7}	39
Lead	Pb	28	8.0×10^{7}	4.1×10^{6}	20
Rare-earths	-	-	1.1×10^{7}	1.3×10^{5}	85

1) Reserves refers to the sum of platinum-group metals (platinum, palladium, rhodium, ruthenium, iridium, and osmium)

2) Rare-earths refers to rare-earth metals

3) Production refers to primary production

4) Production refers to iron content

contributing a reduction of 21% in GHG emissions from the transport sector and 4% from the domestic sector.

The pessimistic and optimistic scenarios show the same trend as the baseline scenario (Fig. 6). In 2030, GHG emissions are 16%–30% less than the emissions in 2009, contributing to a 14%–29% reduction in GHG emissions

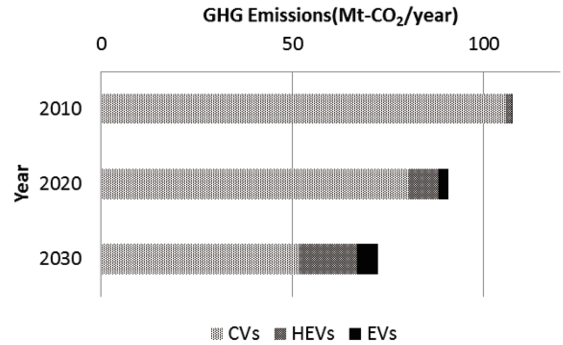


Fig. 4: GHG Emissions from vehicle operation (baseline scenario)

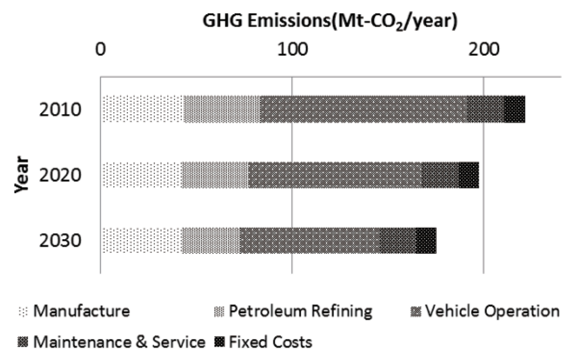


Fig.5 : LC-GHG emissions from vehicles (baseline scenario)

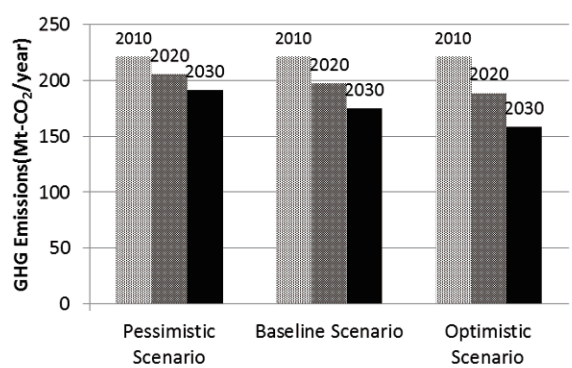


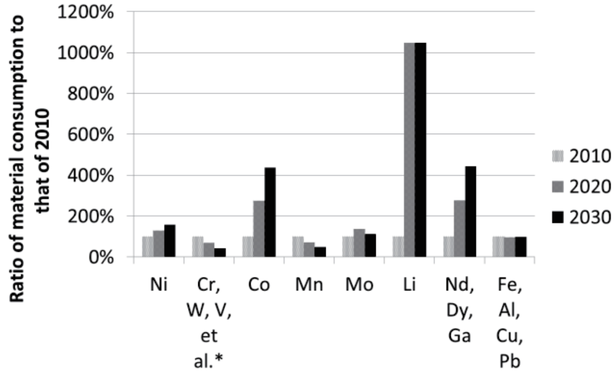
Fig. 6 : LC-GHG emissions from vehicles (three scenarios)

from the transport sector and 3%–6% from the domestic sector.

3.2 Material consumption

The structure of material consumption changed significantly (Fig. 7) over time in the scenarios. The consumption of some metals increased, whereas the consumption of others did not.

For example, lithium (Li), which is used as a cathode material for lithium-ion secondary batteries, neodymium



* : Cr, W, V, Mg, Nb, Sr, Ti, Zr, S, B, Pt, Rh, Pd, Ir, La, Y

Fig. 7: Ratio of material consumption to that of 2010 (baseline scenario)

(Nd), dysprosium (Dy), and gallium (Ga), which are used as permanent magnets in motors show an increase in consumption. In contrast, the consumption of metals such as chromium, manganese, and molybdenum decrease. Consumption of iron (Fe), aluminum (Al), copper (Cu), and

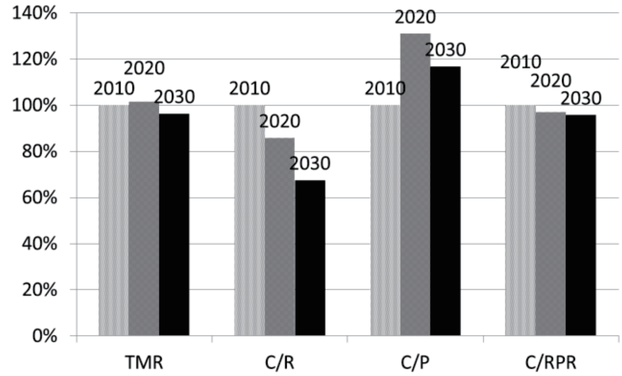


Fig. 8: Comparison of evaluation indices (baseline scenario)

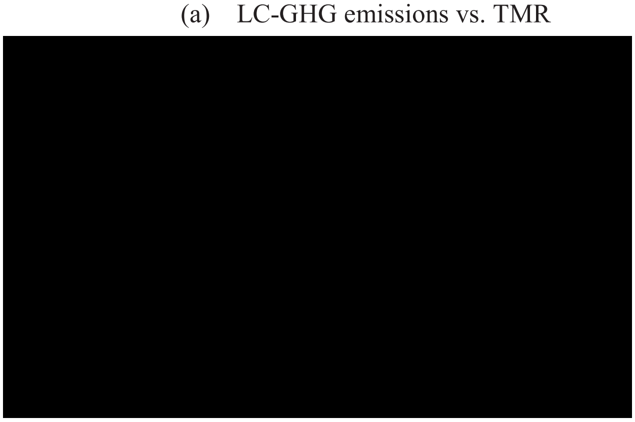
lead (Pb) is relatively unchanged. The other two scenarios show the same trend.

3.3 Integration of indices

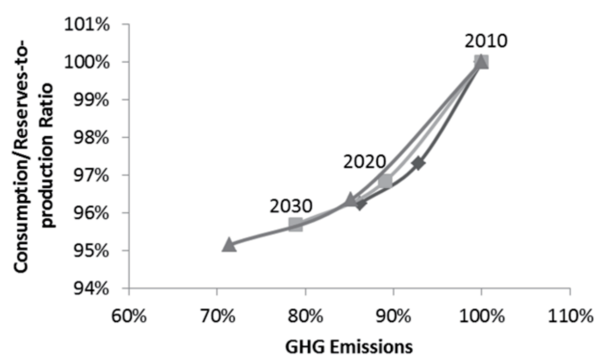
Fig. 8 shows the comparison of material consumption measured by the four indices. The TMR index and the consumption/mine production (C/P) index show a similar

(a) LC-GHG emissions vs. TMR

(b) LC-GHG emissions vs. consumption/reserves



(a) LC-GHG emissions vs. consumption/mine production



(b) LC-GHG emissions vs. consumption/reserves-to-production ratio

Pessimistic Scenario Baseline Scenario Optimistic Scenario

Fig. 9: Correlation between GHG emissions and material consumption indices

trend, while the consumption/reserves (C/R) and the consumption/reserves-to-production ratio (C/RPR) show a similar trend (Fig. 8).

C/R shows a decreasing trend; in contrast, C/P shows an increasing trend when we consider the entire period. Hence, it can be implied that demand for metals that have large reserves but little current production (such as lithium) will be greater by 2030.

3.4 Correlation between GHG emissions and material consumption indices

Fig. 9 shows the correlation between indices of GHG emissions and material consumption as a percentage of the 2010 indices.

Fig. 9 (a) showed trade-offs between GHG emissions and TMR until 2020. However, it also indicated win-win relationships after 2020 (Fig. 9 (a)), indicating that the diffusion of NGVs is beneficial by 2030.

The same type of profile is evident for the relationship between GHG emissions and consumption/mine production (Fig. 9 (c)), but in this case, the diffusion of NGVs does not result in a win-win option by 2030.

For all the three scenarios, the relationship between GHG emissions and consumption/reserves and GHG emissions and the consumption/reserves-to-production ratio do not s how any trade-offs but only win-win profiles (Figs. 9 (b), (d)).

4 CONCLUSION

The main results of our research can be summarized as follows:

(1) We developed an integrated model that combines a vehicle cohort model and an environmental impact model. We showed that this model enables future projections of GHG emissions based on the three diffusion scenarios of NGVs.
(2) The modeling results showed that diffusion of NGVs reduces GHG emissions. However, environmental impact of material consumption may increase by 2020. Further discussions are required about the risk of metal unavailability.

ACKNOWLEDGEMENT

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Eco-innovation by Cross-Field Green Scenario Value-Adding Program

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Abstract
This paper describes a research and development activity of eco-innovation by promoting cross-field green scenario value-adding program in Taiwan. The idea and structure of this eco-innovative R&D model is explained in detail by the processes of executing cross-field green scenario value-adding program during 2009-2011. The cross-field teams were mediated and formed after the green scenarios were selected. Then, the technical feasibility and market potential were evaluated. Finally, the prototypes of the green products were successfully developed. Some eco-innovation examples are demonstrated in this paper to illustrate the capabilities of proposed eco-innovative R&D model.

Keywords:
Eco-innovation, open innovation, cross-field, green scenario, value-adding, R&D model

1 INTRODUCTION

The development of technology plays a crucial role in modern economic growth but it also is the key factor of environmental crisis. It is usually emphasizing the novelty and economic usefulness of an innovation product but neglects its environmental impacts. Currently, many eco-design methods have been developed to support the designer for reducing the environmental impact of the product throughout its life cycle. However, those methods are focused on the redesign or optimization of existing products. Therefore, there is a need to develop a product eco-innovative design method for this situation.

The difficulties during the design and development of an innovative eco-product often encountered due to the requirement of cross-field knowledge. Eco-innovative capacity in the exploration or exploitation of a product, process, service or business model has been a key driver of efforts from both academics and practices to tackle with environmental challenges nowadays. As attention has been broadened to include innovation in and oriented towards from resource and energy efficiency, greenhouse gas reduction, reuse and recycling, new materials, to eco-design, eco-innovation calls for emerging breakthrough technologies, systematic and potential application of available solutions, and structural change in business process and economics imperatively.

In order to spur eco-innovation, a cross-field value-adding program has been initiated in Taiwan. Due to the nature of such a "from mind to market" innovation process, it needs to integrate cross-field knowledge through bridging different communities into an open innovation effort. Yet, it encounters the difficulties during this cross-field collaboration process and within such an eco-innovative system when participants with diverse eco-knowledge as well as different research efforts are directed toward exploring an eco-innovation model.

The concept of "Open innovation" is first proposed by the University of California, Berkeley Haas School of Business professor Henry Chesbrough in 2003 by his first "Open Innovation" book [1]. In this book, he claims companies should break the traditional boundaries of the closed R & D organization, to the outside world to obtain a wide range of innovative materials and energy. More advance research on open innovation can be found in Reference 2. Study about the operation of open innovation platform include the innovation process of low-medium technology industries rely on non-formal R & D activities and the extent of external technology sources [3], open innovation communities in over the role of process [4-5], scenarios and group decision support system in the open innovation process be used [6].

This paper describes a research and development activity of eco-innovation by promoting cross-field green scenario value-adding program in Taiwan. The idea and structure of this eco-innovative R&D model is explained in detail by the processes of executing cross-field green scenario value-adding program during 2009-2011. Some eco-innovation examples are demonstrated in this paper to illustrate the capabilities of proposed eco-innovative R&D model.

2 CONCEPT OF CROSS-FIELD GREEN SCENARIO VALUE-ADDING PROGRAM

The research results of engineering division of National Science Council in Taiwan have accumulated abundant

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engineering solutions. However, only a few engineering solutions were transferred into commercialized products. Based on the concept of open innovation and the concept of open innovation communities, this promotion program establishes an open innovation platform. At beginning, this platform is based on the Beehive prototype value-added competition platform of ITRI, for mediating the cross-field communities of ecodesign, green technologies and business. Through the "Eco-Innovation and Implementation" competition, a new R&D model by cross-field value-adding will be developed to enlarge the value of NSC project results. The experiences obtained in this promotion program will provide a promotion mechanism and the recommendation of standard operation procedures of cross-field value-adding projects for National Science Council.

The concept of cross-field green scenario value-adding program can be illustrated as Fig. 1. The eco-innovation ideas (green scenarios) from academic were collected by call for scenario competition. Through the selecting potential green scenarios, technology feasibility study & evaluation, prototyping stages and the input from cross-field experts (industry, research institute or academic), some eco-innovative products can be commercialized.

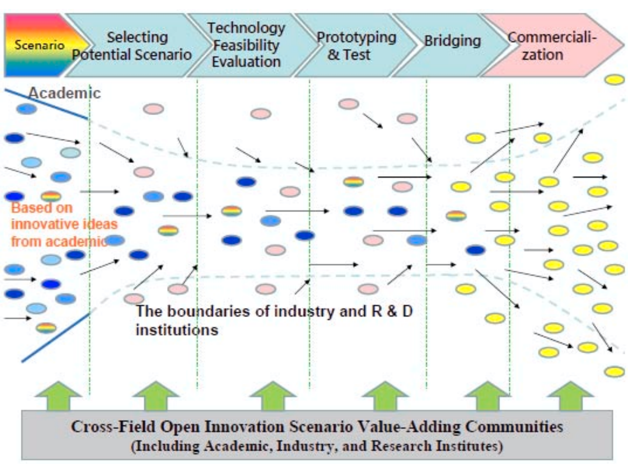

Fig. 1: Concept of cross-field green scenario value-adding program

3 STRUCTURE OF ECO-INNOVATIVE R&D MODEL

3.1 Framework of cross-field green scenario value-adding program

The framework of cross-field green scenario value-adding program is shown in Fig. 2. Open innovation platform is used to build a cross-field open innovation platform, mediating scenario from academic with the required engineering solutions from industry, research institute, and academic. The scenario and technology value-adding process is performed by "call for scenario", "scenario evaluation", "call for feasibility proposal", "feasibility project evaluation", and "prototyping: stages. The cross-field teams were mediated and formed after the green scenarios were selected. Then, the technical feasibility and market potential were evaluated. Finally, the prototypes of the green products were successfully developed.

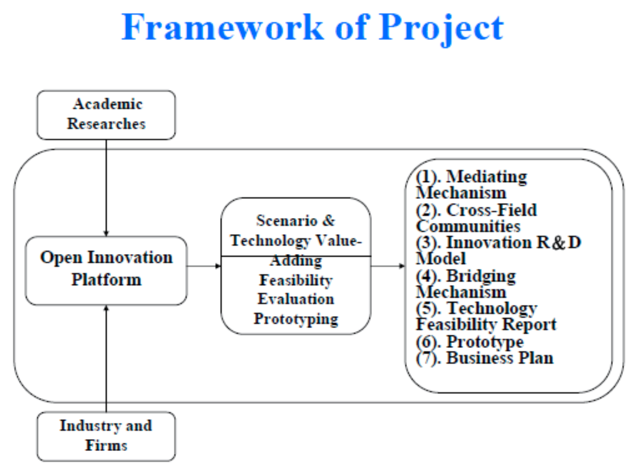

Fig. 2: Framework of cross-field green scenario value-adding program

In addition to technology feasibility report, prototype, and business plan, this innovative R&D model also supported by mediating mechanism, cross-field communities, and bridging mechanism. The role of mediating mechanism is for mediating cross-field communities, combined with market pull and technology push to promote academic research and industry open to innovation cooperation. The role of bridging mechanism is to promote industry-university bridging for the possibility of promoting open innovation and technology transfer opportunities. It also builds open innovation networking to promote open-bridge results and venture capital opportunities.

3.2 Platform of executing cross-field green scenario value-adding program

The platform shown in Fig. 3 for cross-field green scenario value-adding is open innovation type. The purpose of the platform is to promote university-industry-institute cooperation and enlarge the value of academic research results. Since the platform has fruitful resources of expert and talent bank, it could mediate demanding technology teams with key technologies experts, and provide opportunities to realize scenario proposals jointly. Another function of the platform is cooperation, it provide an interactive space for team members. Moreover, the platform has another essential function--results promotion, which could exhibit R&D results in the form of multimedia continuously, and provide opportunities for the sectors such as industries, academies and research institutes to access such information. It is believed that the platform could increase the possibility of R&D results and applications, as the display of R&D results has no limit of time and space.

Fig. 3: The Beehive prototype value-adding competition platform of ITRI

Table 1: Important dates of first run program

Working items	Dates	Number of teams
Preparing open innovation platform	2009/8	
Call for scenario	2009/9	101 scenarios
Selecting scenario	2009/10	20 scenarios
Call for feasibility proposal	2009/10-2010/01/10	25 proposals
Mediating cross-field team	2009/10-2009/12	
Selecting feasibility project	2010/02/05	14 projects
Executing feasibility project	2010/03/20-2010/09/20	13 projects
Feasibility project evaluation	2010/09/24	13 projects
Selecting prototyping proposal	2010/09/24	9 projects
Executing prototyping project	2010/10/01-2011/02/28	9 projects
Prototyping project evaluation	2011/02/17	9 projects
Attending 2011 30th new generation design exhibition	2011/05/23-2011/05/26	9 projects
Project outcomes bridge forum	2011/03/22 2011/05/20	9 projects
Attending 2011 Taipei International Invention Show	2011/09/29-2011/10/02	9 projects

4 RESULTS

4.1 Progress of first run program

The first run of cross-field green scenario value-adding program begins on August 2009 by preparing open innovation platform at the Beehive prototype value-adding competition platform of ITRI. Detail working items and the dates are list in Table 1.

This program receives 101 scenarios during the call for scenario stage. Twenty scenarios were selected for call for feasibility proposal. After mediating scenario with the expert who has required engineering solutions on open innovation platform, Twenty-five proposals were received for call for feasibility stage. Fourteen projects were selected for six months feasibility study. However, only thirteen projects finished the feasibility study. Finally, nine of them were selected for prototyping study. After five months prototyping study, this program produces nine eco-innovation prototypes.

4.2 Results of nine prototyping projects

The team name and project name of the final 9 teams enter prototyping stage is shown in Table 2.

Table 2: Nine prototyping projects

Team Name	Project Name
Floating Bay	Floating Bay- Solar snorkeling vehicles
BAGEL	Automatic classification and recycling equipment with stored value unit
NKFUST GIID	Low-carbon emissions bionic communications products
Green Nanocomposite	Recycling ABS of waste appliances to form plastic natural fiber composite materials
CALIFE	Energy saving touch lighting switch
Fresh Splash	Self-contained solar desalination shower system
Flying electric riding	Human-power luminous children park
Energy saving UFO	Intelligent power saving device
G-water	Green water system

The outcome of prototype eco-products during prototyping stage of nine projects is shown in Fig. 4. The commercialization and industry service center of ITRI are invited to help promoting nine prototypes to industry companies for developing commercialized eco-products.

Fig.4: Final nine prototypes

4.3 Promotion and bridge of project results

This project uses physical promotion and virtual extension approaches to help the interdisciplinary team bridge results. One type of physical promotion is organizing a workshop to present the final prototype. Another type of physical promotion is attending 2011 30th new generation design exhibition and 2011 Taipei International Invention Show to demonstrate the final prototype eco-products.

As for virtual extension, the project results are shown by online multimedia playback and 3D virtual exhibition. The web page of 3D virtual exhibition is shown as Fig. 5. This 3D virtual exhibition can allows members browsing online anytime. The long-term display can provide opportunities to improve the bridge. Currently, three prototypes are already promoting to industry companies for developing commercialized eco-products.

Fig. 5: 3D virtual exhibition

5 CONCLUSIONS

This paper presented a research and development activity of eco-innovation by promoting cross-field green scenario value-adding program in Taiwan. The first run of this open innovation type of eco-innovative R&D model is explained in detail. Nine eco-innovation prototypes from this program demonstrated the capabilities of proposed eco-innovative R&D model. Three prototypes are already promoting to industry companies for developing commercialized eco-products. Currently, the second run of this program is on the way and will be reported in the future publication.

6 ACKNOWLEDGEMENTS

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Integration of detailed/screening LCA software-based tools into design processes

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Abstract
Existing studies and methodologies for eco-design of products have not sufficiently taken into account the integration of different types of lifecycle assessment (LCA) software-based tools in design processes in detail, and their application has not systematically matched these with design process stages. On the other hand the ever increasing pace of new IT tools for Life Cycle Assessment of products requires that old eco-design methodologies are revised and updated according to the new pool of new software-based tools for environmental impact assessment. In order to study the suitability and timely integration of the different type of LCA software-based tools (detailed/streamlined-screening) within the design process, as well as showing their advantages/disadvantages; this paper presents a case study of the design/development of an eco-lighting product where two types of LCA software-based tools: Simapro (detailed LCA software-based tool) and Sustainable Minds (screening LCA software-based tool) are used to support the design and development of the product. The results of the study provide useful insights and guidelines about which type of LCA software-based tools to use, and when they are used during the design process.

Keywords:
Eco-design, Life Cycle Assessment tools, Environmental impact assessment, Lighting products, Detailed LCA software-based tools, Screening LCA software-based tools

1 INTRODUCTION

Life Cycle Assessment (LCA) software-based tools have been integrated in the past in design processes [1, 2, 3, 4, 5, 6, 7, 8, 9 and 10], but the timing (along the time-line of the design process) of its integration in the design processes has not been studied in detail. For example, although the use of these tools during the design process was suggested in the past, it was not studied in which exact moment they had to be used during the design process, and/or which type of LCA software-based tool had to be used at each stage of the design process. In addition, the existing studies about integration of these type of tools (and other tools for assessment) suggested by eco-designers/engineers are beginning to be out of date, due to the rapid growth of LCA software-based tools that are available in the market to support eco-decision making. These new tools are more reliable and objective than matrix-based tools (i.e., MET matrix, etc.) and other more subjective environmental impact assessment methods used at the beginning of the eco-design design methods/assessments. These are also more flexible, and today there is a wide range of LCA software-based tools available for different purposes. For example, some of these allow to carry out quick (screening), streamlined, or detailed assessments; and some of these also allow the possibility to model and assess new processes and materials assessment if these do not exist yet in the databases of the software. In addition, some of these tools have been developed to assess specific categories of products (i.e., packaging), which makes them very efficient and suitable for designers/engineers working in a specific field. It is therefore sensible to begin to explore and study the integration of this on-going developing group (LCA software-based tools) of tools in design processes in order to update, and improve the efficiency of the next methodologies which will be used by the future eco/sustainable designers/engineers to assess their products/services and processes. The aim of this paper is therefore to explore and study these tools and how they can be integrated in design processes/methods, so guidelines and insights can be obtained to be applied by future eco-designers/engineers in their eco-design processes.

2 DESIGN PROCESSES

The creation and definition of a product usually follows a generic step by step process from its original conceptual definition until its full functional development, and preparation for manufacturing. There are many established design processes models/methods, for example [6, 7, 8],

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which have been defined by experts in the field of design methodologies. For the present study of LCA software-based tools it has been used a design process created from the combination of several of these known design methods [11, 12, 13, 14, 15, 16, and 17]. The aim of this combination was to adopt the best conceptual framework/parts of each method, and combine them into one more optimal/realistic method, according to the development process followed by the lighting products assessed. Fig. 1 below shows a simplified version (due to space constraints) of the design process which is used as a reference for this study.

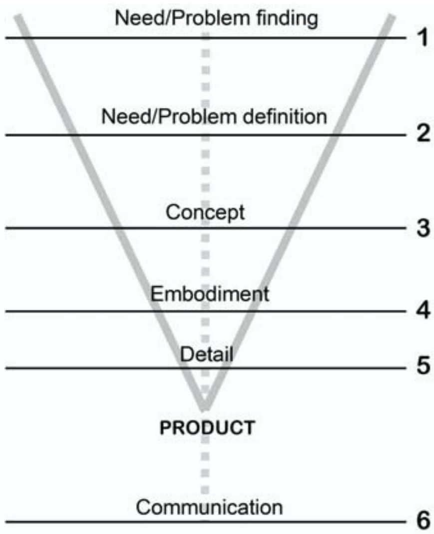

Fig. 1: Design process

In the design process described above (Fig.1), it can be seen how the process is divided into several stages (i.e., 1, 2, 3, etc.). Each of these stages is carried out along a time-line during the design process of the product, and usually follows the order described above (Fig.1). The diagram (Fig.1) shows the design process in a linear simplified manner; however in real life is a more complex non-linear process (with feedback loops between stages). Nevertheless, due to space constraints, this diagram is detailed enough, for the purpose of the study, to explain which specific LCA software-based tool can be used, and at which stage. The design process is basically divided in 6 stages; these stages correspond to: 1) *Need/problem finding:* In this stage background research is carried out to find out the need/problem to be solved. 2) *Need/problem definition:* In this stage the briefing, the state-of-the-art, and the Product Design Specifications (PDS) are carried-out/defined. 3) *Concept:* In this stage concepts are developed and defined according to the PDS defined before. 4) *Embodiment (preliminary/definitive layout):* In this stage, final definition of materials, industrial processes, components, finishes and tolerances are selected. During this stage it is also usually modelled the geometry and behaviour of the product, its assembly/disassembly operations, and optimization of parts/components is carried out. 5) *Detail:* In this stage, technical drawings of the product (for production) are developed. 6) *Communication:* In this stage, the product is finished and ready to be manufactured, and it has to be communicated for commercialization; this includes informing about its environmental impact (through LCA reports, eco-labels and Environmental Product Declaration (EPD).

3 LCA SOFTWARE-BASED TOOLS

The majority of tools that can assist product designers in eco-decision making are based on life cycle approaches that take into account the whole life-cycle of the product from extraction of materials to the End of Life (EoL) stage. This is necessary in order to take into account the full environmental impact of all materials/processes/activities involved during the life cycle of the product. Only then, the impacts can be identified and reduction/elimination of these can be implemented. Numerous tools have been developed [18, 19 and 20] in order to assist to reduce/eliminate environmental impacts caused by products; however this study will focus only on analytical LCA software-based tools.

Analytical tools focus on assessment/analysis [18] of resources and processes involved in the whole life-cycle of products. They are used to assess the environmental impact of inputs (material/energy) and outputs (waste/emissions) required/produced at each stage of the whole product life cycle. All analytical tools take a life cycle approach but they may use different techniques (matrix, Polar diagrams, and software) to carry out the assessment.

Analytical Software-based tools use software applications to support analysis and assessment of the environmental impact of products, and can be classified mainly in two types: *screening/streamlined* and *detailed* depending on the quantity/quality of data required for the assessment, the type (objective/subjective) of analysis, and the type of assessment results (quantitative/qualitative).

3.1 Screening/streamlined LCA software-based tools

These tools can carry out screening/streamlined environmental impact assessments supported by software applications, which usually have integrated databases, and use environmental impact assessment methods to support the analysis and results of the assessment. The results of the assessment of these tools are usually less quantifiable and objective, and less thorough than detailed LCA software-based tools. The main purpose of these tools is to easily screen the product in order to find design features or life cycle product stages that could have major environmental impacts [21]. These are usually used when there are resource constraints (time, financial budget, expertise, etc.), thus providing a more practical option to identify and assess design actions than using detailed LCA software-based tools. These tools allow the simplification (or streamlining) of the assessment by allowing the possibility to reduce the scope of the assessment, or by reducing data needs through the substitution of surrogates (generic databases for estimated impact of processes/materials, etc.) for data that may not be readily available to the designer at the design stage [22].

3.2 Detailed LCA software-based tools

These tools can carry out detailed environmental impact assessments supported by software applications, which usually have integrated databases, and use environmental impact assessment methods to support the analysis and results of the assessment. Although sometimes these tools can also carry out streamlined/screening assessments, their interfaces are less user-friendly (for non-LCA experts), and therefore more difficult to use. The results of the assessment of these tools are quantifiable and objective, and more thorough than screening/streamlined LCA software-based tools. The main purpose of these tools is to assess in detail the product in order to carry out a comprehensive and full life cycle assessment of the product. These are usually used when there are no resource constraints (time, financial budget, expertise, etc.), thus making difficult its use to projects with few resources. These tools usually allow using a larger number of databases and environmental impact assessment methods for the assessment. In addition, they also allow creating new databases (after assessments of new processes) of new materials or processes which could not be found in existing databases. These also allow carrying out more precise assessment through features like sensitivity analysis or different end of life scenarios (even for different parts or processes), which can be modeled in great detail. They also provide more transparency of the assessment (i.e., results are shown at a chemical compound level), which is usually demanded by LCA experts, in order to 'track' which compounds cause more impact.

4 INTEGRATION OF LCA SOFTWARE-BASED TOOLS IN DESIGN PROCESSES

4.1 Case study

In order to study LCA software-based tools and their integration in design processes, a case study [23, 24] was used. This consisted on designing an eco-lighting product with less impact than other lighting product produced by the same lighting manufacturer. In order to do this, it was necessary to find out the environmental impact of the product already manufactured (reference product) and use it as a benchmark. On the other hand, the new eco-lighting product had to be developed from scratch, and its environmental impact had to be assessed at different stages of the design/development process. In order to support designers' eco-decision making, two different types of LCA software-based tools were used: Simapro (for detailed assessment), and Sustainable Minds (for screening/streamlined assessment). In the following points is explained which type of LCA software-based tool, when they were used during the design process, and their advantages/disadvantages.

4.2 When/which LCA software-based tools are used along design processes

In the diagram below (Fig.2) it is shown where two different LCA software-based tools (D: Detailed and S: Screening/streamlined) were used during the design process.

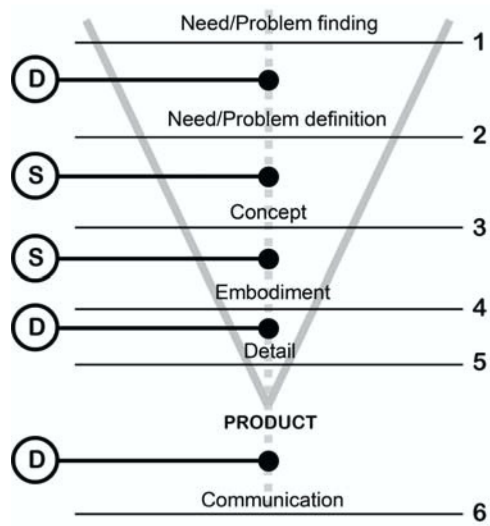

Fig. 2: Integration of LCA software-based tools in the design process

It can be seen (Fig.2) how Detailed LCA software-based tools *(D)*, were used at *stage 2* (need/problem definition) to assess the environmental impact of the reference product. This type of tool was selected because the quantity/quality of data required is available when the product has been manufactured, sold and used already. This is because data about all stages (manufacturing, transport, use, EoL) of the product is known, so the quantity/quality o data is quite reliable and accurate (not based on estimates) which is usually required in detailed LCA software-based tools. The information obtained from this assessment is used to inform the Product Design Specifications (PDS) of the new eco-product. At *stage 3* (Concept), Screening/streamlined LCA software-based tools *(S)* are used. At this stage the product is not defined yet, and rapid assessments (what if) had to be done continuously every time some design features change during the design process definition. The assessments at this stage are based on estimates, and although not accurate, they provide broad guidelines about the impact of features (i.e.: materials, industrial processes, energy used) and 'hot spots' of the concepts being developed. At *stage 4* (embodiment), the product is more defined and there is more data (and more accurate) to support the analysis, however there are still areas of the product which need further refinement, so flexibility in the assessment is required, which is usually provided by screening/streamlined tools. *At stage 5* (detail), the product is more defined and there is enough data to carry out the first comprehensive detailed assessment with detailed tools. Due to the lack of data of the use, transport and end of life phases, the analysis can be done only from 'cradle to gate', that is, from extraction of materials until the product leave the manufacturing facilities. Alternatively, this can be complemented with transport, use and end of life estimated data, as there is no factual data about these stages yet. *At stage 6* (communication), the product is already defined and a first run has been sold, thus factual data about all stages is available, the results of this assessment can be used to compare the final total environmental impact of the product developed with the reference product, in order to know if environmental impact has been reduced and in which stage/s. It can also be used for internal use of the company, or to inform eco-labels, suppliers and Environmental Product Declarations (EPD) requirements.

4.3 Advantages/disadvantages of LCA software-based tools

The advantages/disadvantages of the LCA software-based tools used during the case study following the design process selected (Fig.2) are described in the table below

Table 1: Advantages/disadvantages of LCA software-based tools

	Detailed tools	Screening tools
Input	More data and better quality (factual) is needed	Less data and less quality (estimated) is needed
Output	Quantitative/reliable/ Accurate/objective /detailed/sometimes need to be interpreted	Qualitative/estimated/ not very accurate/subjective/ less detailed/ don't need to be interpreted
User	More experience and time is needed/more suitable for LCA experts/Interface less user-friendly	Less experience and time is needed/more suitable for product designers/Interface more user-friendly
Assessment	More impact assessment methodologies available/more databases available/ it is dificult to create 'what if' scenarios/possible to use different types of indicators for results	Less impact assessment methodologies available/less databases available/it is possible to create 'what if' scenarios/ limited type of indicators for results

(Table 1). The criterion used to assess them was based on 4 key issues: 1) *Input* needed for the assessment, 2) *output* needed for the assessment, 3) *user*, and 4) *assessment*.

1) *Input data required for the assessment*:

Detailed LCA software-based tools require, and are better prepared, to make the most of higher amounts of data, and in more detail than Screening/streamlined LCA software-based tools, because these tools are better prepared to analyze higher amounts and at a higher level of detail (at a chemical compound level) than screening tools. Screening tools are also more prepared to use estimated data in assessments, and usually provide databases with materials, industrial processes, and sometimes parts/components which make easier the 'estimated' assessment of products. 2) *Output data required for the assessment*: The output of detailed LCA software-based tools is more quantitative, and usually more accurate, detailed and objective than screening tools, this is so because the input data is higher and more factual, which results in more reliable results, that is why is also more time-consuming. Its output usually needs to be interpreted by LCA experts in order to be useful to product designers, whilst screening tools' outputs don't need to be interpreted. 3) *User:* The interface of Detail LCA software-based tools is usually more complex, which is a direct result of the fine detail of data that can be input for assessment, as well as the higher number of features that can be used to support the assessment. In addition these tools allow for greater level of transparency of how the assessment was done by the software, and can be customized, which is a feature appreciated by LCA experts. Product designers however can find it time-consuming, not flexible, and too demanding in terms of data required. In addition, many of the advanced features, which are useful for experts, are usually not used by product designers because this level of detail is not required for their needs, and it is too complex (time consuming) to understand.

4) *Assessment:* The assessment itself depends on the functional features provided by the software to carry out the assessment. Detailed LCA software-based tools allow use/choose a higher number of impact assessment methodologies and databases to support the assessment. It also allows displaying the results with a higher number of indicators. One of the main differences and advantages of LCA screening software-based tools is that they are more prepared to create 'what if' scenarios, which are very common (and useful) in design processes. For instance, designers can constantly check what impact would have the product if a material/industrial process was changed; these tools usually allow changing quickly the assessment to see the results and compare them with other options to support decision-making.

5 CONCLUDING REMARKS

One of the reasons why streamlined/screening tools are used at some stages is because information about the product at that stage is not complete, and therefore the type of tool that demands or is prepared to use high level of detail (detailed tools) cannot be satisfied or it will not be suitable. Another reason is that Streamlined/screening tools are less time-consuming to use, and usually require also less expertise. However detailed tools have more life cycle impact assessment methods available and usually a higher quantity/quality pool of databases. Detailed LCA software-based tools can also be used at initial design phases (i.e., Concept). where Streamlined/screening tools are used; this can be done simply omitting the quantity of data required by this type of software, and carrying out the assessment, however Screening/streamlined tools not only require less quantity/quality of data from the product to be assessed, but also allows to choose and assess complete parts, components, and other processes, in an easier manner (user-friendly interface). For instance, Detailed LCA software-based tools do not allow including packaging boxes, and the amount of packaging is calculated only by weight, whereas some screening tools allow doing this by volume. In addition, they also allow modelling the lifecycle of the product, and creating end-of-life scenarios easier than detailed tools. As the user don't need to work with factual data (i.e., the user don't have to model and assess each process or material of the product life-cycle, he/she can use databases of generic average materials/processes impacts) is less time-consuming but also more unreliable and inaccurate. LCA screening/streamlined software-based tools also allows the user to create 'what if' scenarios, and compare product assessments' results in an easier manner than detailed tools. Another disadvantage of detailed tools is that they present higher number of advanced features, to provide better transparency and accuracy of the assessment, which is not very useful for designers/engineers (product designers) at design stage, where product designers are more concerned with time and 'hot spots' (parts/life cycle phases of high impact) of the product, but not with subtle differences.

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Dynamic environmental assessment: scenarios, foresight and challenges

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Abstract

With the environmental challenges in recent years, the assessment of impacts of human activity becomes a major issue for our societies. Nowadays it is well established that our activities can cause negative effects on the balance of the ecosystem. In order to asses our impact**s**, several tools and methodologies, such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Carbon Footprint, etc. have been developed. Each of these approaches have some limitations with respect to their ability to meet the increasingly operational needs of stakeholders, experts and policy makers. For example, the lack of temporal dimension in LCA is one of the major limitation. Recent research suggested a dynamic approach taking into account the temporal. This paper aims to present a road-map for an integrated framework for an efficient assessment of dynamic LCA in the production sector of wheat.

Keywords:

Environmental assessment, dynamic LCA, Material Flow Analysis

1 INTRODUCTION

With human development, the consumption of raw materials and natural resources has greatly increased in the last decades. The environmental impacts of such a high consumption are evident today (e.g. climate change, threats against biodiversity, ...). To deal with these issues, several tools and methodological approaches based on the environmental impact assessment has been developed since twenty years. Among these ones one can mention: Life Cycle Assessment (LCA) [1, 2], Material Flow Analysis (MFA) [3], Substance Flow Analysis (SFA) [4], Input-Output Analysis (IOA) [5], Carbon Footprint [6]. The most advanced among these tools is the Life Cycle Assessment (LCA) which is worldwide used in several sectors of activities. However, this methodology presents several limits. For example this approach, as developed, does not take into account: (i) the social dimension surrounding the production, (ii) some environmental flows and (iii) the uncertainty of data from the processes. Zamagni [7] and Finnveden [8] present some advantages and disadvantages of each methodology, their different insights and output result. One of the most important limit is the lack of temporal resolution. For a longtime, one uses classical approach which consists in a static LCA. But with the current level of consumption rate, it is obvious that one needs to improve the computation methodology. Since some few years, several improvements have been proposed such as the development of hybrid Input-Output LCA or uncertainty analysis [8]. However, these novel approaches do not include dynamic LCA. Others studies have developed the dynamic LCA, yet with a restricted focus on the greenhouse impact [9; 10]. In this paper we argue that a more complete approach passes through: (i) the determination of the scenarios that help to select relevant value sets of parameters, (ii) the dynamic assessment of inventory to be transferred in environmental impacts, or the development of temporal integrated indicator and finally (iii) the implementation and validation of the new approach on case studies. Then we present the main challenges associated with each of these steps. Among these challenges one will focused on: how to model an industrial system in an appropriate way to assess the environmental dynamic impacts? How integrate the temporal dynamics of such a system with the environmental assessment? And what are the conditions (scale, temporal constraints, etc.) for the application of the dynamic LCA to the real case studies? The paper ends by setting up a road-map for an integrated framework for an efficient assessment of dynamic LCA in the production sector of wheat.

2 LIFE CYCLE ASSESSMENT METHODOLOGY

2.1 Classical Life Cycle Assessment

The most advanced method for evaluating the impacts of an industrial system (or a product?) to the environment is probably LCA. This methodology provides environmental indicators, such as acidification, ozone layer depletion, global warming potential, eutrophication, etc.

Typically, the formula used to assess each indicator in LCA is:

$$E = \sum_i M_i(t).P_i(t) \tag{1}$$

With:

- E: the considered environmental impact;
- M_i: the masses of substances contributing to impact E;
- P_i: contribution factors of substances for impact E .

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In the case of global warming potential, Pi is calculated with the well-known Radiative Forcing value (RF) [11], which has CO_2 equivalent as reference, and can be interpreted as the heating power of the atmosphere [12]. One can use the following formula to obtain Pi:

$$Pi = \frac{\int_0^{TH} RF_i}{\int_0^{TH} RF_{CO2}} \qquad (2)$$

With:

• TH: Time Horizon;

• RF_i: Radiative Forcing of substance E in W/m²;

• RF_{CO2}: Radiative Forcing of CO2 in W/m².

2.2 Limits of the classical Life Cycle Assessment

Finnveden [8] and CALCAS [13] have discussed the limits of classical LCA, which indeed do not include:

- The origin of raw materials, the social conditions of production and other qualitative aspects;
- The details of environmental flows and other site aspects;
- The uncertainty of data from the processes (absence of real Input / Output evaluation).

However, the most important limit of classical LCA is probably the absence of temporal resolution. Actual life cycle assessments do not consider the time distribution of life cycle processes. Inventory data contain only aggregated mass loadings, representing the sum of several amounts of each emission for each compartment (air, water, soil) by different processes dispersed in space and time.

3 DYNAMIC LIFE CYCLE ASSESSMENT AND IDENTIFICATION OF THE CHALLENGES

Müller [14] has assessed dynamically quantities of substances, yet not specifically for LCA indicators. To our knowledge, this research had no practical results. Several improvements have been proposed for few years, such as the development of hybrid IO-LCA or uncertainty analysis [8]. However, dynamic LCA is not included in such developments. Others studies have developed dynamic LCA, yet with a restricted focus on the greenhouse impact [9; 10]. Recently, Kirkinen [12] has tried to improve the quality of Radiative Forcing (RF), and few studies were presented in the conference "Life Cycle Assessment IX" [15] in Boston.

The most advanced research in the field is the study of Levasseur [10]. The objective of her project is to develop a dynamic LCA methodology where inventory results would be function of time instead of aggregated values and where impact assessment would take into account the dynamic profile of the inventory. In parallel, consequential LCA has been developed for few years. It considers future effects and emissions and calls for prospective scenarios [16]. But as a matter of fact, "functional" methodologies for dynamic LCA are not fully developed yet.

We propose to integrate dynamic aspect in LCA as follows:

• Determine scenarios so as to define value sets of parameters;

• Elaborate dynamic inventory to be translated in environmental impacts,

• or develop temporal integrated indicator.

So we propose to move from the static (classical) LCA described in (1) to a dynamic (cumulative) LCA of the following form:

$$E = \sum_{i,j} \int_{T_j}^{T_{j+1}} M_i^{(j)}(t).P_i^{(j)}(t)dt \qquad (3)$$

With:

• T_j: the inferior time considered;

• $M_i^{(j)}$: the masses of substances considered from T_j to T_{j+1};

• $P_i^{(j)}$: the contributions of the considered impact from T_j to T_{j+1}.

This formulation in terms of "time intervals" makes it easier to split the time horizon of the assessment. Note that the choice of "time interval" can be adapted, depending on the context.

Our key research questions are:

• How to model an industrial system in an appropriate way for our goal?

• How, in specific cases, interfacing the temporal dynamics of such a system (inputs, processes, outputs) with the environmental assessment?

• What are the difficulties in applying dynamic LCA to real case studies?

4 CASE STUDY

4.1 Presentation

For this case study, a simple study is proposed with the environmental impact of wheat production. Wheat is one of the most famous cereals that were used for a long time. The production of wheat is increased since 1960 with the using of such a fertilizer as nitrogen.

Then, to obtain 1 ton of wheat, we can associate the using of the fertilizer. In this case study we propose to estimate use of the nitrogen fertilizer and its influence to the global warming potential, especially on dinitrogen monoxide that contains in the nitrogen fertilizer.

We can find the production of wheat from 1815 [17] and the quantity of fertilizer used for this production from 1900 [18] around.

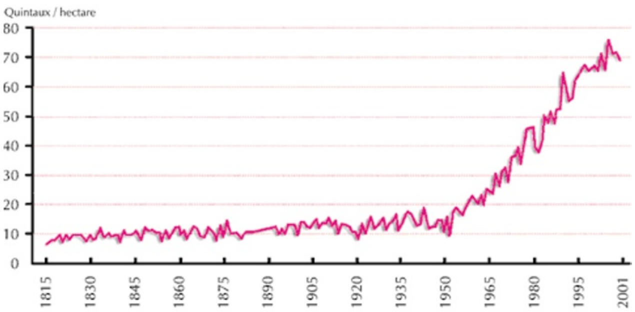

Fig. 1: Wheat production since 1815

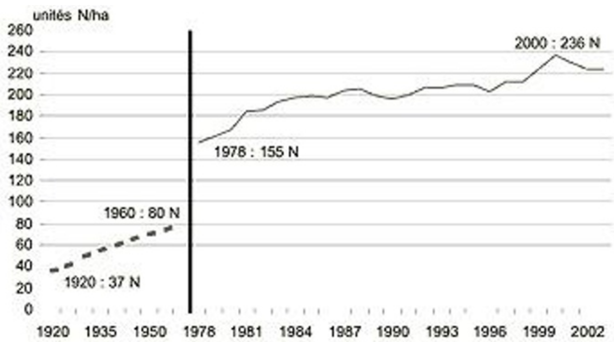

Fig. 2: Using of the nitrogen fertilizer since 1920

For this study the data comes from Ecoinvent [19] and IPCC 2007 [11] and it is used to assess the global warming potential.

4.2 Results

Beginning with classical LCA that makes static evaluation, the global warming potential is assessed. As referenced in ISO 14044, the most frequently used timeframe for this indicator is 100 years for a hierarchic approach.

So far, using the data described before in each year LCA, we can obtain the next results:

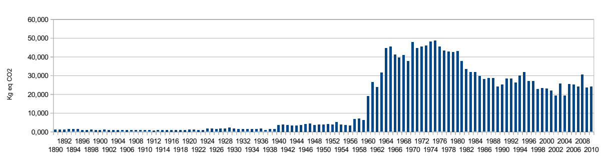

Fig. 3: Influence of dinitrogen monoxide for global warming potential 100 years

We can observe than the using nitrogen as fertilizer in sixties in Europe has considerably increased the global warming potential.

But, one of the limits of this methodology is that we don't consider cumulative and temporal aspects of the substances lifetime. Then, we propose to use the same data, but considering these aspects. The obtained results show greater impact of global warming potential, than in the previous study.

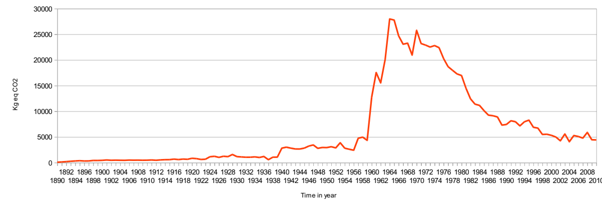

Fig. 4: Influence of dinitrogen monoxide for global warming potential considering temporal aspect

Thus we could see that in classical LCA the indicators could be underestimated by not taking into consideration cumulative and temporal aspects. As, for example, the lifetime of dinitrogen monoxide is around 115 years, but LCA considers the impact in 100 years, so then we lose the integrated aspect.

5 CONCLUSION

With this example, we can clearly see the limits of a classical LCA. The impact of one ton of wheat varied from 1 kg to 50 kg of CO_2 equivalent but with dynamic LCA the results vary from 1 kg to 28000 kg of CO_2 equivalent. This difference must be attributed to the cumulative aspect.

This paper is a first attempt that sketches a more complete approach that takes into acount the cumulative aspect in time of a single substance as contributor to the global warming. These results (in dynamics) reflect more the reality of the global warming potential of the wheat production. In this example only the dinitrogen monoxide was considered, but the next step of this methodology will be to integrate the others substances of Kyoto protocol (as CH_4, CFC, CO_2…).

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Design and Development of Multi-scale Product Design and Lifecycle Simulation System

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Abstract
It is important for product designer to forecast the influences of designing product easily and quickly. In order to support product designer and material designer, multi-scale product design and lifecycle simulation system is proposed. multi-scale product design and lifecycle simulation system is made for continuous product design and product lifecycle simulation from micro/nano scale level to human scale level.

Keywords:
product design, material design, multi-scale CAD/CAE, product lifecycle simulation

1 INTRODUCTION

The field of product design is expanding. Very small designed structure directly influences property and shape of product. It is important for product designer to forecast the influences of designing product easily and quickly by computer simulations before prototype making.

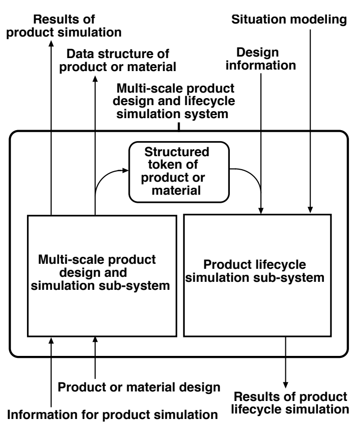

Fig. 1: Concept of MPDLS system

Multi-scale product design and lifecycle simulation (MPDLS) system is made for continuous product design and product lifecycle simulation from micro/nano scale level to human scale level [1]. MPDLS system consists of multi-scale product design and simulation (MPDS) sub-system and product lifecycle simulation (PLS) sub-system. MPDS sub-system is a trial to bridge the gap between micro/nano scale level and human scale level continuously. The concept of PLS sub-system is based on growth and decline of subject in the flow of physical, social, and economic entities. Product lifecycle simulation of PLS sub-system is based on input, output, and stock of physical, social, and economic entities of subject.

2 MPDS SUB-SYSTEM

2.1 Framework of MPDS sub-system

MPDS sub-system is a kind of multi-scale CAD/CAE system. MPDS sub-system consists of multi-scale spatial model and multi-scale simulation modules. Multi-scale spatial model is a model of physical space from micro/nano-scale level to human scale level. The candidates of multi-scale simulation modules are FEM (Finite Element Method) simulation, MD (Molecular Dynamics) simulation, FPMD (First Principle Molecular Dynamics) simulation, and quantum field simulation.

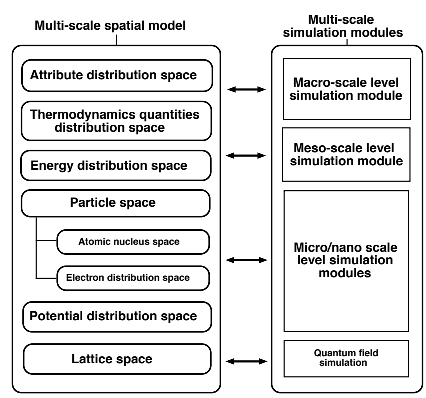

Fig. 2: Framework of MPDS sub-system

2.2 Multi-scale spatial model of MPDS sub-system

Figure 3 shows the concept of multi-scale spatial model of MPDS sub-system. Multi-scale spatial model consists of product level space, spatial element, region, grain, spatial cell, particle, and spatial unit. Product level space and spatial element are macro scale level spaces. Spatial cell is meso scale level space. Spatial unit is micro/nano scale level space. Region is a frame for re-meshing of spatial

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elements. Grain includes some spatial cells. Grain and region are the mechanism for representing the diversity of objects. Particle represents molecule. Spatial unit simulates the quantum field.

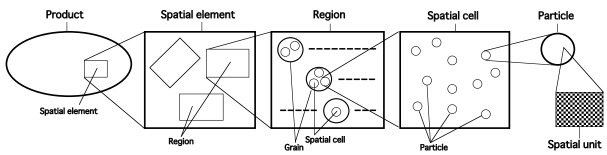

Fig. 3: Concept of multi-scale spatial model

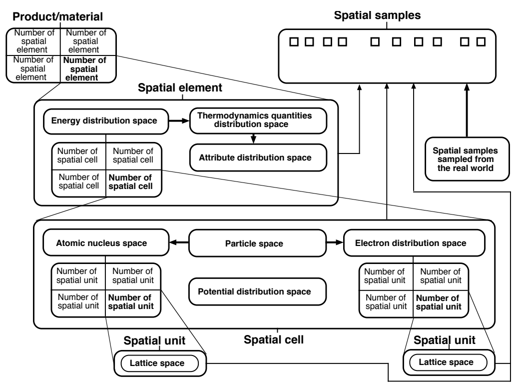

Fig. 4: Multi-scale spatial tree and spatial samples

Figure 4 shows multi-scale spatial tree and spatial samples. Product/material level space maintains product and material data for FEM simulation. Spatial element includes attribute distribution space, thermodynamics quantities distribution space, energy distribution space, and reference of spatial cell. Spatial cell includes particle space, atomic nucleus space, electron distribution space, potential distribution space, and reference of spatial unit. Spatial unit includes the information of lattice space. Atomic nucleus space and electron distribution space are derived from the information of particle space of spatial cell. Atomic nucleus space and electron distribution space include the information for first principle molecular dynamics (FPMD) of multi-scale simulation modules.

Spatial sample is a master and a candidate of space referencing by the spaces of multi-scale spatial model. A spatial sample is assigned repeatedly. A spatial sample is made with character string expressing the information of the space. A spatial sample is made from the result of simulation or the sampled data from the real world [16].

2.3 Distribution space, particle space and lattice space

Attribute distribution space, thermodynamics distribution space, energy distribution space, and potential distribution space are distribution spaces. The distribution space is represented by distribution surfaces. The distribution surface of distribution space is generated by spatial interpolation. Figure 5 shows the concept and example of distribution space.

The particle space includes the information of molecules for molecular dynamics (MD) simulation of multi-scale simulation modules. The lattice space of MPDS sub-system is a model of quantum field for quantum field simulation.

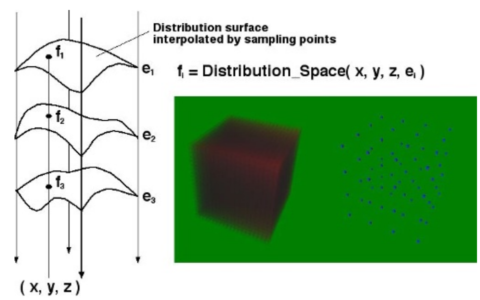

Fig. 5: Concept and example of distribution space

2.4 Upward and downward space constructions

Figure 6 shows the upward and down ward space constructions. Downward space construction uses the result of simulation of simulation module. And, the lower scale level space is updated. The information of updated lower level space is converted and transferred to the higher scale level space.

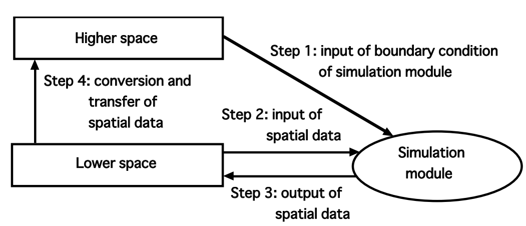

Fig. 6: Upward and downward space constructions

2.5 Implementation method of MPDS sub-system

Figure 7 shows the implementation method of MPDS sub-system in multi-process environment. Multi-scale spatial tree and spatial samples are maintained in the file of MPI2 (message passing interface 2) [22]. The processes of product level, spatial element level, spatial cell level, and spatial unit level manipulate the multi-scale spatial tree and the spatial samples. Lattice space is made by a set of processes.

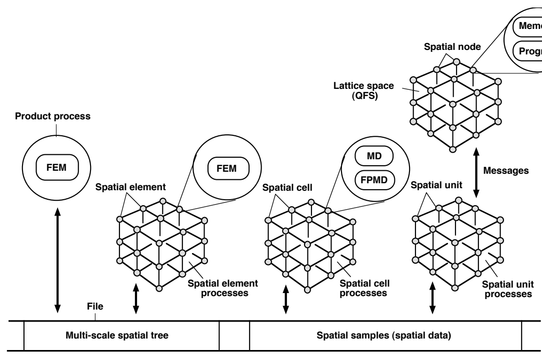

Fig. 7: Implementation method of MPDS sub-system

3 PLS SUB-SYSTEM

3.1 Framework of PLS sub-system

Figure 8 shows the framework of PLS sub-system [1]. The concept of PLS sub-system is based on growth and decline of subject in the flow of physical, social, and economic entities. Subject of PLS sub-system is factory, company, shop, organization, group of people, or individual.

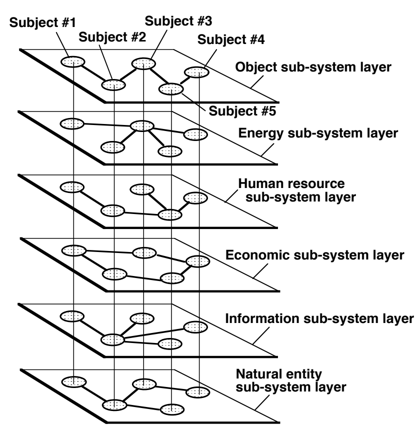

Fig. 8: Framework of PLS sub-system

PLS sub-system consists of (1) object layer, (2) energy layer, (3) human resource layer, (4) economic layer, (5) information layer, (6) natural entity layer. Subject of PLS sub-system contains transformation matrices of entities and storage of entities. Physical, social, and economic entities are represented by structured tokens. Malfunction and recovery of subject are represented with the transformation matrix of subject and the structured tokens. Product lifecycle simulation of PLS sub-system is based on input, output, and stock of physical, social, and economic entities of subject. PLS sub-system is implemented using message passing interface (MPI).

3.2 Representation of flow of entities

Physical, social, and economic entities are represented by structured tokens. Figure 9 shows the meeting and parting phenomena of physical, social, and economic entities represented by structured tokens. Figure 10 shows the components of structured token with entity structure information.

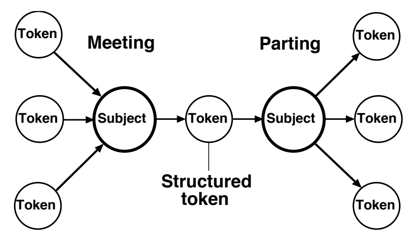

Fig. 9: Meeting and parting of entities

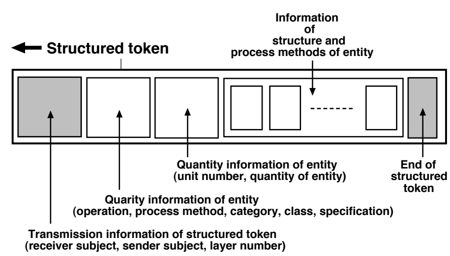

Fig. 10: Components of structured token

3.3 Representation of subject of PLS sub-system

Figure 11 shows the representation of subject and the flow in a subject. A subject consists of filters, matrices and storage of structured tokens. A subject receives the structured tokens from the layers of sub-systems. The structured tokens transformed by the subject are sent to another subject. The subject includes entity filters, malfunction/recovery matrices, subject network matrix, entity transformation and estimation matrix.

3.4 Malfunction and recovery of subject

Nano product and chemicals have not only high performance but also potential hazard to human and environment [17]. PLS sub-system aims to find out and prevent the potential hazard to human and environment of designing product. The malfunction and recovery matrix of subject represents the hazard against subject caused by entity. The malfunction/recovery matrix acts on the entity filter.

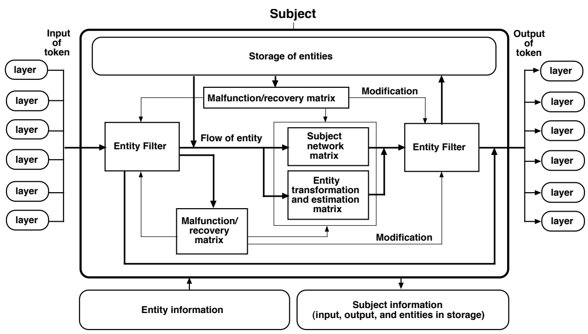

Fig. 11: Representation of subject of PLS sub-system

4 SUMMARY

Necessity of multi-scale product design and lifecycle simulation system for product designer and material designer is indicated.

The concept of multi-scale product design and lifecycle simulation system is proposed. And, multi-scale product design and lifecycle simulation system is implemented using message passing interface (MPI).

Nano product and chemicals have not only high performance but also potential hazard to human and environment. Multi-scale product design and lifecycle simulation system aims to find out and prevent the potential hazard to human and environment of designing product.

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SLCA to Support Evaluation of Environmental Conscious Production Process Alternatives: An Industrial Case

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Abstract
This paper presents an industrial case study of production process re-design to reduce both environmental impact and production costs and to improve overall product quality. The proposed solution is based on the concept of a closed-loop supply chain (CLSC) model. Simplified life cycle assessment (SLCA) has been used to identify and compare the sustainability and environmental performance of alternative production processes, while supporting strategic decision-making. A company producing shower trays whose process eco-sustainability is quite low acts as the focal enterprise for the case study. Experimental results relating to economic and environmental competitive advantages are discussed on both a quantitative and qualitative base.

Keywords:
simplified life cycle assessment, closed-loop supply chain, recycling, value-added recovery

1 INTRODUCTION

The concept of sustainability, and sustainable engineering in particular, has become increasingly important both locally and globally, and has influenced the decision making and activities of many communities and of humanity as a whole as it works towards a future which offers increased harmony between human activities and the systems of the biosphere. It was during the early 1980s that the term *sustainable development* first came into use. It gradually began to replace earlier concepts within what had been known in the 1970s as the philosophy of *eco-development*. The latter had featured a heavy focus on scientific principles rather than practical and political applicability, and thus had limited its potential to gain a more widespread acceptance. Sustainable development represents a comparatively complex and normative concept with many different, sometimes ambiguous, definitions. However, for modern sustainability engineering, a discipline that spans all of the traditional engineering fields concerned with the design and development of processes and products using a collection of raw materials and energy to implement aspects of sustainability, concrete principles are far more important than a definition of the concept itself.

In the last decade, sustainability has become a critical issue. While facing the problem of reducing the environmental impact of their processes and products, commercial enterprises still need to continuously improve the quality of their services and products, while keeping costs under control. Within the industrial context of wellness products, the problem of how to enable and support a feasible evaluation of production processes in relation to environmental, economic and ecological issues is a research field still lacking substantial industrial experience, know-how and computer-based tools. The approach of the work presented in this paper is to promote a sustainable engineering solution by employing the principles of sustainability science and engineering as given in [1]. This is based on the application of life cycle assessment (LCA) as a tool to support enterprise decision-making in regard to the environmental performance of products and processes and the management of the same. In particular, the adoption of simplified life cycle assessment fosters the implementation of eco-design strategies as early in the design stages as possible. Economic and stakeholder issues are addressed by taking into account the latest results of supply chain management within the context of an extended enterprise. The concept of closed-loop supply chains in particular has been chosen to devise efficient implementation of recycling and remanufacturing, while achieving economic revenue through value-added recovery activities that in turn are capable of creating synergic relationships within the supply chain.

2 BACKGROUND AND RELATED WORK

2.1 The concept of CLSC

Research on closed-loop supply chains (CLSC) has gained increased attention both in the field of industrial practice and with academia, due to its enormous economic and environmental potential, which had been overlooked for quite some time. Besides the concept of reuse, product recovery represents one major element in the foundation

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of facilitating the design and development of industrial systems which are economically and environmentally sustainable. Recovery in this context is associated with commercial returns, end-of-use returns, end-of-life returns, and repair and warranty returns relating to activities such as product disposition, reverse logistics, used-product acquisition, remanufacturing, and repair. The concept of CLSC focuses on bi-directional supply chains and considers both forward logistics and reverse logistics. Reverse logistics concentrates on taking back products from end users with the economic aim of recovering added value and the environmental aim of reducing waste and raw material demand by reusing the entire product or a selection of its components and parts. Current work on CLSC is focusing mainly on research directions concerned with the costing of CLSC [2], the development of recovery networks [3], inventory control [4], and sustainability issues [5]. Further details on and references for the development of CLSC research in both economical and environmental directions can be found in [6,7,8].

2.2 The concept of SLCA

In recent years, discussion about LCA methodology, especially regarding the feasibility of simplification and adaptation to designer needs [9], has been on the rise. Different methods have been proposed. For example, simplification has been suggested in regard to the reduction of data requirements by excluding different levels of life-cycle stages and/or substituting external databases for these [10]. The use of qualitative and semi-qualitative LCA [11] instead of full-scale LCA has also been mooted. Another approach, reported in [12], is also aimed at reducing complexities associated with the practical application of LCA. It focuses on the manufacturing life cycle stage by employing so-called *component manufacturing analysis* (CMA), which requires the identification of all product components and their associated weights. Simplified life cycle assessment (SLCA), especially in the conceptual design phase, is also supported by identifying the basic characteristics of materials and products, and using this information early in the design process to identify where significant environmental impact may occur [13]. Yet another approach aimed at facilitating a simplified preliminary analytical environmental assessment in the early design stages is related to the use of artificial neural networks [14]. For discussions on current developments and further literature references see [15].

3 PROBLEMS AND APPROACH

Increased global competition, shortened life cycles, expanded environmental legislation and even more consumer attention to sustainable products and services force companies both to implement eco-design strategies and to adopt a life cycle approach to products in order to integrate all product returns into the business model for the product. The achievement of the first goal requires the use of life cycle assessment tools within the early design stages to support decision-making oriented towards the improvement of environmental product performance. The second needs the design of a forward and reverse supply chain to take advantage of the extended enterprise involvement (i.e. strong partnership, reduced lead time and reduced costs) and of all possible types of product returns. Both imply the creation of a new business model supported by a novel way of conceiving products.

The proposed approach aims to create a new model for the design of sustainable products, by choosing the best manufacturing process to support the recycling of end-of-life returns and by realizing a closed-loop supply chain to reduce product costs, while achieving economic revenue from the implementation of life cycle approaches. It consists of the following steps:

1) Study of the AS-IS processes from raw material extraction to manufacturing, and continuing right up until product disposal. This requires the identification of main activities and of stakeholders' roles (material suppliers, manufacturers, retailers, etc.) and also of the main drawbacks in terms of eco-sustainability. It allows the definition of product design specifications, which are aimed at improving the environmental performance, in order to meet customer needs and eventually to fit with the supply chain requirements.

2) Evaluation of alternative manufacturing processes that allow the fulfilment of product requirements, while taking into account environmental and economic performance along with CLSC implementation. For this purpose, a metrics-driven analysis has been used for measuring LCA performance, manufacturing cycle time and production costs. SLCA tools have been chosen to support the evaluation of the environmental performance in terms of waste and pollution generation and resource consumption. Although the LCA is simplified, it is still of a quantitative nature in regard to information used for compiling and assessing the life cycle inventory. The use of a simplified method is due to the fact that decision-making in design permits only a short time for the comparison of design solutions and focuses only on those processes that impact strongly on environmental performance in this case study, namely manufacturing equipment design and supply chain arrangement.

3) Choosing the best design and production solution and subsequent definition of a TO-BE cycle that completely re-designs the current manufacturing process and the existing supply chain. Economic revenue calculation needs to be carried out; as it is one of the major triggers for promoting life cycle-oriented approaches in real industrial cases.

4 THE CASE STUDY

4.1 The industrial context

The focal enterprise and main industrial research collaboration partner is Teuco Guzzini S.p.a., a leading enterprise in the design and production of wellness products (e.g. showers, whirlpool bathtubs, equipped columns, steam saunas). By their nature, the products are a combination of aesthetics and technology. Indeed, several aspects contribute to final product definition: market trends, aesthetic impression, product functionalities, customer taste, marketing requirements, ergonomic satisfaction, manufacturing and technological constraints, environmental normative standards, etc. Therefore, all products need to address consumer requirements by differing from others in size, shape, materials, technological components and additional functions such as aromatherapy, chromo-therapy and ultrasound massage.

Thermoforming is a widespread technology in the manufacturing industry, and is used to produce shaped plastic artefacts. It is the AS-IS process used to manufacture shower trays at Teuco. The AS-IS process involves draping a heat-softened plastic sheet onto the surface of a thermoforming mould. When the plastic sheet cools down, it takes up the shape of the mould, producing thin-walled parts with large areas. PMMA (polymethylmethacrylate) is generally used for the plastic sheet. Thermoforming also implies the use of reinforcing supports to improve structural performance. Reinforcement is usually achieved by applying a wooden board behind the plastic sheet, and by spraying a mixture of resin and fiberglass beyond.

The AS-IS process is actually carried out by a four-company supply chain, with Teuco as the leading company. In particular:

- Teuco Guzzini designs the final product, assembles the components (thermoformed tray, electronic boards, hydraulic plant, glass closing structure, user control interface, etc.) and puts the final product on the market.
- G.M.P. S.r.l. supplies materials, both raw and recycled, and provides several recycling services (material grinding, enrichment, etc.).
- DRAG Stampi S.r.l. designs and produces steel and aluminium moulds on demand for plastic moulded products.
- CS Plastic Stampi S.n.c. designs moulded products in collaboration with the leading company, optimizes the production by considering specific moulding constraints, and moulds final items for third parties.

The actual process has been analyzed by interviewing personnel of the industrial partners, by collecting data from the supply chain, and by studying internal company documents and reports. Functional analysis has been carried out to highlight process activities and input/output data flows in term of energy, materials and data.

4.2 SLCA for product design: how to choose among alternative solutions?

In order to properly compare different manufacturing processes, the authors have pointed out the main product requirements and the main drawbacks of the actual process. Indeed, product requirements represent the starting conditions for identifying and choosing from several alternative processes that should be able to guarantee almost the same product quality and process performance. Next, we identify those limitations that need to be overcome for each of the alternative processes. In our context, the product requirements for the Teuco tray design can be summed up in four points:

1. High aesthetic quality of the top surface: the tray must not have any surface irregularities or inconsistent finishing, any color blemishes, etc.
2. High structural rigidity and chemical stability: the tray must pass a set of laboratory tests as required by the regulations, certifying the deflection under vertical loads, impact resistance, thermal shock, chemical resistance, drainage verification, and dimension conformity.
3. Low environmental impact: sensible reduction of CO_2 emissions (40%), elimination of styrene emissions, total recyclability (100%).
4. Economic revenue: supply chain process optimization and reduction of the actual unit production cost (ca. 20%).

The AS-IS process based on thermoforming guarantees the first two aspects. However, it implies some drawbacks, significantly: air emissions, considerable consumption of energy and additional costs due to some manufacturing operations (movement of thermoformed plastic sheets, positioning of the wooden boards, high-quality resin finishing, etc.). It is impossible to recycle because the product components are no longer separable as the resin adheres strongly to the plastic sheet. Furthermore, product disposal is not managed, so that the goods end up in landfill. During the analysis phase, taking into account product design in aesthetics, surface quality, structural performance, and production costs, two manufacturing processes have been identified, namely over-moulding and co-injection moulding (Fig.2). Over-moulding combines thermoforming and injection moulding by thermoforming a thin PMMA sheet through a traditional process and then injecting the reinforcing material by inserting the formed sheet into an injection mould. The reinforcement is made of recycled PMMA. Different material compositions have been tested using FEM analysis (100% recycled PMMA or recycled PMMA with the addition of some other virgin materials such as PMMA or ABS). Co-injection uses only the injection moulding press machine in order to obtain a final product by injecting two distinct materials, one virgin and one recycled, into the same mould. In this case too, different material compositions have been tested with varying ratios of virgin and recycled elements.

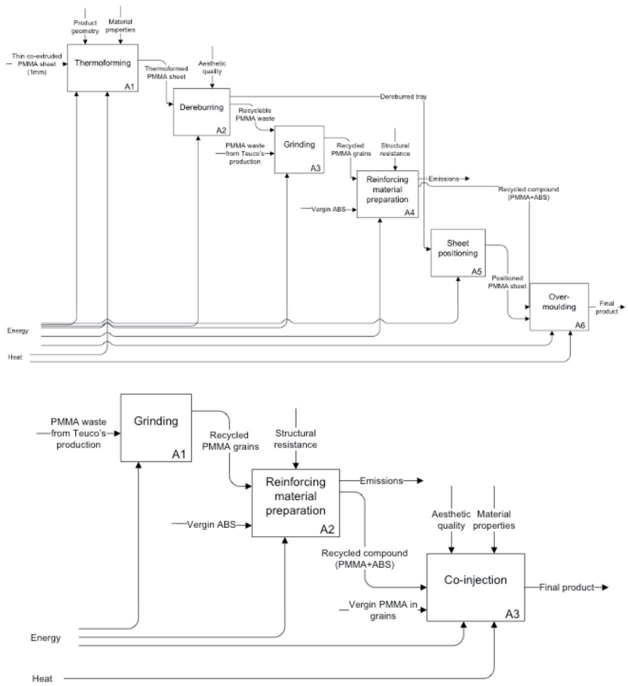

Fig. 2: IDEF diagrams of the over-moulding and the co-injection process analysis

The process redesign has been approached employing a set-based methodology. Alternative solutions for moulding have been developed in parallel and product design has been continuously redefined and adjusted.

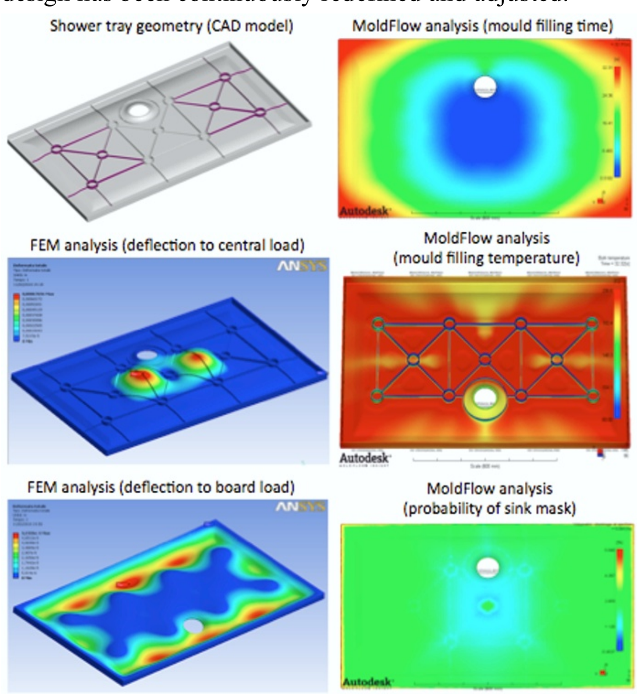

Fig. 3: Design, simulation and re-design of the shower tray according to set-based methodology

Continuous process iterations from SLCA to product shape redesign have been carried out, using finite element mesh structural analysis and computer-aided moulding simulation (see Fig. 3) in order to define the best process solution. Processes have been analyzed and developed right up to the final physical prototyping. Then, a three-column matrix has been used for a comparative process assessment considering process efficiency and environmental as well as economic benefits.

4.3 Experimental results and evaluation

The use of the method described in section 4.2 allows the assessment and comparison of two different TO-BE processes, considering both requirement satisfaction and the process performances in terms of environmental impact, cost savings and feasibility within the supply chain. The evaluation also considers the economic revenue from closed-loop supply chain implementation. The processes have been compared in detail by considering materials, energy flows and consumption, process costs, etc. Fig. 4 shows some of the activities carried out during prototyping and process testing. In the case of over-moulding, a mixture of recycled PMMA and ABS was used as reinforcement. The proportion of recycled material in the final product was about 83% (1.4 kg of PMMA sheet to about 7 kg of recycled mixture). In the case of co-injection, the same mixture of recycled PMMA and ABS was injected in combination with non-recycled PMMA. The proportion of recycled material was about 88% (1.1kg of raw PMMA to 8.6kg of recycled mixture).

Fig. 4: Prototyping and testing of the two alternative processes

Experimental testing and product prototyping revealed that over-moulding allows for a better aesthetic quality and easy customization of product colors, due to the top thermoformed sheet. However, it requires several additional activities (sheet transfers, sheet polishing and positioning inside the mould, etc.) and involves two different press machines. As a consequence, cycle time increases and process implementation in a closed-loop chain is more complex. On the other hand, co-injection guarantees a simpler process and increases efficiency and agility by reducing the equipment cost and process activities. There are some limitations in the selection of recycled materials due to adherence properties and there is additional cost for the second moulding injector.

Table 1: Process results in comparison

Metrics	Over-moulding	Co-injection
LCA parameters		
EI99, EA	- 54.88%	- 62.96%
air emissions	- 53.56%	- 60.96%
water emissions	- 73.53%	- 97.05%
ground emissions	- 75%	- 50%
CO_2 emissions	- 57.7%	- 60.9%
carbon footprint (equiv. kg CO_2)	- 53.74%	- 58.05%
Efficiency		
production cycle time (in minutes)	- 37.33% (13.16 vs 21)	-70.48% (6.2 vs 21)
Effectiveness		
production unit cost (in European Euro)	- 34.23% (34.78 vs 52.8)	-24.70% (39.80 vs 52.86)

Table 1 shows the most significant results according to the three selected metrics. Data refer to reductions obtained compared to a traditional thermoforming process. They show that co-injection allows a significant reduction in production cycle time as well as reduced environmental impact. Process complexity is limited and no additional machinery is required. This solution guarantees higher product quality and simpler industrialization.

4.4 Outline and structure of the TO-BE process

The Teuco supply chain was chosen as a starting point for investigation of the new closed-loop supply chain model. This was used to identify necessary activities and to estimate a new business model. Co-injection and over-moulding gained similar LCA scores. Concerning the unit product cost, over-moulding allows the reuse of considerable quantity of recycled PMMA from the closed-loop, which increases the product affordability. However, co-injection maximizes both environmental and efficiency performances and improves the final aesthetic quality, if taking into account additional technical aspects such as mould conditioning and air ducts. Furthermore, co-injection simplifies the closed-loop process by involving all partners in the chain in the new process and realizing complete product recycling. From a global viewpoint, it allows the creation of a lean closed loop supply-chain and higher economic revenue by containing process changes and investments. As a consequence, co-injection has been chosen as the new process, especially as it offers complete recycling. Fig.5 shows the TO-BE process that realizes the closed-loop chain. Each actor has his own role and takes advantage of component recycling. In particular:

- Teuco (the leading enterprise) designs the final product and assembles product components as in the AS-IS process. It also provides production waste and recovered products for material recycling. Finally, it benefits from the recycling carried out by chain suppliers and takes part in remanufacturing.
- G.M.P. (supplier 2.1) provides chemical compounding both raw and recycled. In the new process it also handles product recycling and produces recycled mixture as required by grinding and combining waste materials.
- DRAG Stampi (supplier 1) designs and builds steel moulds according to the final product design, ensuring that they are suited to the characteristics of materials used.
- CS Plastic Stampi (supplier 2) implements injection moulding for the leading enterprise. It also collaborates with suppliers in order to produce suitable materials.

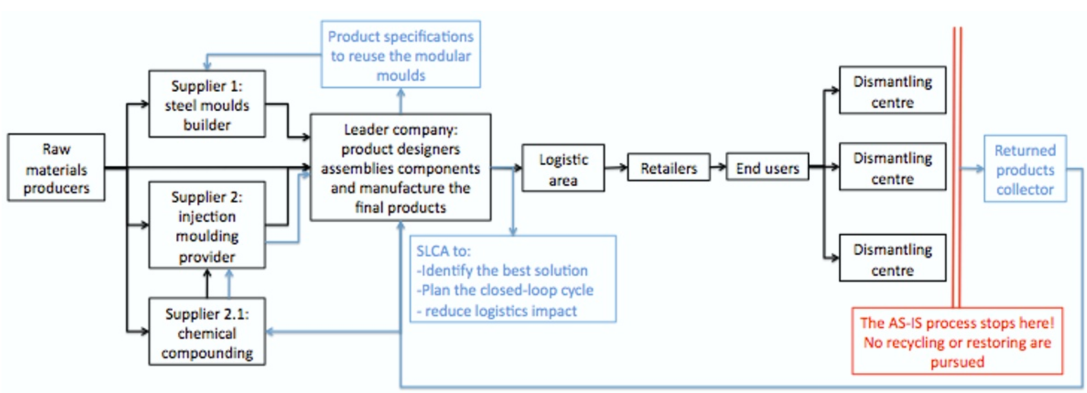

Fig. 5: Structure of the TO-BE process

5 CONCLUSION

The present research proposes a method for redesigning a complex manufacturing process within the context of a larger enterprise and several small suppliers. The solution is based on adoption of the best performing technological process within a closed-loop supply chain. Process selection considers environmental impact, sustainability and process efficiency, by adopting a SLCA approach. The TO-BE process achieves closed recycling and re-schedules the chain partners' roles.

The central elements of the approach are the integration of SLCA into the design cycle, the use of SLCA as a tool to foster remanufacturing, and the implementation of closed-loop supply chains related to cost assessment. It also introduces innovations in the particular industrial sector of medium-sized enterprises regarding the design of modular products, costs savings due to the integration of recycling and remanufacturing, and competitive advantage for the supply chain.

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Resource sharing method among multiple production systems to reduce initial investment for inverse manufacturing

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Abstract

The objective of this study is to propose a resource sharing method among multiple production systems to reduce initial investment for inverse manufacturing. To this end, this paper introduces a transferability benefit index (TBI), the ratio of the benefits to difficulties, to identify the most promising resources for sharing among multiple production systems. This papers also provides a simplified example calculation to illustrate the method and discuss its result and the future development needs of the methods.

Keywords:

1 INTRODUCTION

Due to growing concern about environmental problems, it is becoming important for manufacturers to add more value while causing less environmental impact. In order to reduce the environmental impact of products over their entire life cycle, adequate reuse and recycling of products and their components are quite promising [1,2]. In this context, it is quite important for manufacturing firms to establish efficient closed-loop manufacturing systems (CMS) [3] in which products are made from used components and materials as well as new ones. Some firms have successfully established quite efficient CMS from both environmental and economical viewpoints. CMSs for one-time-use cameras [4] , photocopying machines [5], and automobile components [6] are typical examples.

However, establishment of an environmentally and economically efficient CMS is not easy, mainly due to high uncertainty associated with the return flow of post-use products. Since product usage conditions and lifetimes differ from user to user and cannot, in general, be controlled by manufacturers, there are significant fluctuations in the quality and quantity of product return flows [7,8]. In addition, the return flow of post-use products may contain different product models in different conditions, each of which requires different remanufacturing operations (e.g., some may need cleaning and inspection while others may need disassembly into their components). Therefore, CMS should have higher flexibility and redundancy than conventional production systems to adapt these significant fluctuations.

Both of these requirements are quite expensive to meet. Flexible machines and labours are generally more expensive (sometimes less effective) than fixed purpose ones. In addition, the differences in necessary operations for each used product need frequent reprogramming and set up for manufacturing equipment. This hinders the automation of CMSs and results in higher operation cost, especially in developed countries where labour cost is expensive. The high redundancy in production resources also leads to their less efficient utilization and causes higher investment cost than conventional ones.

The objective of this study is to propose a strategic decision making method for designing environmentally and economically efficient CMS while maintaining the flexibility and the redundancy to adapt the significant fluctuations in product return flows. Especially, this paper deals with the investment reduction of a CMS through effective sharing of its resources across multiple production systems. To this end, we introduce a transferability benefit index (TBI), the ratio of the benefits to difficulties, to identify the most promising resources for sharing among multiple systems. We also provide a simplified example calculation to illustrate the method and discuss its result and the future development ideas of the methods.

2 TRANSFERABILITY BENEFIT INDEX (TBI)

2.1 Benefits of sharing production resources

The wide fluctuations in the return flow of used products cause inefficient utilization of resources in a CMS. Thus, sharing idle resources among multiple CMSs may significantly reduce the initial investment over these systems.

Generally speaking, utilization rate of each resource is

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given by the ratio of actual working time to the whole working hours (e.g., 8 hours or 24 hours etc.) of the system. The resources with low utilization rate (long idle time) have great possibility for sharing across multiple CMSs to reduce the total number of the same kind of resource over these systems. Theoretically, each resource can be transferred to the other systems and utilized until the summation of its utilization rate over different systems reaches 1. Therefore, the benefit potential for its sharing is evaluated by Equation 1, assuming that the same (or similar) resources in different CMSs have the same initial investment cost.

$$b_i^j = (1 - u_i^j) \cdot c_i \qquad (1)$$

where i, j, b_i^j, u_i^j, and c_i, denote the index for each resource, the index for each CMS, the benefit potential for sharing the resource i in the CMS j with other systems, the utilization rate of resource i in the CMS j, and initial investment cost for the resource i, respectively.

When the resource i is shared across n_i production systems, the actual benefit for the sharing b_i is given as follows;

$$b_i = (n_i - 1) \cdot c_i \qquad (2)$$

where

$$\sum_{j=1}^{n_i} u_i^j < 1 \qquad (3)$$

2.2 Difficulty of sharing resources among multiple CMSs

Even if resources have high benefit potential when shared among multiple systems, it is possible that some of them are very difficult to transfer from one system to the others. Thus, the difficulty of sharing should also be considered in determining which resources hold the most promise for sharing.

Generally speaking, the difficulty of sharing a certain resource among multiple systems that use similar resources depends on the number of its interactions with other elements in a set of production systems. For example, in order to transfer one piece of equipment to another CMS, adjustment and reprogramming of system segments that are connected to that equipment will likely be needed in addition to adjustment and reprogramming of the equipment itself. These additional necessary operations can be regarded as the main source of difficulty in sharing the equipment.

In order to represent the interdependence among multiple resources in CMSs and formulate the difficulty of resource sharing, we used a design structure matrix (DSM) [9]. The DSM, which is sometimes called an interdependency matrix, is a product or project representation tool that is widely used for representing interdependence among all constituent subsystems or activities to improve the structure of a product or project. Table 1 shows a typical DSM. It lists all constituent activities along rows and columns and shows interdependency with a digit number 1 in each cell where the activity in the corresponding row of the matrix depends on the activity in the cell's column in some ways. For example, the number 1 in the 2nd row and the 1st column of the matrix shows that the activity 'b' depends on the activity 'a'.

Table 1. Example of Design Structure Matrix

		Element activity							Row No.
		a	b	c	d	e	f	g	
Element activity	a								1
	b	1		1			1		2
	c		1						3
	d		1	1					4
	e								5
	f					1		1	6
	g			1			1		7
Column No.		1	2	3	4	5	6	7	

Since the necessary time or cost is different for each task, it is necessary to weight the difficulty of each task by introducing weighting factors into the DSM.

The difficulty weight assigned to each task is generally evaluated as its necessary labor time or cost. However, it sometimes happens that some of them need special labor skills or conditions that are difficult to evaluate as a function of labor time and cost. In such cases, difficulty weights are determined on an empirical basis considering these factors other than labor time and cost.

First, all the necessary tasks for transferring a resource (i.e., removal and reinstallation) from the CMS j are listed across the rows and columns of interdependency matrix M_{kl}^j. Each element of the matrix takes a Boolean value of 0 or 1. If task k should be executed whenever task l takes place, M_{kl}^j is assigned to be 1. Otherwise its value is 0.

Then, by using a weighting factor w_k^j, the total difficulty of task l in the CMS j is calculated as shown in Equation 4.

$$d_l^j = \sum_k w_k^j M_{kl}^j \qquad (4)$$

where d_l^j and w_k^j denote the difficulty of operation l in the CMS j and the weighting factor for operation k in the CMS j, respectively.

The total difficulty of transferring resource i in the CMS j is calculated as the sum of the difficulties of necessary tasks associated with it, as given by Equation 5.

$$d_{S_i^j} = \sum_{l \in S_i^j} d_l^j \qquad (5)$$

where S_i^j denotes the set of tasks necessary to transfer resource i in the CMS j.

The total difficulty of sharing a resource among a set of CMSs is formulated as the sum of the difficulties over these systems as follows:

$$d_{S_i} = \sum_{j \in S_i} d_{S_i^j} \qquad (6)$$

where S_i denotes a set of given CMSs among which the resource i is to be shared.

2.3 Transferability benefit index formulation

All resources can be classified into three categories as shown in regions I, II, and III in Figure 1, considering the benefit of and the difficulty for their sharing, which are represented by horizontal and vertical axes of the figure, respectively. Manufacturers should consider the sharing of resources located in region I because their sharing produces larger benefit with relatively smaller difficulty. In addition, the resources located in region II also hold the promise for the sharing, especially when it is possible to reduce the difficulties for their sharing. They should be redesigned and modified to reduce their interdependency on the other resources in CMSs. In other words, these resources should be replaced with more flexible and reconfigurable resources to ease the sharing across multiple CMSs. For the resources located in region III, there are no immediate needs for the sharing.

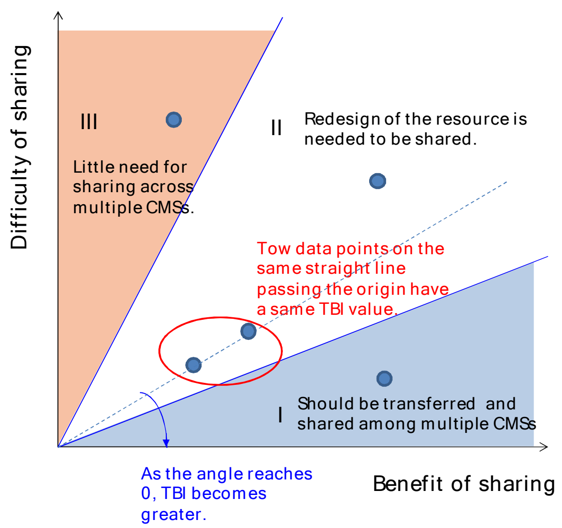

Figure 1. Decision making diagram for resource sharing

In order to identify which resources are located in region I, a Transferability Benefit Index (TBI) is introduced, which can be calculated using Equation 7.

$$TBI = \frac{benefit\ of\ a\ resource\ sharing}{difficulty\ \ for\ the\ sharing} \quad (7)$$

A high TBI value means that sharing the corresponding resource has a relatively large benefit compared to its difficulty.

Using Equations 1 and 5, the TBI of the resource i in the CMS j is given as follows;

$$TBI_i^j = \frac{(1-u_i^j)\cdot c_i}{\sum_{l\in S_i^j} d_l^j} \quad (8)$$

As shown in Figure 1, two data points on the same straight line passing by the origin have the same TBI value and the region closer the horizontal axis has higher TBI. Thus, TBI is an adequate index for identifying the most promising resources.

When a set of CMSs S_i among which the resource i to be shared is given, TBI of sharing the resource i across n_i systems from S_i is given by using Equations 2 and 6 as follows:

$$TBI_i^{S_i} = \frac{(n_i - 1)\cdot c_i}{\sum_{j\in S_i} d_{S_i^j}} \quad (9)$$

3 DECISION MAKING PROCEDURE FOR SHARING RESOURCES AMONG MULTIPLE PRODUCTION SYSTEMS

Step 1: Define a set of CMSs among which the resources are to be transferred and shared

The designer should first define a set of CMSs among which the constituent resources are to be transferred and shared. Then the designer identifies the resources to be considered for sharing taking into account their applicability to their corresponding tasks in each CMS. The cost reduction target by the sharing of the resources is also defined in this step.

Step 2: Estimate sharing benefits

The investment cost and utilization rate are estimated for each resource element identified in the previous step. The designer can then calculate the benefit potential for sharing each element in each CMS using Equation 1. The actual benefit for sharing each element in a set of CMSs given in previous step is also calculated by Equation 2.

Step 3: Estimate sharing difficulties

The tasks necessary to transfer each resource element to each CMS (e.g., mechanical adjustments, reconfiguration of software settings) are identified first. Then, the designer weights each individual task, considering its difficulty in terms of cost, lead-time, necessary tools, and labor skills required. Interdependencies among these tasks in each CMS are also identified and represented by M_{kl}^j. Using interdependency matrix M_{kl}^j and weighting factors w_k^j for each task in each CMS, the difficulty of sharing each element in a given set of CMSs is calculated using Equations 4, 5, and 6.

Step 4: Identify the most promising resources to be shared and transferred

The TBI of each element is calculated using its sharing benefit and difficulty. Then the resources with the highest TBI values are selected one by one until the total benefit of their sharing satisfies the cost reduction target defined in step 1.

Step 5: Define a set of CMSs among which the resources are to be transferred and shared

Finally, the feasibility of each element sharing is evaluated by considering its summation of utilization rate over a given set of CMSs. Each element sharing is feasible only if it satisfies Equation 3.

Some resources need to be redesigned and modified before sharing across multiple CMSs. For these resources, the feasibility and the possible cost for the redesign and modification should also be evaluated.

If the estimated benefit does not satisfy the cost reduction target defined in step 1, the designer moves to step 4 and selects the resource with the next highest TBI value until the target is satisfied.

4 CASE STUDY

In order to illustrate a decision-making method for sharing resources among multiple CMSs, a simplified case study is provided in this section.

4.1 Define a set of CMSs among which the resources are to be transferred and shared

Figure 2 shows a set of two disassembly systems to be considered; disassembly system 1 for used air conditioners and disassembly system 2 for used refrigerators. Each system is assumed to consist of four pieces of equipment and three of them; namely, belt conveyor 'b,' refrigerant gas collector 'c,' and crushing machine 'd' can be applicable to both systems. The other equipment, disassembly stations 'a' and 'e' are specialized equipment for each system and cannot be applicable to the different system. The cost reduction target is defined as 5% in this case study.

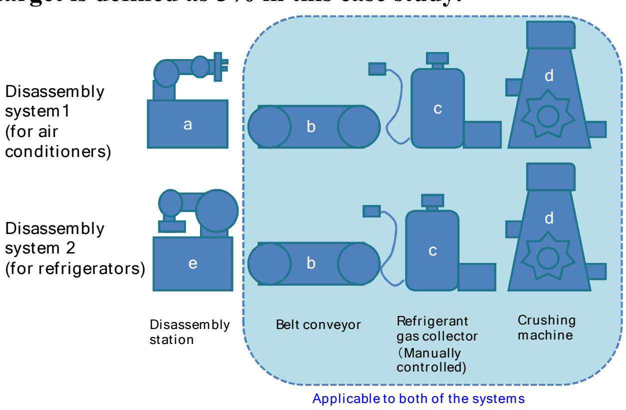

Figure 2. Case study: two disassembly systems with similar structure

4.2 Estimate sharing benefit

Initial investment for each piece of equipment and its utilization rate are assumed as shown in Table 2. Since the fluctuation in the volume of returned air conditioners is larger than that of refrigerators, the utilization rate of each piece of equipment in disassembly system 1 is smaller than that of corresponding one in system 2. Substituting these values into Equation 1, the benefit potential for sharing each piece of equipment is calculated as shown in the 4th row in the table. The benefits for sharing resources 'b', 'c,' and 'd' among both systems are calculated by using Equation 2 as shown in the 5th row in Table 2. For example, the benefit potential for sharing equipment 'b' is calculated as 1600 [euro] by substituting its initial investment cost (i.e., 2000 [euro]) and utilization rate (i.e., 0.2) into Equation 1. Substituting 2 to n_2 in Equation 2, the benefit for sharing equipment 'b' is calculated as 2000 [euro].

4.3 Estimate sharing difficulty

Since each system contains different equipment from each other, its interdependency pattern also differs from each other. Thus, two interdependency matrix (M_{kl}^1 and M_{kl}^2) are calculated as shown in Tables 3 and 4, respectively.

Necessary tasks for transferring each piece of equipment and their difficulties are first identified as shown in the tables. Interdependence among these operations is assumed as given in the 1st to 10th rows in the tables. For example, three operations (i.e., physical adjustment, software installation, and reprogramming) are required to remove/install a disassembly station 'a' from/to the disassembly system 1. Since the resource is not manually controlled, its removing and installation also require the physical adjustment and reprogramming of its connected equipment, belt conveyor 'b.'

Then, difficulty weight for each operation (w_k^j) is assigned as shown in the shaded cells in these tables. Among them, physical adjustment of resource 'd' assumed to be the most difficult task since it is too large to transfer (i.e., $w_8^1 = 9$ and $w_8^2 = 9$).

Substituting these values into Equation 4, total difficulty of each task is calculated as shown in the 11th row in Tables 3 and 4. The difficulty of transferring each piece of equipment is calculated by using Equation 5 as shown in the 12th row in Tables 3 and 4. Overall difficulty for sharing each resource among both systems is given by the total of the difficulty for transferring each piece of equipment over two systems. Using Equation 6, overall difficulty of the sharing is calculated as shown in the 3rd row in Table 5, which summarizes the calculation results.

For example, focusing on 'b' in disassembly system 1, the difficulty of operation physical adjustment (d_4^1) is calculated as follows by using Equation 4;

$$d_4^1 = 1\times 1 + 1\times 0 + 3\times 1 + 3\times 1 + 1\times 0 + 3\times 0 + 3\times 1 + 9\times 1 + 1\times 0 + 1\times 1 \quad (10)$$

Aggregating the difficulties of three operations (i.e., d_4^1, d_5^1, and d_6^1), the difficulty of transferring 'b' from/to disassembly system 1 ($d_{S_2^1}$) is calculated as 35.

Overall difficulty for sharing 'b' across the two systems is the total of transferring difficulty of 'b' for

Table 2. Benefit of sharing each piece of equipment

Equipment	Disassembly system 1				Disassembly system 2				Total investment	Row No.
	a	b	c	d	e	b	c	d		1
Initial investment [euro]	8000	2000	5500	40000	7000	2000	5500	40000	110000	2
Utilization rate	0.2	0.2	0.01	0.4	0.5	0.5	0.02	0.9		3
Benefit potential	6400	1600	5445	24000	3500	1000	5390	4000		4
Actual benefit for the sharing		2000	5500	40000		2000	5500	40000		5
Resource No. i	1	2	3	4	1	2	3	4		6
Column No.	1	2	3	4	5	6	7	8	9	

each system (i.e., $d_{S_2^1}$ and $d_{S_2^2}$), which is given as follows by using Equation 6.

$$d_{S_2} = 35 + 39 \tag{11}$$

Table 3. Weighting factors and interdependency among transferring tasks in disassembly system 1

		Weighting factors w_k^1 (difficulty)	Necessary tasks for transferring resources from/to disassembly system 1										Row number
			a			b			c	d			
			Physical adjustment	Software installation	Reprogramming	Physical adjustment	Software installation	Reprogramming	Physical adjustment	Physical adjustment	Software installation	Reprogramming	
Necessary tasks for transferring resources from/to disassembly system 1 — a	Physical adjustment	1	1			1							1
a	Software installation	1		1			1						2
a	Reprogramming	3		1	1	1	1	1					3
b	Physical adjustment	3	1		1	1				1			4
b	Software installation	1					1						5
b	Reprogramming	3	1		1		1	1		1		1	6
c	Physical adjustment	3				1			1				7
d	Physical adjustment	9				1				1			8
d	Software installation	1									1		9
d	Reprogramming	1				1		1			1	1	10
Difficulty of each task			7	4	9	20	8	7	3	15	2	4	11
Difficulty of transferring resources from/to disassembly system 1			20			35			3	21			12
Resource Number i			1			2			3	4			13
Column Number			1	2	3	4	5	6	7	8	9	10	

Table 4. Weighting factors and interdependency among transferring tasks in disassembly system 2

		Weighting factors w_k^2 (difficulty)	Necessary tasks for transferring resources from/to disassembly system 2										Row number
			e			b			c	d			
			Physical adjustment	Software installation	Reprogramming	Physical adjustment	Software installation	Reprogramming	Physical adjustment	Physical adjustment	Software installation	Reprogramming	
Necessary tasks for transferring resources from/to disassembly system 2 — e	Physical adjustment	3	1			1							1
e	Software installation	3		1			1						2
e	Reprogramming	3		1	1	1	1	1					3
b	Physical adjustment	3	1		1	1				1			4
b	Software installation	1		1	1		1						5
b	Reprogramming	3	1	1	1		1	1		1		1	6
c	Physical adjustment	3				1			1				7
d	Physical adjustment	9				1				1			8
d	Software installation	1									1		9
d	Reprogramming	1				1		1			1	1	10
Difficulty of each task			9	10	10	22	10	7	3	15	2	4	11
Difficulty of transferring resources from/to disassembly system 2			29			39			3	21			12
Resource Number i			1			2			3	4			13
Column Number			1	2	3	4	5	6	7	8	9	10	

4.4 Identify the most promising resources to be shared and transferred

Figure 3 and Table 6 summarizes the result of the TBI calculation. As shown in the figure, crushing machine 'd' has the greatest potential to reduce initial investment cost with relatively small effort compared to other equipment items.

Since the benefit of sharing 'd' is calculated as 40,000 [euro] , which is larger than the target value 5,500 [euro], 5% of the total investment cost (i.e., 110,000 [euro]), the designer proceeds to the next step.

Table 5. Difficulty of sharing each piece of equipment

	Equipment b	Equipment c	Equipment d	Row No.
Difficulty of transferring a resource from/to disassembly system 1	35	3	21	1
Difficulty of transferring a resource from/to disassembly system 2	39	3	21	2
Total difficulty for the sharing	74	6	42	3
Resource No. i	2	3	4	

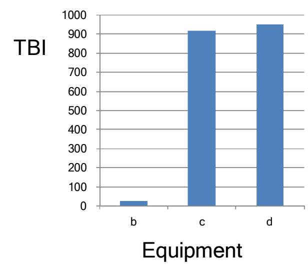

Figure 3. TBI of each piece of equipment

Table 6.TBI calculation results

	Equipment b	Equipment c	Equipment d	Row No.
Overall benefit for the sharing	2000	5500	40000	1
Total difficulty for the sharing	74	6	42	2
TBI for the sharing	27	917	952	3
Resource No. i	2	3	4	

4.5 Evaluate the feasibility of the sharing

Although crushing machine 'd' has the highest TBI value, it cannot be shared because the total of its utilization rate over two systems is calculated as 1.3, which is larger than 1. Thus, the equipment with next highest TBI, refrigerant gas collector 'c' is chosen to be shared. As the overall benefit of the sharing is calculated as 5,500 [Euro], which satisfies the cost reduction target defined in step 1, designer stops the calculation.

5 DISCUSSION

We introduced TBI measure to determine the most promising resources in a case study. Although the example consists of a small number of resources, it is also possible to apply this method to the systems consisting of many resources with complicated interdependency patterns. Thus, TBI can be a useful tool for selecting resources to be shared among multiple CMSs.

TBI can be applied not only to the resource sharing problem among multiple CMSs but also to the product sharing business design (i.e., use-oriented Product Service System design) problems. Once the necessary operations, prerequisites, and constraints for transferring a product (e.g., automobile, bicycle, camping chair etc.) from each user to the others and its utilization rate and initial cost are identified, TBI of the product is easily calculated. By comparing TBI of the multiple products and plotting them on the decision making diagram as shown in Figure 1, the designer can systematically identify a set of promising products to be shared or redesigned to ease their sharing.

Although in this paper we focus on the sharing of resources with high TBI values, which are located in region I of Figure 1, sharing those located in region II also holds promise if they can be redesigned to reduce the difficulty of necessary tasks to transfer them among systems. Development of a redesign method to improve resources' transferability will also be part of our future work. The DSM, which is used to estimate the difficulty of sharing resources among multiple CMSs in this paper, can also be used to determine workable structures for such systems and resources.

In this paper, we only focused on the initial investment cost reduction over multiple CMSs. However, the benefit of the sharing is not limited to the economical benefit. Resource sharing also leads to the environmental impact reduction in many cases. Thus, the introduction of the environmental aspect to the TBI method will be promising and will also be included in our future work.

6 CONCLUSION

This paper proposes a decision-making method for sharing resources among multiple CMSs, aiming at reducing the cost of reuse and recycling of used products. We introduce a transferability benefit index (TBI) in this paper, and the feasibility and validity of a method for using it is demonstrated by a simplified case study of two disassembly systems with four pieces of equipment. Future work includes the following topics:

- **Development of a simpler method to calculate resource-sharing difficulties among production systems with different interdependency patterns.**
- **Development of a redesign method to reduce the difficulty of sharing resources among multiple production systems.**
- **More practical case studies to evaluate the effectiveness and feasibility of the methods.**

ACKNOWLEDGEMENTS

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Digital Eco-Factory as an IT Platform for Green Production

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Abstract

This paper describes a proposal of a concept and a construction method for the digital eco-factory to support and promote implementation of green production. The proposed digital eco-factory is a virtual factory and IT platform for sustainable production planning. The digital eco-factory is constructed on the digital factory which is constructed by applying multi agent system technology. In the digital factory, all factory elements including produced products are configured as software agents. In the digital eco-factory the production scenario is examined both from manufacturing efficiency and an environmental view.

Keywords:

virtual factory, green production scenario, multi agent system, product agent, simulation

1 INTRODUCTION

At present, manufacturing industries are required to optimize service to users of products with consideration to environmental sustainability of the global society. Thus, manufacturing which considers the entire product's life cycle, has now become commonplace. There are DfE (Design for Environment) and CADE (CAD for Environment) for assisting in the design of a product's life cycle. On the other hand, LCA (Life Cycle Assesment) methodology is available from the published ISO 14000 series (ex. [1][2][3].) The above approaches are considered as an approach to a recycling society with a focus on the product life cycle perspective. From this view, the manufacturing system usually includes not only forward processes but also inverse processes for the product's life cycle such as reuse and recycling. In addition, the manufacturing system itself should be sustainable. As a result, IT tools for supporting design of sustainable production scenarios by simulation and evaluation is required.

This paper is intended to build a environmental IT platform for the promotion and support of green production for mechanical products. This environmental IT platform is called *digital eco-factory* in this paper. The proposed digital eco-factory is a virtual factory and IT platform for sustainable production planning. In the digital eco-factory the production scenario is examined both from manufacturing efficiency and an environmental view. The digital eco-factory is constructed by integrating existing technologies from the viewpoint of the production system.

2 COMPUTER AIDED GREEN PRODUCTION

2.1 Requirements from society

There is a strong demand from society to promote green production. For the construction of a recycling-oriented society and zero-waste society, it is necessary to perform a green production, and IT support is necessary to promote green production. A framework for promoting green production using the digital eco-factory as an IT platform, is shown in Fig. 1. The digital eco-factory would carry out a prior environmental evaluation of various production scenarios, including manufacturing equipment composition of a shop floor and a manufacturing processes for a product. In addition, the digital eco-factory would suggest environmentally improving points in the scenario. When this digital eco-factory is available as a Web service such as Cloud service and SaaS (Software as a Service), it become possible to review production scenarios using IT tools before the actual production. Because it does not require a high ICT investment, not only big major companies but also small and medium-sized enterprises can easily use the digital factory. In addition, an already running scenario can also be checked again environmentally. As a result, green production is utilized widely. If a certification system for a prior assessment of the manufacturing process by production scenarios is available, significant promotion of green production can be expected. This trend of IT tools for green innovation is now widely seen in the office-automation area. When an IT platform for green manufacturing is available this trend will spread to the factory-automation area. Finally, an eco-friendly society is possible.

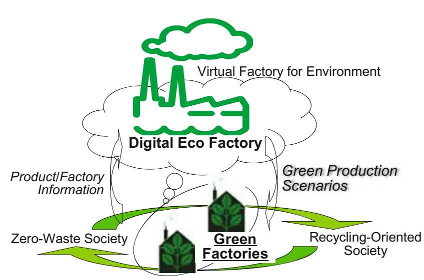

Fig. 1: Promotion of green production

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DOI 10.1007/978-94-007-3010-6_122,

2.2 Environmental assessment in manufacturing

From the manufacturing factory view point, several product life cycle lines lead to or come from the manufacturing process as shown in Fig. 2. In the production stage, not only new materials but also recycled materials or re-used parts are candidates for manufacturing objects. Also the same shop floor which consists of various manufacturing machines is used for production of various kinds of products. In the manufacturing phase, the environment assessment should be done from both view points of the product life cycle and the manufacturing shop floor.

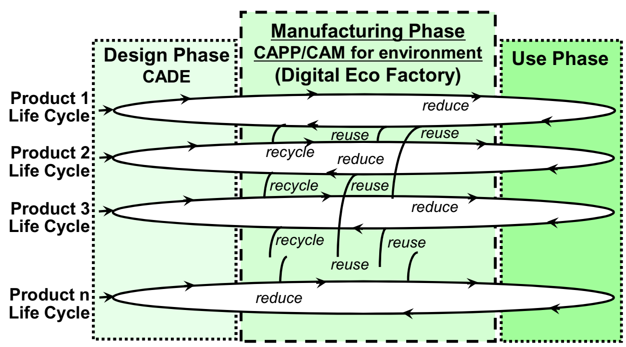

Fig. 2: Computer aided green production

When product life cycle design tools, manufacturing process planning tools including inverse process planning, and LCA tools will be integrated at the point of view from the production stage, this integrated IT platform will be provided as a digital eco-factory. By using this digital eco-factory for simulation, the scientific, quantitative and objective assessments of environmental impact will be added on the manufacturing processes including decomposition and re-use processes. Then, it will become possible to provide a production scenario with low environmental impact and showing how to achieve it.

3 REQUIREMENTS FOR THE DIGITAL ECO-FACTORY

3.1 Usage of the digital eco-factory

The concrete image of a digital eco-factory is that, if a machine tool, a robot, a conveyance machine, a worker, etc. who are the components of a factory are defined through a user interface, and are modeled in a computer, they constitute a virtual factory which is a digital factory. By carrying this out easily, a composition is performed, a change of virtual equipment can be made, and detailed modeling also including the operation of each component can be attained. On the other hand, when the product model of the product is also designed with consideration of the environment using the eco-design tool, a process design is performed and all proposals of the production scenario that also took recycling/reuse into consideration are listed. Virtual manufacturing is carried out on the above-mentioned digital eco-factory according to these production scenarios. LCA is performed on the whole scenario, each process, equipment, etc., and production scenarios with the fewest environmental impact are chosen for actual use. Fig. 3 shows the use case diagram of the digital eco-factory. Estimated major users/actors are the product designer, production engineer and plant manager.

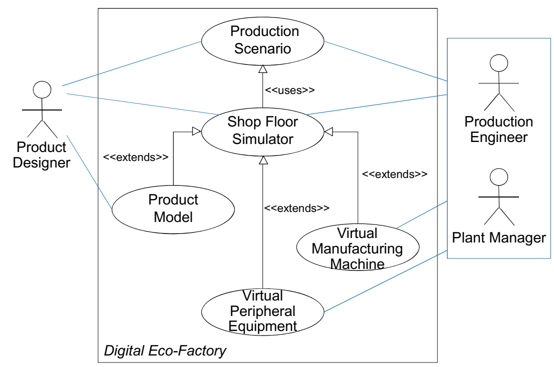

Fig. 3: Use case of the digital eco-factory

3.2 Required functions

Expected functions for the digital eco-factory are:

- precise simulation of production scenario and each process,
- precise simulation from the device view and product view,
- visualization of the relationship between environmental indicators and an indicator in cost-oriented conventional processes such as delivery time and production cost,
- evaluation of the double view points from optimizing labor and machine productivity and optimizing the environmental impact,
- technology for the proper evaluation of each process by carefully making individual components one by one, and technology that evaluates the entire system based on this,
- environment where an information technology can be used well:
  - evaluation of various production scenarios
  - pre-assessment of various device/line configuration
  - comparison of several production processes,
- easy input of optimization parameters, device/equipment configuration, production schedule, process plan and change of schedule/plan, and
- support for making production scenario with less of an environmental impact.

Details of requirements for simulation function are:

- computation of environmental items such as the amount of raw materials and various energy intensities (ex. CO_2, NO_x, SO_x, energy consumption) in addition to conventional items such as costs and delivery time,
- monitoring the status of each and every process (machine), every product, and the system as a whole,

- monitoring in chronological order with different grains of resolution,
- Simulation which also includes added peripheral equipment such as an air-conditioner to equipment which is directly used in the production,
- Comparison between the process being performed automatically or manually
- Calculation of standby electricity required.

Requirements for the user interface are:

- ease of input of device configuration and information of manufactured products by using templates,
- easy change of setting for the process and optimization parameters,
- graphical display of the results,
- display of the result in chronological order,
- status of processes, products and machines that can see each view,
- chronological changes in energy consumption,
- view in terms of energy intensities such as CO2.

4 DIGITAL FACTORY AS A BASIS

4.1 Multi-agent structured digital factory

A digital factory is introduced as a basis of the digital eco-factory. In the digital factory introduced, all factory elements such as machine tools, assembly machines, robots, AGVs and workers are configured as software agents. In addition to these agents, manufactured products, machined workpieces and assembled parts are also configured as software agents. Fig. 4[4] shows the conceptual structure of the agent based digital factory. The digital factory has mirrored the structure of the actual factory. In Fig. 4, the shop floor is modeled as a virtual shop floor by machine agents as shown in the upper part of Fig. 4. The lower part of Fig. 4 shows the actual shop floor. There are two areas constituting the shop floor. One is the machining line, and the other is the assembly line. The installation and/or deletion of shop floor elements are simulated as installation and/or deletion of equipment agents[4].

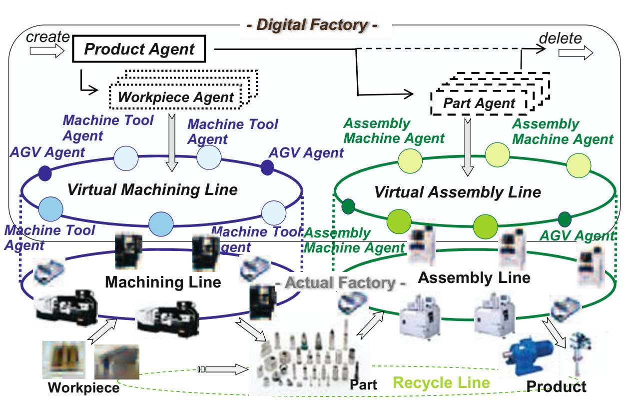

Fig. 4: Conceptual structure of the digital factory

4.2 Agents in the digital factory

In the digital factory, all of the constituent elements are constructed as agents including manufactured objects. When a product agent is generated according to the production plan, its virtual production is started. The product agent plans its own production processes to output the complete product. The product agent puts the workpiece agent on the virtual machining line. The workpiece agent selects machine agents to complete itself as a part. After virtual machining, the product agent puts the part agent on the virtual assembly line as the base part of the product. This part agent also leads the assembly processes for making the complete product. When the product is completed, the product agent and its related agents are deleted[4].

A machine agent is a machine tool agent for the virtual machining line and assembly machine agent for the virtual assembly line. A machine agent consists of a work estimator and operation/task planner, task scheduler, task manager, machine model and the machine operation simulator. In the machine model, the capability and specification of the machine is described[4].

The structure of the workpiece agent is shown in Fig. 5[5].The workpiece agent with the target part model is created by the product agent when the workpiece is input to the virtual machining line. The workpiece agent is deleted when the part is completed. The workpiece agent has a similar structure to a part agent. A workpiece agent consists of the part model, machining job planner, job allocator and transfer/machining requester. The job planner generates the machining work plan and the job allocator assigns machining works to the machine[4].

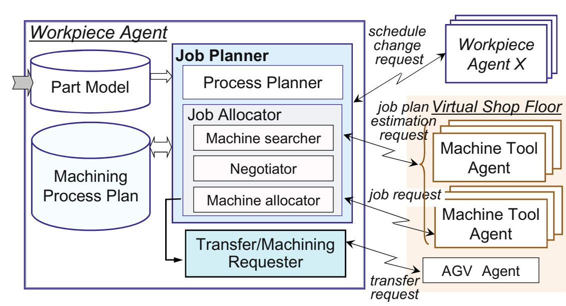

Fig. 5: Structure of a workpiece agent

4.3 Implementation of the digital factory

When considering the implementation of the digital factory, it is implemented as a simulation system with a multi-agent structure. The operator of this simulation system can set up the initial shop floor configuration through the user interface. According to this configuration, machine agents are generated. When the configuration is changed, it is automatically and easily reflected by the deletion/generation of machine agents. The operator controls the occurrences of machine error and repair. The operator also controls the generation of product agents by means of inputting a production order. Or the operator can directly input a production scenario and various parameters.

Implementation of the virtual assembly line based on the proposed concept has been tried. Fig. 6[4] shows the structure of the trial system. In this trial, the product agent has not yet been implemented. The human operator inputs parameters about the product lot. The parameters are for the assembly such as the kind of products and numeric targets. Assembly process plan data are also input by the operator. According to the input data, the part agent is generated by the system[4].

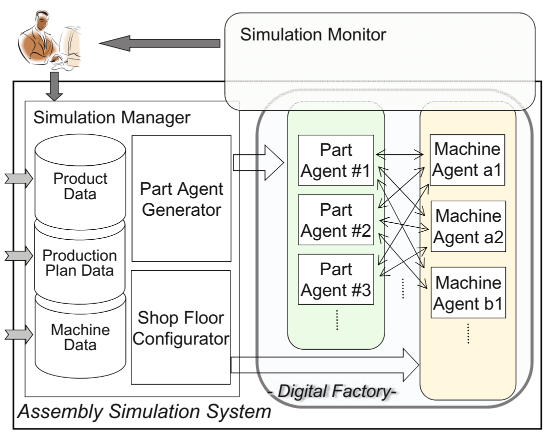

Fig. 6: Structure of the experimentally implemented virtual assembly system

5 CONSTRUCTION OF DIGITAL ECO-FACTORY

5.1 Agents in the digital eco-factory

To configure the digital eco-factory, functions in the environmental aspects are added to each agent. Product agent and machine agent are major agents in the digital eco-factory.

Product agent

In the manufacturing process, the substance of the product changes its form from workpiece to complete product through parts or sub-assembled parts. The product agent plans the processes required to turn the workpiece into the target product. The product agent with the product model is generated when its virtual production is started according to the production schedule. The Product agent monitors the virtual production performed on the virtual shop floor from the productivity view and environmental view. The structure of the product agent is shown in Fig.7.

The product agent is consists of the product model, work planner and process plan estimator. By referring to the product model, the work planner plans which component parts are machined in-house and which parts are manufactured outside of the factory. The product agent creates the workpiece agent for the part which is machined in-house. For assembly, the parts are categorized into a base part that forms the basis of the assembly operation and sub parts that are assembled with the base part. The work planner does the assembly process planning based on the product model, and obtains the assembly process model through the part relation model. Then, the work planner creates the part agent for the base part by referring to the process model. The part agent with the part model and the assembly process model is created by the product agent corresponding to each process when a new base part is input to the virtual assembly line[4]. The process plan estimator monitors the machine operation status, collects environmental data and productivity data, calculates environmental index, and estimates the process plan.

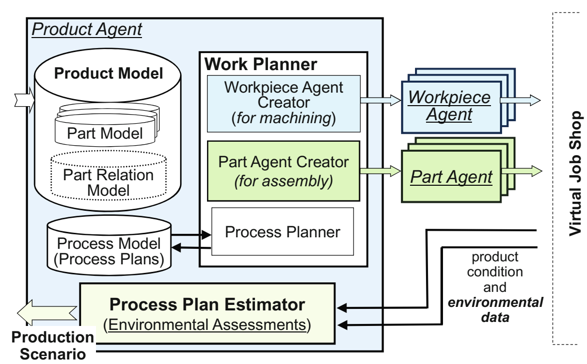

Fig 7: Product agent in the digital eco-factory

Machine agent

The general structure of a machine agent is shown in Fig. 8. When the workpiece/part agent asks whether a requested process can be performed by a machine, the operation planner in the machine agent determines which operations can be processed by the machine itself, generates its own schedule in the light of environmental parameters and replies with the possible operations and schedule. Once a job is allocated by a workpiece/part agent, the job manager and the job scheduler in the machine agent autonomously schedules operations,

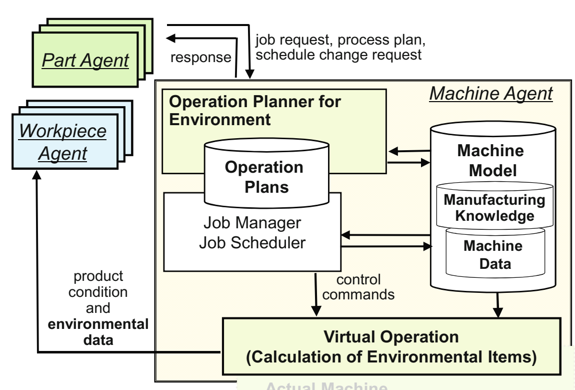

Fig. 8: Machine agent in the digital eco-factory

simulates controls and executions of the tasks, calculates environmental items, and reports the simulation status and results. When the machine agent is installed in the actual machine or when the machine agent directly controls the corresponding actual machine, it means real time planning, monitoring and control. The machine model is referred to at every stage. Specification data of a machine, operations which the machine can perform, knowledge on how to operate processes, and knowledge on how to calculate environmental indexes are described in the machine model.

5.2 Structuring of a digital eco-factory

The structure of the digital eco-factory configured as a multi-agent systems is shown in Fig. 9. The digital eco-factory is constructed as a multi agent system like a simple digital factory. There are three panels which have almost the same functionalities as a blackboard model in general multi-agent systems. Three panels are the plant panel, the infrastructure panel and product panel. The plant panel is showing the status and configuration of devices/ machines which is used to produce products in a virtual factory. The infrastructure panel indicates the status of infrastructure in the plant such as air conditioning and lighting. The product panel is functionally corresponding to the product agent. In addition, these panels also function as a user interface. The user can provide production scenario, configuration of the factory, energy saving plan and etc. by entering data on the panels.

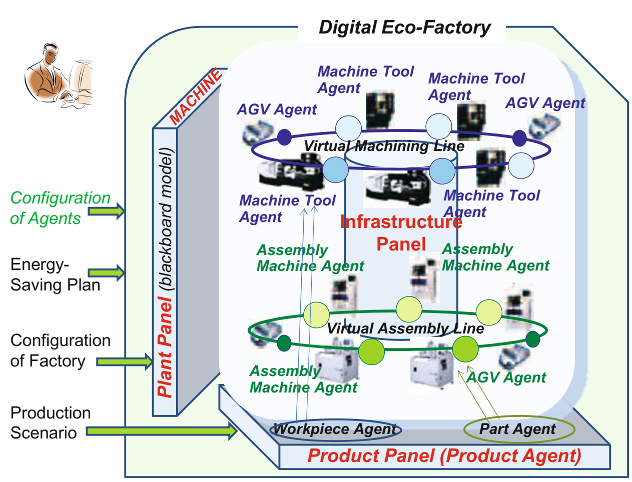

Fig. 9: Structure of the digital eco-factory

6 CONCLUSIONS

The digital eco-factory as an IT platform for supporting and promoting implementation of green production is proposed in this paper. The conceptual structure and a construction method of digital eco-factory is also discussed. Further refinement of the system design and prototyping the system are promoting the expectation to be able to provide the digital eco-factory as a SaaS on the Web.

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Cutting Condition Decision Support System Using Data Mining -Application of Life Cycle Assessment on Estimation of Cutting Conditions-

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Abstract:
A CAM system can only calculate the tool passing that followed to be used to control the tools for creating the material mold shape designed by using only a CAD system. However, the chosen tools and cutting conditions depend on the expert engineer's knowledge and experience, because expert engineers manufacture products by way of trial and error until they obtain the appropriate cutting conditions. We previously proposed data mining methods to make decisions about which end-milling conditions to use on the basis of the catalog data. Even inexperienced engineers can instantly decide on stable cutting conditions by a using cutting conditions decision support system. Thus, in this study, we investigate the different cutting conditions of the tool and the power consumption to evaluate the utility of our cutting conditions decision support system. The environmental burdens from the viewpoint of global warming were quantitatively evaluated using LCA (Life Cycle Assessment). We cut hardened die steel JIS SKD61 under three kinds of cutting conditions: catalog conditions, mined conditions and expert engineer conditions. The cumulative environmental burden was the lowest under the expert condition, which indicates that this condition has the most usefulness. However several trial-and-error processes must be repeated in order to reach the expert condition. We designed an index model of the environmental burden in the technical mastering process under this condition. The results show that unskilled engineers could decrease the cumulative environmental burden by working under the mined condition in the initial stage. Recommending the use of the mined condition in the initial stage is therefore considered best.

Key Words : Data mining, End-milling, LCA, Cumulative environmental burden, Learning curve

1 INTRODUCTION

Metal molds have recently been designed by using a computer-aided design (CAD) system, CL data created from the computer-aided manufacturing (CAM) system, and metal molds that have been manufactured at machining centers. The CAM system can only calculate the tool passing that followed to be used to control the tools for creating the material mold shape designed by using only a CAD system. However, the chosen tools and cutting conditions depend on the expert engineer's knowledge and experience, because expert engineers manufacture products by way of trial and error until they obtain the appropriate cutting conditions. Any wasted abolishment occurs at the stage prior to quantity production by taking the cost and developing time into consideration.

Mankind encountered some environmental issues due to the increasing amount of waste products based on large scale production and consumption of goods. Thus, modern society has taken more interest in these environmental issues, and eco-friendly products and manufacturing practices are becoming more main stream: [1] [2] [3] [4]. In particular, a lot of work has been done in the manufacturing field to achieve minimal CO_2 emissions, which is a requirement of ISO14001. A great deal of research has been conducted in the area of machining. Some studies have focused on evaluations to predict the environmental burden various systems have on the machining processes. This environmental burden prediction system has already been applied to the production process. However, little research has focused on reducing abolishment and the length of the mold manufacturing trial stage from the environmental burden viewpoint.

We have previously proposed data mining methods to make decisions about the end-milling conditions on the basis of the catalog data, and we have clarified the combination effect of hierarchical and non-hierarchical clustering. Even unskilled engineers can use our "cutting conditions decision support system" to instantly determine stable cutting conditions. In this study, we investigated different cutting conditions in terms of their power consumption to evaluate the effectiveness of our system. The environmental burden under various conditions was quantitatively evaluated using LCA (Life Cycle Assessment). We cut hardened die steel JIS SKD61

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(hereafter referred to as SKD61), under three different cutting conditions: those recommended in the catalog, those derived by data mining and proven cutting conditions recommended by expert engineers for die machining.

2 DATA MINING

2.1 Catalog mining process

We focus on catalog mining in this study , which is a data mining method that can be used to extract knowledge hidden in the catalog data: [5] [6]. The catalog mining process flow we used is shown in Fig. 1. Data on the square end-mills listed in the catalog from the largest tool maker in Japan were selected from a cutting tool catalog and stored as target data. The cutting conditions recommended by the cutting tool maker constitute a massive amount of accurate data reflecting solid experimental results the tool maker has personally overseen. In the data cleansing process, the target data was grouped using the K-means method, which is a non-hierarchical clustering method for the tool shape. It was performed using VMStudio (Mathematical Systems, Inc.). In the next step, as a statistical analysis, we determined a tree data structure using a variable cluster analysis, which is a hierarchical clustering method. We used a multiple regression analysis to predict the conditional equations. Since catalog mining is simple, fast, and comparatively more intelligible than other data mining methods, it should be easy for analysts who may be unfamiliar with the data mining techniques to use.

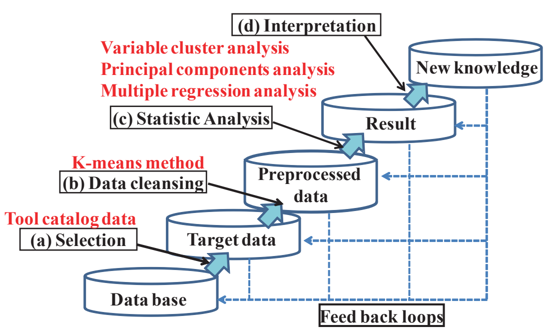

Fig. 1: Catalog mining process.

2.2 Catalog mining results

Fig. 2 shows a diagram of a cutting tool and the results obtained by the K-means method. It also shows the results of the variable cluster analysis and PCR on Cluster 2 (typical shape). We used three variables -L/ℓ, ℓ/De, and Ds/De- and visualized the shape of the end-mill using the K-means method. Cluster 2 accounts for 56% of the total data, which is the highest amount. We used the variable cluster analysis and Principal Component Regression (PCR) for each cluster classified by the K-means method from the viewpoint of the end-mill shape. This type of analysis shows the relationships between the structure of the predictor variables and any correlation with the criterion variables that were quantitatively calculated by the PCR. We compared the correlation coefficients with the criterion variable between the high predictor variables and the reduced low correlation by using the variable cluster analysis and PCR results. We were able to determine the cutting condition decision equations using the variables determined to be significant in the multiple regression analysis. As an example, the equations for Cluster 2 consisted of a criterion variables vector, a coefficient matrix, and a predictor variables vector (as shown in Eq. (1)). We consider the determination coefficient R to be generally significant in cases where it is 0.5 or more. In this study, we use the LCA to test whether Eq. (1) obtained by catalog mining is a significant cutting condition from the viewpoint of the environmental issues.

$$\begin{bmatrix} Ad(R0.79) \\ Rd(R0.30) \\ S(R0.26) \\ F(R0.04) \\ V(R0.04) \\ f(R0.06) \end{bmatrix} = \begin{bmatrix} 0.87 & -0.13 & 0.12 & 0 & 0 & 0 & 2.50 \\ 0.07 & -0.04 & 0 & 0 & 0 & 0 & 2.39 \\ -222 & 53 & 0 & -132 & 0 & 0 & 7978 \\ -22 & 22 & 0 & 0 & -9 & 0 & 581 \\ 0 & 0.45 & 0 & 0 & 0.58 & -0.81 & 74 \\ 0.002 & 0 & 0 & 0 & 0 & 0 & 0.039 \end{bmatrix} \begin{bmatrix} D \\ HRC \\ L \\ l \\ \theta \\ z \\ 1 \end{bmatrix} \quad (1)$$

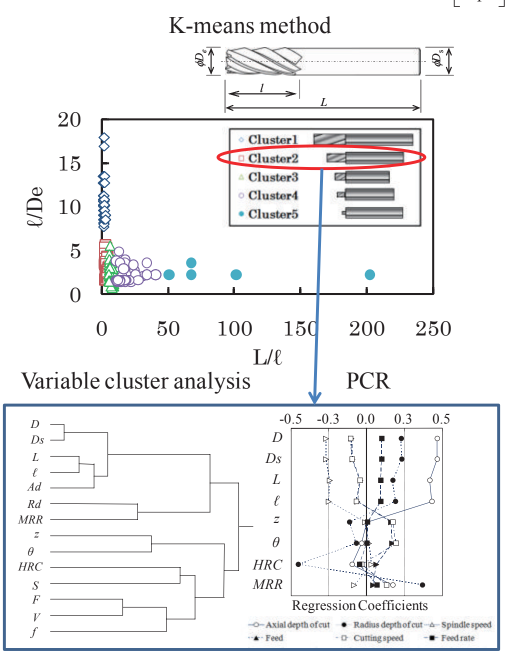

Fig. 2: Data mining results of Cluster 2.

3 ENVIRONMENTAL BURDEN ASSESMENT

3.1 Life Cycle Assessment

A Life Cycle Assessment (LCA), which is a method that quantitatively evaluates the environmental burden in the life cycle of the excavation of the material used for a product, from fabrication through to transfer, usage, and disposal, is the standard for measuring the contribution level of sustained economic development. As prescribed in ISO14042, a LCA consists of four elements: goal and scope, life cycle inventory, life cycle burden assessment, and interpretation. We created a function of the object product and the standard to clearly perform a LCA and set the goal and scope. Next, we determined the range of the

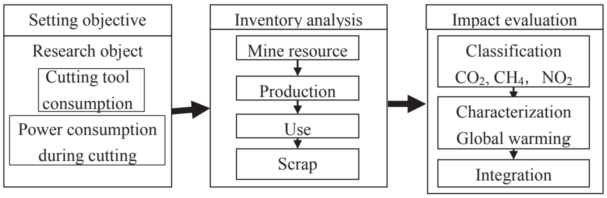

Fig. 3: LCA flow.

Table 1: Cutting conditions used in experiments.

Data type	Catalog conditions	Expert engineer	Mined conditions
Spindle speed rpm	20000	9600	7739
Feed mm/min	7200	2304	2368
Cutting speed m/min	377	181	146
Feed rate mm/tooth	0.06	0.04	0.05
Axial depth of cut mm	6	4	9
Radius depth of cut mm	0.30	0.30	0.50
MRR cc/min	12.96	2.77	10.46

process related to the life cycle of the products and investigated the environmental burden. JEMAI-Pro was used as the LCA software. The background data was obtained from the JEMAI-Pro archives.

3.2 Research objective setup

We focused on three cutting conditions: those recommended by the catalog, those derived by catalog mining and the proven cutting conditions suggested by expert engineers. Our aim was to test the availability of mined conditions by comparing three conditions from the viewpoint of the environmental issues. Thus, we used a LCA. The LCA flow is shown in Fig. 3. The research objects we used are the tool consumption and power consumption while cutting under three cutting conditions for Eq. (2).

$$C = T + E \tag{2}$$

C: cumulative environmental burden kg-CO_2
T: environmental burden of cutting tool kg-CO_2
E: environmental burden of power consumption of machine tool kg-CO_2

Since we determine the environmental burden of cutting tool T and the power consumption of machine tool E, we performed tool life experiments and measured the power consumption of a machine tool under three cutting conditions. We cut SKD61, which is commonly used in die machining as a workpiece. Table 1 lists the data mining results (cutting conditions) obtained by substituting the tool parameters into the above equations (mined conditions), the catalog cutting conditions (catalog conditions), and the cutting conditions suggested by expert engineers (expert engineer). We used the tool (ϕ6 radius end-mill) shown in Fig. 4. The tool we used belongs to Cluster 2, which is the cluster with the most data. The experiments involved processing (down-cut, one pass) a flat surface. The machine tool was an ACCUMILL4000 made by Mori Seiki (maximum spindle speed: 20000 rpm). We performed a precision cutting in which the tool run-out had to be 5 µm or less. The tool extension was 30 mm. All the cuttings were conducted under dry conditions. Since the environmental evaluation is based on global warming in Japan, we

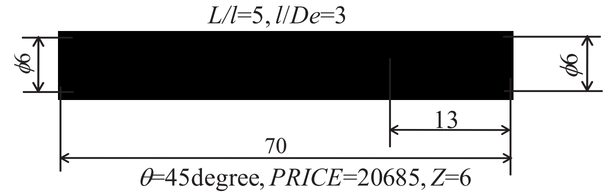

Fig. 4: Tool shape parameters.

Table 2: Global warming characterization factors.

	CO_2	CH_4	N_2O
Global warming potential (GWP)	1	21	310

selected global warming as the environmental effect item. We measured the amount of CO_2, CH_4, and N_2O that were emitted, as these three are the key factors influencing global warming. All the emissions were converted to equivalent CO_2 emissions by multiplying them by some characterization factors. Their environmental burden as an indicator was calculated by adding all the emissions. As shown in Table 2, the global warming potential (GWP) of a 100-year burden was used as the characterization factor. In this study, the system boundary was limited to just one machine tool (ACCUMILL 4000) for the usage stage and cutting tool abolishment. This enabled us to write off the materials and power consumption used in the machine tool construction and disposal. The work materials were also written off, because chips and broken cutting tools are not recycled for work or as a tool used in precision cutting, and we did not consider chip recycling. We performed cutting experiments and measured the power consumption of a machine tool under the three cutting conditions.

3.3 Environmental burden of cutting tool

We determined the environmental burden of producing and disposing of the cutting tool. This burden is expressed as

$$T = \frac{TUT}{TL} \times (TPe + TDe) \times TW \times W \tag{3}$$

T: environmental burden of cutting tool kg-CO_2
TL: tool life m
TUT: cutting distance of a workpiece m
TPe: environmental burden of cutting tool production kg-CO_2/kg
TDe: environmental burden of cutting tool disposal kg-CO_2/kg
TW: tool weight kg
W: number of workpieces

We used the CO_2 discharge rates from the cutting tool production and disposal proposed in a previous study. These CO_2 discharge rates refer to the environmental burden of cutting tool production TPe = 33.7 kg-CO_2/kg and the environmental burden of the cutting tool disposal

Table 3: Results of lifetime experiments.

	Catalog conditions	Mined conditions	Expert engineer
Longevity distance m	43	50	501
Cutting distance mm	2150	1250	2150

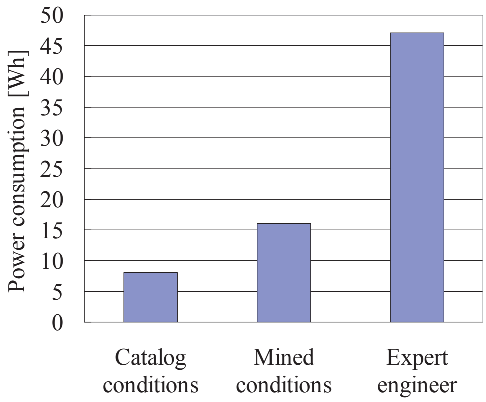

Fig. 5: Power consumption under each cutting condition.

$TDe = 1.3 \times 10^{-2}$ kg-CO_2/kg: [7].We consider the weight of the cutting tool used in this study (Fig. 4) to be TW= 29 g, which is given in Eq. (4) from Eq. (3).

$$T = 0.98 \times \frac{TUT \times W}{TL} \quad (4)$$

The tool life experiment, which was conducted for the three cutting conditions is performed to use Eq. (4), was performed during the side milling in the down cut, one path direction. The experimental results as well as the cutting distance leading up to the finished shape under each cutting condition are listed in Table 3. This enabled us to calculate the environmental burden of the cutting tool during side milling under all three conditions. The environmental burden under the catalog condition during side milling T_c kg-CO_2, under the mined condition during side milling T_m kg-CO_2 and under the expert condition during side milling T_e kg-CO_2 are given as Eqs. (5), (6), and (7), respectively.

$$T_c = 4.9 \times 10^{-2} \times W \quad (5)$$

$$T_m = 2.4 \times 10^{-2} \times W \quad (6)$$

$$T_e = 4.2 \times 10^{-3} \times W \quad (7)$$

3.4 Environmental burden of machine tool's power consumption

In this study, we set the power consumption of machine tool (ACCUMILL4000) cutting one workpiece using the cemented carbide radius end-mill (as shown in Fig. 4) to the inventory data as the environmental burden of machine tool's power consumption. The measurement results are shown in Fig.5. These results demonstrate that high-speed cutting is predictably effective. However, our study is slightly different in that we highlight the importance of using appropriate cutting conditions to enable long life cutting, especially when working with SKD 61. The environmental burden of the power consumption of the machine tool under catalog condition E_c kg-CO_2, mined condition E_m kg-CO_2, and expert

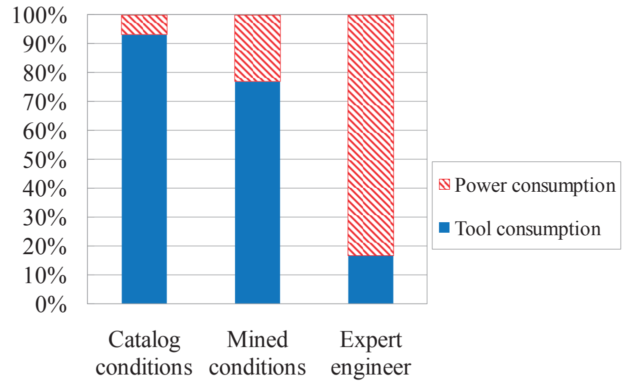

Fig. 6: Ratio between tool and power consumption under each cutting condition.

engineer condition E_e kg-CO_2 is shown below in Eqs. (8), (9), and (10), respectively.

$$E_c = 3.6 \times 10^{-3} \times W \quad (8)$$

$$E_m = 7.2 \times 10^{-3} \times W \quad (9)$$

$$E_e = 2.1 \times 10^{-2} \times W \quad (10)$$

4 CONSIDERATION

We combined the cumulative environmental burden under the three cutting conditions from the view point of global warming with the environmental burden of both the cutting tool and the power consumption. The cumulative environmental burden under catalog condition C_c kg-CO_2, mined condition C_m kg-CO_2, and expert engineer condition C_e kg-CO_2 are given in Eqs. (11), (12), and (13), respectively.

$$C_c = 5.2 \times 10^{-2} \times W \quad (11)$$

$$C_m = 3.1 \times 10^{-2} \times W \quad (12)$$

$$C_e = 2.5 \times 10^{-2} \times W \quad (13)$$

First, we compared the cumulative environmental burden for the three cutting conditions from Eqs. (10) - (12). C_m roughly accounts for 60% of the C_c, C_m roughly accounts for 124% of the C_e. Second, we calculated the ratio between the environmental burden of the tool and its power consumption to obtain the overall cumulative environmental burden. The results are shown in Fig.6. The environmental burden of the cutting tool accounted for 17% of the cumulative environmental burden under the expert conditions, 77% under the mined condition, and 94% under the catalog condition. This demonstrates that the expert condition is preferable for reducing the amount of tool consumption and the catalog condition is preferable for reducing the machine tool power consumption. In the case of the expert condition, the cutting condition that reduces the amount of tool consumption has a smaller cumulative environmental burden than the cutting condition that reduces the machine tool power consumption during cutting. The amount of tool consumption was the lowest under the expert condition, which indicates that this condition has the most usefulness from a global warming perspective. However

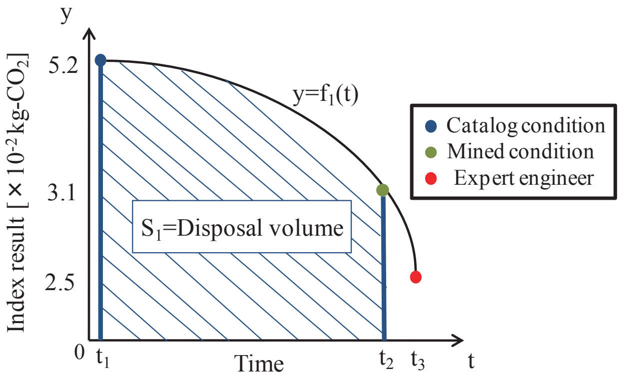

Fig. 7: Learning curve (case 1).

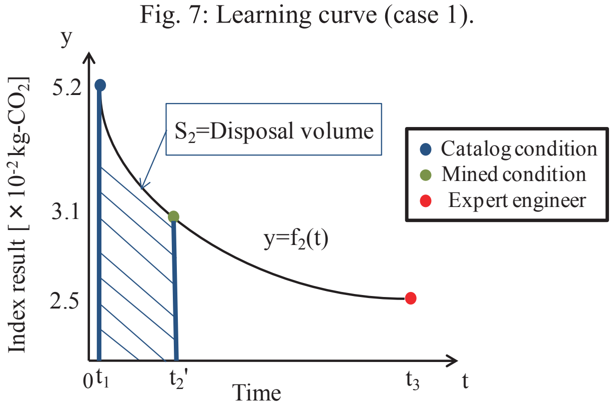

Fig. 8: Learning curve (case 2).

to reach the expert condition, several trial-and-error processes, which consumed not only time but also cutting tools and electric power, must be repeated. Thus, we designed an index model of the environmental burden in the technical mastering process. We referred the technical mastering process to a learning curve: [8]. The learning Curve defines that the more the production volume is doubled the shorter the processing time by a constant ratio. Since the learning curve depended on the learning level, we proposed two patterns and they are shown in Figs. 7 (Case 1) and.8 (Case 2). Case 1 is $t_2 > t_1 + t_3/2$ and Case 2 is $t_2' < t_1 + t_3/2$ under the $t_1 < t_2' < t_2 < t_3$ condition, respectively. The area indicated by the diagonal lines shows the cumulative environmental burden during the period between the catalog and mined conditions. The area indicated by the diagonal lines expresses Eqs. (14) and (15).

$$S_1 = \int_{t_1}^{t_2} f_1(t)\ dt \tag{14}$$

$$S_2 = \int_{t_1}^{t_2'} f_2(t)\ dt \tag{15}$$

Both S_1 and S_2 are show a disposal volume during the period between the catalog and mined conditions, which are to say, using mined conditions can decrease the disposal volume, and $S_1 > S_2$ shows that Case 1 can decrease more disposal volume than Case 2. When comparing between the curves of Case 1 and Case 2, We see that it is hard to acquire expert conditions in Case 1. Thus, Case 1 has a lot of advantages when using the mined conditions, and takes a little more time to achieve the expert conditions. Case 2 takes reasonable advantage when using the mined conditions, and still has a long way to achieve the expert conditions. As a result, using the mined conditions decreases the disposal volume in the initial stage. Recommending the use of the mined condition in the initial stage is therefore considered best.

5 CONCLUSION

The expert condition is preferable for reducing the amount of tool consumption and the catalog condition is preferable for reducing the machine tool power consumption. The expert condition has the smallest cumulative environmental burden under the three conditions. Several trial-and error processes must be repeated in order to reach the expert condition. To solve this problem, we propose technical mastering process model, and recommend using the mined condition in the initial stage.

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Resource efficiency assessment of discrete manufacturing processes: Comparison between energy- and exergy-based metrics

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Abstract
Recent applications of exergy analysis on discrete manufacturing process have been stimulated by the quest for more sustainable industrial systems. However, the benefits and drawbacks of exergy analysis in comparison to energy analysis are less prevalent in the discrete manufacturing literature. Therefore, this paper contributes to this discussion by presenting a comparison between the two analyses for a discrete manufacturing process.

Keywords:
Sustainable manufacturing, exergy analysis, resource efficiency, discrete manufacturing process

1 INTRODUCTION

The significance of sustainable manufacturing for sustainable development has been widely studied and reviewed [1], [2]. Improving resource efficiency of manufacturing processes has become one of the main concerns toward attaining sustainable manufacturing. In order to do that, first the process input and output need to be quantified. Given the variety of inputs and outputs, as well as the presence of different sustainability objectives, the number of metrics required to fully quantify the process can be quite excessive.

Among different available approaches, the application of thermodynamic metrics has been proposed as a fundamental way to perform resource accounting in manufacturing process setting ([3], [4]). It is based on the first and second law of thermodynamics, where the first law analysis utilizes mass and energy balance as the main tools and the second law analysis can be considered as exergy-based analysis. The efficiency metrics derived from each analysis are then employed to describe the resource efficiency of the corresponding process.

Exergy is defined as the maximum obtainable work from a system, as it is brought to equilibrium with its environment or reference state [5]. Unlike energy, exergy is not conserved; thus, exergy can be destructed in a system. In-depth discussions on the development and application of the exergy concept in general can be found in the literature [5, 6].

One of the early studies on the implementation of exergy analysis on a discrete manufacturing process was conducted by Creyts and Carey [7]. They utilized exergy analysis to evaluate the environmental performance of machining processes. In a more recent study, Gutowski et al. have developed a thermodynamic framework to analyze a generic manufacturing process [3]. They also calculated the exergy efficiency of different manufacturing processes. On a manufacturing system level, Saiganesh and Sekulic applied exergy analyses for a production line of printed circuit boards [8]. Their study shows the applicability of exergy analysis in locating the potential improvements within a production system.

Similar to exergy analysis in power generation and process industry systems, the exergy analysis in a discrete manufacturing system aims to detect and evaluate thermodynamic imperfection and indicate possibilities for improvement. However, unlike in the traditional thermal-process literature, the benefits and drawbacks of exergy analysis in comparison to energy analysis are less prevalently discussed in the discrete manufacturing field. Therefore, this paper attempts to contribute by presenting a comparison between both approaches as they are applied to a discrete manufacturing process. A laser cutting process is selected as a case study to illustrate the benefits and drawbacks of each approach.

2 METHODOLOGY

2.1 System boundary

As widely known from traditional engineering analysis and more recently from life cycle engineering studies, the importance of defining system boundaries in an analysis is of high importance. The relevance and significance of analysis conclusions are heavily dependent on the system boundary.

There are two types of system boundary considered in this study: spatial and temporal boundaries. The spatial boundary for the present study is a discrete manufacturing machine, as illustrated in Figure 1.a. Supporting sub-systems of a machine, such as a cooling system and a

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process gas generator, are included within the boundary as long as they are integrated within the machine. As for the temporal boundary, every sub-process involved in manufacturing a product is included within the boundary, as shown in Figure 1.b. For example, the batch pre-heating and cooling phase in a laser sintering process is regarded as an integral part of the manufacturing process, in addition to the sintering process itself. Later in the analysis, a modified system boundary will be used in order to illustrate particular discussions and to underline the importance of system boundaries in interpreting the results.

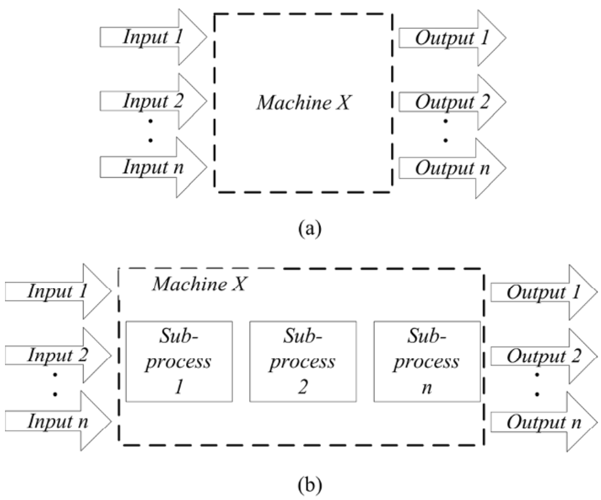

Figure 1. Generic system boundaries:
(a) Spatial; (b) Temporal

2.2 Energy and mass analysis

The general energy balance of a system is given in Equation (1). In this study, we assume a steady state condition for all processes; thus, the left-hand side of Equation (1) equals zero. The enthalpy term, H includes the enthalpy rate of the workpiece, product, waste and support materials such as process gas.

$$\frac{dE}{dt} = \Delta\dot{Q} + \Delta\dot{W} + \Delta\dot{H} \tag{1}$$

It should be noted that Equation (1) is based on an open thermodynamic system which involves continuous flows of various materials and energy transfers. However, in a discrete manufacturing process, the workpiece material enters and exits the system in a non-continuous manner. In the current study, each material and energy quantity will be considered to be an integrated value along the process time.

Determining the energy efficiency of a discrete manufacturing process is not as straightforward as in energy systems. This is because the "desired output" of a manufacturing process is not always obvious; furthermore, there are arrays of different processes with various intended effects. Therefore, the numerator of energy efficiency needs to be adjusted according to the analyzed process. For example, the desired effect of a cutting process is material removal, so the numerator in Equation (2) is the enthalpy of the removed material.

$$\eta_{energy} = \frac{E_{desired\ effect}}{E_{input}} \tag{2}$$

As a way to overcome the aforementioned problem, several authors have proposed to use the minimum theoretical work as the numerator of the energy efficiency metric [9, 10]. It will be obvious from the case study that this is practically the same as Equation (2) when the energy required for the "desired effect" is calculated theoretically.

In order to take into account the non-energetic resource utilization, a material efficiency metric is included in this study. The metric is based on the mass of materials involved in the manufacturing process, which includes the workpiece material and other auxiliary materials, such as compressed air and process gases. In the present study, the material efficiency is defined as the ratio of useful product to the total input mass.

$$\eta_{material} = \frac{m_{product}}{m_{input}} \tag{4}$$

2.3 Exergy analysis

In its simplest form, the exergy balance of a system can be written as in Equation (5). Here, B_{in} represents the sum of the exergy of all input streams, while B_{out} defines the output streams' exergy, as illustrated in Fig. 2. The internal exergy loss $B_{loss,int}$ is exergy loss due to internal irreversibilities in the system. Details on the derivation of the exergy balance from energy and entropy balances can be found in Szargut et al. [5] and Gutowski et al. [3].

$$B_{loss,\mathrm{int}} = B_{in} - B_{out} \tag{5}$$

As in case of the energy metric, there are several definitions of exergy efficiency which can be utilized in a discrete manufacturing process. A brief description will be given in the following paragraphs. A more detailed discussion on different exergy efficiency definitions can be found in Renaldi et al [11].

For this study, the utilizable exergy coefficient η_u will be used for additive and mass-conserving processes, while the efficiency of removal η_r will be employed for subtractive processes. The utilizable exergy coefficient η_u is defined by Sorin et al. [12] as the ratio between produced utilizable exergy and consumed exergy.

$$\eta_u = \frac{B_{pu}}{B_c} = \frac{B_u - B_{tr,u}}{B_{in} - B_{tr,in}} \tag{6}$$

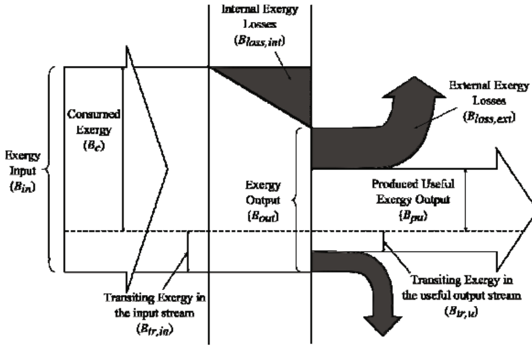

Figure 2. Graphical representation of different types of exergy streams (adapted from [12]).

Branham and Gutowski [13] defined the efficiency of removal η_r as the ratio of exergy content of the removed material to the consumed exergy (i.e. removed material exergy and any other necessary exergy input such as electricity and consumables).

$$\eta_r = \frac{B_{removed}}{B_c} \tag{7}$$

3 CASE STUDY: LASER CUTTING PROCESS

The investigated laser cutting process is performed on a high power (5kW) conventional CO_2 laser cutting machine tool for sheet metal cutting operations. In this study, the laser cutting is employed to cut a 1 mm thick S235JR steel sheet with 1.6 m cutting length. The details on power consumption and different machine modes of the laser cutting machine are available in [14].

As shown in Table 1, the input to the system includes the workpiece, electricity and process gas, while the output comprises the product, waste material and purged gas. The process gas, Nitrogen in this case, is assumed to pass through the system unmodified. In reality, a small amount of Nitrogen will react and produce NO and NO_2, but these quantities are negligible.

3.1 Energy analysis

Table 1 summarizes the energy analysis of the laser cutting process. The enthalpy of steel sheet input, product and waste steel output are zero because they enter and exit the system at the ambient temperature, i.e. 298 K, which is utilized as a reference to determine the enthalpy change. Furthermore, the higher cut material enthalpy includes the enthalpy change of the material from the ambient temperature to the melting temperature and the latent heat of fusion. For the steel sheet workpiece, melting temperature T_m = 1808 K, standard temperature T_0 = 298 K, average specific heat capacity between T_0 and T_m $c_{p,ave}$ = 0.7 kJ/kg K, and enthalpy of fusion, h_f = 270 kJ/kg. Using these properties, the specific enthalpy of the cut material is approximately 1327 kJ/kg.

The desired effect of this process is to remove part of the workpiece material by heating up and melting the kerf. By assuming the absence of conduction losses and of vaporization, the theoretical energy consists of the required energy to heat the kerf to melting temperature and to melt it (Eq. 9 [15]).

$$P_{theor.} = P_{heating} + P_{melting} = m_{cut} c_p (T_m - T_0) + m_{cut} h_f \tag{9}$$

Thus, the theoretical required energy is the product of mass and the enthalpy difference of the cut material. The value is approximately 8.2 kJ. Using this value and the total energy input, the energy efficiency of the process can be estimated to be approximately 1%.

The material efficiency calculation is relatively straightforward since it is based on mass. For the laser cutting process, the material efficiency is 57.8%.

Table 1. Summary of the energy and exergy analysis of the laser cutting process

	Material / Energy	**Mass (kg)**	**Specific enthalpy (kJ/kg)**	**Energy (kJ)**	**Total energy (kJ)**	**Specific exergy (kJ/kg)**	**Exergy (kJ)**	**Total exergy (kJ)**
Input	Steel sheet	0.247	0	0	784.9	6750	1667.25	2453.93
	Nitrogen	0.073	1.93	0.14		25.7	1.87	
	Electricity			784.8			784.8	
Output	Product	0.185	0	0	784.9	6750	1248.75	1680
	Cut steel	0.00624	1327	8.2		8497	53	
	Waste steel	0.05576	0	0		6750	376.38	
	Purged N_2	0.073	1.93	0.14		25.7	1.87	
	Waste heat			776.5				

3.2 Exergy analysis

The exergy analysis of the laser cutting process is also shown in Table 1. Since most of the inputs and outputs are at ambient pressure and temperature, only the specific chemical exergy contributes to the exergy value. One exception is for the cut material, which leaves the system at an elevated temperature. In this case, the physical exergy due to the difference in temperature has to be considered. The difference between the physical exergy at melting and at ambient temperature is calculated as follows:

$$\Delta B_{ph} = \left(h_{T_m} - h_{T_0}\right) + T_0\left(s_{T_m} - s_{T_0}\right)$$
$$= c_{p,ave}\left(T_m - T_0\right) + h_f + T_0\left[c_{p,ave}\ln\left(\frac{T_m}{T_0}\right) + \frac{h_f}{T_m}\right] \quad (8)$$

Plugging the respective properties into Equation (8), the difference in physical exergy between the two states is approximately 1747 kJ/kg. Therefore, the exergy value at the melting temperature is the sum of the standard chemical exergy and the physical exergy.

For calculating the exergy efficiency, the efficiency of removal (Eq. 7) is used as the metric because laser cutting is a subtractive process. The exergy value of the cut material is the numerator, while the denominator is the sum of the exergies of the cut material, nitrogen and electricity inputs. The efficiency of removal is approximately 6.3%.

3.3 Discussion

In both the energy and the exergy analysis, the thermodynamic properties of the input-output components need to be determined as a part of the resource accounting process. For discrete manufacturing process, this step can be less straightforward than, for example, the traditional thermal system. In comparison, the exergy values of many engineering materials are not as readily available as its enthalpy values. This has been arguably one of the barriers that hamper the application of exergy analysis in non-thermal-process industrial settings. The calculation methods and simplified assumptions are available in textbooks and research papers, but these sources are less widely recognized outside the respective field. Another related problem is the less tangible nature of exergy, since it is related to the "quality" of energy.

It can be seen from Table 1 that the major difference between energy and exergy analysis of the laser cutting process is the quantification of the material flow which leads to the relative value of material over energy component. In the exergy analysis, the workpiece material has a significantly higher value than the electricity, while the exact opposite is true in the energy analysis. In the energy analysis, material is quantified with its mass and enthalpy value. The corresponding material efficiency is then based solely on the mass of the material, which does not show the quality of the different materials. On the other hand, the exergy approach integrates the physical and chemical exergy of the material in the analysis; thus, the relative importance between energy and material is well represented. Therefore, resource efficiency improvement measures can be taken according to this relative importance.

The Sankey (energy) and Grassmann (exergy) diagram of the laser cutting process are depicted in Fig. 3 to assist further comparison of both analyses. The system is illustrated between the two parallel vertical lines. It should be noted that Fig. 3(a) and (b) are not on the same scale. The contribution of nitrogen gas is not depicted here due to its relatively low value.

From Fig. 3(a), the electricity can be perceived as the major contributor in the input side, while the waste heat serves the role in the output. The energy analysis gives an impression that the majority electricity input ends up as waste heat, with a small portion being utilized to heat up the cut material. It is obvious that this slightly distorted view is not correct since the electricity provides the required energy for different sub-units inside the machine in order to ensure that it can deliver its goal to cut the workpiece material. In order to illustrate this, a more granular spatial system boundary is required. A view on different sub-units inside the machine is considered for this purpose.

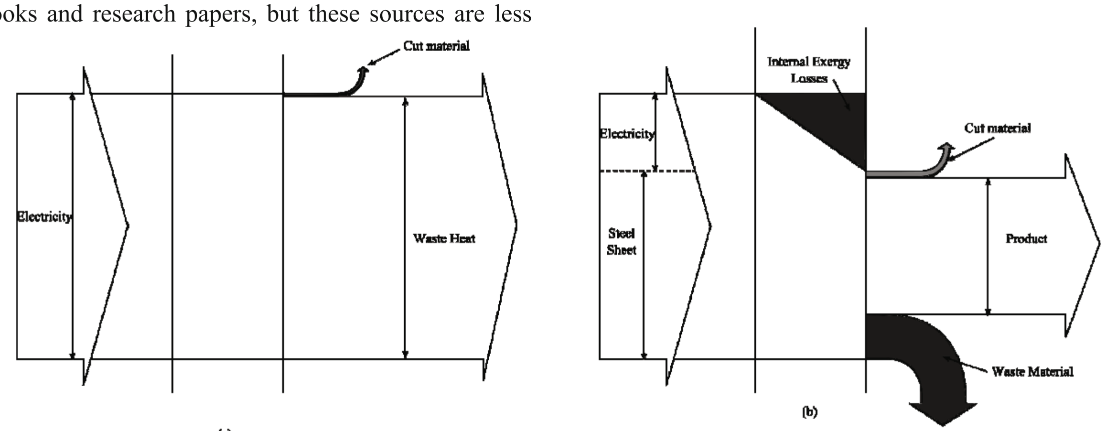

Figure 3. (a) Sankey diagram (energy) and (b) Grassmann diagram (exergy) of the laser cutting process

The energy flows from the electricity input to different sub-units are illustrated in Fig. 4. It should be noted that the diagram represents the laser cutting machine, instead of the process. It shows that the laser source has the highest share of power consumption, followed by the cooling unit. Therefore, as concluded in [14], the improvement in these two sub-units will have a significant impact on the energy efficiency of the machine.

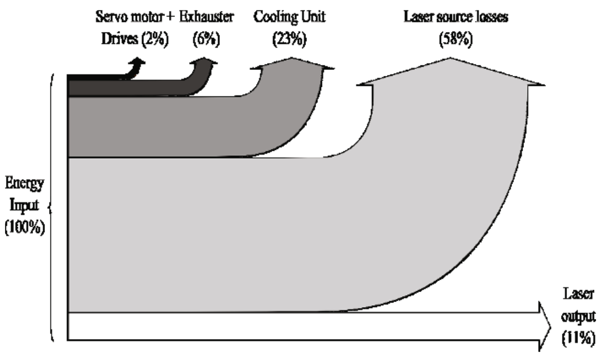

Figure 4. Energy diagram of the laser cutting machine

Unlike in the energy analysis, there is discrepancy between the total input and output exergy, which can be contributed to the internal exergy losses due to inherent irreversibility of the system. This internal irreversibility loss is depicted in the Grassmann diagram of the laser cutting process (Fig. 3(b)). Therefore, in contrast to the energy diagram, it is readily clear from the exergy diagram that the electrical exergy input is partly utilized to melt the kerf and mostly consumed inside the system.

Although the misleading perspective in the energy analysis is directly avoided in the exergy analysis, the improvement potentials in different sub-units can only be identified by the exergy analysis if it was applied with the same granular spatial boundary as used in the previous energy analysis. This would lead to the similar diagram as Fig. 4, since energy equals exergy for electricity.

Three improvement potentials can be deduced from Fig. 3(b). The first one is reducing the internal losses, which was explained in the previous paragraphs. Second potential is in reducing waste material, for example by improving the nesting efficiency of the laser cutting process. Finally, the cut material also represents an improvement potential since its specific exergy value is relatively higher than the input material and theoretically, this exergy can be recovered. However, it is clear from real cutting process that the high temperature of cut material will be quickly lowered to the ambient temperature by heat transfer due to convection from the nitrogen and radiation to the environment. Therefore, this example clarifies the fact that the exergy analysis can detect and evaluate the improvement potentials, but cannot indicate whether such potentials are feasible.

Table 2. Different resource efficiency metrics of the laser cutting process

$\eta_{material}$ (%)	η_{energy} (%)	η_{exergy} (%)
57.8	1.04	6.31

The results of the different efficiency metrics from the energy and exergy analysis are summarized in Table 2. The material efficiency has a significantly higher value than the other two metrics. In the case of laser cutting, this value is more heavily determined by the nesting efficiency rather than by process variables. Despite its relatively low value, the energy efficiency metric can be useful to compare two similar processes, for example laser cutting and plasma cutting process. These two processes have basically the same physical mechanism to remove the workpiece material, i.e. melting the kerf. To reach the theoretically required energy is basically impossible in a real process due to inherent irreversibility and the need of auxiliary sub-units; therefore, this value can serve as an absolute benchmark to compare different processes with the same basic mechanism.

The importance of the basic mechanism in comparing two processes based on their energy efficiency cannot be overlooked. Branham et al. have discussed one of the problems with using isentropic energy efficiency as a metric, which is the variety of approaches for calculating the theoretically required energy [10]. For example, there are three possible ways to calculate the minimum required energy for material removal. An option to solve this problem is by constantly using one approach in comparing different processes. It should be underlined that these processes must have the same basic physical mechanism.

Since laser cutting is a subtractive process, the efficiency of removal is used as the exergy efficiency metric. In this case, its value lies between the material and energy efficiency. The exergy efficiency value considers both material and energy usage in one metric. Unlike the material efficiency, exergy efficiency includes not only the mass of the material, but also the quality relative to standard condition.

A unified resource efficiency metric which combines material and energy efficiency is proposed by Reinhart et al. [9]. It is achieved by adding the two metrics, with prescribed weight for each of them. For example, if the material and energy efficiency have the same level of importance, then the resource efficiency is calculated as the average between the two metrics. The prescribed weight arguably makes this metric less natural than the exergy efficiency metric because of the subjectivity in determining the weight. On the other hand, the exergy value has its own inherent weight stemming from thermodynamic principles. Although it is also fair to mention that the unified resource efficiency metric is relatively more straightforward to calculate than the exergy efficiency.

4 SUMMARY

Comparison between energy and exergy analysis of a discrete manufacturing process has been described in this paper, with a laser cutting process serving as a case study. Both approaches have their benefits and drawbacks in regards of determining the thermodynamic properties during the resource accounting step, relative importance between material and energy components, and the ability to detect improvement potentials.

Determining the thermodynamic properties is in both analyses less straightforward than with thermal systems. This is especially true for the exergy analysis, which makes it less applied in the industry. However, exergy analysis succeeds in quantifying resources on a level playing field and in detecting the improvement potentials of the corresponding system.

The exergy efficiency is a useful resource efficiency metric since it considers both material and energy utilization in one metric. Unlike the material efficiency, exergy efficiency includes not only the mass of the material, but also the quality relative to standard condition. On the other hand, the energy efficiency metric can be useful to compare two similar processes which have the same basic physical mechanism.

5 ACKNOWLEDGEMENTS

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Reciprocal design of industrial value chain

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Abstract
This report is discussing the merit of reciprocity in the industrial value chain for our society to be sustainable. Reciprocal schemes of manufacturing and delivery are necessary to continue our copied mass-products based lives long[1][2]. A case study of lighting devices such as CFL(Compact Fluorescent Lamp)s and LED lamps shows a great amount of reduction of resources[3]. Continued use of their products with such reciprocal schemes increases the RPR(Resource Performance Ratio) of products while the Inditial value of the renewed one which is re-created as a result of the applied additional resources to a product keeps its value[4]. Where in the lighting device case the RPR is evaluated as the total amount of light emission vs total resources that are applied to the device and consumed for the emission. New design of printed circuit board is also discussed in order for the reciprocal mass-manufacturing schemes to be successful. Schemes of replacing deteriorated parts are discussed from mechanical view and also on necessary parts information and on relating rights aspect. This also scopes smaller "manufacturing by hand" case from a trial study[5].

Keywords:
Reuse, Reciprocal design, Resource Performance Ratio, Inditial value, CFL, LED lamp

1 INTRODUCTION

People must agree with the concept of the benefit for all that more products can be used for less resources[6]. Reuse is the answer to the concept and the Reciprocal Design will proceed the reuse schemes.

Our society is supported by the large amount of mass-produced copies of electronics devices. So it is very useful for this objective that the scheme of repairing devices with minimum resources for recovering most functions of the new ones.

There are pessimistic opinions against such Reuse schemes because of the profit of one-way oriented value adding chain structure of the mass-producing industry.

In every step such as materials, parts and assemblies, manufacturers can find to add great values between the one-way value chain because of the lower cost of the input resources for the higher price of their value added output products.

So the manufacturers try to find more efficient lower cost schemes to get higher grade output namely by introducing non-reversible assembling schemes with higher reliability parts, i.e. from screw to rivet, from socket to solder.

Such non-reversible schemes have been introduced in mass-production industry.

2 REPAIRING SCHEMES

It seems that the repairing schemes are not estimated to lead to the lowest cost system. This is because but there are not enough environment of such replacing in today's one-way oriented manufacturing sites.

But the value adding mechanism for the manufacturers means that there are possibility to redo their work in such value adding steps by replacing simply deteriorated inputs

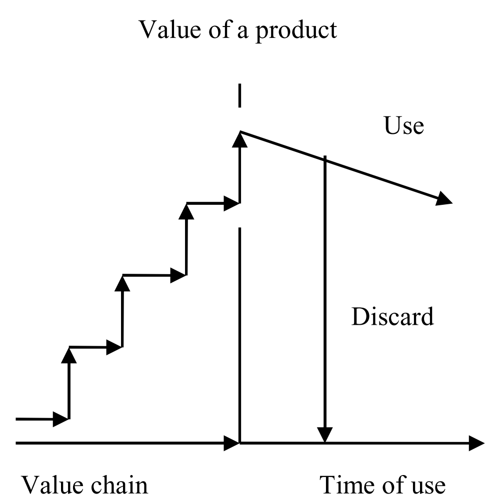

Fig. 1 :One-way value chain

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with new ones to get renewed output products with the lowest cost and lowest resource consumption.

Efficient repairing system will be an important issue among manufacturers for their competitiveness as far as their benefits are from the value adding chain system.

Sockets and connectors are widely used. Edison's E-type light bulb sockets are being used still today.

Most of these specifications are welcome because of the stability and reliability from both electrical and mechanical views although with their rather bulky and "sometime not smooth" features.

Technology of soldering has been greatly progressed toward higher density PCBoard(Printed Circuit Board) Jisso. But the technology has not well been developed with dis-soldering scheme[7].

Technically it seems to be easy that current robots for the PCBoard assembly can be up-versioned to reciprocal model that can put or insert parts to the board and also remove installed parts from the board.

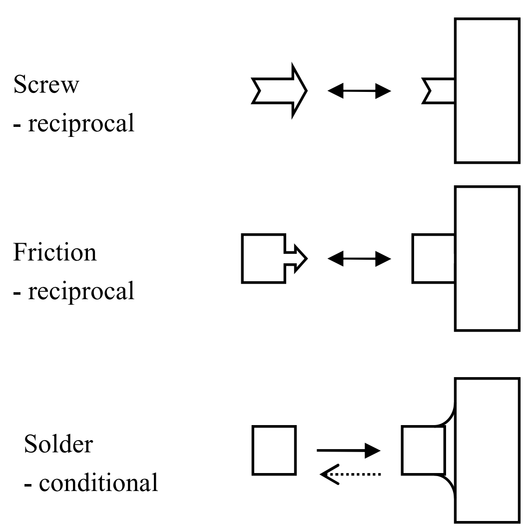

Fig. 2 :Reciprocal mechanisms

Parts such as condensers, registers, transistors etc. have greatly advanced in compact-size, in lower resource and energy consumption and also in lower cost namely by surface mount technology.

Jisso technology for the parts surface mounting has been developed as efficient one-way mounting scheme.

And by developing parts dis-mounting scheme, the assembly will get more profit from Reciprocal assembly system and be welcome as a great waste reducing system.

Prior to develop universal dismounting scheme, it is useful to apply a kind of socket or dis-soldering method to particular device such as heat sensitive chemical condenser particularly in light emission device[8].

Traditional "Incandescent lamp shaped" CFL(Compact Fluorescent Lamp) and LED lamp contain AC to DC circuit with a chemical condenser typically inside the Edison type socket. The leads are connected by soldering to the output of a diode bridge on the PCBoard. Deterioration of the condenser by high temperature and time will cause degradation of light emission. It is welcome that any scheme of easy to replace the condenser with a new one.

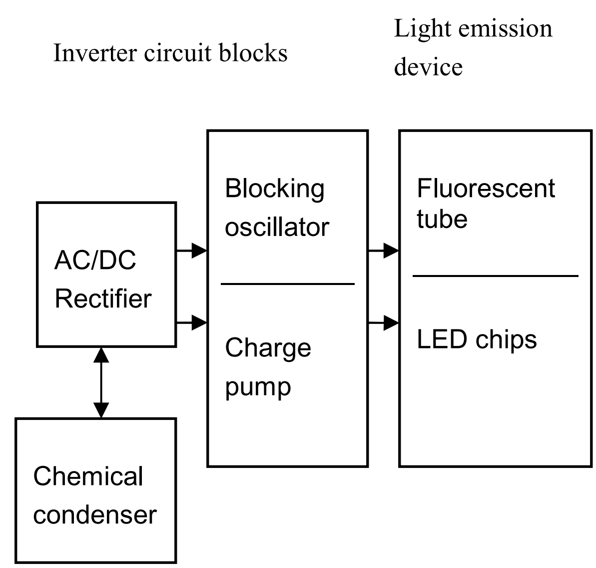

Fig. 3 :Integrated lighting devices

3 RECIPROCAL SYSTEM

Industrial value chain is consisted of the participants that are, manufacturers, dealers and consumers. The reciprocal design of the chain is first to find merit of participant to go backward and to go forward again. It is natural that the value adding participant must get merit from such reciprocal movement. The participant can go backward with minimum effort than by others, and go forward to get profit again with minimum resource than by others too.

Especially in case of PCBoard assembling, dismounting erratic parts from the board increases its value because the board gets chance to be a valued one again. Mounting new parts on the ready to renewable board makes profits again also.

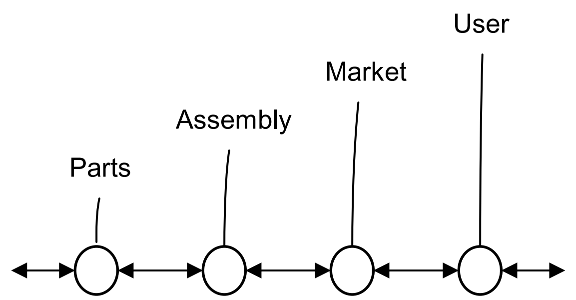

Fig. 4 :Reciprocal value chain

According to such reciprocal scheme, most of the circuit board can work along their full lifespan.

This ecology condition will be mandate to avoid huge wastes for our sustainable society.

Technologies will make efforts to stretch lifetime of parts and assemblies. This is a strong demand of the society and is welcome.

On the other hand, IT-technology based society seems always to need rapid advance of the IT-tools. Where RPR(Resource Performance Ratio) means to estimate knowledge, idea and work for sustainability within shorter term and with less resources for greener tools.

So it is important to design a smart version-up Jisso scheme utilizing the life stretched devices.

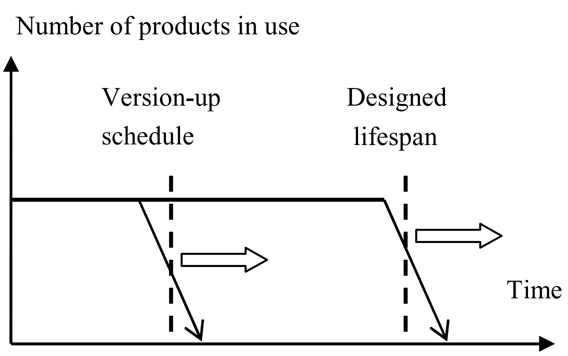

Fig. 5 :Lifespan stretching

Replaceability will make new profit for manufacturers. Parts and interfaces are standardized with scalability to ensure easy to purchase and easy to replace environment.

Reciprocal tools for replacing parts will enforce repairing capability and reduce cost of repair.

Information exchanging system is needed in the value chain and useful for the replacing. Quality and reliability of the result of replacing parts on assembly are ensured along with the exchanging information including grade and alternates.

Considering rights will be necessary especially in version-up and alteration case. The technical works of MPEG （ISO-IEC/JTC1） as Digital-Item-Definition and Rights-Expression-Language is showing useful knowledge for the participants on the reciprocal value chain to find conditions of the replacement[9].

Decreasing of discarding "not yet life-over" means increasing renewed products in the market.

Varieties of services will activate the market with the information exchange schemes in relations to the replacing records.

Consumers will have better choices instead of discarding disappointed product.

4 CFLS AND LEDLAMPS STUDY

CFLs and LED lamps are both integrated products of energy controller circuits and light emission devices. The controllers are of matured designs, showing around 90 percent efficiency and mostly no need of replacement.

But the light emission devices are in different conditions. The LED lamps are on the way of rapid growing efficiency although their lifespan are estimated far long. And CFLs are running in shorter lifespan[10].

So both the light emission devices are recommended to be replaceable in order to avoid discarding the circuit blocks with their remaining long lifetime.

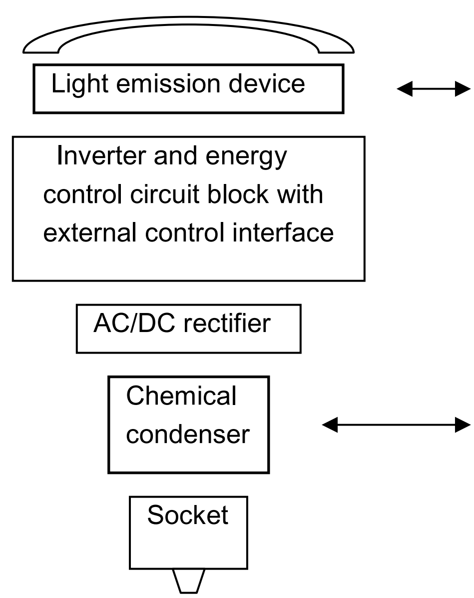

Fig. 6 :Replaceable structure of lighting device

Additionally lighting devices will be required to have some intelligent functions to communicate to the smart grid system. The built-in energy controlling circuit blocks are recommended to have an intelligent interface for the communication. Such interface will also be applied to the repairing schemes.

RPRs of LED lamps or of CFLs will grow higher along with continued use by renewing light emission device with more efficient new ones.

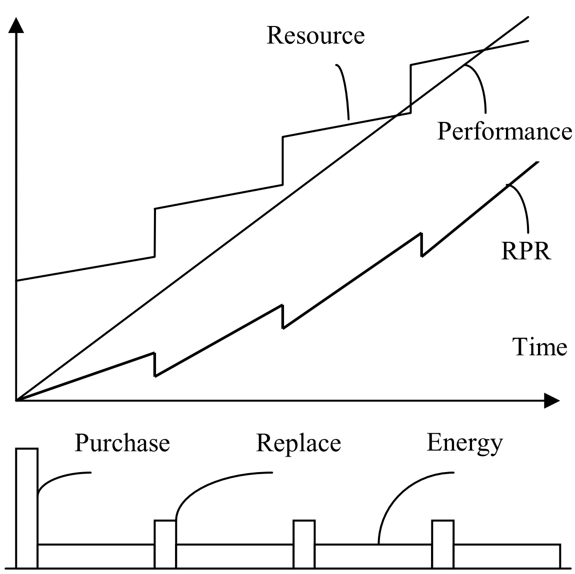

Fig. 7 :RPR of lighting device

5 COCNLUSION

Reciprocal design of industrial value chain will proceed Reuse of the copied mass-product electronics devices. And reciprocal repairing tools will increase renewed products with added value with another profit and will reduce wastes.

The reciprocal system will be proceeded not only by advancing manufacturers but by consumers who have recently moved the world to replace incandescent lamps with more efficient compact fluorescent lamps[11][12].

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Building “Genba” Capability and Sustainable Manufacturing : Case of Cooperation Small and Medium Enterprise with Vendor

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Abstract
This paper aims to provide Information Technology and Factory Automation concept that supports building “Genba" capability of Small and Medium-Sized Enterprises (SMEs). For sustainable manufacturing realization, necessity to evolve SMEs admits no question in Japanese manufacturing industry. However, SMEs cannot afford to allocate the resource to KAIZEN activities. To solve this problem, they must manage to find time for improvement, and then heap up KAIZEN according to worker’s active effort. There is very difficult trial in SMEs. Company A try these difficult task. This paper consider and prospects directions for building good genba of SMEs according to analyze Company A’s excursion.

Keywords:
Genba, Small and Medium-Sized Enterprises, KAIZEN, Information Technology and Factory Automation platform

1 INTRODUCTION

This paper aims to provide IT (Information Technology) and FA (Factory Automation) concept that supports building “genba" capability of Small and Medium-Sized Enterprises (SMEs) of manufacturing industry. Genba means the space and the group who operate an artifact in an environment, in order to produce an artifact with value (industrial goods and services). It is the burning problem how to keep and to make a “highly performance genba” in Japanese industry’s future [1] [2]. Building genba capability demand persistence for KAIZEN activities ("improvement" or "change for the better” in operation field).

However, SMEs cannot afford to allocate the resource to KAIZEN activities. SMEs are a lot of numbers, and has distributed to various places in Japan. They support many industries (for example, automobile industry). Therefore, the improvement of SMEs genba is a high-priority issue. If a good genba can be making in various places, it is profitable as the local economy, the national economy and industries of Japan. There is a chance of the activation of local economy. The concept which considers "genba" to a basic unit is important for the sustainable manufacturing. SMEs are asking for support of building genba capability and should support the activity to which industrial policy (National and Regional) also united the focus with it.

For sustainable manufacturing realization, we focus on the genba of SMEs and are conducting the proving test of "new fusion of a Monozukuri (Open Manufacturing) concept and advanced technology (IT, FA)". We conducted the actual proving test of our platform in Company A from last year. The point of this test is that IT and FA vendor, and SMEs are cooperating and furthering platform development of a bottom-up type. This paper give a report of essence that Company A’s achievements. When SMEs attempt to improve capabilities, what problems are they facing, how are the solving and how do help they with vendor ? These are the central issues of this paper.

2 THE CONCEPT OF GOOD GENBA AND GENBA CAPABILITY

2.1 Manufacturing Organizational Capability

We consider that good genba consistently evolve manufacturing organizational capabilities. Figure 1 show “manufacturing organizational capabilities & performance” framework. This framework thinks that profitability of manufacturing industries decided to three levels of factors: “external competitiveness”, “internal competitiveness” and “manufacturing organizational capabilities” [3] [4]. “Internal competitiveness” affects external competitiveness. Internal competitiveness is measured by productivity, costs, lead time, etc, which customers cannot always see. It is “manufacturing organizational capabilities” to support internal competitiveness. Manufacturing organizational capabilities is level of ability to do things on site (for example, continually high-productivity, short production

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lead time). Though internal competitiveness is not directly linked to external competitiveness, it is necessary that firms improve manufacturing organizational capabilities.

Similarly, Yoshimoto/Fujimoto (2010) assert that manufacturing organizational capabilities is considered capabilities to create a good flow of design information [1] [5]. Their argument is based on the viewpoint of design theory (For design theory, see [6] [7]). This theory interpret manufacturing as “making design information into things”. According to this idea, Japanese blue-chip companies (for example, Toyota Motor) of manufacturing have the following characteristics: First of all, they create a smooth design information flow. As a result, performance of QCT (Quality, Cost, Time: Lead Time) will improve.

Thus we can think that good genba always improve the flow. Japanese blue-chip companies of manufacturing actions are noteworthy. Instead of aiming to better short-term performance, they give preference to improving the flow. Therefore to build good genba requires continual KAIZEN activities. Moreover organization member need to awake to KAIZEN in workplace. Imai (2010) thinks essence of KAIZEN to be philosophy that incremental improvement with involvement of workers [8].

Therefore good genba meet following condition: To aim long-term rise of performance, genba heap up KAIZEN according to worker’s active effort. When organization is in these state, we resume it harden “genba capability”. The genba capability is smaller than the manufacturing organizational capabilities concept, and is mainly viewpoint of genba. But the evolution of genba capabilities of production field is very difficult. This evolution requires long time, change constitution of organizational culture, need to scientific approach for KAIZEN. It is particularly difficult to SMEs that are busy in their daily work.

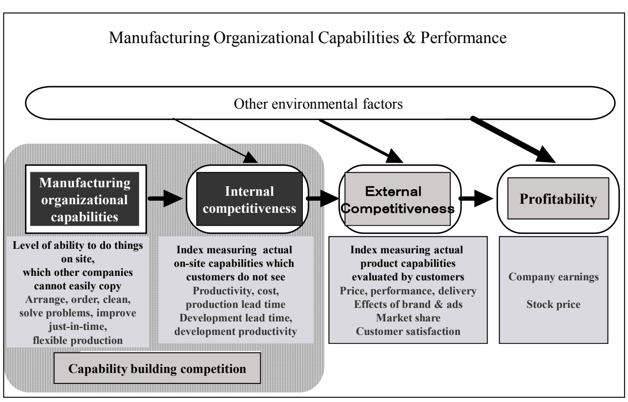

Fig. 1. Manufacturing Organizational Capabilities & Performance

Source: Junjiro Shintaku, Tomofumi Amano (2009): Emerging Market Strategy of Japanese Firms: Reshaping the Strategies in the Growing Markets, *Manufacturing Management Research Center Discussion Paper*, No.278 ([4]), Fig. 2, p.5. Takahiro Fujimoto et al: *Study of Manufacturing Management, Kobunsha Shinsho*, Fig. 1-1-2, p.26

2.2 Why SMEs are difficult to build genba capabilities?

Actively KAIZEN is very difficult in many SMEs. The following two problems concerning “trigger (chance)” and “persistence” for KAIZEN have been frequently mentioned. Firstly, cause the problem that there is no chance to study way of KAIZEN. Secondly, various factors (for example, workers recognize KAIZEN extra work, lack of human resources) are difficultly established of continuous KAIZEN.

If there is a system that provide “trigger” and “persistence”, then this problem will be solved. Yasu City and University of Tokyo works to construct system that trigger is offered (For this system, see [1] [5]). Yasu has developed a curriculum for monozukuri (Japanese basic concept of Open Manufacturing) instructors. Monozukuri instructors are senior manufacturing people who take the training that offers manufacturing knowledge. They instruct SMEs in knowledge for a certain period. They come up with problem, teach the workers how to deal with the problem, and advance a variety of suggestion in workplace.

However, we think not enough only by “trigger”. After an instruction, there is a possibility that SMEs returns to the previous state. Because SMEs are busy in their daily operation, it is difficult to pursue the problem and measure data of the production process. SMEs could not make the time for KAIZEN. Accordingly building system of persistence that maintains continuous KAIZEN is necessary. We think that system of “persistence” is produced by effective introduction of IT and FA platform.

3 CASE: COMPANY A

We discussed the two obstacles to KAIZEN in the SMEs: trigger and persistence. Below, we explain Company A’s excursion into untying two obstacles. Particularly, we focus on persistence issue (about trigger issue, see [1] [5]).

3.1 Company A Overview

Let us first look at capital, number of employees and product of Company A. Company A's capital is about 13 billion yen. Number of employees is approximately 1,900 persons (consolidated, Term ended March, 2009). Company A design, produce and sell high-density multilayer printed wiring boards (PWBs) and automated visual inspection for inspection process of PWBs. Company A sell product to variety field: Automobiles, Consumer electronics, Amusement equipment and so on. A’s factories are located in Japan and China. Company A has five plants in Japan, are making the division of labor between these plants.

Company A has received the teaching of the monozukuri instructors. The instructor assisted the “genba a” of the five plants in Company A. PWBs are produced in two ways: The photographic method and the print method. Genba a make the resist and the pattern of PWBs by The photographic method. In the genba a, internal failures was affecting the cost competitiveness. Monozukuri instructors focused on the internal failures and worked on improving this problem.

But genba a is the thinness of improving awareness in workplace. This was the genba a's biggest problem. KAIZEN was the ad hoc. In fact, Company A's manager said that many improvements were sense of workers, not scientific approach. Moreover characteristics of the failures that convert good product by rework had confusing the problem. Monozukuri instructor's aim was that genba a can actively improve flow. After an instruction, genba a became necessary to create a system that maintains continuous KAIZEN. Therefore vendors and we work on actual proving test for creating this system in genba a.

3.2 Actual Proving Test In the Curtain Coater

Figure 2 shows the production process that we are targeted at. This process is called "Curtain Coater". In genba a, curtain coater is the core of internal failures.We decide to target the curtain coater according to discussion by Company A and vendors. In curtain coater, they paint surface of PWBs liquid solder resist ink. Process flow of curtain coater is as follows: Paint, Preliminary drying, Exposure, Developing, Drying (see Fig. 3).

Internal failures was "unevenness of liquid solder resist ink". Occasionally, effect that not well painted with ink was caused in curtain coater. Genba a took two approaches to improve. They attacked task of measuring the changing working environment on the one hand, and analyzing defective product on the other.

Measuring the Changing Working Environment

Genba a kept a daily record of working environment in written form. The worker recorded condition by hand, are called "Sagyou nippou". But anybody did not exploit these documents. When working environment was turning nasty, worker adjusted a condition to standard for situation. Genba a could not grasp causation of unevenness, and explained the basis for their question: Why the working environment had changed, what did worker adjust, were failures directly caused by changing working environment?

First of all, genba a grasped relationship between failures and working environment. This task had three phases. In the initial phase, they converted daily document into database, and analyzed it. Vendor's comment and Flow-Oriented Approach (FOA) suggestion helped the progress of the converting materially (For FOA, see [9]). FOA is view that IT system of user initiative need for SMEs. One of FOA's ideas is that worker know better than anyone else for causation of failures. Genba a decided to convert the data in the two indices (temperature of ink and room temperature) on this FOA view. They identified lot number by inspection, and then checked variation of environment by database. In intermediate phase, they tried to gather date from curtain coater device automatically. Genba A inotroduced following two device: The device for monitoring temperature of ink, and for measuring room temperature. Vendor supplied genba a with knowledge and know-how about device in this phase. They advance, at present, into the closing phase. They try everyone within the organization can see the internal data. We note the fact that they decided to introduce automation device after careful consideration in the initial phase, did not put a higher priority on the introduce programs. In other words, genba a further the expansion of KAIZEN.

These efforts brought about the four outcomes in Company A. Firstly; they know that failures were not directly caused by changing environment (temperature of ink and room temperature). Secondly, they enhance the prospect for improvement. Anyway, fluctuation of working environment is not good. An increase in temperature of ink and room would affect their operation considerably. Therefore, they need to solve this fluctuation. Thirdly, they get knowledge for which they can practical application in another production process. Finally, it points out the importance, they are likely to afford time for KAIZEN. We think that automatic gathering date produced a margin for improvement.

Analyzing Defective Product

Genba a analyzed the causes of defective product rigorously under a electron microscope, and finally found out the "core" about failures. As a result of the element analysis, then they understood clearly what "core" is. "Core" is made from an ingredient α. In brief, this infusion brings about dispersion of outturn. They discovered an ingredient α under an electron microscope but not stereomicroscope. However, any material that use in the curtain coater did not include an ingredient α. Therefore, they arouse next question: Why is an ingredient α mixed into surface of PWBs, Where an ingredient α is being introduced? At present genba a is engaged with solution to these question. They begin to explore front-end process, and airflow in process of curtain coater. To comprehend airflow, they invest the device for measuring particle and are analyzing a problem.

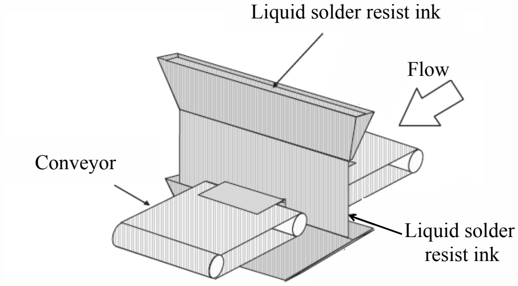

Fig. 2. Process of Curtain Coater

Source: Company A

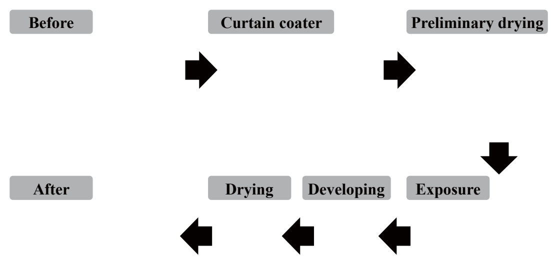

Fig. 3. Process Flow of Curtain Coater

Source: Company A

4 BUILDING GOOD GENBA

To improve process, it is important to manage to find time that worker try various remedies and determine working environment. Activity of KAIZEN demand different time from what they daily work. However, part of this time contains workhour that does not yield added value. Though precise determination of the working environment give worker good grounding in KAIZEN, it does not raise performance (Q, C, T). Consequently, determination is not necessary and sufficient condition to solve the problem in the workplace.

Figure 4 shows relation among workhour and determination. First of all, let us describe span of problem solving as "KAIZEN Lead Time" (For KAIZEN Lead Time, see [1]). KAIZEN lead time is composed of two factors. One of factor is determination of the working environment. Another is task as follows: Worker consider a appropriate way to solve problem and a matter under consideration closely among everyone for workplace, Worker get a clue to improve process by trial and error etc. It might not improperly be called "Net KAIZEN Hour". This net KAIZEN hour is directly linked to rise in performance (Q, C, T). If KAIZEN lead time is the same as ever, net KAIZEN hour increase as more and more of determination is reduced (see figure 4 after 1). Moreover if KAIZEN lead time can be shortened, then genba carry out various activity: They get down another matters for improvement and so on (see figure 4 after 2). That is to say, number of problem solving rise in the genba.

To build good genba, it is important to method for growing of net KAIZEN hour. Let us see genba a case again. Even though genba a's attempt has not been achieved yet, we will be able to infer a cycle of KAIZEN process according to extend genba a's experience. Genba a introduce automation device as needed at conference with vendor. For that reason, they could shorten KAIZEN lead time, or can increase net KAIZEN hour. Then they make a start in the analysis of defective product, or improvement of front-end process. In this way improvement that starts at the particular process affect another process and problem. We tag these KAIZEN process as " The System of Small Turning Circle " (see figure 5). The system of small turning circle is the very essence of IT and FA platform of bottom-up type. Certainly the system of small turning circle is a merely tentative theory. But this concept could guess at essence of KAIZEN process. If they keep this system in successful operation, genba a can develop intense consciousness of KAIZEN among worker by degrees according to produce a little outcome, and then can build IT and FA platform by degrees. This system exists as providing "persistence" device for KAIZEN. As a result, performance of QCT will improve. Ultimately, this system heap up genba capability, and then good genba will be constructed in Company A.

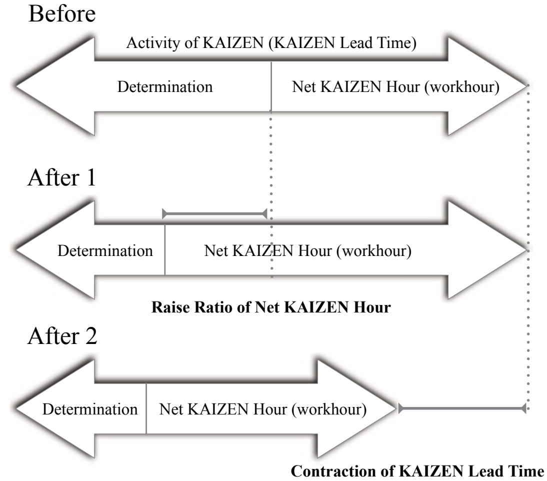

Fig. 4. The Concept of KAZIEN Lead Time

Source: made Tetsuo Yoshimoto/Takahiro Fujimoto (2011): Tyusho・Tyuken Kigyo no Genba Nohryoku Kohchiku - Kaizen Shien FA・IT Dohnyu no Toriaru -, *Seimitsu Kohgakkai Sohgoh Seisan Shisutemu Senmon Iinkai 2010 Nendo Katsudoh Hohkokusho*, The Japan Society for Precision Engineering (Seimitsu Kohgakkai) ([1]).

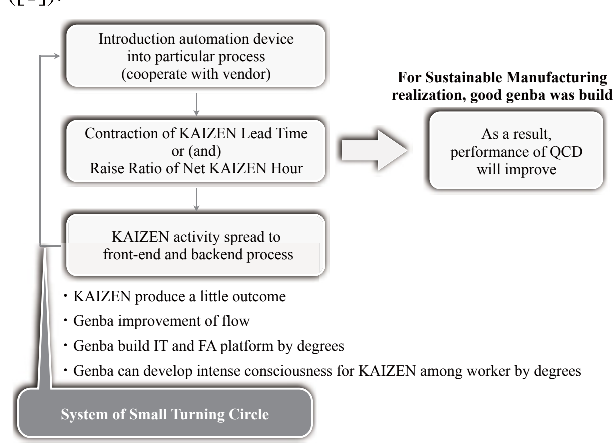

Fig. 5. The System of Small Turning Circle

5 SUMMARY

This paper discussed issues from the aspect of providing IT and FA concept that supports building "Genba" capability of SMEs by examining the case of Company A (and genba a). For sustainable manufacturing realization, necessity to evolve SMEs admits no question in Japan. The point of building good genba is that they run system of small turning circle speedy. This system brings about an evolutionary change in KAIZEN lead time or net KAIZEN hour. As a result, workers more actively engage in KAIZEN. IT and FA that offers by vender is a most effective means of building this system. In addition, process of building this system will enable vendor to make new business model. Company A's case suggest that genba of SMEs is still plenty of scope for improvement in cooperation with vendor. To building good genba, it will be important that vender fill the following role: Not as supplier that sell IT and FA for short-term benefits (for example, improvement of productivity), but as ally that support long-term continuous KAIZEN.

In the meantime, we did not define IT and FA platform clearly. We did so in order to avoid next view: If genba introduce the existing IT and FA system, this system enrich performance of genba immediately. We consider that IT and FA platform of bottom-up type is constructed on the accumulation of genba capability by degrees in SMEs. We make it ours chief aim to describe the process of that construction.

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Resource and Cost Oriented Innovation Steering in Sustainable Product Design

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Abstract

Product development in industry is exposed to intensifying pressure in the context of environmental aspects both from legislative regulations as well as from the market. Governments are steadily increasing the standards and customers around the world are becoming more aware of ambient issues. Furthermore the prices for non-renewable resources are rising and even resource-shortages are to be expected. This demanding development can be converted into a valuable competitive advantage for companies embracing the challenge. Resources and emissions linked to a product's lifecycle are subject to increasing considerations in the buying decision and have substantial influence on the success of innovations. In order to optimize both the usage of resources as well as emissions of a product (also: product service system) at competitive cost engineers need a systematic framework to support them.

Keywords:

Sustainability, Lifecycle Framework, Conceptual Design, Bio-Balance, Multi-Domain-Matrices (MDMs), Target Costing, TRIZ

1 INTRODUCTION

A to be expected continuous increase of legislation concerning environmental aspects as well as market pressure for non-renewable resources must be encountered with a methodological approach enabling engineers to design products that allow companies to keep their competitive edge. Both the volatility and complexity of market and boundary conditions contribute to making it very challenging for product developers to oversee and actually comprehend the entity of requirements. Since that forms the basis for the development of successful products it is key to create consciousness about the engineering environment.

2 INITIAL SITUATION

The area of „green technologies“ is characterized by rapid technological development as well as regular legislative interference on both national and international level. The development of subsidies concerning renewable energy, recycling and e-mobility, just to name some, emphasize the volatility of boundary conditions. The quick adaption to the situation and the exploitation of the possibilities that are inherent are crucial factors for economic success. The German solar industry is taking a global leading position due to technological advance gained in a few years of governmental promotion. At the same time it became evident that the whole branch is still very reliant on subsidies, when governmental support was decreased and demand diminished. Many innovation decisions are currently taken from a rather intuitive and experience-based than strategic point of view, in parts due to missing methodological support. Especially small and medium companies are in need of a "set of tools" that enables them to increase rational decision making in terms of technological and economic dimensions.

3 THEORETICAL FOUNDATIONS

Resource efficiency has taken up a central position as an optimization potential in industry and economy [1]. In the later past the focus lay primarily on labor and energy efficiency. The fact that in many cases the majority of resource consumption and costs emerge during the lifecycle of technical products and systems is not addressed accordingly. It is substantial, that an improvement of resource efficiency can only be achieved if all levels of value generation are taken into account and a lifecycle oriented approach is followed [2]. The phase of conceptual design has a crucial role within the creation of more sustainable products, since the grand majority of technology and cost determining factors are defined at this stage [3].

The systematic acquisition and concentration of all requirements and boundary conditions related to a technical system during its entire lifecycle is prerequisite for successful product development. The practical execution in industry is complicated by several factors, though. On the one hand, a lifecycle perspective increases the degree in which requirements follow contradictory goals and thereby stand in conflict with one another [4]. On the other hand, the shift in perspective that is necessary to achieve a long-term oriented, sustainable product generation has not been fulfilled in industrial practice, yet.

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Despite increasing consciousness concerning non-infinite resources and sustainable action, it is difficult for companies to achieve revolutionary product innovation instead of incremental, evolutionary improvements and move from minimization of negative Key Performance Indicators (KPIs) to a holistic optimization of product concepts [5]. This may be due to the fact that the accomplishment of abstract objectives (reduction of emissions, resource consumption, etc.) is identified with sustainability and the understanding of sustainability as a business perspective is neglected. On the other hand Eco Design tools are predominantly put to use at an advanced stage of the product development process, where most conceptual decisions have been fixed already and there is only "optimization in the margins" left to be done [6]. Last but not least, lifecycle orientation frequently leads to higher initial product costs due to more sophisticated materials, production processes and complex systems [7]. Since the initial product costs are one of the most perceived criteria for customers when making buying decisions, this psychological factor is a serious obstacle on the road for solutions that optimize cost per output unit and form holistic product approaches deliver cost advantages.

Methodological tools to support the analysis of boundary conditions and to model essential aspects of engineering situations are described in literature both in depth and width and are being used broadly in industry. QFD, FMEA and diverse approaches of Function Modeling, just to name some, belong to the common day business of many product developing companies. Scenario Technique allows taking into account different future developments and supports the developer in handling uncertainties.

In the area of idea generation and creativity the classic intuitive method of Brainstorming, most of all, but also Synectics, the Delfi-Method and other setups are applied in many companies. Moreover literature names various tools of Eco-Innovation that have proven useful in the target oriented development of more economical as well as ecological technical systems [8].

The systematic planning, regulation as well as controlling of innovation processes is being considered crucial for successful execution of innovation projects [9]. Accordingly, the innovation controlling is taking up a key position, because it tracks effectiveness as well as efficiency of the product development process [10][11][12]. To assure a market and customer oriented product development, Target Costing is applied as instrumentalism to provide the financial frame engineers need for conception of products and systems in early phases of development [13]. The provision of a monetary basis only, with given product specification, misses to incorporate the augmented importance of resource efficiency and other intangible environmental and stakeholder factors and their effect on the company and innovation success, though [14]. Systematic approaches for the integration of such exist in Live-Cycle-Assessments and "Bio-Balances" (comp. [15]) but their complexity as well as need for large amount of high quality data present a significant hindrance, especially for SMEs, to actually but them into practice. In order to provide an applicable approach, it will be essential for the success of Innovation Controlling to be able to reduce the large variety of requirements resulting from customer, resources, environmental and stakeholder requirements to a set of several handle able, significant factors.

4 METHODOLOGICAL APPROACH

The methodological approach presented in this paper aims at an early integration of resource and environmental requirements into the innovation process and consists of three phases: Target identification, target synthesis and target attainment.

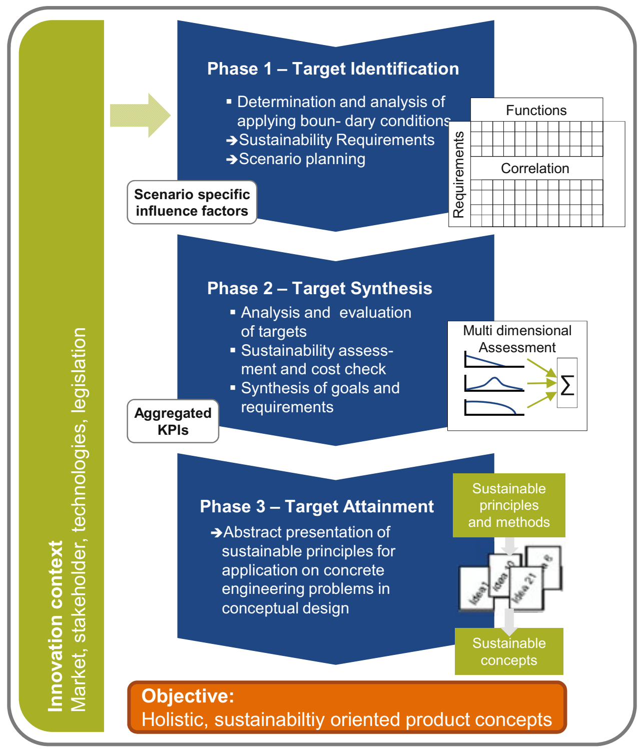

Fig. 1. Procedural model

During target identification a holistic understanding and mapping of the innovation system is to be established. It includes a fundamental analysis of the individual market mechanisms as well as relevant legislations. The dynamic relation of those boundary conditions as well as characteristic product performance parameters to sustainability is established by assigning sets of boundary conditions to probable scenarios. Multi domain matrices (MDMs) are applied to map the relations of the identified influence factors within the scenarios and thereby found the basis for determination of the "Bio-Balance" of product-concepts within those.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1					x
Factor 2					
Factor 3		x		x	
Factor 4	x				
Factor 5			x		

x: Dependency

Fig. 2. Multi Domain Matrix (MDM)

A general understanding of the innovation system allows for a pragmatic development of tools and methods in order to improve the situation of a company in its business environment. Furthermore the influence of sustainability related requirements has to be transparent. Following points are proposed to be addressed during the phase:

- Determination of the market position of the company.
- Market and environment analysis for an understanding of the structure of the innovation system. In this point the focus lies especially on current and future sustainability aspects (raw material and energy efficiency). The relation of social development (Design, High-Tec) legislative boundary conditions (emission regulations) and resulting products/ technologies is to be assessed.
- Estimation of the material and energy flows caused by current products.
- Determination of representative future scenarios and localization of relevant influence factors to the product requirements.
- Derivation of quantified potentials as to the increase of resource efficiency on the product/company level. At this stage a lifecycle assessment is essential. Design optimization, material substitution and functional changes are to be considered just as production factors and other company processes.
- Comparison of measures and abstraction of the sustainability impact. Diverse sustainability requirements and influences shall be displayed in a generalized and summarized way.

The target synthesis phase focuses on the aggregation of the identified target parameters and requirements to achieve a reduction of complexity and dimensions. Contradictory demands are identified, evaluated and weighed against one another. Analog to the Target Costing approach a determined goal is to be set. In the case of sustainable product design monetary goals are to be brought into balance with a small number of significant goals representing lifecycle resource use and to be integrated into one target-system that actually allows engineers to benchmark their products.

The procedure for the synthesis can be divided into five steps, in which the sustainability requirements from phase 1 are taken up for further calculations:

- In the first step requirements and demands are related. In this way goal conflicts can be identified and a strategic prioritization conducted.
- In step two an operationalization of non-monetary factors has to be established. By means of criteria trees a reduction in complexity can be achieved and a hierarchical aggregation of singular factors leads to representative KPIs.
- In step three the operationalized non-monetary KPIs are integrated into the target system, so that a holistic examination can take place. Individual value-functions can be used to describe the use of the improvement of singular factors. Uncertainties have to be processed with adequate instruments, such as approaches from the fuzzy logic.
- In step four the aggregation of singular factors as well as target and evaluation criteria derived from the requirements takes place.
- In step five the actual evaluation and comparison of of goals and requirements is conducted by multi-criteria approaches.

The result of phase two is a ranking of targets and sustainability requirements in the form of few related KPIs containing all aggregated singular influence factors.

Finally, the target attainment phase of the methodology addresses the conversion of the consolidated findings in respect to market, environmental and stakeholder requirements into the concrete technological context of the product system. The focus in this step lies on the efficient use of resources and the application of that consciousness as a driver for Innovation in order to achieve competitive advantages in the global environment. In this phase three steps are proposed:

- In the first step the boundary conditions of the scenarios are put into the context of the technical system. Modeling of the problem situation as well as identification of concrete conflicts are the consecutive acts. The consciousness of engineers is hereby guided towards a holistic lifecycle perspective.
- The second step addresses the solution of technical contradictions and conflicts by methodological support. The uses of tools from the area of Eco-Design (Lifecycle Assessment, strategy wheel) of innovation methodology (TRIZ) and of principles of sustainable design (technologies, product-service-systems, leasing/sharing models) find consideration. Goal is the compilation of a methodology, which aids in the systematic generation of alternative concepts with life-cycle focus in early product development phases.
- Step three includes the quantification of causal relationships between factors influence able by product development and degree of sustainability as well as costs during the entire product lifecycle. Technical

parameters such as weight, materials and geometry but also manufacturing technologies and service aspects are mapped onto the product lifecycle in order to provide a basis for a concept decision for multi-criteria evaluation approaches.

The phase makes use of established systematic approaches of TRIZ (Theory of inventive problem solving) such as Function-Analysis, which addresses the modeling of the product structure and functional interaction within its environment and Trends of Technical Evolution, which assist in estimating the value of a technical system and to elaborate on the most promising directions of improvement [16]. Multi-criteria evaluation methods that incorporate the findings made in target identification and synthesis allow for transparent concept selection.

5 CONCLUSIONS

This paper introduces a methodological framework consisting of the three phases Target Analysis, Target Synthesis and Target Attainment in order to design more sustainability oriented products. Each of the three phases includes several steps that indicate a line of action that allows for a development of more sustainability oriented products or technical systems. For many of those steps established methodological approaches are proposed that support to perform the action. The methodological framework aims at providing an effective guideline for engineers to attain a lifecycle-oriented product design.

6 DISCUSSION

The exact arrangement as well as alignment and further development of the methods to fit sustainable product development and its implied lifecycle perspective are essential in order for the methodological framework to optimally support engineers in their day to day work and effectively provide the capability to design products both sustainable as well as cost-effective. Further research and practical implementation of the approach will be necessary for subsequent, iterative development and optimization of the array. The application of the entire framework in industry case-studies will outline strengths and shortcomings and lead the way to continuously improve it until a sophisticated and practice-proven methodology can be derived.

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Time has begun that Technology shall take responsible for a lifestyle – Nature Technology -

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Abstract

Despite rising awareness of environmental issues, and numerous activities to address these problems, it is becoming increasingly clear that the world is facing multiple, serious global environmental crises. We should learn from Nature, because it is rich in useful technologies. Moreover, there is wisdom contained in these technologies that can help in creating lifestyles for humans that are more in tune with their environment. We dub such profound wisdom derived from nature as "Nature Technology". What is needed for human civilization to continue is a dramatic re-thinking of the relationship between technology and culture, and that relationship's influence upon modern society. Instead of relying on a finite resource-based paradigm that threatens our existence, we should be paying greater attention to the elegant simplicity of nature's technology, and fully appreciate its ability to provide sustainable and natural technological solutions to the problems we face. Nature has provided the framework for a sustainable society by repeatedly selecting natural processes that consume very little energy to circulate materials in the most perfect way. Moreover, we are given limitless access to renewable energy sources to take advantage of this technology. What is missing from this equation is a cultural shift that is both willing and able to make best use of Nature's wisdom.

Keywords: Global environmental issues, Eco-dilemma, Industrial revolution, Back cast thinking, Nature Technology

Although environmental consciousness of people is high where abundant eco-technologies are introduced to the market, a lifestyle is seriously concerned with structure of the accelerated environmental deterioration(eco-dilemma).
It is not too much to say that, the time has come that technologies take responsible for the lifestyle. What form of lifestyle we have to create? A back casting method was traced based on the environmental restriction in 2030 and its latent conscious was extracted. In addition, what is the technology necessary for the lifestyle? Considering with nature of its perfect circulation with a minimum energy and the industrial revolution in England in 18th Century succeeded by breaking with nature, it is quite reasonable direction to look for its answer in nature.

We should learn from Nature that is rich in technologies. Moreover, we could learn the wisdom of a new living style. We name such wonderful wisdom of nature as "Nature Technology".

Despite many efforts being made to solve the environmental issues, the global environment continues to deteriorate. If nothing is done, this will trigger the collapse of civilization around 2030. At first, what are the global environmental issues?, energy and resource depletion, degradation of biodiversity, water and food distribution issues, climate change influenced by global warming, rapid population growth, etc, which are apparently caused by human activities. The actual solution to global environmental issues is to find ways to stop or shrink the bloating human activity while

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guarantying a life that is good for one's soul, which is the nature of humankind.

Now what we are being asked is to create a civilization based on the blessings of the sun and natural resources rather than strengthening the underground resources based civilization.

Nature created a sustainable society by repeatedly selecting natural processes that consumes very little energy to circulate materials in the most perfect way.

Japan led the world in creating [the culture of smartness], by accepting the laws of nature and interpreting it beautifully without violating the same. Thus, the Nature Technology was born by tracing the concept of smartness and integrating it into technology by using the wisdom of nature. And this is the form of technology that is required for the creation of a new civilization.

The temperatures in Savannah Zone where termites live are 50℃ during daytime and below 0℃ at night. How is the temperature inside termite nests is steadily maintained at 30 ℃ ? Apprehension of this nature technology triggered the generation of power consumption-free air-conditioner. Why a shell of snail remains clean? The mechanism behind this phenomenon helped the development of building materials that remain stain-free when exposed to rainwater and also stain-resistant kitchen. The cleaning function of bubbles derived from the convection of heat and ultrasonic wave generated during bursting has led to the birth of no water bath.

Now, such technologies are being born one after another and a new life style has come into existence. There is not much time left and now it is the time to turn the wheel largely from the underground resources based civilization to the civilization for our own existence. And we, the Japanese, who still have the ability to view the nature thoughtfully, have the responsibility to deliver this new stride to the world.

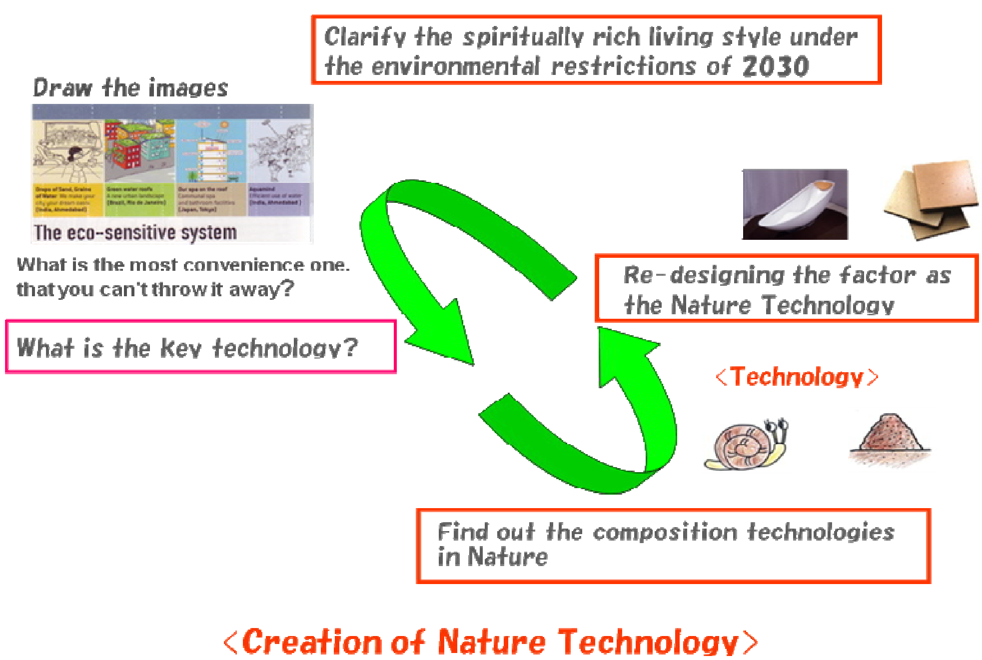

Fig. 1 Nature Technology Creation System. Draw the life-style first and find out the key technology in nature is the important concept.

Comprehensive Technology Governance in Emerging Bio-Mimetic Technology Field

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Abstract
Comprehensive technology governance in emerging bio-mimetic technology (BMT) field is discussed referring to the strategic R&D investment in nanotechnology field in the past ten years. The point is how to promote the basic research in BMT field and facilitate its application to the society prior to the establishment of technology managements such as risk assessment and management, standards, relevant laws, and another social platform. In such stage, addressing the technology governance based on the mutual communication with society is momentous for nurturing trust between science & technology and society.

Keywords:
Biomimetic Technology, Technology Governance

1 WHAT IS BMT ?

Bio-Mimetic Technology (BMT) is a multi-disciplinal fusion of biology, physics, chemistry, mechanical engineering, environmental engineering, agriculture, sociology, socio-economics, and so on. This emerging BMT creates the novel systematized engineering acquiring from bio-diversity and biological process, and the technology enables the sustainable society.

Although BMT is future promising multi-disciplinary system, unprecedented scientific uncertainties will be inevitable also in this emerging field. So, we have to address the comprehensive technology governance based on the mutual communication with society in order to facilitate responsible research and development of BMT. There would be considerable difficulty in risk management and risk communication in the emerging BMT area. For all the difficulties, we have good fortune to refer the practice of technology governance which has been developed and integrated for the past ten years in the strategic investment in nanotechnology R&D. This is because the socio-economic potential of BMT will be relized through the technological methodology closely related with nanotechnology, especially in the early stage of R&D. For instance, water repellent lotus effect is a good example of BMT originated in nanotechnology, and its antifouling property is widely applied in our daily life.

2 LESSONS LEARNED FROM NANOTECHNOLOGY ABOUT TECHNOLOGY GOVERNANCE

With the start of the twenty-first century, Japan began strategically investing in nanotechnology R&D based on its national science and technology policies. The ten-year period has just passed over in which the government has been inputting R&D resources into strategic research and development under the Second Science and Technology Basic Plan from fiscal 2001to 2005, and the Third Science and Technology Basic Plan from fiscal 2006 to 2010. The Nanotechnology R&D in Japan today is described as having a special feature, that is, the completion of the scientific foundations of nanotechnologies, which represent emergent sciences and technologies built upon a variety of disciplines and requires the fusion of diverse fields. In particular, scientific knowledge has been increasing at a dizzying pace since the beginning of this new century, and for nanotechnologies—expected to achieve scientific advancement as well as practical applications—there is an urgent need to improve the infrastructure that will ensure the restructuring and creation of comprehensive indicators of knowledge relating to sciences and technologies for further development.

Here we introduce a measure to evaluate the current status of nanotechnology. Figure 1 shows the statistical profile of the change in number of the nanotechnology-related articles appeared in domestic newspapers and magazines, which is adopted as a reference index of societal interests in nanotechnology R&D and its application.

The statistical profile shown in Figure 1 clearly indicates that Japan's nanotechnology R&D experienced a period so called "Nano-Hype" [1] at around 2003. From 2001 to 2003, social interest and anticipation in nanotechnology was puffed up quickly. As a reaction of nano-hype, the interest and anticipation were cooled down year by year after 2004. Negative hype is obvious from 2004 to 2010. The point is when the negative-hype hit the bottom. Obviously, we are getting through the trough of disillusion right now, and making our way to plateau of productivity in the innovation hype cycle proposed by Fenn and Raskino [2]. To facilitate the return to the society, we have to take up the scientific findings integrated in the past ten

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years, and continuously support exploratory research under the coherent science & technology policy.

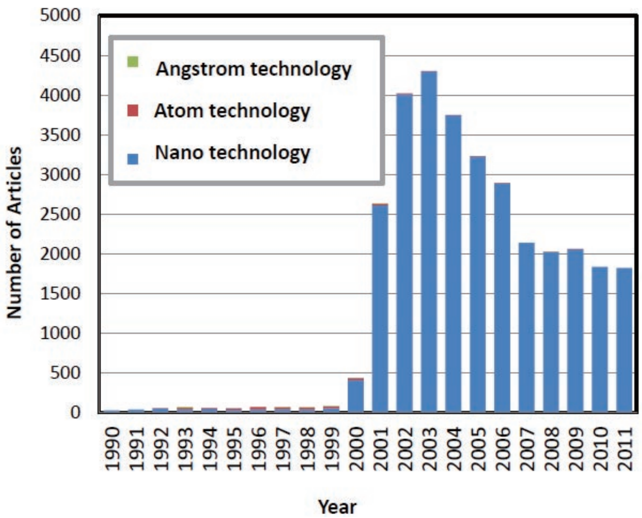

Figure 1. Number of nanotechnology-related articles appeared in the domestic newspapers and magazines. The data for 2011 is estimated by duplation of the number of articles from January to June. Database "NikkeiTelecon 21" was used in the analysis.

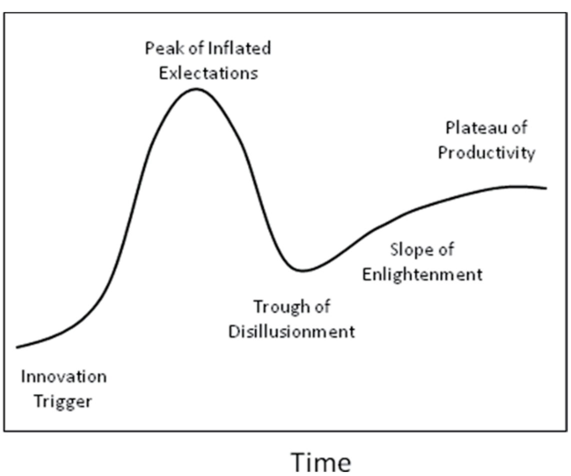

Figure 2. Schematic profile of innovation hype cycle proposed by Fenn and Raskino[2]. The hype cycle is composed of two elements, that is, hype level appeared mainly in the left hand, and maturation of engineering and/or business gently appeared in the right hand.

3 EHS ISSUE OF NANOTECHNOLOGY

The inter-ministerial coordination program of Science and Technology Project of the Council for Science and Technology Policy of Cabinet Office had conducted in an initiative titled "Developing Nanotechnologies and Engaging the Public" since fiscal 2007 to 2009. During the course of inter-ministerial coordination program, 1.7 % of national budget in nanotechnology area was invested to the environmental health and safety issue (EHS) and ethical legal and societal issue (ELSI) of nanotechnology. The budget was not sufficient, but the regulatory science initiated with this budget was successfully collaborated and cooperated with the international frameworks such as "ISO TC229 Nanotechnologies" and "Working Party on Manufactured Nanomaterials" established in the OECD's Chemical Committee. The comprehensive approach to risk management of nanotechnology is a good example for emerging BMT.

To accelerate the mutual information flow with society, we are publishing a online magazine "PEN", which is an abbreviation of Public Engagement with Nano-based Emerging Technologies. We qualify the PEN as an important tool for technology governance of BMT based on science- and risk-communication prior to setting up the technology management such as risk management and standardization.

4 FUKUSHIMA TESTS "SCIENCE & TECHNOLOGY IN SOCIETY"

In the last 120th month of ten years strategic investment in nanotechnology field, the Fukushima nuclear power plants were hit by tsunami following catastrophic Tohoku earthquake. The Fourth Science and Technology Basic Plan from fiscal 2011 to 2015 was suspended at the end of March for review, especially on Basic Act on Energy Policy. The question is whether the accident at Fukushima nuclear power plant was natural disaster or man-made disaster. In the comment on the accident, term "unexpected situation" was frequently used, intending to the lack of risk management against the worst case.

We have to address challenges that the Fukushima poses. BMT with lessons from nanotechnology is able to present possible answer for the challenges by proposing the minimized impact on environment, environmental conscious production system. Comprehensive technology governance is essential for BMT to realize this goal.

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Social acceptability of lifestyles and Nature technology

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Abstract
The global environmental issues came to be placed as important issues. Necessity of the reduction of the environmental load in not only the products but also the whole of lifestyle is suggested. So changing the lifestyle becomes urgent issue now. Then, we designed the lifestyles which were low environment load on the basis of environment constraints of 2030 with the concept of learning from nature and compared with the Japanese lifestyles before the World War II. In this study, we analyzed social acceptability of the lifestyle 2030 and old lifestyles. This result implies that old Japanese lifestyle is environmentally low burden, a living with Nature and sustainable but the factor not 'trendy' may disturb social acceptance.

Keywords:
lifestyle, design, sustainable, social acceptability, living with nature

1 INTRODUCTION

The global environmental issues came to be placed as important issues and the Tohoku earthquake 3.11 with Fukushima nuclear power plants accident also happened to change their way of thinking on environmental problems . This natural disasters are speeding up innovation for environment. Many environmental innovation such as energy saving technologies, products and services came to the market recently and introduced. Necessity of the reduction of the environmental load in not only the products but also the whole of lifestyle is suggested. Especially, after the Tohoku earthquake 3.11, there will be not enough energy supply in order to continue our lifestyle as we do now. So it is urgent issue now to change the lifestyle into low environmental load dratistically.

In order to promote environmetal innovation and change to the new environmental lifestyles, we have been developed the methodology of 'Life style design' using backcasting method. This methodology designs lifestyles which are low environmental load on the basis of environmet constraints of 2030 with the concept of Nature technology[1]. Using 'Life style design' methodology (Fig.1), we designed 100 lifestyles and chose 30 lifestyles. We took an evaluation grid method and picked up and evaluation factors. We gathered much evaluation factors to 40 by KJ method and made a lifestyle evaluation factor[2][3]. We measured the social acceptability of 50 life styles by the Internet questionnaire survey and analized the relationship between lifestyle elements and social acceptability. This study suggested that higher social acceptability of the lifestyle includes more elements of 'Nature', 'Fun', 'convenience', 'self-development' and 'social connection'.

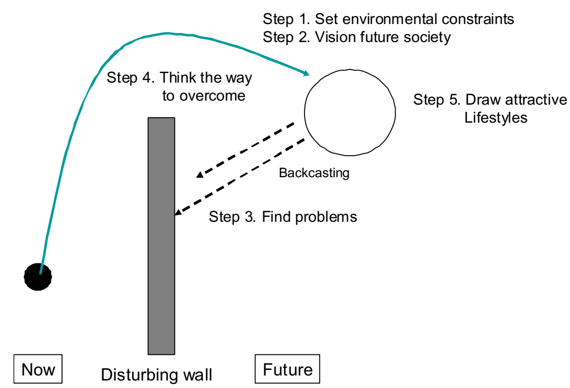

Fig. 1: Life style design method

On the other hand, about 70 years ago before the world war II, every lifestyles in Japan were low environmental load and sustainable. They had lived with Nature connecting with community. Therefore, these old Japanese lifestyles that about 90 years-old people knows around 1940's are fruitfull for sustainable lifestyles. Their lifestyles include precious know-how and technologies which we are going to lose in several years because of lacking memories in them. So it is important to verify the methodology of 'Life style design' using old Japanese sustainable lifestyles.

In this study, we compared 50 lifestyles by methodology of 'lifestyle design' and 40 old lifestyles of 70 years ago in Japan using lifestyles evaluation factors and analysed the social acceptability.

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2 METHODOLOGY

2.1 Interviews

In order to design old Japanese lifestyles, we interviewed 65 people in Miyagi prefecture in Japan who are older than 85 years old in 2010. The interview took about 2 hours and interviewer made interview memos after that. Then 65 interview memos were analyzed deeply by the research group and 40 kinds of lifestyles are extracted from them.

2.2 Questionnaire survey

We measured the social acceptability of 40 old Japanese lifestyles and structure of these lifestyles by the Internet questionnaire survey with 40 lifestyle evaluation factors. And 10 dummy lifestyles for benchmarking were also evaluated at the same Internet questionnaire survey. 100 monitors evaluate each lifestyle and one monitor evaluates 5 lifestyles in the questionnaire.

2.3 Analysis

We classified 40 old Japanese lifestyles into 5 kinds by a cluster analysis and performed a factor analysis in every lifestyle group, and analyzed social acceptability for each five lifestyles cluster. The social acceptability was estimated using the ratio of the number of people who can accept the lifestyle.

3 RESULTS

3.1 Social acceptability

The social acceptability of the 40 old Japanese lifestyles was various (Fig.2) and the average of the social acceptability was 29.1%. It is 23.4 points lower than that of lifestyles of 2030 using Life style design method[3]. This means that new designed lifestyles are much acceptable than old Japanese sustainable lifestyles.

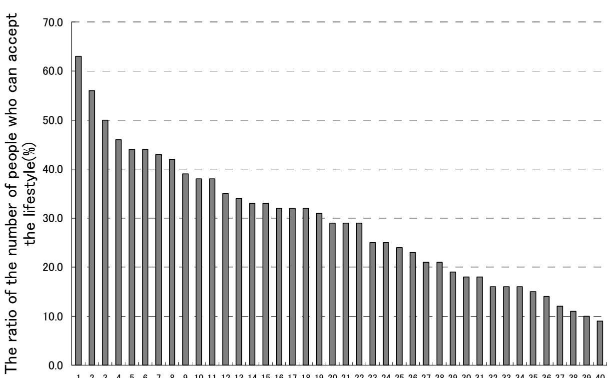

Fig. 2: Social acceptability of old Japanese lifestyles

3.2 Factors related to the social acceptability

The average of the social acceptability of each clusters are caluculated and Table 1 shows the relationship between each cluster's factor and social acceptability. The Cluster 1 shows highest social acceptability and this cluster has 'Nature' and 'Fun' factors possitively. And the Cluster 2 shows second highest social acceptability and this cluster has 'Nature' and 'Social connection' possitively. This result is consistent with the analysis of new lifestyles in 2030. But 4 out of 5 clusters have factor 'Trendy' negatively. This factor decrease the average of social acceptability of old Japanese lifestyles.

Table.1: Factor analysis of old Japanese lifestyles and social acceptability.

No.	1st factor	2nd factor	3rd factor	4th factor	Social Acceptability(%)
Cluster1	Nature +	Trendy -	Fun +	Convenience -	39.3
Cluster2	Nature +	Trendy -	Social connection +	Convenience -	33.1
Cluster3	Fun -	Trendy -	Nature -	Convenience -	29.3
Cluster4	Social connection -	Trendy -	Nature +	Convenience -	28.8
Cluster5	Nature +	Fun -	Convenience -		16.2

This result implies that old Japanese lifestyle is environmentally low burden, a living with Nature and sustainable but the factor not 'trendy' may disturb social acceptance. Our lifestyle should be sustainable but we can not go back to 70 years ago. Instead, Life style design method may succeed in higher acceptable lifestyle design.

4 CONCLUSION

This study found that old Japanese sustainable lifestyles which has higher social acceptability has the factor 'nature', 'fun', 'social connection', but the factor not 'trendy' disturbs social acceptability. Life style design method may succeed in higher acceptable lifestyle design in trendiness.

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Insect Inventory as a Biomimetic Database

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Abstract
Biomimetics" means a scientific field where scientists analyze structure and function of natural organisms physically and chemically, and apply the results into technology in the future. Some scientific fields of the insect science recently attract technologists' and chemists' attention. For example, structural color, water-repellent or hydrophile property, moth eye (anti-reflection coating or film), and etc. Biomimetic analyses of insect structure and function tends to face with a difficulty of too large diversity of insects in various natural conditions. Additionally, taxonomic system for identification of insects is often unstable or not enough. But a similar function recognized among separated insect groups is very remarkable in technology and in evolutionary biology. Database usable in biomimetic purpose is needed for effective study of insect structure and function covering large insect groups. For building a biomimetic database effectively and systematically, information on biological inventory should be utilized.

Keywords:
biomimetics, insect, inventory, database, systematics

1. What's "inventory"?

The technical term "inventory" used in biology and science biodiversity since around 2000 is a daily english word originally meaning a list of property or that of stock. It became to mean in biology, a list of animal or plant species known from an area, or that of animal or plant specimens preserved a museum or an institution. In broad meaning, it is "a list of animal or plant species (or specimens) from an area (or an institute). We have many works and publications on local inventory and the others on biology.

2. Structure and function of insect body surface

Insect is an animal group having "exo-skeleton" and the integument is usually rigid. External surface of the insect integument sometimes has special ultrastructure, and they are usually observable by SEM. Special ultrastructure usually has special function, for example, stridulatory organ comprising from file and scraper is observed in various insect species. Its structure and the function is drastically varied by insect species.

Among various insect body structures, the followings are well studied and discussed to introduce technologically: structural color, flying mechanism, hydrophobicity-hydrophilicity, moth-eye, sticking structure. And the other strictures shown below are also possible: stridulation (sound production), hair structure, genital structure, jumping organ. For example, structural color inspired from the structure of Morpho butterfly was already introduced to industry. The structural color is not occurred only in Morpho butterfly, but also in various insect groups.

3. For the next "biomimetics"

The word "biomimetics" means mimicry of structure and function from nature

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and wildlife for design, structure and material of artificial product. The flow of biomimetic study can be shown as follows: 1) searching "biomimetic structure" in nature (including insects); 2) Physical and chemical analyses of biomimetic structures; 3) Application the result into industrial technology or product. In the searching "biomimetic structures" shown as 1), inventory data can be utilized effectively.

As a sample case, moth-eye structure discovered in the hyaline wing of a cicad species *Terpnosia nigricosta* (Hemiptera), (Japanese name: ezo-haruzemi) is dealt with. It is comprising from a large number of nano-piles (each 50-100 nm diameter, 200 nm height). The function is probably anti-reflection against sunlight and hydrophobicity to dues by change of temperature. Using inventory data, the special structure was studied and it was known to be distributed in some other cicad species and the shapes and the sizes of nano-piles are slightly different by species and very different between hyaline and non-hyaline parts.

4. Conclusion

1) The technichal term "biomimetics" means application or mimicry of natural structure bearing special function to technology and industrial products.
2) Biomimetic structures in insects are well studied recently and very hopeful in the following field, namely, structural color, hydrophobicity, moth-eye, etc.
3) To develop biomimetic study, a database on insect inventory must be helpful for technologists, and it is needed.

Biomimetics for Plant Protection

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Abstract
Studies on biomimetics of biological interactions in agricultural ecosystems are expected to create more sound sustainable technologies for plant protection over a long term. We are trying to develop effective strategies to enhance plant immune systems by using insect-produced elicitors and to control behaviors of insect pests by using acoustic information for environmental friendly plant protections.

Keywords:
insect-plant interactions, insect-produced elicitors, ultrasound, pheromone, Lepidoptera

1 INTRODUCTION

It is well known that herbivore attacks induce many plants to exhibit dynamic biochemical changes, which work as direct and indirect defenses. A typical example of indirect plant defenses is an intervention by natural enemies [1,2]. Natural enemies use volatile compounds released by herbivore-attacked plants as chemical cues to locate their hosts. Releases of volatiles are regulated by elicitors present in herbivore oral secretions. Four types of insect-produced elicitors are reported: β-Glucosidase [3], fatty acid amino acid conjugates (FACs, 1a-c)[4,5], inceptin (2)[6], and caeliferins (3a-b)[7] (Fig. 1). These insect-produced elicitors are defined as chemicals to partly mimic herbivory. Among the elicitors, FACs, specifically volicitin (1a) [*N*-(17-hydroxylinolenoyl)-L-glutamine], represent the most broadly active elicitors examined so far [8]. From evolutionary perspective, why a caterpillar would produce these potent elicitors has been an open question. Recently, we have investigated this question based on biochemical studies regarding the biosynthesis of glutamine-based FACs and revealed that the essential role of Gln containing FACs in nitrogen assimilation by *Spodoptora litura* larvae [9].

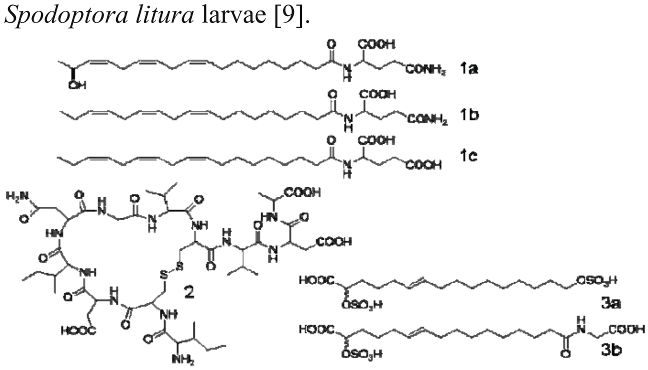

Fig. 1 : Chemical structures of insect-produced elicitors

Insects use acoustic information, i.e., sounds and vibrations as well as pheromones in sexual context. We found that several moths across taxonomic groups including a moth pest, *Ostrinia furnacalis* produce ultrasounds during courtships. This suggests that sexual communication using ultrasounds is widespread among moths. Moths have developed a variety of ultrasound-producing mechanisms, e.g., stridulation between wing scales and thoracic scales in *O. furnacalis* and buckling hard cuticular apparatus in *Spodoptera litura*. In addition, we found that a beetle pest, *Monochamus alternatus* utilizes vibratory information for sexual communication and predator-avoidance behavior.

As shown above, we are trying to develop effective strategies to enhance plant immune systems by using insect elicitors and to control behaviors of insect pests by using acoustic information for environmental friendly plant protection.

2 FACS APPILIED ONTO WOUNDED PLANT TISSUES CAN MIMIC HERBIVORE FEEDING

2.1 Structure-activity relationships of FACs

Identification of absolutely configuration of volicitin.

The absolute configuration of the hydroxylinolenic acid moiety of volicitin from the larvae of the three noctuid species, *H. armigera*, *M. separata*, *S. litura*, which are major agricultural pests in Japan, was determined by HPLC [10]. After methanolysis of volicitin purified from the larvae and conversion of the resulting ester with (*R*)-DBD-Pro-COCl, the retention time of the natural volicitin derivative was compared with that of the (17*S*)- and (17*R*)-synthetic references. HPLC analysis concluded that natural volicitin from the caterpillars of all these three species had the 17*S* configuration in high ee: 89% ee for *H. armigera*, 91% ee for *M. separata*, and 96% ee for *S.*

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litura (N=3).

Elicitor activity of volicitin and N-linolenoyl-L-amino acid conjugates.

To study the structure-activity relationships, a series of analogs to volicitin-related compounds, including unnatural (17*R*)-volicitin, was tested for biological activity to trigger the release of volatiles from corn seedlings. When the seedlings were treated with natural (17*S*)-volicitin, (*E*)-β-farnesene, (*E*)-α-bergamotene, β-caryophyllene, indol, and linalool were identified as volatile compounds, based on comparisons with authentic samples. Unnatural (17*R*)-volicitin also induced *Zea mays* seedlings to release a blend of volatiles, which are statistically equivalent to those released from plants treated with natural (17*S*)-volicitin ($P>0.05$, Tukey correction for multiple comparisons). *N*-Linolenoyl-L-glutamine was significantly less active in triggering emissions with an approximately 30-40% relative release rate compared with that of synthetic volicitin. These results indicate that the chirality at the 17th carbon of the linolenic acid moiety of volicitin did not affect the activity to release volatiles from the treated plants, although the existence of the hydroxyl moiety significantly affected the elicitor activity [10]. More interestingly, the substitution of L-leucine, L-phenylalanine, L-proline, and L-threonine for L-glutamine resulted in a loss of the elicitor activity [10]. Recently, Truitt et al. have shown that the first experimental evidence for the existence of a volicitin-binding protein in *Zea mays*, and also that volicitin may not directly serve as a mobile messenger in triggering the release of volatile compounds systemically [11]. Considering the existence of a volicitin-binding protein, the results presented here suggest that the L-glutamine moiety of volicitin and FACs played an important role in binding. At this point, we do not know how a volicitin-binding protein functions as an activator of second messenger(s) to trigger the release of volatile organic compounds at undameged sites of plants.

2.2 Biosynthesis of FACs in caterpillars

Since the first FACs including volicitin were isolated from regurgitant of *S. exigua* larvae [4], their role of elicitors of induced responses in plants has been well documented. A longstanding question is why caterpillars would produce such elicitors despite the propensity of FACs to elicit volatile emission in plants, thus, ultimately attracting caterpillar's natural enemies.

Lait et al. reported a key enzyme involved in the biosynthesis of *N*-linolenoyl-L-glutamine in alimentary tissues of *Manduca sexta* [12]. Our study of volicitin biosynthesis by *S. litura* revealed that glutamine is selectively incorporated into FACs even though other amino acids are also found in the hemolymph and lumen of the gut [13,14]. These results suggest that FACs could be involved with glutamine metabolism. So we investigated the biosyntheses and the physiological role of FACs in *S. litura* larvae.

By using ^{14}C-labeled glutamine, glutamic acid, and linolenic acid in feeding studies of *S. litura* larvae, combined with tissue analyses, we found glutamine in the midgut cells to be a major source for biosynthesis FACs. Furthermore, 20% of the glutamine moiety of FACs was derived from glutamic acid and ammonia through enzymatic reaction of glutamine synthetase (GS). To determine whether FACs improve GS productivity, we studied nitrogen assimilation efficiency of *S. litura* larvae fed on artificial diets containing $^{15}NH_4Cl$ and glutamic acid. When the diet was enriched with linolenic acid, the nitrogen assimilation efficiency improved from 40% to >60%. In the lumen, the biosynthesized FACs are hydrolyzed to fatty acids and glutamine, which are reabsorbed into tissues and hemolymph. These results strongly suggested that FACs play an active role in nitrogen assimilation in Lepidoptera larva and that glutamine containing FACs in the gut lumen may function as a form of storage of glutamine, a key compound of nitrogen metabolism [9].

2.3 FACs diversification in insects

Not only glutamine-based but also glutamic acid-based FACs have been identified from 15 species belonging to three families (Noctuidae, Geometridae, and Sphingidae) [15-20]. However, the presence of FACs in lepidopteran species outside of these three families has not been investigated thoroughly. So, we conducted FAC screening of 24 lepidopteran species belonging to 16 families.

Among the species investigated, FACs were identified from 14 species of 9 families and there were 10 species, in which no FACs was found [21]. Furthermore, FAC patterns were classified into four types: (A) glutamine conjugates only, (B) glutamine and glutamic acid conjugates, (C) glutamine conjugates and those with hydroxylated fatty acids, and (D) all of them. These results strongly suggest that FACs are more commonly synthesized in a broad range lepidopteran caterpillars than was previously known (Fig. 2)[21]. All FAC containing species had *N*-linolenoyl-L-glutamine and/or *N*-linoleoyl-L-glutamine, which suggests that they might be evolutionarily the older FACs. Interestingly, glutamic acid-based FACs with only trace amounts of glutamine-based FACs were also found in two closely related crickets (Orthoptera: Glryllidae), *Teleogryllus taiwanemma* and *T. emma*, and in *Drosophila melanogaster* larvae (Diptera: Drosophilidae) [22]. These findings are significant, as they indicate that FACs might have physiological roles in additional orders of insects besides Lepidoptera.

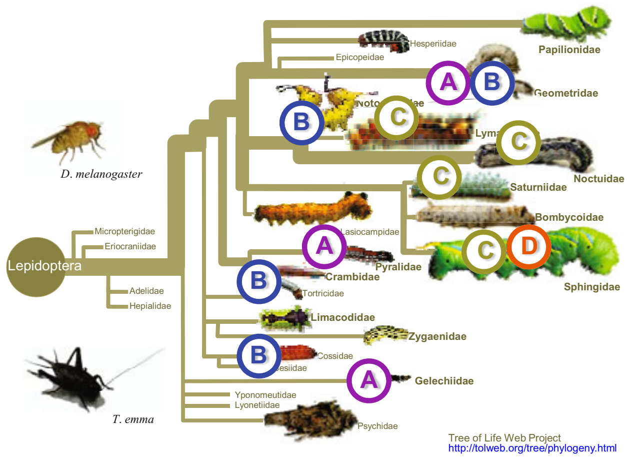

Fig. 2 : FAC-pattern classification and phylogenetic relationship. The phylogenetic tree based on the Tree of Life Web Project. 2003. [Lepidoptera. Moths and Butterflies. Version 01 January 2003 (temporary). http://tolweb.org/Lepidoptera/8231/2003.01.01 in The Tree of Life Web Project, http://tolweb.org/.]

3 ULTRASOUND AND PHEROMONE COMMUNICATIONS IN MOTHS

3.1 Ultrasound hearing and production

Moths have tympanal ears sensitive to ultrasound. The tuning of hearing to bat calls as well as the degeneration of hearing in bat-free areas indicates that ears of moths have most likely evolved to counteract predation by insectivorous bats [23]. The location and morphology of ears vary across superfamilies of moths, suggesting the independent evolution of ears in each taxon after the divergence of superfamilies [23]. Subsequent to the development of ears, a relatively small number of moth species developed sound-producing organs, and utilized the sound either for defense against bats or rival males, or for attracting mates [24,25]. The ultrasounds used in these contexts are characterized by high sound pressure levels (SPL) ranging from 76 to 125 dB SPL at a distance of 1cm [26].

Males of the Asian corn borer moth, *Ostrinia furnacalis* (Crambidae), produce low-intensity ultrasonic courtship songs of ca. 46 dB SPL at 1 cm [27]. These songs increase the mating success of the males by making the females motionless, which corresponds to the freezing response elicited by ultrasonic bat calls [27,28]. In addition to the sound pressure levels, temporal and spectral features of the sound should be under the control of selection pressures imposed by conspecific female mates and/or unwanted eavesdroppers. There is only one well-known example in moths (i.e., *Achroia grisella*), where females show preference for specific temporal and spectral features of ultrasonic calling songs of conspecific males [29]. Despite the importance of the variation in temporal and spectral features of the sound to mate recognition, reproductive isolation, and speciation, no comparative study on variations of ultrasonic courtship songs among closely related moth species has been made to date.

3.2 Sex pheromone communication

Sexual communication using female sex pheromones is widespread across various moth species [24]. The European corn borer, *Ostrinia nubilalis* (Crambidae: Lepidoptera), and its Asian congeners, *Ostrinia furnacalis* and *Ostrinia scapulalis*, exhibit within-species and between-species variation in their pheromone communication [30-32]. *Ostrinia* moths use ultrasounds as well as pheromones for sexual communication, however, variations in ultrasounds in the three congeners have not been addressed to date.

3.3 Variation in ultrasounds and pheromones of *Ostrinia* moths

Here we investigated features of ultrasound production and hearing in *O. nubilalis* and *O. scapulalis*, and compared them with those of *O. furnacalis*. As in *O. furnacalis*, males of *O. nubilalis* and *O. scapulalis* produced ultrasounds during courtship by rubbing specialized scales on the wings against scales on the thorax [27,33]. The covering of these scales muffled the sounds and significantly reduced mating success in *O. nubilalis*, showing the importance of ultrasound signaling in mating [33]. The ultrasounds produced by *O. nubilalis* and *O. scapulalis* were similar, consisting of long trains of pairs of pulses with a main energy at 40 kHz [33], but distinctly different from the ultrasound produced by *O. furnacalis*, consisting of groups of pulses peaking at 50 kHz and with substantially more energy up to 80 kHz [27]. There was no significant difference in hearing among the three species with regard to the most sensitive frequencies and hearing threshold levels [33]. Despite overall similarities, temporal and amplitude features of the sounds produced by *O. nubilalis* (and *O. scapulalis*) of different pheromone type differed significantly. The patterns of variations in the songs and pheromones well reflected those of the phylogenetic relationships, implying that ultrasound and pheromone communications have diverged concordantly [33].

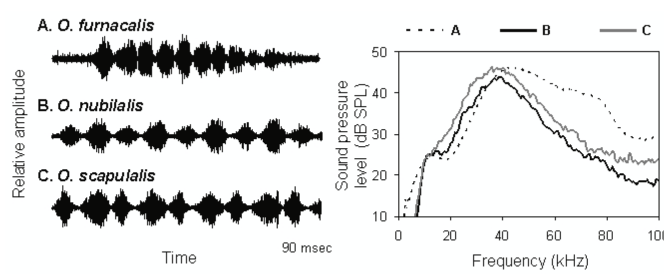

Fig. 3 : Courthship ultrasounds in thee *Ostrinia* moths.

3.4 Ultrasounds in various moths

In order to widely explore acoustic communication in moths, we recorded and analyzed courtship ultrasounds of 13 moth species from Noctuidae, Arctiidae, Geometridae and Crambidae, which are distantly related to *Ostrinia*. Males of nine species produced broadband ultrasounds with a peak power frequency ranging from 38 to >100 kHz [26]. Courtship ultrasounds appear to be widespread among phylogenetically distant groups of hearing moths that utilize sex pheromones.

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A chemosensillar design discriminating between nestmates and nonnestmates in ant species: Its functional property and influence on their social form

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Abstract

Ants use chemical sings of colony specific blend of cuticular hydrocarbons (CHCs) as the nestmate and nonnestmate discriminating pheromone. We investigated the functional design of a particular type of antennal sensillum sensitive to CHCs and compared its utility between monogyne and polygyne species. The CHC sensillum of a monogyne *Camponotus japonicus* responds to the CHC blends of nonnestmates and other species but not to the nestmate blend. On the other hand, the CHC sensillum of a polygene species, *Formica yessensis* responded not only nonnestmates but also nestmate CHC blends. The responsiveness to CHCs of the own species was relatively weak in comparison with that to CHCs of other ant species.

Keywords:

ant, social form, nestmate recognition, chemosensillum, chemical communication

1 INTRODUCTION

Ants have developed a sophisticated sensory system to discriminate between nestmates and nonnestmates to maintain their societies. They use colony specific CHC blends as nestmate and nonnestmate discriminating pheromone [1][2][3]. Since we discovered the particular antennal sensillum responding to opponents' CHC blends [2], we have investigated the corresponding sensillum of other ant species in its functional characteristics and its role for nestmate recognition.

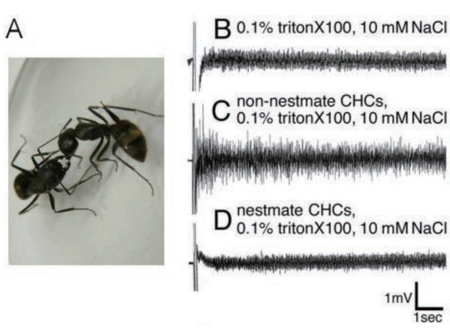

Fig. 1: *Camponotus japonicus*

A: Aggressive behavior toward nonnestmate

B: Electrophysiological response to CHCs

Camponotus japonicus is a monogyne species that has a single queen in a nest. The workers of monogyne species are rejected by other nests' workers. Besides monogyne species there are polygyne ant species which have multiple queens in a nest. In polygyne species very often forming supercolony such as *Formica yessensis*, it was known that workers are easily accepted in other nests [4]. This behavioral difference between monogyne and polygene species is probably concerned with nestmate recognition system

2 CHC SENSILLUM OF MONOGYNE SPECIES

The particular CHC sensillum of *C. japonicus*, which is ~20 μm length and 4 μm width houses 100< sensory cells. This means that logically more than 2^{100} different CHC blends can be discriminated with each other by on and off combination of those cells. Presumably, this unique sensory system is ready to respond to huge body of CHC blends including unexpected blends to be encountered. Actually, Argentine ant should not have been encountered toward *C. japonicus* until about 10 years ago. Nevertheless, *C. japonicus* did respond to the CHC blends of Argentine ant, which consist of different combination of hydrocarbon components from that of *C. japonicas*.

The CHC sensillum of *C. japonicus* responded not only the CHC blends of nonnestmate but also those of other species but not to nestmate blend. Thus the nestmates and the nonnestmates were sharply discriminated by this sensory system.

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3 CHC SENSILLUM OF POLYGYNE SPECIES

On the other hand, the polygene species, *Formica yessensis*, have a similar shape of sensilla on the antennae. This sensillum responded not only nonnestmates but also nestmate CHC blends. The responsiveness to CHCs of the own species regardless of nestmetes or nonnestmates was relatively weak in comparison with that to CHCs of other ant species. The chemosensory dullness in the CHC sensillum might be concerned with behavioral property of the polygene species, which behave so tolerantly in their own species that they can construct supercolonies consisting of multiple nests.

In polygyne species, supercolonies might be considered to correspond to colonies in monogynespecies, because workers, which tolerantly behave within supercolony, were still agressive among supercolonies

Thus, the CHC sensillum of *F. yessensis* cannnot sharply discriminate between nestmates and nonnestmates but between own species and other species.

4 PERIFERAL AND CENTRAL ROLES

As mentioned above, The CHC sensillum of monogyne species works as a sort of nestmate information-cut filter. Also in the electrophysiological experiment in an antennal preparation isolated from head, the CHC sensillum works as a nestmate information-cut filter. Thus, we excluded feedback effects of brain on the filter function. It is therefore concluded that the nestmate and nonnestmate discrimination is accomplished at this peripheral sensory system. In polygyne species, however, nestmate and nonnestmate discrimination is not completed at the peripheral sensory system, but probably final decision between acceptance and rejection of encounters is made at the central nervous system.

5 SUMMARY

Ants recognize their opponents by discriminating CHC mixing patterns with a particular chemosensillum sensitive to CHCs. The CHC mixing pattern is different among nests in monogyne species or supercolonies in polygyne specie. The single CHC sensillum houses more than 100 sensory neurons, activating pattern of which is involved in CHC mixing pattern discrimination.

Such a chemosensory unit with multiple sensory neurons as the ant CHC sensillum is a biomimetic model of differential detector of odors consisting of multiple components.

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A Novel Dry-Preservation Technology Inspired by Desiccation Tolerant Insect, *Polypedilum vanderplanki*

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Abstract
Some multi-cellular organisms can stand complete desiccation. This phenomenon called "anhydrobiosis" iindicates that theoretically our cells could be stored in a dry form at room temperature. An African insect, *P. vanderplanki* is going to teach us how to preserve cells and tissues at room temperature.

Keywords:
Anhydrobiosis, *Polypedilum vanderplanki* Trehalose, vitrification, LEA proteins, DNA repair,

1 INTRODUCTION

Anhydrobiosis is literally a status of life without water and defined as the state of an organism when it shows no visible signs of life and when its metabolic activity is hardly measurable or comes reversibly to a standstill under almost completely dehydrated conditions (Keilin, 1959; Clegg, 2001). Once desiccated, anhydrobiosis may last several decades of years unless water is given.

So far tissues and cells are preserved at either low or sub zero temperatures, and this is energy requiring. In contrast, dry preservation at room temperature is an energy-free, novel technology, which we should establish once we learn what anhydrobiotic organisms do. A devastating earthquake that hit us on 3.11 brought us a shortage of electricity through the shutdown of atomic power plants. Another huge quake may hit us anytime anywhere in the future as multiple continent plates are beneath the Japanese archipelago. Reducing energy consumption is becoming an ever pressing task, and the dry preservation technology could be the answer.

2 THE SLEEPING CHIRONOMID

Larvae of a desiccation atress tolerant chironomid, *P. vanderplanki*, living in the temporary rock pools in the semi-arid regions of the African continent are an example of such an organism. When the rock pools dry up, the larvae become completely dehydrated. However, within about an hour of water becoming available upon the next rain, the larvae are able to revive (Fig. 1). The sleeping chironomid, *Polypedilum vanderplanki*, is the highest and largest multicelluler animal with anhydrobiotic ability (Hinton, 1951; Hinton, 1960). Anhydrobiotic *P. vanderplanki* larvae stored for 17 years could revive after rehydration and followed by further normal development.

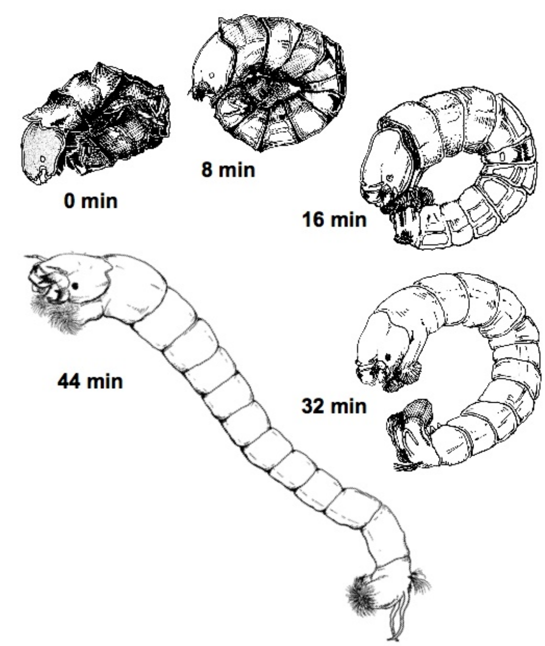

Fig. 1 Reviving larvae after rehydration

3 RESPONSIBLE MOLECULES

3.1 Trehalose

Many anhydrobiotic animals accumulate large amounts of disaccharide called trehalose, which serves as a compatible solute that is thought to protect desiccating tissues by replacing the primary water of hydration. Larvae of the anhydrobiotic *P. vanderplanki* indeed accumulate massive amounts of trehalose, which accounts

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to about 20% of their dry weight (40 μg/individual). Physico-chemical analysis revealed that the anhydrobiotic larvae enter a vitrified state, in which its molecules and the cell membranes were certainly stabilized under complete dehydration (Sakurai et al., 2008)

3.2 LEA proteins

Proteins called the LEA (late embryogenesis abundant), initially isolated from plant seeds, also occur in the larvae of *P. vanderplanki*. and both hydrophilic molecules (trehalose and LEA proteins) were contributing massively to the glass formation.

3.3 Trehalose transporter

A trehalose transporter gene, *tret1*, was isolated from *P. vanderplanki*, which permeates trehalose into the cells, followed by vitrification upon dehydration (Kikawada et al., 2007). This gene has a great potential for application such as in anhydro- and cryo-technology.

3.4 DNA repair enzymes

Desiccation stress upon anhydrobiosis was however unexpectedly severe, so that larval DNA was found to be damaged due to generation of superoxides during anhydrobiosis, though subsequently repaired. Indeed the expression of genes encoding the DNA repair enzymes occurred upon desiccation, indicating the occurrence of The DNA damage including double-strand breaks, followed by its repair (Gusev et al, 2010).

3.5 Antioxidant proteins

The mature antioxidant proteins also accumulated in the dry larvae and the total activity of antioxidants increased by 3–4 fold in association with anhydrobiosis. This provides a new insight into how *P. vanderplanki* larvae deal with oxidative stress to survive complete desiccation.The process leading to the general recovery of nuclear DNA integrity in rehydrated larvae is still unclear. There are at least two possibilities: (1) fragmented DNA is restored by DNA repair systems; or (2) damaged cells are eliminated by apoptosis while the remaining intact cells proliferated. The latter hypothesis seems less plausible, because we did not observe any significant increase in the number of dead cells in the fat body of either anhydrobiotic larvae.

4 APPLICATIONS

4.1 Dry preservation

We have successfully generated cultured cell originated from *P. vanderplanki* embryo, which is highly desiccation tolerance. This cell will provide us enormous hints for establishing the dry preservation technology.

4.2 Science education kit

As dried *P. vanderplanki* larvae can revive within about an hour after rehydration (Fig. 1), this amazing process can be seen under microscopes at biology class. The science education kit by using the dried midge is now available for teachers at school.

4.3 Food for fish

Dried *P. vanderplanki* larvae could be living food being able to store at room temperature.

4.4 Space midge

As anhydrobiotic *P. vanderplanki* larvae can be kept in a vacuum condition, e.g. outer space, several experiments at International Space Station is under progress.

5 SUMMARY

Some multi-cellular organisms can stand complete desiccation. This phenomenon called “anhydrobiosis” indicates that theoretically our cells could be stored in a dry form at room temperature. An African insect, *P. vanderplanki* is inspiring us in order to establish a novel dry preservation technology for cells and tissues. Several molecules responsible for desiccation tolerance are isolated from the midge, such as trehalose, LEA proteins, a trehalose transporter, antioxidants and DNA repair enzymes. The cultured cells originated from *P. vanderplanki* embryo were successfully generated, which is highly desiccation tolerance. This cell will provide us enormous hints for establishing the dry preservation technology. Several applications by using the Africa midge are rightly carried out.

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Mathematical Physics and the Moth-Eye Structure

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Abstract
In this paper the antirelective structure is discussed from the view point of mathematical physics. The moth-eye structure is of special interest, because it does not create the reflected wave. By considering the structure via the approximation to inhomogeneous stratified media, we see that the problem on determing the refractive index of the media has a close relationship with the inverse spectrum problem for the Schroedinger operator. We further pose an open question related to the optical nano-field which is an important notion to overcome the diffractive limit

Keywords:
antireflective structure, inhomogeneous stratified medium, scattering theory

1 INTRODUCTION

In this paper the antirelective structure is discussed from the view point of mathematical physics. The moth-eye structure is of special interest, because it does not create the reflected wave at all. This impressive fact is a starting point of my study in this direction. In the section 2, it is explained that the moth-eye structure can be regarded as an idealized object of a multilayer film which consists of infinately many films, that is, an inhomogeneous stratified medium. This observation goes back to Lord Rayleigh in 1978. In the section 3, we try to asscociate the problem on the refractive index of inhomogeneous stratified media with the inverse spectrum problem for the Schroedinger operator. Inverse spectrum problem is a major subject of mathematical physiscs. In the section 4, we pose an open question related to the optical nano-field which is a very important notion to overcome the diffraction limit.

2 ANTIREFLECTIVE STRUCTURE

2.1 The moth-eye structure

In 1962 Bernhard and Miller [1] found there exist so many cones on the surface of insect compound eyes. Such a structure is now called the moth-eye structure (see Fig.1). It is an interesting object not only from the biological view point but also from the view point of photonics. As a matter of fact, it is observed by experimentation that <u>the moth-eye structure is quite effective for antireflection</u>. Based on the development of nanotechnology, many contributions for creating such a structure are recently done by making use of the self-assembly process (see e.g. [2]).

2.2 Multilayer film

Reflection and refraction are observed at an interface between two different media. But, for some practical reason, one wishes to have antireflective nature for the reflecting surface. <u>Multilayer film has been widely used for getting lower reflectance</u> as much as possible. Indeed, by choosing each film with suitable refractive index, we can control the resulting reflectance of the multilayer film, thanks to the effect of multilayer interference. However, antireflective property of such devices is a bit restrictive, because <u>its performance depends on the incidence angle</u> <u>and wavelength of the incident wave</u>.

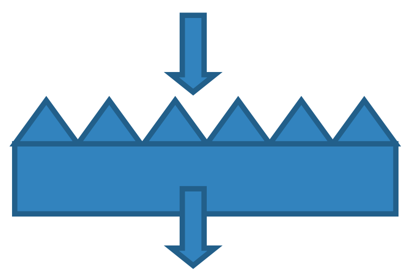

Fig. 1: Moth-Eye Structure

2.3 Inhomogeneous stratified medium

An idea for improving the performance of the multilayer film is to increase the number of films in a suitable way. As a limit, we arrive at a notion of an inhomogeneous stratified medium whose refractive index in the transit zone gradually changes (see Fig. 2). Such a medium was considered by Lord Rayleigh in 1879. He assumed that <u>the transverse wave in the inhomogeneous stratified medium satisfies an ordinary differential equation of second order which involves the refractive index as a potential</u>, and that the potential is inversely proportional to the square of the spatial variable in the transit zone and is a constant function in the other regions. By solving the differential

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equation, he was able to conclude that the reflectance from the transit zone becomes small, regardless of the incident angle and wavelength of the incident wave.

If we suppose the transit zone consists of many thin films, then the conclusion would be interpret as follows. Since the difference of the refractive indices between adjacent films is small, the amplitude reflection coefficient is also small. In addition, reflected waves appeared in each film have gradually different phases, so that the waves are canceled out after summing them up, provided the depth of the transit zone satisfies the condition of interference. Anyway, it is surprising for me that he made such a deep observation before the Maxwell equation was established.

More than 100 years later, such an idealized medium is realized by mimicking the moth-eye structure. In other words, the moth-eye structure can be understood via the observation for the inhomogeneous stratified media due to Lord Rayleigh.

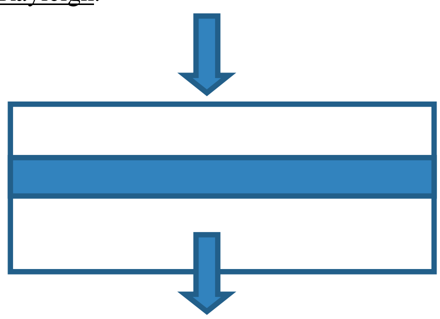

Fig. 2: Inhomogeneous Stratified Medium

3 SCATTERIING THEORY

Scattering theory has a long history and is one of the main topics of mathematical physics. In the context of quantum mechanics, the first step of scattering theory is to study spectra for Schroedinger operators with a given potential (see e.g. [4]). A typical example of potential is a square-well potential. This kind of consideration is an analogue in a Hilbert space to the eigenvalue problem for matrices in the Euclidean space.

It turns out that the problem for inhomogeneous stratified media studied by Lord Rayleigh has a close relationship with spectrum problem for Schroedinger operators in one space dimension, because the refractive index of the media can be associated with the potential in the Schroedinger operator. We remark that, in one space dimensional case, not only the spectrum problem but the inverse spectrum problem has been well developed (see e.g. [5]). Here, the aim of the inverse spectrum problem for the Schroedinger operator is to reconstruct unknown potential from given information of spectra.

It seems an interesting question whether some result of inverse spectrum problem is useful for reconstructing the refractive index of the inhomogeneous stratified media from suitable spectral data or not. This question would be meaningful, because one can determine the refractive index in the transit zone from the experimentation if the answer is affirmative. Unfortunately, we don't have any answer up to now. Indeed, in the scattering theory the potential is usually assumed to decay at spatial infinity, but it is not the case when we consider the inhomogeneous stratified medium. Hence, the problem on antireflective structure provides a challenging question in the field of scattering theory.

4 FURTHER OPEN PROBLEM

As we have seen in the previous sections, the moth-eye structure can be analyzed via the approximation to the inhomogeneous stratified media. In fact, the refractive index in the moth-eye structure gradually changes from the refractive index of the air to that of the basis of eye. However, in this approximation, we completely neglect the micro structure on the reflecting surface, or the effect of diffraction. Actually, if there is a micro structure on the reflecting surface, then we observe diffracted waves. We underline that diffracted waves of higher order don't appear when the period of the structure is much smaller than the wavelength of the incident wave. This type of diffractive grating is called **sub-wavelength structured surface**, and the moth-eye structure is a typical example.

But, what is curious for me is the fact that the moth-eye structure does not create the diffracted wave of the zero order, i.e. the reflected wave, as well. I wonder what is happen for the incident wave from the viewpoint of the conservation of the energy. One possible interpretation would be that the incident wave changes its type to "non-propagating". At first glance, it is strange to consider the wave which does not propagate in the medium. But, in the optical nanotechnology, the optical near-field which is considered a droplet of non-propagating light plays an essential role (see e.g. [6]). Therefore, it would be nice to bridge between the trapped wave in the sub-wavelength structured surface and optical near-field.

5 SUMMARY

Starting from the moth-eye structure, we arrive at two interesting questions. One is to develop scattering theory in the framework of non-decaying potential. The other is to characterize the trapped wave in the sub-wavelength structured surface in terms of the optical near-field.

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Opal photonic crystals for sensor applications

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Abstract
We have been working on smart photonic materials with tunable structural color. The mechanism of tuning lattice distance or refractive index in a tropical fish, squid, octopus and beetle inspired us to fabricate smart material which have tunable structural color. In this presentation, we will report soft opal films and their potential applications in sensors.

Keywords:
Colloidal crystal, Bragg's diffraction, Structural color, Strain sensing, Opal film

1 INTRODUCTION

Some kinds beetle, fish, octopus and squid can change surface structural color [1,2]. The tropical blue damselfish, *i.e.* cobalt-blue, reversibly change structural color from blue to green. The mechanism of tuning structural color was studied by Fujii and Oshima[3]. Figure 1A shows the concept of motile iridophore of cobalt blue. In the iridophore, the reflecting guanin nano-plates with a high refractive index 1.83 are regularly arranged in cytoplasm with a low refractive index of 1.37. This nanostructure is similar to the multilayer interference as shown in Figure 1B. Furthermore, the interspace of d in the iridophore can reversibly vary. The tuning interspace cause the color change of cobalt blue. Active structural color in organisms give us inspiration to design new photonic materials.

Figure 2 shows an opal photonic crystal and mechanism of tuning interspace of colloidal particle array [4]. A composite film made of polystyrene (PS) colloidal crystal and infilling polydimethyl siloxane (PDMS) elastomer. Fig. 2A shows SEM image of the composite film. In the opal photonic crystal, PS particles are formed a cubic closely packed (CCP) structure shown in Fig. 2B. In this model, multilayer of CCP(111) planes causes Bragg's diffraction of visible wavelength light. Fig.2C shows a concept image of opal composite film. The interspace of CCP(111) planes is reversibly tune between d_1 and d_2. In this meeting, we will demonstrate this composite film for strain sensing [5,6].

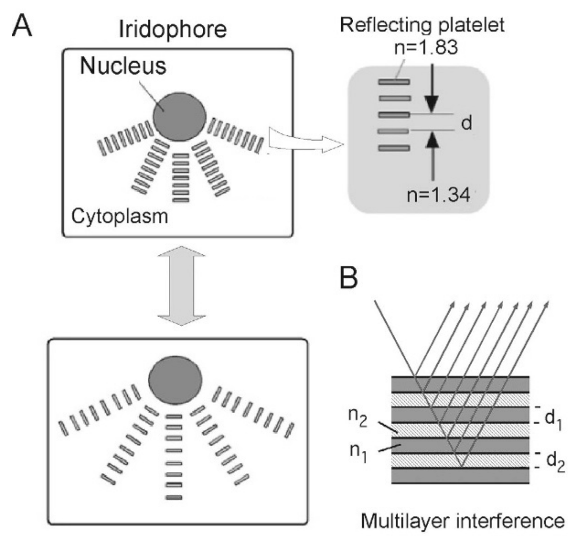

Fig. 1: Motile iridophore and mechanism.

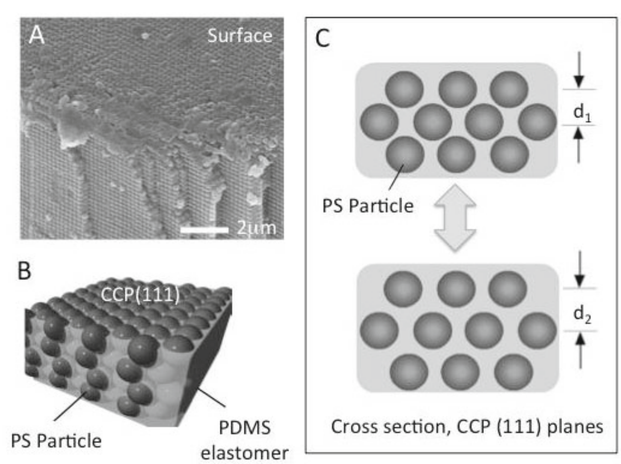

Fig. 2: Opal photonic crystal with variable lattice.

2 EXPERIMENTALS

Polystyren, PS, aqueous suspension was synthesized by conventional emulsion polymerization from styrene monomer. Monodispersed 200 nm PS particle was obtained using initiator of potassium persulfate and surfactant of sodium dodecyl sulfate. As a silicone elastomer, Sylgard 184 polydimethylsiloxane, PDMS, elastomer kit, was obtained from Dow Corning. A fluorosilicone (FVMQ, produced by Momentive) of 0.5 mm thickness was used as a rubber sheet.

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Colloidal crystal films were fabricated by drying the colloidal suspension on a FVMQ rubber sheet. The sheet surface was modified as hydrophilic by plasma cleaning. Then the surface was wetted with PS colloidal suspension. During drying the suspension, the surface was covered with silicone oil to control water evaporation. After crystallization, the void among the crystallized PS particles in colloidal crystal was infiltrated with the PDMS precursor and cured. As a result, opal photonic crystal films were fabricated on the FVMQ rubber sheets.

The opal photonic crystals coated on FVMQ rubber sheets were stretched with one-dimensional mechanical stage. The reflection spectra of the opal photonic crystals were taken using a miniature fiber optic spectrometer (Ocean Optics, HR2000). The incident light was aligned perpendicular to CCP (111) planes of the composite films.

3 STRAIN SENSING AND PROSPECTIVE

Figure 3A shows a dog bone type test specimen for elongation strain on the mechanical stage. This test specimen indicates red structural color. Figure 3B shows the spectrum of the specimen in initial condition. A sharp and single diffraction peak is located near 640 nm. The structural color of the specimen reversibly and repeatable changed from red to green by mechanical deformation. When the rubber sheet was stretched horizontally, the composite film on the sheet reduced its vertical size as shown in Fig. 2C. Figure 3C shows the relationship between elongation and peak position. The peak position linearly decreased as a function of mechanical strain for up to 35%. In this region, the interspace of CCP (111) planes, d, also decreased as same ratio. This mechano-optical behavior can be applied to strain gage indicators. Figure 4 shows a prospective application for infrastructure monitoring. In case of applying opal photonic crystal on plastic deformation of the metal substrate, mechanical damage of the metal structure may be easy display without special equipment. Furthermore, this sensing material is low cost and environmental friendly fabrication. We expect that opal photonic crystal become an ecodesign.

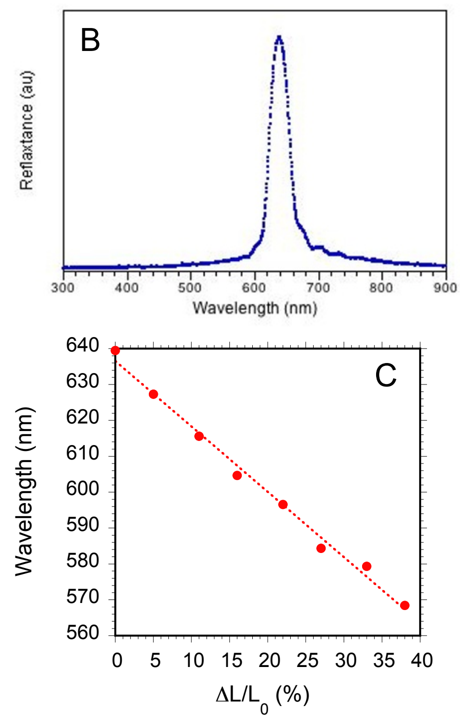

Fig. 3: Tuning diffraction peak by elongation.

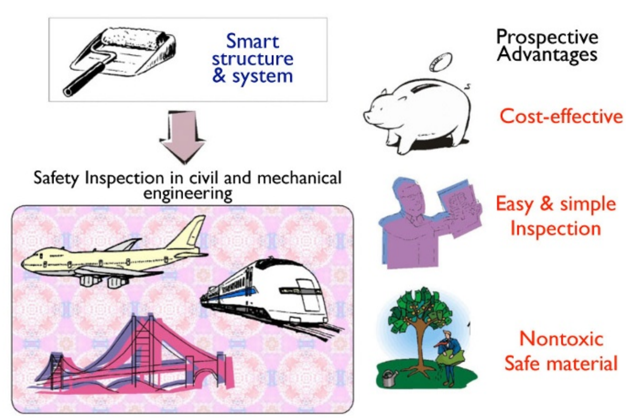

Fig. 4: Prospective application for strain imaging.

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Simple Manipulation of Liquid on Tunable Microwrinkles

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Abstract
Methods of shaping and manipulating liquids on small scales are important for micro-patterning, microfluidics, and biosensing, and may provide fundamental insights into nonlinear chemical phenomena in confined small spaces. Here, we report a very simple technique for shaping liquids into micrometre-scale filaments. Microgrooves on microwrinkles generated by thin film buckling on elastic substrates can function as open channel capillaries for liquids with appropriate wettabilities.

Keywords:
microwrinkle, patterning, self-organization, microfluidics

1 INTRODUCTION

Methods of controlling the shape and position of liquids on small scales are important for various applications based on microfluidics [1] and micropatterning [2], such as biosensors [3], printable electronics [4], and photonic materials. Many of these methods rely on the patterning and manipulation of liquids on solids on or below the micrometer scale. Generally, a non-spreading liquid forms a line of contact on a solid, and the triple line has a specific contact angle because of balanced surface tensions in the equilibrium state. The mean curvature of the liquid-air interface is constant and proportional to the Laplace pressure. Thus, the distribution of the contact angle or the Laplace pressure (mean curvature), which can be produced externally or internally, can induce droplet motion [5-8] or shape deformation [9,10]. Moreover, the dewetting of liquid films [11-18] and the fingering instability of the receding triple line [19,20] have been reported as methods for transporting, shaping and patterning liquids on small scales.

Open capillary channel phenomena have been studied extensively. This type of capillary motion, especially in open microchannels, is likely to be useful for patterning and shaping liquids into long liquid filaments (LFs), particularly on a small scale. However, there is little published in the literature on this technique because the methods and materials for the in situ control of capillary action are limited. Electrowetting, where the contact angle of a dielectric liquid is modified by applying an electric field, is one such method.

Microwrinkles are suitable for use as an array of open microchannel capillaries because their microtopography is tunable, and therefore allows in situ control of capillary action. In addition, microwrinkles can be easily fabricated over a large area. On the basis of this idea, we have developed a simple and general method for shaping and patterning various liquids on a micrometer scale [21].

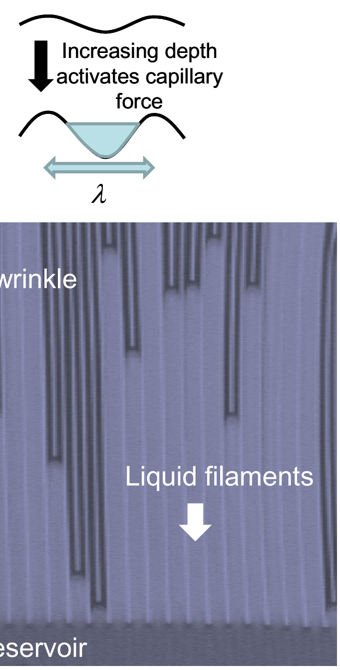

Fig. 1. Schematic for the concept of the tunable open capillary using shape-tunable microwrinkles (top) and image of the LFs that fill wrinkle grooves only; crests are left exposed to the air (bottom).

In biological systems, they manage the flow/circulation of liquid in their bodies or on body surfaces without electric pumps and the closed/open channels are naturally developed or self-organized. For the present method, neither the conventional lithographic techniques for fabrication of micro-channels nor micro-pumps to drive the liquids are required. Therefore, the use of the self-organized microwrinkle with shape-tunability has many advantages as an ecological fabrication process, which conceptually mimics the nature technology of managing liquids

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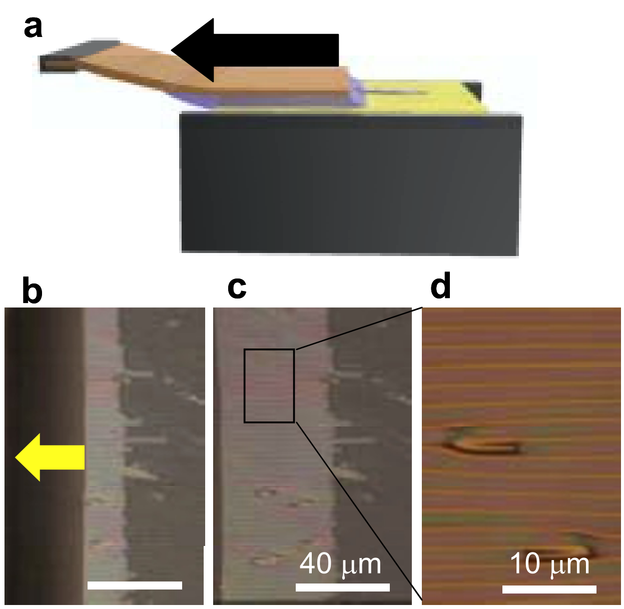

Fig. 2. Preparation of a LF array using a simple bar-coating method for large area patterning. (a) Schematic of the method. (b)-(d) Optical microscopy images of LF array. Where there are topological defects in the stripe pattern, the grooves are shallow, which leads to unfilled sections of the array.

2 RESULTS AND DISCUSSIONS

Initially, the critical conditions for capillary action were determined (refer to ref [21] for experimental details). The capillary action of a large liquid droplet placed on a microwrinkle surface was observed as the groove depth was gradually increased. At a critical point, the liquid flowed into the wrinkle grooves; the wrinkle crests were still exposed to the air (Fig. 1). Consequently, we have found that the capillary phenomena is governed by two key parameters: the equilibrium contact angle, θ, of the liquid on a smooth surface; and the aspect ratio, R, of the microwrinkle groove, which is defined as $R = 2A/\lambda$. R can be changed by applying compressive strain perpendicular to the groove direction. The critical aspect ratio of the groove for capillary action, R^*, was determined at a fixed value of θ. Changing the combination of the liquid and the material of the wrinkle surface altered the value of θ, and the critical condition, expressed by the function $R^*(\theta) \approx \alpha\theta^{\beta}$ was obtained, where α and β are positive constants and β is less than one. This experimentally determined critical condition was also obtained by theoretical methods, within experimental error [21]. The general condition for capillary phenomena on microwrinkle grooves is important because it also indicates the stability of LF on the microwrinkles. Through choosing the parameters (R, θ) we can selectively fill the grooves with liquid to obtain a centimeter-scale LF array, using a simple method, such as bar-coating (Fig. 2).

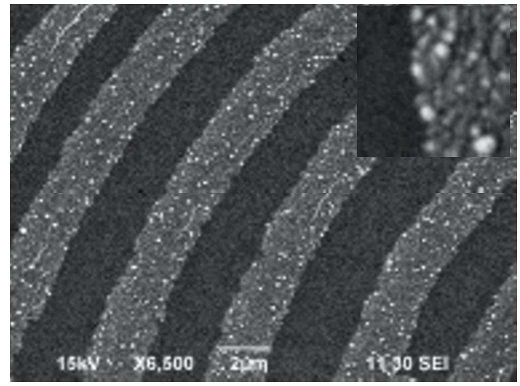

Fig. 3. Scanning microscopy image of rough gold nanoribbons transferred to another substrate.

Because the LF array is a line-and-space pattern of a liquid and a solid, the pattern can be used as a unique template for further patterning. We have demonstrated that the LF array can be used to fabricate novel nanoribbons based on the thermal evaporation of gold (Fig. 3) [22]. On the liquid part of the substrate, rough gold ribbons form because the deposited gold atoms can diffuse, grow, and aggregate in proximity to the liquid-air interface; flat gold films form on the solid part of the substrate. The rough gold nanoribbons can be peeled away by contact with water, because of the surface tension, and transferred to other substrates. The extinction spectrum of the rough gold nanoribbons suggests a characteristic surface plasmon absorption. It may be possible to exploit the control over the shape of these rough gold nanoribbons for use in plasmonic technology. The novelty of this method for obtaining micropatterns is that the process is simple and does not require conventional lithography. We expect that there will be other suitable applications for this LF array.

We have also investigated the response of the LF to changes in the groove direction [23]. In the perpendicular groove direction, the LF was divided into small droplets (Fig. 4). Since the stability of the LF shape depends on the groove shape, the LF becomes unstable when the groove direction changes. The shape of the droplets was controlled by tuning the contact angle (see [23] for experimental details). At lower contact angles, the droplets spread in the direction of the newly formed groove, although at higher contact angles the spreading was suppressed. Since $\lambda \approx 2.2$ µm in Fig. 4, the droplet volume is less than 1 fL (volume $\approx R\lambda^3/2 \approx 0.75\times10^{-18}$ m^3 ≈ 0.75 fL, where $R \approx 0.15$). This method for preparing microdroplets with a specific volume is very efficient because of the simplicity of applying strain to the sample macroscopically.

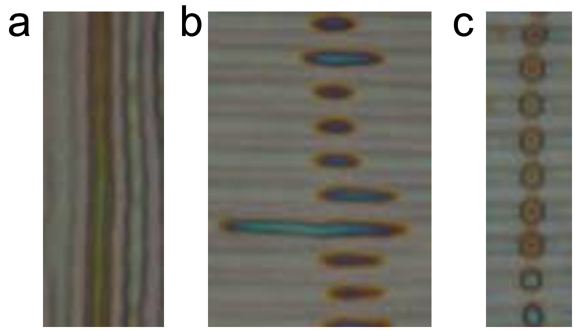

Fig. 4. Division of LFs into small microdroplets with a particular volume. (a) LFs before division. Divided micro droplets with (b) lower and (c) higher contact angle. Microwrinkle wavelength is 2 μm.

3 SUMMARY

We believe that these liquid transformations on a nanometer or micrometer scale will find applications in switchable light diffraction gratings and lab-on-a-chip systems, in addition to simple liquid micropatterning. This technique may also be used to investigate the properties of liquids in a confined small space, which are thought to be very different from the bulk properties, such as fluctuation of the liquid surface and liquid crystal alignment. Because the system is very easy to be controlled without any precise spatial controls, the use of the self-organized microwrinkle with shape-tunability has many advantages as an ecological fabrication process, which conceptually mimics the nature technology of managing liquids.

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"Mechanobio-Materials": Design of Micropatterned Elastic Gels To Control Cell Mechanotaxis and Motility-Related Functions

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Abstract

Cell functions are known to be regulated not only by the biochemical or physiological conditions of extracellular milieu but also by the mechanical conditions of substrate surface or extracellular matrix. The detailed understandings for the cellular responses induced by such mechanical field or mechanical stimuli, and its application for systematic design of mechanical field of cell culture substrate are expected to establish solid basis for constructing high-functional cell manipulation materials. To develop such biomaterials that manipulate cell mechanobiology, we focus on the control of mechanical taxis of cell movement, mechanotaxis, by the micropatterned elastic gels. The potential application of the systematic design of micromechanical field of elastic substrate for cell functional regulation is discussed.

Keywords:

mechanotaxis, mechanobiology, mechanobio-materials, microelasticity patterning

1 INTRODUCTION

In general, cell adhesion mechanics onto the substrate surface critically affect not only its static shaping behaviors but also the dynamic changes in the cell morphology, i.e., regulation of cell motility. Cell motility plays the essential roles in various physiological and pathological processes such as morphogenesis, wound healing, inflammation, and tumor metastasis etc. Appropriate control of such biological processes is a longstanding task in the development of high-functional biomaterials. Establishment of the surface engineering of biomaterials to manipulate the cell motility has been strongly required as well as the understandings for its mechanism. In relation to this issue, we are focusing on the understanding and control of cell mechanotaxis, which is the substrate-mechanics-induced directional cell movement, one of the new categories of cell thigmotaxis behaviors. The control of mechanotaxis is expected to provide a solid basis for designing biomaterials to manipulate cell mechanobiology. To establish the condition to control cell mechanotaxis, we have developed the photolithographic surface microelasticity patterning method for fabricating a cell-adhesive hydrogel with a microelasticity-gradient (MEG) surface using photocurable styrenated gelatin. On the well-designed micropatterned elastic field, mechanotaxis was successfully controlled.

2 METHOD

cell-adhesive MEG gels were prepared by photocurable styrenated gelatin using a custom-designed reduction projection photolithography systems [1]. Patterned MEG gels were prepared by regulating the photoirradiation power, periods, and positions. Surface elasticity and its two-dimensional distribution were characterized by microindentation tests using atomic force microscopy. On the prepared MEG gel, movement trajectories of 3T3 fibroblast were observed by time-lapse microscopy.

3 RESULTS AND DISCUSSION

To investigate the condition to induce and control mechanotaxis, patterned MEG gels with different absolute surface elasticities in soft and hard regions, elasticity jumps between them, and sharpness of elasticity boundary. Three critical criteria of the elasticity jump and the absolute elasticity to induce mechanotaxis have been identified [1, 2]: 1) a high elasticity ratio between the hard region and the soft one, 2) elasticity of the softer region to provide medium motility, and 3) sharpness of the elasticity boundary. Especially, concerning the characterization of the effect of sharpness of elastic boundary on the induction efficiency of mechanotaxis, MEG gels with the different sharpness of elastic boundary and the same magnitude of elasticity jump between softer and stiffer regions were fabricated. While on the diffuse elastic boundary cells did not exhibit any directional movements, marked enhancement of mechanotaxis was observed on the discrete elastic boundary of ca. 40 kPa jump within 50 μm-wide boundary (Fig.1). Essential condition to induce mechanotaxis was found to be enough sharp elasticity jump in the region where a single cell can adhere and sense it [2, 3].

Based on the above result, more sophisticated microelasticity patterning to fully control mechanitaxis

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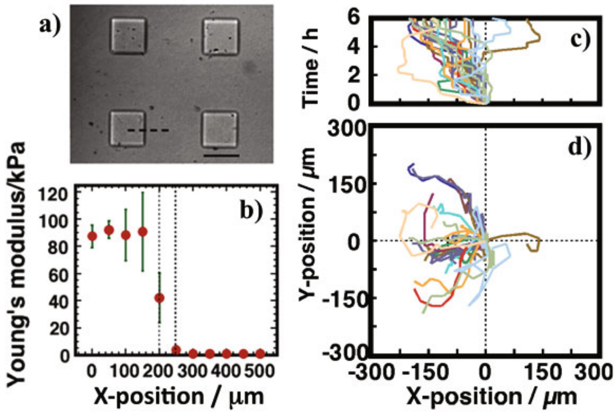

Fig.1. a) Phase contrast microscopic image for microelasticity patterned gels. Domain: hard region, scale bar: 400 μm. b) Surface elasticity distribution around the elasticity boundary. c) Time-course of x-positions, and . d) x-y trajectories of fibroblasts moving around the elasticity boundaries.

was considered. If we can design the asymmetric elastic gradient field which has the sharp elasticity jump and diffuse elasticity gradient coupled in one patterned unit, cells are expected to show mechanotaxis only at the sharp boundary and rectified movement on the saw-like asymmetric gradient field. To confirm this possibility, we prepared the saw-like MEG gels by regulating the photoirradiation dose for the sol surface with asymmetric manner by using XY-microstage, which has elasticity pattern unit with 80 kPa ascending slope in 30 μm-width and descending slope in 60 μm-width. In addition, to enhance the efficiency for the rectification of random cell movement, perpendicular soft lane was introduced on the saw-like MEG gel. Observed trajectory clearly showed the marked rectification movement of cultured fibroblast cells on the saw-like MEG gels (Fig.2). Precise microelasticy pattering of cell culture gels was shown to be a powerful methodology for systematic control of cell mechanotaxis.

4 SUMMARY

We have clarified the essential condition to induce mechanotaxis by utilizing the originally-developed photolithographic elasticity miropatterning for cell adhesive hydrogels: introduction of the elasticity boundary with enough high elasticity jump and narrower boundary width than adhesion area for a single cell. It was found that mechanotaxis can not be induced on the diffuse elasticity gradient field but induced on the sharp elasticity boundary. To make clear this principle, the precise mechanical engineering of gel surface based on the nano/micro-technology was essentially required, suggesting that nano/micro mechanical engineering of soft materials provides novel key platform for the investigation of cell mechanobiology. We call such the platform materials that enable to regulate and to systematically investigate the mechanobiological behaviors of cells as "mechanobio-materials". The sophisticated design of

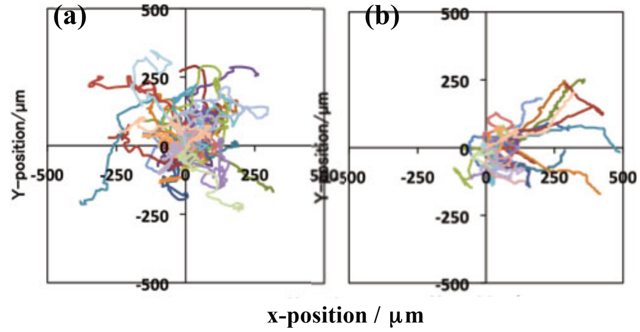

Fig.2 Trajectories of 3T3 cell movement on (a) uniform elasticity distribution (45 kPa) gels and (b) the asymmetric elastic gradient gels with perpendicular soft lane (30 h, n = 30)

mechanobio-materials and its application for the cell motility-related functional regulation will provide the new possibility of biomaterial engineering.

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Study of Airfoils for the Unique Micro Wind Turbine Blade.

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Abstract

An airfoil of insect's wing is completely different from the conventional streamlining airfoil, and it has very thin corrugated cross section. As you can see from the flight of insects, their wings are used in the low speed region, functioning in a speed region different to the ones in which streamlining airfoil is used. Studies on the aerodynamic characteristics of the corrugated wing in the low speed region are very limited, with many aspects still remaining unknown.In order to clarify aerodynamic characteristics of corrugated airfoil in the low speed region, we have developed our own system composed of micro three-component balance and swirl-type experimental water channel, and investigated the aerodynamic characteristics of the corrugated airfoil and curved plate having smooth cross section in the low speed regions (Re=7,000 and 11,000). This investigation revealed that, in the low speed regions the aerodynamic characteristics of the corrugated airfoil was equivalent to or superior than those of the curved plate, and it was also found that the aerodynamic characteristics of the curved plate were very susceptible to the changes in Reynolds number whereas those of the corrugated wing were insusceptible to the changes. In the past, a small wind turbine has not been paid much attention as a source of alternative energy because of its low availably in low wind speed region and of its difficulty in handling it. All of these issues inherent in the small wind turbine will be solved by adopting the corrugated wing in the wind turbine. All of these findings from our investigation are reported in this paper.

Keywords:
Wind turbine, corrugated airfoil, Low Re Number,

1 INTRODUCTION

Insects fly at very low speed, and their Reynolds number region is very low at (Re≦10^3). The streamlining airfoil has been designed such that it can function in Reynolds number region as high as 10^6 to 10^8 (10^6≦Re≦10^8), and it is known that its lift-drag characteristics become largely deteriorated in low Reynolds number region where insects fly. Airfoils that function in low Reynolds number region has been studied as a key technology in the micro flight vehicle development, and its profile of the airfoil has been heavily based on the traditional airfoil design [1]. Insects have a thin corrugated airfoil, the surface of which is a concavo-convex shape. From the fact that some species of dragonfly migrate over the ocean, there is no doubt that insects' gliding ability in low Reynolds number region is great, and thus the aerodynamic characteristics of the corrugated airfoil have gathered attention. The past studies of aerodynamic characteristics of corrugated airfoil have reported that the corrugated airfoil has the sufficient aerodynamic characteristics in low Reynolds number region [2][3][4][5], and from the corrugated wing cross section profile, it has been speculated vortexes are generated around the wing. For the first time in 2009, the study carried out by Obata et al. identified that the vortex trains are formed on the upper surface of the wings along the air flow from the leading edge of the wing, generating lift while preventing the flow from being separated [6]. However, only a few studies have been conducted so far on the aerodynamic characteristics, and not enough research has been conducted to establish the design methodology for low Reynolds number airfoil. Furthermore, it is speculated from its concavo-convex shape that as the Reynolds number increases, the drag also increases, causing the lift-drag characteristics to deteriorate. However this influence on the aerodynamic characteristics from the change in Reynolds number has not been clarified. Therefore, the aerodynamic characteristics of the corrugated and curved plate at Reynolds number of 7,000 and 11,000 (Re=7,000 and 11,000) was measured in this study using a micro three-component balance and a swirl-type experimental water tank. The results were then compared. Furthermore, corrugated airfoil was adopted in a small wind turbine, which has not been fully utilized in the past due to its difficulty in handling and low availably in low wind speed region. Its potential as a new source of alternative energy was also investigated.

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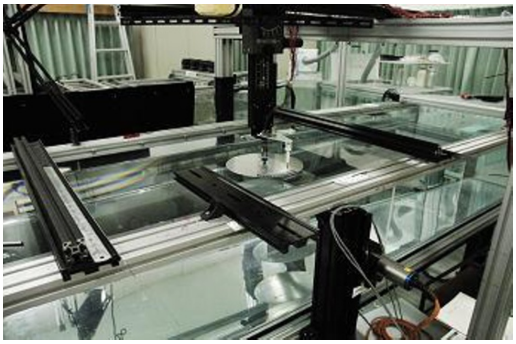
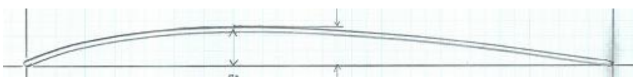
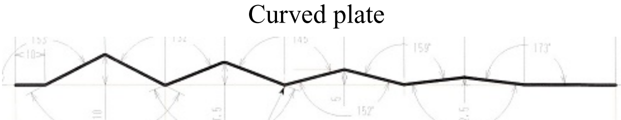


Fig.1: The measurement section of the water channel

Fig.2: Experimental model and The three-component balance

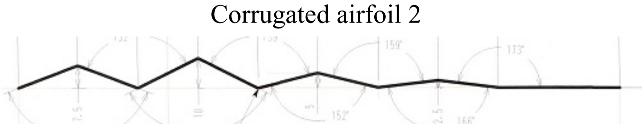


Curved plate

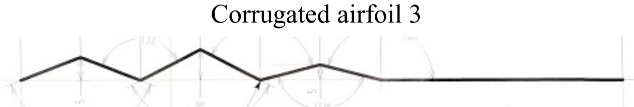


Corrugated airfoil 1

Corrugated airfoil 2



Corrugated airfoil 3



Corrugated airfoil 4

Fig.3: The wing models airfoil sections

2 MATERIALS AND METHODS

2.1 Measurement of aerodynamic characteristics in steady flow

The channel used in the experiment is an open type swirling water channel whose external dimensions are 6m by 3m (6m×3m), and its measurement section is 750mm in width, 0.38m in depth, and 1,900mm in length. A flow speed controller is a multi-screw type unit composed of 4 screws a row and 2 stages in a line, and it can regulate the output by a few percent because servo motors are used. The flow speed can be varied between 2cm/s and 20cm/s. The external view of the measurement section of the water channel is shown in Fig.1. The capability of three-component balance used in the measurement is approximately 0.5N in any directions of the lift (L), drag (D) and moment (M), and its minimum readout is 1×10^-4N. The two-dimensional wing models used in the experiment are made of pure aluminum. The model's cord length is 200mm and span length is 280mm in both the corrugated and curved plate models. In order to provide the model with the two-dimensional property, the circular plate whose diameter is 300mm is attached on the wing tip. Fig.2 shows the wing model and the three-component balance. Fig.3 shows the wing models airfoil sections. These experimental models were fixed to the three-component balance on the middle point of the wing cord and the output from the balance is entered into the conversion equation (a) to calculate L, D, and Mc/4. Drag of the winglet, Dep, measured before the experiment is subtracted from the measured value. Then, these values are non-dimensionalized as shown in the following equation, (b).

(a)

$$L = N\cos\alpha - T\sin\alpha$$

$$D = (N\sin\alpha + T\cos\alpha) - Dep$$

$$M_{\frac{c}{4}} = M_{\frac{c}{2}} - 0.05N$$

(b)

$$C_L = \frac{L}{\frac{1}{2}\rho U^2 S}$$

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 S}$$

$$C_{M\frac{c}{4}} = \frac{M\frac{c}{4}}{\frac{1}{2}\rho U^2 S}$$

2.2 Investigation of corrugated airfoil wind turbine

A small wind turbine with corrugated airfoils with a rotor diameter of 50cm was manufactured and its rotation speed per wind speed was measured in a wind tunnel. Reynolds number of wind turbine blades was qualitatively calculated from the measured rotation speed of the wind turbine to investigate the effectiveness of the corrugated wing. In this experiment, the Goettingen wind tunnel (1m×1m) was used. Fig. 4 shows the corrugated airfoil wind turbine and the Goettingen wind tunnel.

Fig.4 : Corrugated airfoil wind turbine and Goettingen wind tunnel

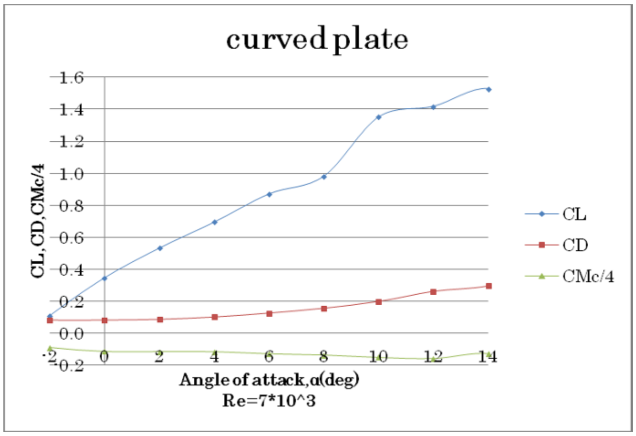


Fig.5 the curved plate 3 force characteristics with in Re=7,000

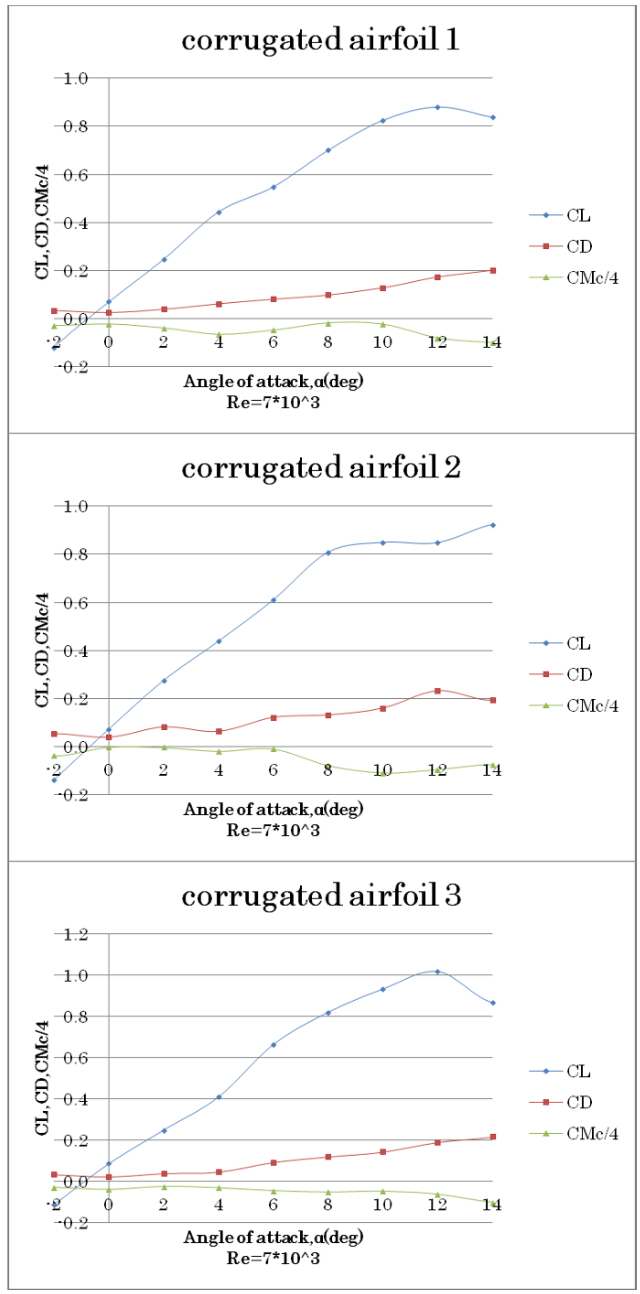
3 RESULTS

3.1 Re=7,000 Curved plate characteristics

In the low range of Reynolds number, the airfoils that cause the laminar to curve have high lift-to-drag characteristics. Therefore, in order to carry out a comparison with the corrugated airfoil, the test used a thin Benedek 6356b airfoil with a camber that follows the camber line. Benedek 6356b airfoils are known as airfoils for model aircraft that fly in the low range of Reynolds number. Fig.5 shows the curved plate 3 force characteristics. The lift curve rises in a curve until it reaches α=8°. When it reaches α=10° the lift coefficient increases sharply. This is considered to be because the laminar separation area close to the trailing edge of the curved plate upper surface is blown by the vortex from the leading edge of the curved plate and the flow is reattached to the airfoil and the lift coefficient increases. Also, because the trend for $C_{Mc/4}$ indentation becomes stronger between 8°and 10°, the separation area at the trailing edge of the airfoil is eliminated. The separation area is reduced, but because the trailing edge flow is disturbed by the vortex, the drag coefficient is not reduced. At α=14°the maximum lift coefficient is 1.5. This can be considered to be because the intense vortex from close to the leading edge of the curved plate causes an increase in lift. Also, when α=14°at the maximum lift coefficient, the previously downward-sloping $C_{Mc/4}$ becomes upward-sloping and, as a result, a strong vortex is generated close to the leading edge of the airfoil. This curved plate has a maximum lift-to-drag ratio of 6.9 at α=6°.

3.2 Corrugated Airfoil Characteristics

The corrugated airfoil used in the test is made up of 4 sheets of uneven airfoil with reference to the cross section of a dragonfly's wing. Fig.6 shows 3 force characteristics for corrugated airfoil No.1 to No.4. The maximum lift coefficient for the corrugated airfoil is smaller when compared to the maximum lift coefficient for the curved plate at approximately 1.0 when α=12°to 14°.



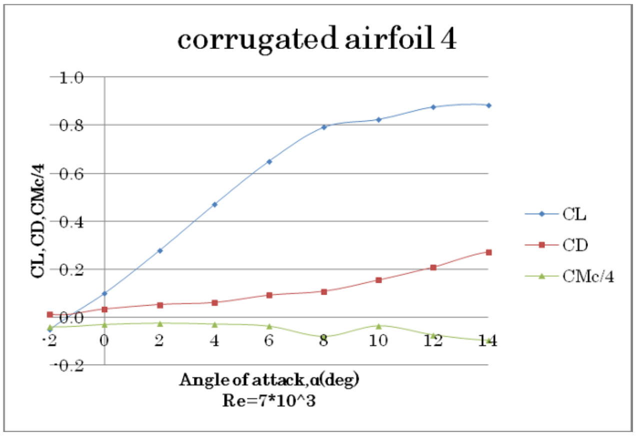


Fig.5: 3 force characteristics for corrugated airfoil 1-4 with in Re=7,000

Also, the lift coefficient does not increase sharply as it does with the curved plate. The corrugated airfoil already creates a vortex street on the upper surface of the airfoil and therefore, irrespective of the angle, a laminar separation area cannot occur as it does with curved plate. The drag coefficient of corrugated airfoil is less than the drag coefficient of curved plate irrespective of the angle. At an angle of α=0°to 4°the drag coefficient value of corrugated airfoil is half the drag coefficient value of curved plateat the same angle. Among the corrugated airfoils, corrugated airfoil No.3 (C_d=0.024) has the smallest drag coefficient. As for recurring features, corrugated airfoil, No.3 has 4 peaks and the second peak from the leading edge is the highest peak. The configuration of corrugated airfoil No.4 is very similar to corrugated airfoil No.3 in that it does not have the lowest peak close to the trailing edge. However, at α=0°the drag coefficient of corrugated airfoil No.4 (C_d=0.034) is greater. This is because the surface area of the flat surface close to the trailing edge of the airfoil is increased due to the absence of the fourth peak from the leading edge and is not directly subject to viscous drag particularly at the trailing edge lower surface. With corrugated airfoil No.4 and the very similar corrugated airfoil No.3 the circulatory flow within the fourth peak from the leading edge is thought to lessen the viscous drag effect on the airfoil lower surface. It is evident from the above that there is less drag when there is a circulating flow around the airfoil that does not inhibit the vortex and flow. Corrugated airfoil No.2 has 4 peaks, the same as corrugated airfoil No.3. The highest peak is the first peak from the leading edge. There is almost no difference between the configurations of these airfoils, but when the flow is compared using a visualization image, the airfoil upper surface vortex swelling for corrugated airfoil No.3 is thinner than for corrugated airfoil No. 2 when α=0°at the maximum drag coefficient and in contrast to corrugated airfoil No.2 where the vortex is extremely violent when α=4° at the maximum lift-to-drag ratio, with corrugated airfoil No.3 the vortex cleanly flows along the airfoil. It can be concluded from the above that the positioning of the corrugated airfoil highest peak conditions the vortex flow and results in a reduction in drag.

3.3 Re=11,000 Curved plate Characteristics

Fig.6 shows the three component force characteristics of curved plate in Re=11,000 conditions. Between α=6°and 8°, the lift curve slope becomes large, and the lift increases. At that stage, the $C_{Mc/4}$ point's tendency to tilt forward becomes more pronounced. This is the same phenomenon as the airflow change that occurred from 8°to 10°in Re=7,000 conditions, and this was caused when the vortex generated by the curved plate leading edge blew off the separation region. Unlike what happens in Re=7,000 conditions, though, is that in this case the angle of attack causing this airflow change is smaller, and so the influence on the lift has become smaller. It is presumed that the change in the Reynolds number from Re=7,000 to Re=11,000 has weakened the influence of viscous force. As can be seen from The greatest lift coefficient (C_{Lmax}=1.71) is achieved with an angle of attack α of 14°. The lowest drag coefficient (C_d=0.038), on the other hand, is achieved with an angle of attack α of -2°. Compared with the maximum lift coefficient and the minimum drag coefficient obtained in Re=7,000, the lift coefficient increased by 12% and the drag coefficient was reduced by half of more in each condition. Therefore, curved plate characteristics in Re=11,000 conditions are markedly superior to those observable in Re=7,000 conditions. The greatest lift and drag characteristics (L/D_{max}11.7) are realized with an attack angle α of 4°.

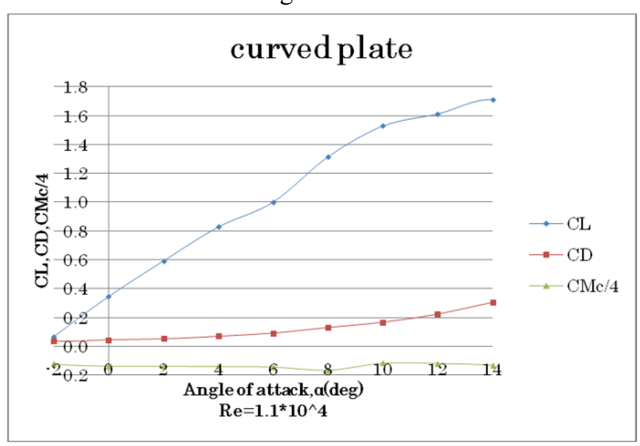
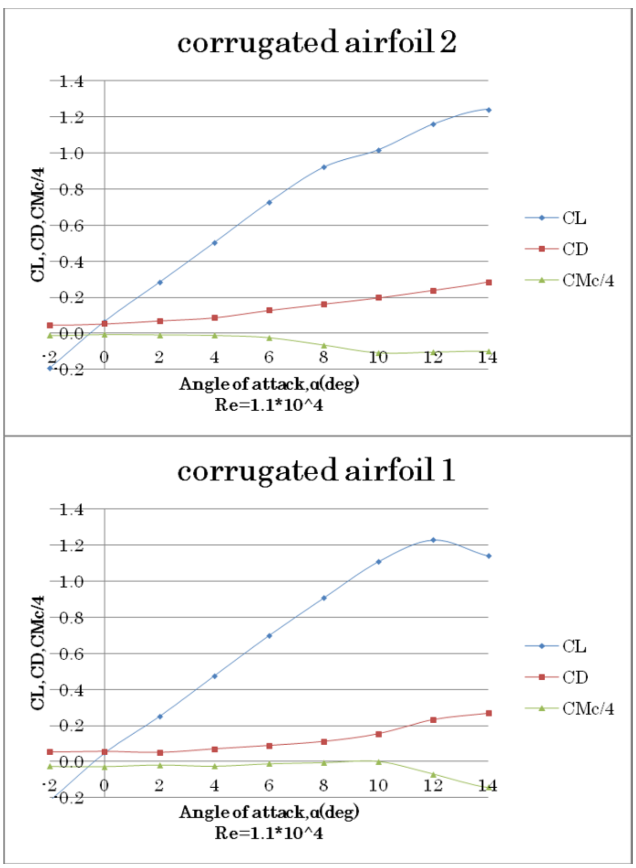


Fig.6: the three component force characteristics of curved plate in Re=11,000

3.4 Corrugated Wing Characteristics

Fig.7 shows the three component force characteristics of corrugated wings in Re=11,000 conditions from No.1 to No.4. The maximum lift coefficient of corrugated wings is lower than that of curved plates, i.e. about 1.2 for an angle of attack α of between 12°and 14°.The reason why a change in the angle of attack does not cause a major change in lift curve is the same as under the Re=7,000 conditions. Among the set of corrugated wings devised, the one with the smallest drag coefficient (0.035 with an angle of attack α=0°) is Corrugated Wing No.4. With its lowest number of corrugations, Corrugated Wing No.4 is the one that best minimizes drag. Comparing the minimum drag value of corrugated wings by Reynolds number, the results show that there were more drag in Re=11,000 conditions than in Re=7,000 conditions. By comparing visualization photographs of flows at the same angle of attack for Re=11,000 and Re=7,000 conditions, it is evident that as the Reynolds number increases, the size of vortexes generated by corrugated wings increases as well, causing stronger drags. The corrugated wing that offers the greatest lift to drag ratio (9.8, with an angle of attack α=4) is Corrugated Wing No.4. However, in a Re=11,000 condition, the lift and drag properties of curved plate excel that of the corrugated wings, indicating that their performances have reversed.



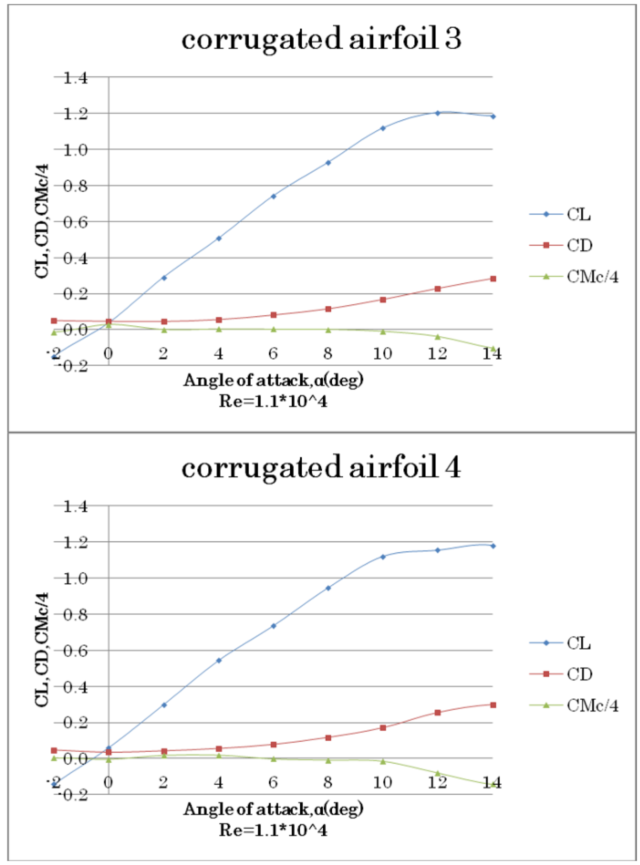


Fig.7: the three component force characteristics of corrugated wings in Re=11,000

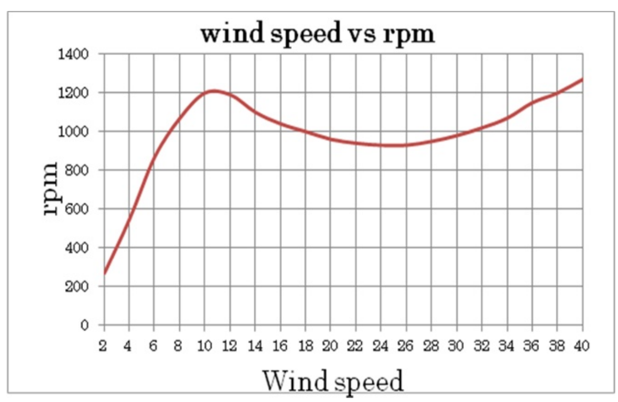


Fig.8: wind speed and rpm of a turbine,

3.5 Corrugated blade type turbine tests

Fig.8 plots the uses airfoils identical to those of Corrugated Wing No.4 as blades. A feature of this corrugated blade-fitted turbine is that it reaches max. rpm under a 10m/s wind speed, while under any slower wind speed, its rpm remains constant. For these two rpm values, the Reynolds number of these blades was roughly Re=1*10^5.

Judging from the measured aerodynamic characteristics of the corrugated airfoils tested for this study, their performance deteriorates as their Reynolds number increases. From the turbine's rpm experiment, it became evident that a) the performance of the blades deteriorates in direct correlation with rpm increases, and b) turbines have an absolute ceiling rpm they cannot exceed.

4 CONCLUSIONS

In the low Reynolds number region, corrugated wing types display characteristics that are better than those that have traditional smooth sections, and that of all possible cross-section shapes, some are better suited to airflows generated under low Reynolds number conditions. Furthermore, as the Reynolds number increases from 7,000 to 11,000, the curved plate lift and drag characteristics surpasses that of corrugated wings, with their characteristics showing reverse performances. It also became clear that in response to a Reynolds number change from 7,000 to 11,000, corrugated wings, unlike curved plate, do not display any great changes in lift and drag characteristics. From the turbine rpm test, it was speculated from the change in rpm that even in high Reynolds number region exceeding 10^4, the performance of corrugated wings keeps deteriorating. When corrugated airfoils are used as turbine blades, a possibility that rpm can be regulated without the use of a complex mechanism was indicated. Moreover, since corrugated airfoils are very thin with practically no body thickness, they have now paved the path for making turbines of unprecedented lightness. By adopting corrugated blades for small turbines, it may be possible to solve issues related to small turbines including a handling problem and low availability.

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Sustainable Ecodesign Mapping of End-of-Life Strategies for Improved Products/Processes Management

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Abstract

There is immense pressure from various stakeholders for producers to become more environmentally sustainable. Using ecodesign considerations to manage product and operations process decisions is often viewed as the next frontier in organizational competitiveness. When considered in early design stages of a product, ecodesign decisions can significant improves life cycle sustainability although substantial hurdles have to be overcome to ensure ecodesign methods remain viable. We review past research to identify strategic elements of sustainable ecodesign mapping for various end-of-life strategies related to managing products and operations processes. Ecodesign mapping for sustainability is discussed with challenges addressed for industry practitioners.

Keywords:

Ecodesign mapping, end-of-life strategies, sustainability.

1 INTRODUCTION

'"When we look at a chair, we see the wood, but we fail to observe the tree, the forest, the carpenter, or our own mind. When we meditate on it, we can see the entire universe in all its interwoven and interdependent relations in the chair. The presence of the wood reveals the presence of the tree. The presence of the leaf reveals the presence of the sun." Ecological design recognizes that all problems - hence, all solutions - spring from this connectedness.'

Thich Nhat Hanh (as quoted in [1]).

There is immense pressure from various stakeholders for producers to become more environmentally sustainable. Restricting legislation on raw material use and extended producer responsibility (such as the WEEE and RoHS directives), improvements in the competitors' performance in terms of more eco-friendly products being launched onto the market, and increased consumer awareness about sustainability and environmental issues are forcing manufacturers to reevaluate their product development.

In particular, "ecodesign" (that is, designing products and processes using a proactive view of sustainability that aims to reduce the total environmental impact) is increasingly being recognized as being key to improved and sustainable product development [2]. When ecodesign decisions are considered early on for a product, they can significant improve its life cycle sustainability. Furthermore, they can have far-reaching ramifications throughout the value chain in terms of important performance metrics. Using ecodesign considerations to manage product and operational process decisions is often viewed as the next frontier in organizational competitiveness.

Organizations, however, have to overcome substantial hurdles to ensure that ecodesign methods remain a viable option in early design stages. To ensure that ecodesign methods are effective and have a significant impact, the methods selected need to be based on sound design and engineering principles that lend themselves to being supported throughout the design and manufacturing process [3]. The end-of-life ecodesign methods generally include more than one end-of-life strategy. Since complexity varies substantially from product to product, some components, systems or sub-systems are easier to be recycled, or revalorized, or remanufactured, or reused, than others.

This paper presents an overview of past research of relevant operations management and environmental management literature. Strategic elements of sustainable ecodesign mapping are identified for various end-of-life strategies related to managing products and operations processes. Appropriate strategic elements will be discussed as part of ecodesign mapping. The paper also addresses challenges for industry practitioners.

2 ECODESIGN CONSIDERATIONS FOR BETTER PRODUCTS / PROCESSES

Ecodesign is about developing products in a way that reduces their environmental impact. The aim is to design products that are functional, desirable, cost-effective, and have no harmful side effects on the environment. The key

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to ecodesign is to understand environmental impacts of product throughout its life cycle, that is, from raw materials extraction or harvesting, through to how the product is disposed of or recycled at the end of its life.

2.1 Why Focus on Ecodesign?

Most of the environmental impacts of a product usually get "locked in" at the design stage, when materials and processes are specified. Design of products and processes determines:

- if extraction of raw materials will contribute to land degradation or biodiversity loss, etc.
- if toxic or hazardous wastes will be produced in the manufacturing process,
- if the product will be easy or difficult to recycle…

Some ecodesign tools are straightforward to implement while others take considerable planning and organizational resources. These strategies can take many forms: designing a new 'greener' product; making minor changes to an existing product (for example, moving from 100% virgin materials to 30% past-consumer recycled materials); introducing packaging redesign to reduce waste and improved efficiency; offering supply chain options to take waste back from customers to reprocess into these products; new labeling to encourage responsible disposal or recycling.

2.2 Drivers for Implementing Ecodesign

There are internal and external drivers for implementing ecodesign strategies products and processes in organizations as summarized in the Table 1. Internal drivers originate in organizations themselves while external drivers come from sources outside of organizations [4].

Table 1: Drivers for Implementing Ecodesign.

Internal Drivers	External Drivers
-Social equity	-Public opinion
-Strong social policy	-NGO pressure
-Governance and management systems on social aspects	-Legislative requirements
	-Eco-labeling schemes
-Green marketing	-Consumer organization requirements
-Environmental awareness	-Norms and standards
-Reaching new consumers	-Suppliers competition
-Product quality improvement	-Consumer demand
-Saving costs	-Market competition
-Product innovation	
-Brand differentiation	
-New opportunities for value creation	

Irrespective of its antecedents, implementations of ecodesign strategies stand to add immense value to organizations in terms of their competitiveness in the industry. Such considerations can lead to cost reductions (in using resources (materials, energy, transport) and minimizing waste [5], providing a competitive edge in market segments that are characterized by enhanced environmental awareness [6]. Furthermore, ecodesign considerations can help organizations meet product stewardship regulations across the globe [7] while improving corporate reputation (impacts on share price, access to finance) [8]. It can help improve relationships with stakeholders in an organization's supply chain [9] and can even become a new source of product / process innovation in many organizations [10].

3 ECODESIGN STRATEGIES FOR END-OF-LIFE STAGE

The role of ecodesign, in its traditional interpretation, is to help design so that the environmental impact is reduced during the whole life cycle—from materials, production, packaging supply chain, installation and maintenance, actual use, and end-of-life as illustrated by Figure 1.

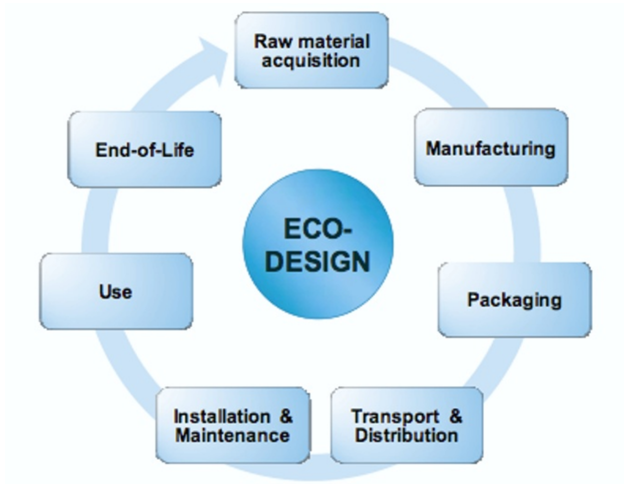

Figure 1. Ecodesign in context of a product life cycle.

Among other stages, the end-of-life stage offers a fertile ground for ecodesign considerations. This is in spite the fact that on average this particular stage amounts to less than 10% of the environmental load in a product's life cycle (as opposed to about 50% during its use and about 25 % for materials).

3.1 End-of-life

Generally speaking, ecodesign strategies can be designed considering the following end-of-life considerations, the 6RE principles [4]:

- Re-think the product and its functions, e.g., how products may be used more efficiently and offer value during and after their end-of-life.
- Re-duce energy and material consumption throughout products' life cycle and at their end-of-life to facilitate use and eventual disposition.
- Re-place harmful substances in redesigned products with more environmentally friendly alternatives.
- Re-cycle select materials from products that can be recycled and build products in ways that it can be easily disassembled for recycling.

- Re-use parts in products (remanufacture) to extend its useful life.
- Re-pair products those are easy to repair so that the replacement can be postponed.

3.2 Ecodesign Principles

The first step in reducing impact on the natural environment is to design products with the environment in mind. Ecodesign strategies are based on four guiding design for Environment (DfE) principles [11]:

Principles of Efficient Design

Efficient Design refers designing products that keep the consumption or input of resources to a minimum. The principles of efficient design are to avoid unnecessary components and processes, minimizing resource use in the production process including raw materials, energy and water, use of renewable resources wherever possible, and reducing the use of "throwaway" consumables in the production and distribution processes.

Principles of Safe and Clean Design

Safe and Clean Design refers to designing products that avoid toxic or hazardous substances in the raw materials themselves and during the production process. The principles of safe and clean design are to minimize and avoid processes that generate emissions of volatile organic compounds, and minimize and avoid materials and finishing processes that produce toxic waste.

Principles of Cyclic Design

Efficient Design alludes to designing to enable materials to be continuously cycled through natural or industrial systems. It focuses on eliminating waste. Strategies for natural cycles include using renewable energy, specifying materials that are renewable and sustainably harvested, specifying biodegradable materials, select the right biodegradable material for the disposal environment, and designing the product so that it can actually biodegrade. Strategies for industrial/technical cycles consist of specifying materials that are technically recyclable and which have an existing collection/recycling system, design for disassembly and recycling, using recycled materials, establishing product stewardship programs (take-back).

Principles of Communication Design

Communication design encourages responsible consumer behavior, it also aims to ensure product and packaging related communication is informative and accurate. Strategies for communication design include labeling plastic components (PIC or international codes), using energy and water labels, providing information on recyclability / appropriate disposal, and providing information on other environmental attributes.

As all of these ecodesign principles are relevant to management of end-of-life products and related processes, it is worthwhile to map ecodesign strategies to improve products / processes.

3.3 Ecodesign Mapping

The ecodesign strategies are constrained by the economic, geographical, technological, and legislative uncertainties, which made optimizing for end-of-life fairly challenging. In today's global economic conditions, not only organizations creating new products, but the ones dealing with second hand and disposed products are feeling the pressure. Consequently, a careful mapping selection of appropriate ecodesign strategies to improve products and processes is highly likely to affect their potential successes after implementation. An example of one such mapping, which classifies ecodesign strategies based on their complexity and purposes [12], is offered in Figure 2:

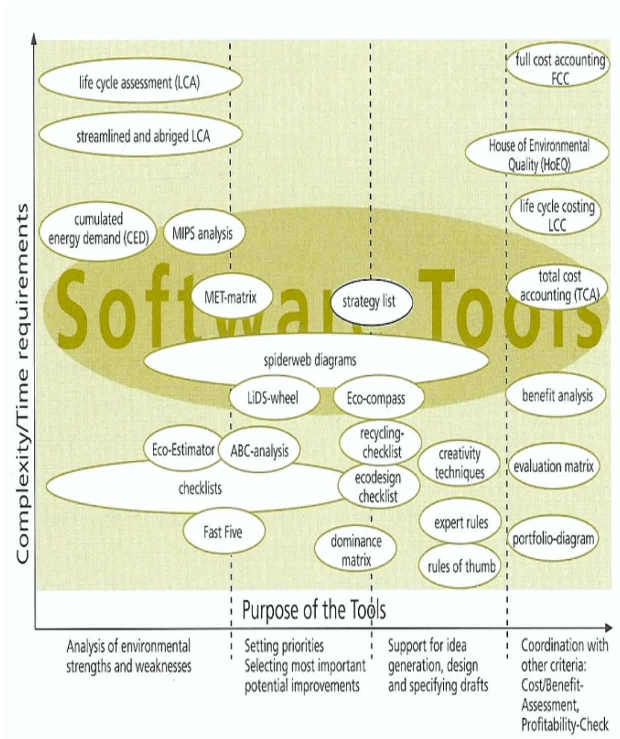

Figure 2: Ecodesign Mapping.

4 CHALLENGES

Early ecodesign decisions can have a dominant impact on the sustainability of product realization. The decisions have to be made based not only on structure, material, and manufacturing choices, but also on management of supply chain during end-of-life phase.

Although LCA is among the widely used and most objective methods to evaluate the environmental sustainability of a product or process, it still quite challenging when applying to support ecodesign decision making in general. Consequently, LCA is used more often as a compliance tool in practice.

Another challenge is the fact that relatively comprehensive databases used to support LCA, like the ones in EU, have not been yet developed around the world.

Also, addition investigation is warranted on ecodesign for sustainable product family. This area involves evaluating the effect of platform sharing in product family design and recovery and end-of-life decision-making for products / processes.

Another important area is to quantify the impact of regulatory and business decisions in product recovery during end-of-life. By quantifying these decisions, a new business model may emerge through linking new product marketing and used product take-back through incentive-based mechanisms.

One other concern is the low levels of product take-backs and/or high variability of quality of end-of-life products for product remanufacturers. Past research does provide alternatives for improving quality of end-of-life products [13, 14, 15]. Analytic methods for identifying ecodesign strategies and corresponding end-of-life recovery options are likely to become a critical component for simultaneous design/recovery decision-making.

5 SUMMARY

The ecodesign of products and processes is the main determinant of environmental impact. The design engineers and environmental managers in an organization can reduce an emission and waste, but not in a meaningful ways. Ecodesign is the key intervention point for making radical improvements in the environmental performance of products, all their by-products, and related processes as well.

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A Study of Trend and Characteristic Analyses of Business Activities from the Examination of CSR Reports

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Abstract

Increasingly, private enterprises have been required to become conscious of their social responsibilities. They ought growingly to pay attention to such issues as environment problems and social sustainability. As those results, they must be publishing an environment report on a voluntary basis. As consumers, they must find out how serious these companies really are in regard to environmental and other social concerns. They, as a result, have to buy their companies' product and service on their own. Therefore, we need to assess from overview points, which include the environmental activity. Through those backgrounds, the purpose of this study is to analyze the CSR Report and Sustainability Report for 36 private enterprises to what extent and how serious various companies have been to a number of socially significant issues. By doing this, we hope that the analysis of these reports would point to trends as well as characteristics of companies' concerns and commitments to critical environmental aspects of our societies.

Keywords:

environmental assessment, CSR report, text mining, factor analysis

1 INTRODUCTION

Companies have a long history of coping with environmental problems. For example, an outbreak of *Minamata* disease (a neurological syndrome caused by severe mercury poisoning) and *Itai-itai* disease (cadmium poisoning from mine contamination) occurred due to wastewater discharge from factories [1]. They then called "pollution" and became social problems. Nowadays, environmental pollutants, such as dioxins and carbon dioxide, are being emitted not only from industrial activities but also from our daily lives. They also have the global warming, the constitution of continued growth society and life's diversity problems. Methods of coping with these environmental problems are being heatedly discussed not only in Japan but also globally.

Given such circumstances, it is essential for a company to undertake environmental protection activities as a corporate social responsibility, although such activities may not be directly linked to generating profits. For example, in an attempt to reduce carbon dioxide emissions, a company may invest in facilities to reduce the environmental burden. The other ways are adopted a life cycle management approach to manage the total life cycle of products and serviced from design to end-of-life, and obtained ISO 14000 certification. In addition, a company may publish an environmental report that summarizes its activities to protect the environment. They called "Environmental report," "CSR report" and "Sustainability report." The publication of an environmental report is discretionary, and there is no standard report format. The development of such a corporate environmental report takes considerable time and effort for a company. However, it is not clear what kind of impact a company's environmental protection activities and this corporate environmental report may have on the purchase behavior of consumers. A company would like for consumers to fully understand its corporate efforts to protect the environment before they decide to purchase goods and services. If consumers act in this way, environmental protection activities will contribute to a company's profits, thereby providing further incentive for a company to promote environmental protection activities.

On the other hand, an environmental report is extremely important in assessing a company's overall performance. In today's business environment, a company's business performance should be measured not simply by sales and profits but from a holistic perspective, including social activities. Therefore, instead of relying on a company's environmental report alone, it is necessary to develop a methodology that enables comparisons of a company's overall performance with that of other companies.

Hereafter, we observed the previous studies and have to clear the purpose of study. At first, the government and some group prepare the environmental assessment. For example, Ministry of the Environment in Japan gives the guideline, which called "Environmental Accounting

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Guidelines [2].” Same as, they have IFAC’s “International Guidance Document [3],” UK’s “SIGMA [4]” and UN’s EMA [5]. Minister of Economy, Trade and Industry in Japan also gives the method, “Material Flow Cost Accounting [6].” Concretely, in the castle district of transfer of materials and energies, the company must measure in physical units and metal. They, after all, are able to calculate whether the extent to the reducing rate of the environmental impact.

On the other hand, in the research field, many researchers have been conducted [7] [8] [9] [10] [11]. These studies are often be evaluated the environmental activity from the financial aspect. The other famous approach is “Eco-Efficiency [12] [13] [14].” Those approaches, however, are focused on only financial information and very complicated to introduce the company. In other words, these evaluations have not been founded to the overall assessment.

Second, they have to assess from the report contents or image from the consumer. From the report contents, they have the method using the text mining [15] [16]. They are, however, only focus on the financial report. They need to extend to include the environmental activity. On the other hand, to recognize the consumer aspect about the environmental activity, they give the questionnaire survey to find the company image [17] [18]. Even so, they need the questionnaire before evaluating the company from the viewpoints of environment. They also have been not made to clarify the influence of a company’s environmental report on the purchase decisions of consumers.

Through those backgrounds and previous studies, therefore, this study primarily focuses on the following two points: First, the study focuses on the kind of information that consumers might use as a reference when making purchase decisions on environmental products and services (hereafter called “EPS”), as well as on the kind of EPS they are willing to purchase. We will investigate and analyze this point through a questionnaire survey. Through such an investigation and analysis, we will consider the positioning and importance of an environmental report in terms of a company’s business activities. Second, we will execute a text mining analysis of an environmental report to extract a company’s character as manifested in its environmental report and the trends in environmental reports. Through the text mining analysis, we will consider the approaches taken by each company and by each industry to protect the environment.

2 QUESTIONNAIRE TO SURVEY CONSUMER AWARENESS OF A COMPANY’S ENVIRONMENTAL REPORT

A questionnaire concerning consumer awareness of a company’s environmental report was administered to 435 adults between the ages of 18 and 65. A total of 85% of the respondents were in the 18 to 21 age group.

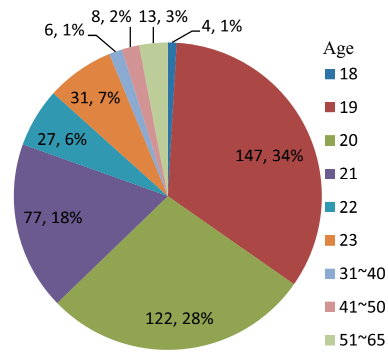


Fig. 1: The couting numbers and the percentage of respondents

The purpose of the questionnaire was to investigate the kind of information consumers’ use as a reference to make purchase decisions on EPS. The questionnaire consisted of four steps. As the first step, the questionnaire asked respondents the broad question: “What kind of information do you use as a reference when making purchase decisions on environmental products and services?” From the second step onward, respondents were asked to conjure up images of specific EPS, which included green vehicles or environmentally friendly vehicles (hereafter called “environmental car”), the solar power generation, and the wind power generation.

A list of potential information that consumers might use as a reference included the following:

(a). Company and product name

(b). Price

(c). Commercial messages, magazines, newspapers, etc.

(d). Information on the ranking of environmental products and services by using a rating from one (☆) to five stars (☆☆☆☆☆).

(e). Information on the effects of environmental products and services converted into monetary terms, such as electricity costs.

(f). Safety, place of origin, production place, etc.

(g). Clerk, Salesperson, Contractor.

(h). Referrals from acquaintance.

(i). Information on benefit programs of environmental products and services, such as the Eco-point incentive program.

(j). A CSR or Environmental report.

(k). A company’s business strategy.

(l). A company’s top leadership.

(m). Achievements of a company’s environment-oriented business management (reduction of carbon dioxide emissions or water usage volume).

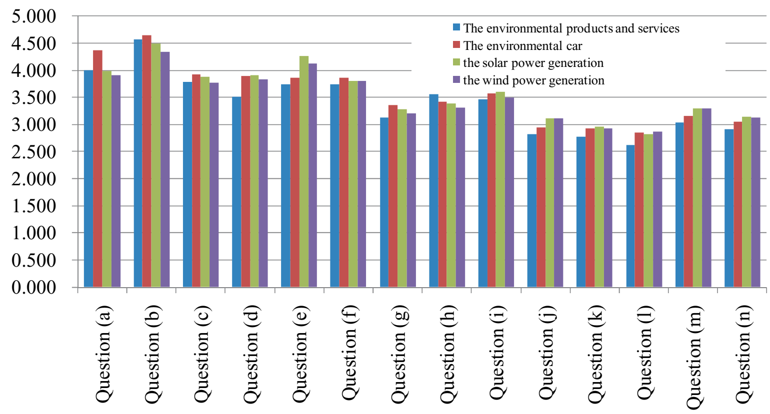


Fig. 2: Survey results by each product

(n). A company's social action programs (arts and local community contribution programs other than environment protection activities).

Respondents were asked to rate the information in the following five categories: (5) Definitely use it, (4) Use it sometimes, (3) Can't say either way, (2) Do not use it very often, and (1) Do not use it at all.

As a general characteristic, it can be seen that price-related information, Question (b), is most extensively used as a reference when making purchase decisions on EPS. We assume that this indirectly suggests that respondents are very conscious of the cost effectiveness of EPS. This is further evidenced by the fact that respondents gave high ratings to "(e). Information on the effects of environmental products and services converted into monetary terms, such as electricity costs" and "(i). Information on benefit programs of environmental products and services, such as the Eco-point incentive program." "(a). Company or product name" is also high ratings. On the other hand, respondents gave low ratings to "(j). A CSR or environmental report," "(k). A Company's business strategy" and "(l). A Company's top leadership."

Looking at the results individually, in the case of environmental car, "(a). Company or product name" and "(h). Referrals from acquaintance" are one of the major purchase motivations. At the same time, in the case of solar power generation and wind power generation, "(m). Achievements of a company's environment-oriented business management" and "(n). A company's social action programs" are among the major purchase motivations. "(j). A CSR or Environmental report," which is the main theme of this study, is rated extremely low as reference information that consumers use when making purchase decisions on EPS. In other words, a company's environmental report does not directly impact consumer purchase decisions on economically friendly products and services.

3 CLASSIFICATION METHOD AND RESULTS OF ENVIRONMENTAL REPORT

3.1 Target Companies and Classification Method Text Area

In order to extract the characteristics of target companies and trends relating to environmental reports, the following two actions were taken:

A) Extract, through a subjective analysis, the target audience, ability to communicate key messages effectively, and points of emphasis in relation to environmental reports. In addition, extract basic data, such as sales and profit, from the environmental reports (hereinafter collectively called "Category A").

B) Perform a text mining analysis of environmental reports (hereinafter called "Category B").

The Category A analysis was performed on the lead-in "Features or Highlights" section of the environmental reports. This is because this section includes a message to which the company would like to draw readers' attention the most. Through an analysis of this section, the target audience and characteristics of a company relative to environmental reports were subjectively extracted. In the Category B analysis, we counted how many times the nouns used in the Guideline for Preparation of Environmental Reports issued by the Ministry of the

Table 1. Table of counted noun

Customer	User	Global	Responsibility
Trading partner	Local residents	Mass media	Public administration
Net sales	Price	Cost	Reduction
Profitability	Clean energy	Operating income	Sales
Environment	Warming	Energy	Eco
Gasoline	Exhaust	Recycling	Reduction
Harmless	Publishing	Peace of mind	Quality
Energy-saving	Efficiency	Communication	Basic unit
Infrastructure	Management	Employee	Issue
Sustainable	Information	CSR	Audit
Packaging	Production	Needs	Accountability
Conservation	Logistics	Weight loss	Compliance
Governance	Design	Society	Air pollution
Waste	Human resources	CO2	Poison
Stakeholders	Investor relations	Low-carbon	Safety
Muda	Green purchasing	Hygiene	Decision making
Profit	Shareholders' equity	Health	Stakeholders
IR	Production volume	Preventative measures	Supplier
Human resource development		Contribution to society	

Environment was used in each environmental report. In other words, we counted how many times the nouns listed in **Table 1** appeared in each environmental report. Then we tried to classify companies through a factor analysis of the results of the counts.The 2010 environmental reports issued by 36 companies from 11 industry sectors were used for this study. (**See Table 2**)

Finally, these environmental reports were classified from the two perspectives of Categories A and B.

3.2 Results of Classification

Take Toyota Motor Corporation for example. Through the Category A analysis, Toyota started their 2010 environmental report by touching upon the company's guiding principles and "back to basics" philosophy in the lead-in section, reflecting the impact of their recent recall problems. In other words, it appears that Toyota's 2010 environmental report was focused on appealing to their employees, customers, and business partners. On the other hand, Nissan Motor's 2010 environmental report was loaded with data on environmental loads and information on environmental technologies and business performance. Simply put, their environmental report was designed to somewhat complement the securities reports and, therefore, was primarily focused on appealing to shareholders. In this way, a subjective analysis was made regarding which audience the environmental reports were primarily targeted.

In the Category B analysis, with the number of basic nouns set at 74, the number of times those nouns appeared in each environmental report was counted, and the results of the count are as shown in **Table 3**.

The count shown in **Table 3** is simply the number of times the relevant nouns appeared in each environmental report. Therefore, it is preferable that the count be adjusted according to the volume of the environmental report. So the rate of appearance was obtained by the following formula:

Rate of appearance

= Number of relevant nouns counted

÷ Number of pages of environmental report (1)

An analysis was made on the rates of appearance thus obtained. First, when the rates of appearance of the 74 nouns were adjusted by removing the ceiling (floor) effect (= mean - standard deviation < 0), the number of basic nouns was reduced to 35. A factor analysis was performed on these 35 nouns using the principal factor method and the varimax rotation method. The commonality estimate was repeated until there were no basic nouns with a rate of appearance of 0.25 or less. As a result, three factors were determined based on the eigenvalue (**Table 4**). Then a factor analysis was performed again. The number of basic nouns was finally narrowed down to 26 after excluding the nouns with the factor loading of 0.4 or less which did not belong to any of the three factors (**Table 5**).

And then the factors were interpreted. **Table 6** lists the nouns with the factor loading of 0.5 or more for each of the factors. The names of the factors were determined as follows:

- ✓ Factor 1: Named as *Social Factor* as this group of nouns includes a lot of words that relate to information and the dissemination of information.
- ✓ Factor 2: Named as *Environmental Awareness*

Table 2. Target Industries and Companies

Automobile	TOYOTA, NISSAN, MITSUBISHI, HONDA
Drink	ASAHI, AJINOMOT, ITOUEN, KIRIN
Chemical	DAIICHI-SANKYO, Mitsubishi Tanabe Pharma, KAO, FUJIFILM, KONIKA
Construction	KASHIMA, MISAWA, DAIWA-HOUSE, SUMITOMO-RINGYO
Steel	JFE , Sumitomo Metal Industries, Mitsubishi Heavy Industries
Production equipment	DAIKIN
Textile	TORAY
Information and Communication Electrical machinery	NEC, CANON, SEIKO-EPSON, SHARP, SONY TOSHIBA, IBM, PANASONIC, HITACHI
Transportation	YAMATO TRANSPORT , JR-EAST
Retail	MCDONALDS
Printing	Dai Nippon Printing, TOPPAN PRINTING

Table 3. Outputs of numbers of nouns in the reports (Partly Extract)

	Customer	User	Stakeholder	Supplier
TOYOTA	141	9	21	43
NISSAN	0	1	176	96
MITSUBISHI	80	1	8	0
HONNDA	136	3	7	2
ASAHI	26	0	11	1
AJINOMOTO	10	0	18	7
ITOUEN	81	0	1	0
KIRIN	71	0	5	1
DAIICHI-SANKYO	3	0	70	2
Mitsubishi tanabe	1	0	7	0

. . .

⋮

Table 4. Eigenvalue after the revolution (the principal factor method and the varimax rotation method)

Factor No	Sum of squares	Coefficient of determination	Cumulative contribution ratio
Factor 1	5.549	0.206	0.206
Factor 2	5.093	0.189	0.394
Factor 3	3.533	0.131	0.525
Factor 4	2.950	0.109	0.634

Table 5. Factor loading after the revolution (the principal factor method and the varimax rotation method)

The variable name	Factor 1	Factor 2	Factor 3
Communication	0.7902	0.0693	0.1646
Human resources	0.4872	-0.0014	0.2211
Cost	0.4757	0.4042	0.2631
Reduction	0.3378	0.8143	0.1711
Environment	0.1390	0.7979	0.3732
Warming	0.0370	0.7975	0.1993
Energy	-0.1080	0.7594	-0.0017
CO2	0.1137	0.7474	0.2556
Air pollution	0.3867	0.2694	0.4592
Recycling	0.1793	0.2741	0.6691
Energy-saving	-0.0463	0.7459	0.0431
Basic unit	0.0790	0.4534	0.5952
Health	0.4925	-0.1929	-0.0278
Contribution to society	0.6565	0.2001	0.3488
Issue	0.6949	0.1150	0.1254
Management	0.5595	0.3853	0.0914
CSR	0.8483	0.1999	-0.0042
Responsibility	0.5867	0.1258	-0.1085
Information	0.7145	0.0150	0.1230
Needs	0.6075	0.0713	0.3613
Society	0.6889	0.1903	0.3181
Efficiency	0.1286	0.5329	0.2440
Conservation	0.3558	0.4389	0.0282
Production	-0.0046	0.3034	0.7147
Logistics	0.2678	0.0094	0.7666
Waste	0.3698	0.5531	0.2418

Table 6. The nouns of more than 0.5 points of factor loading

Factor No	The variable name group		
Factor 1	CSR	Communication	
	Society	Responsibility	Needs
	Management	Issue	Information
	Contribution to society		
Factor 2	Reduction	Environment	Warming
	Energy-saving	Waste	Efficiency
	Energy	CO2	
Factor 3	Logistics	Production	Recycling
	Basic unit		

Factor as this group of nouns includes a lot of words that relate to environmental awareness.

✓ Factor 3: Named as *Internal Factor* as this group of nouns include a lot of words that relate to internal environmental protection activities.

4 CONSIDERATION OF RESULTS OF CLASSIFICATION

Factor scores were computed for each company, and the factor scores were considered. **Figure 3** shows the plotting of factor scores by company with Factor 1: *Social Factor* and Factor 2: *Environmental Awareness Factor* used as coordinate axes. Toray Industries, Inc., and Fujifilm Corporation were highly rated in the ability to communicate key messages effectively, while Daikin Industries, Ltd., Toshiba Corporation, and Daiwa House Industry Co., Ltd., were highly rated in environmental awareness. Characteristically, the factor scores of the companies studied this time other than Honda Motor Co., Ltd., were plotted near the origin. In terms of the actual business activities of the companies, Fujifilm Corporation and Mitsubishi Heavy Industries, Ltd., receive a high mark in environmental awareness and the ability to communicate key messages effectively for their respective environmentally friendly technologies—energy savings through thorough reuse of steam by Fujifilm Corporation and wind power generation technology by Mitsubishi Heavy Industries, Ltd. Likewise, in terms of environmental awareness alone, Sumitomo Metal Industries, Ltd., is noted for nuclear power and energy-saving technologies and Mitsubishi Heavy Industries, Ltd., for wind power generation technology, while Daiwa House Industry Co., Ltd., and Misawa Homes Co., Ltd., offer quality homes with superior energy efficiency. As seen above, it is appropriate to state that this study has successfully provided explanation for the characters of target companies and trends relating to environmental reports to a certain extent.

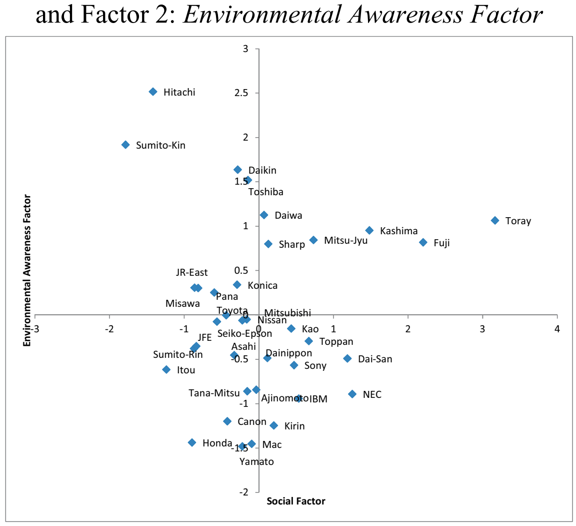
By plotting factor scores by company with Factor 2: *Environmental Awareness Factor* and Factor 3: *Internal Factor* used as coordinate axes, it can been seen that the results of factor scores match up well with the actual environmental protection activities that have been implemented by companies, as evidenced by Toyota Motor Corporation for their hybrid vehicles and Sharp Corporation for Aquos product series, solar power generation, and light-emitting diodes (LED) light bulbs. Based on a subjective analysis of the environmental reports, Kajima Corporation, Mitsubishi Heavy Industries, Ltd., Daikin Industries, Ltd., Toray Industries, Inc., and NEC Corporation have been found to put more focus on environmental awareness. The results of such subjective analysis are consistent with the actual contents of the environmental reports.

That said, there was some aberration. For example, Yamato Transport Co., Ltd., has exercised high environmental awareness from early stages but their factor scores were low. In addition, in the case of Yamato Transport, there was only a low correlation between the factor scores and an ordinary return on sales (ROS) or net ROS. This demonstrates that there is a limit to analyzing environmental reports only by using the rate of appearance.

5 CONCLUSION AND FUTURE PROSPECT

Currently a variety of corporate reports are being published by companies, but there is still a lot of room for

Figure 3. Plotting factor scores by company with Factor 1: *Social Factor* and Factor 2: *Environmental Awareness Factor*



improvement in the methodology for evaluating these reports. Given that background, in this study, a factor analysis was performed by counting the number of basic nouns used and the contents of environmental reports were subjectively analyzed. As a result, the following results were obtained from the study:

a. The characters of companies and trends relating to environmental reports were successfully evaluated.
b. The target audiences of environmental reports were identified.
c. The first step toward developing the methodology for evaluating corporate reports was taken.

But there are some tasks that require further study, which include the following:

a. Expand the scope of study using the rate of appearance to include adjectives and paragraphs.
b. Expand the scope of industry sectors used in the study, thus increasing generality.
c. Establish the evaluation methodology.

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Balancing Supply and Demand in Reverse Supply Chain: A Case Study in Remanufacturing Company

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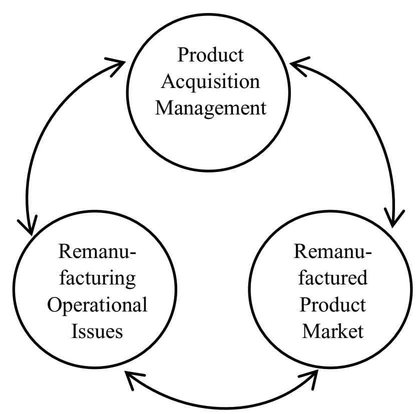
Abstract
There has been plethora of studies examining uncertainties within a single company to recapture residual value of returned products. In a single company, the uncertainties being addressed mostly deal with technical and operational problems during the recovery processes, such as shop floor optimisation, scheduling and facility layout. Other uncertainties coming from external parties which are lack of examination are supply and demand uncertainties. In our sample company, both supply and demand uncertainties come from the industrial customers which externalise their remanufacturing activities to the sample company. Even though the sources of demand and supply are from the same parties, balancing the demand and supply is not a simple task as the company needs to deal with inter-organisational relationships that make this issue become strategic in nature. Because of its strategic importance, this paper attempts to examine them and analyses how to overcome the problems.

Keywords: remanufacturing, reverse supply chain, product acquisition, demand and supply balancing

1 INTRODUCTION

Reverse supply chain be defined as *"the effective and efficient management of the series of activities required to retrieve a product from a customer and either dispose it or recover its value"* [1]. From the above definition, reverse supply chain is different from reverse logistics which mainly focus on managing material flows within a company, reverse supply chain also deals with how to manage interaction, coordination and collaboration with external parties. This is the main feature that distinguishes logistics with supply chains. Most studies investigate a company as an independent entity while the supply chain is a complex interaction involving many parties, hence the lack of insight regarding how to manage the relationship, coordination and interaction among those parties. Those studies investigated the process of value recovery emphasising technical and operational aspects such as shop floor optimisation, scheduling and facility layout. It is not surprising that a plethora of research has been devoted to investigating the problems resulting from these technical uncertainties.

For many years, these problems have not been investigated intensively in scholars work. Companies simply apply minimising cost strategy because sending back products after customers have use them has been viewed as costly activities; rarely does a company consider them as opportunity for competitive advantage even though product returns have been identified as a source of a competitive advantage [2]. Thus there is a need to analyse remanufacturing issues in a more strategic and holistic approach [3].



Source: adapted from Guide and van Wassenhove [4]

Fig. 1: Activities in reverse supply chain

Numerous research investigating the use of tools and managerial practices can be found in, among many others, Fargher Jr. [5] that identifies the use of material requirement planning, Chan et al. [6] that investigates the adoption of just in time and Rubio and Corominas [7] that examines economic order quantity in remanufacturing logistics. These facts are supported by Guide and Van

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Wassenhove [4] opinion stating that research investigating the internal process of product recovery within companies has reached a maturity level as there had been a plethora of works that has been done during the golden age in 1990-2000s as depicted in Figure 1. Those research designating the "golden age" of remanufacturing mostly utilise simulations, case studies or combination of them to address those problems.

In 2000, Guide and Jayaraman introduced the importance of product acquisition management for remanufacturing companies as it is the first step of the remanufacturing process where cores entre the remanufacturing facilities and can potentially create bottleneck [8]. More recent issues emerging are topics related to marketing issues of remanufactured products and how remanufacturers interact with the market [4]. Nevertheless, few empirical research has been devoted to those issues and this paper intends to address those gaps by analysing them as an integral part of reverse supply chain. Based on this brief background, this paper discusses three research questions:

1. *How does the company manage its product acquisition to enable better coordination with the remanufacturing process?* This question examines the supply for reverse supply chain dealing with issues in management of product acquisition: when, how many and what condition the cores arrive at company's facilities.
2. *What strategy does the company utilise to remarket the recovered products?* This research question is related to demand for reverse supply chain examining how to remarket recovered cores.
3. *How to balance the supply of cores from customers with the demand for recovered products?* The last question combines both issues at the supply and the demand sides for reverse supply chain. Without coordination, there will be a bottlenecks which leads to either reduced throughput or stock-out cost resulted from unfulfilled orders from the market. The research presented herein analyses the major process and activities concerning how to balance supply and demand in a remanufacturing company. Also, it illustrates the success of the company on how to manage core acquisition and how to deliver recovered products after the remanufacturing process.

The remainder of this paper is organised as follows: the second section discusses the methodology employed in this study. The third section presents rationales for justifying why the company is selected as a case study. The fourth section presents how the company successfully manages its supply side – core acquisition from the customers – and also demand side, how to remarket remanufactured products. Analysis and discussion regarding the strategies can be found in the next section. Finally, limitations and suggestions for future research can be found in the sixth section.

2 METHODOLOGY

Due to the complex characteristics of the research questions, this study employs case study method. Case study method is appropriate as it enable researcher to identify not only causal relationship but also answer questions of *what*, *why* and *how* [9]. The use of case study with qualitative analysis in this work has received criticism especially concerning objectivity. The key answer to this attack is that the purpose of the research is to provide insight for developing theory and is not intended to test hypothesis. In addition to this reason, the practice of remanufacturing which is strongly related to product return is highly context dependent requiring customised approach [10].

A remanufacturing company based in Rushden, United Kingdom is selected as a case study. The company is a third party remanufacturing provider for Original Equipment Manufacturers (OEMs) for various products ranging from automotive engine, military equipments and aircraft components. As pointed by Wilson and Vlosky [11], the selection of a subject as a sample is determined on its potential contribution to theoretical and knowledge development. Random sampling methods that theoretically generate higher generalisation are not relevant for this research due to the uniqueness of the research questions being investigated. In addition to those rationales, the case in this study is not selected based on criteria such as for those in hyphotesis testing but for the reason of theoretical insight that the company can offer [12].

Data was gathered from company classroom presentation, interview, document checks, and visual inspection in the production facilities. Information was gathered from 4 personnel at middle managerial level during a full day visit. The managers are responsible to manage production planning, forecasting and controlling of remanufacturing operations. Accordingly, they are good sources of information concerning the problems being addressed in this research. Follow up communication was conducted when necessary to clarify information requiring further explanations. Triangulation was performed by comparing and combining data from those informants and from various forms of such as paper documents, electronic documents and visual inspection.

3 THE COMPANY: A BRIEF DESCRIPTION AND JUSTIFICATION

The company is part of a global holding company that covers a wide range of business and operations and has operated remanufacturing service since 1973. The company has grown as one of leading remanufacturing companies in Europe serving customers for European market with specialist varied widely from machinery, equipment, tooling and gauging. The remanufacturing operations mainly deal with engines and major components for industrial customers such as automotive vehicle manufacturers and major fleet owners. The company serves the European market whose customers are spread in countries across the continent. Apart from its main operations in engines equipment remanufacturing, the company also offers services such as maintenance, training, financing, insurance, sales, marketing and logistics support.

The authors decided the company as a subject of this study due to some reasons: first, from macro perspective, it operates in a business environment which is strictly regulated with European Union policies in Waste Electrical and Electronics Equipment (WEEE). This regulation leads the company to operate under the principles of green business practices. Second, the company operates in an industry where the competition has been tightening in recent years indicated with the number of new entrants in similar services. According to Atasu et al. [13], legislation like WEEE can be a trigger to emergence of third-party providers of remanufacturing services and intermediaries between OEMs and remanufacturers. Third, the company has successfully managed its internal operations' uncertainties through adoption of various managerial practices such as Material Requirement Planning, Fishbone diagram, 360 degree evaluations etc. The combination of those factors leads to uniqueness and also one of best practices in remanufacturing companies that can serve as a benchmark for other companies in similar industries and offers significant contribution to knowledge [14].

4 BALANCING DEMAND AND SUPPLY

As described in the Table 1, the company employs similar strategies to cope with uncertainties in both supply and demand sides. It is not surprising that the supply and demand are connected as they come from the same parties. Due to the customers being industrial customers, the availability of cores largely depends of the success of maintaining relationships with customers which is supported with contract agreement and information system for forecasting. But for the middle part of the table, "remanufacturing engine", the strategies are mainly concerned with buffer stock, either by using used or new components. The next section's discussion refers to Table 1 discussing methods and techniques to match supply and demand in the reverse supply chain for remanufacturing company.

4.1 Product acquisition management: managing the supply side

Forecasting is carried out by a commercial team collaborating with customers, the OEMs. The forecast is also regularly revised based on latest information which is provided by customers. As displayed on Figure 3, forecasting is based on information from various sources: last year remanufactured product sales, new product sales of OEMs, last year incoming cores and OEMs feedback. As displayed in Figure 2 (next page), the number of sales of new products is the basis for developing forecast based on the expected period of use of the products.

Like other independent remanufacturers, the main constraint of the production system is availability of cores and also variability of cores' quality. To ensure the availability of cores, the company has contractual relationships developing contracts with customers which also serve as suppliers. The need to build relationship commitment is also emphasised in Daugherty et al. [15]. They found that relationship commitment influences reverse logistics performance while the reverse logistics is a prerequisite to the success of product recovery by minimising uncertainties in term of time and quantity. Hence, building trust with customers indirectly influence the success of remanufacturing processes.

Table 1: Strategies to match demand and supply of cores

Supply side (Product Acquisition Management)	**"Remanufac-turing Engine" (Reman Operations)**	**Demand side (Remarketing Issues)**
Building contracts with suppliers and customers (OEMs)	Production leveling and build stock in used products to maintain operation	Building contracts with OEMs; 1% warranty sales.
Information System for information sharing and drafting production plan	Flexible workers and work cells production layout	Forecasting based on historical data, new product sales, and collaborative forecasting.
Forecasting based on historical data, new product sales, and collaborative forecasting organised by a commercial team.	New parts stocks	Finished product stock and using "dummy components" for out of stock parts

Contractual agreement with customers serves as a mechanism to minimise risk of uncertainties to both the company and OEMs. By signing the contract, the company secures its source of material whereas from the OEMs side they have a reliable vendor who is eager to remanufacture their cores.

For each of the customers, the number of cores supplied from the OEMs shows an interesting pattern. At the beginning of contract with each OEM, a large number of cores are usually available but afterwards decrease steeply and become steady in the rest of the periods. As there is no seasonality pattern, the returns are constant along the year and ease the forecasting process even though variations remain.

Another method for minimising uncertainty is adopting an information system to support communication for minimising uncertainties both for demand and supply sides. Customised information systems for the remanufacturing company is adopted and is connected to the OEMs to enable information sharing and collaborative forecasting. Some OEMs have adopted a well known SAP system for managing their operations but the company decided to adopt the specific information system due to the unique characteristics of its remanufacturing operations.

Compared to Subramoniam et al. [16] based on Nasr et al. [17] who found that remanufacturing firms hold up to one-third of total core inventory to anticipate uncertainties in quantities and timing of the returns, the company is more efficient with less than a quarter of total inventory, based on information from one of the respondents. Nevertheless, this amount is higher compared to the average for conventional manufacturing. This high percentage leads to high cost due to a large amount of capital being tied up in non-liquid assets and need space for storing the cores. In such situation, managing optimal stock level is important as the company needs to ensure that parts needed are always available but has to be at the optimal level to minimise cost.

In remanufacturing process, decision to make or buy for components is performed subjectively based on personal judgment of employee and the assessment is rely on visual inspection and. As contended by one of the employees, visibility is very important in the remanufacturing operations. Procurement staffs, shop floor workers, engineers and finance staff are involved in make or buy decision making but the decision is difficult to standardise as the decision considers various factors with complex interaction. For certain parts that are unique and expensive, repairing used parts is preferred than buying the new ones.

4.2 How does the company manage its "remanufacturing engine"?

The company remanufactures all of the cores that they received at its best effort. In general, the cores experience the following steps: cleaned, disassembled, repaired, tested and reassembled. In each of the decisions there is always a chance to discard the component and at the same time new components are inserted to replace the discarded one as described middle part of Figure 2 below.

As displayed in the centre part of the figure, the number of components is decreasing as unqualified parts are rejected but thereafter new parts are inserted as replacements for the rejected ones. The company undergoes a trade-off between the number of inserted new parts and rejected parts which can be described in Figure 3 (next page). According to the graph, the optimum value from remanufacturing is a function of time and residual value. Time is an important factor as time affects how many new parts should be inserted as a consequence of rejected ones. Hence, in drafting the forecast, the commercial team of the company needs to also consider how long the returned cores have been used by the end users.

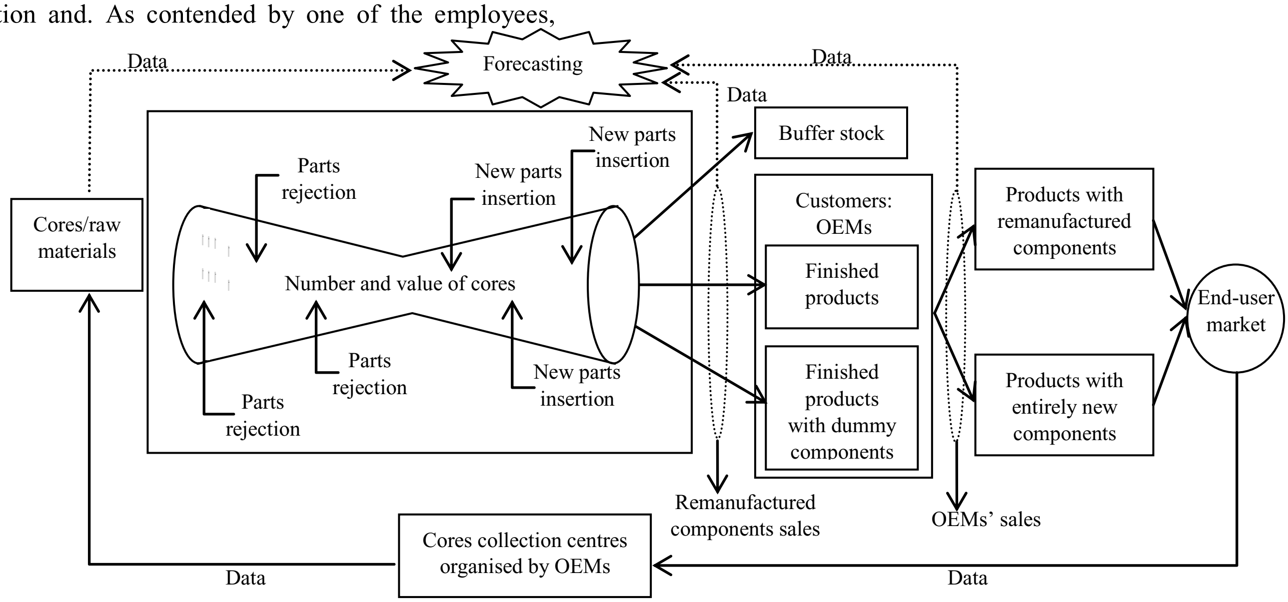

Fig. 2: Number of parts before and after rejection and new parts insertion

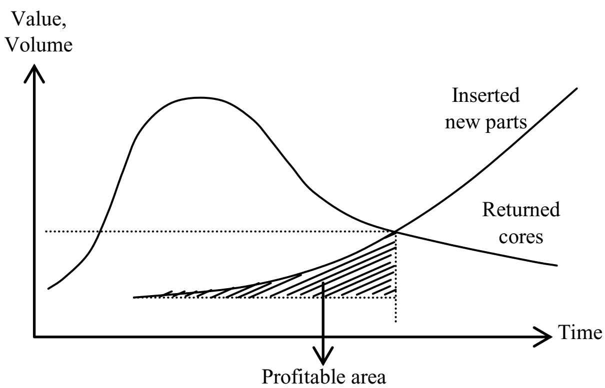

Fig. 3: Trade-off between parts rejection and new parts insertion

The of the practices aforementioned above in the company ensure that problems and issues in the remanufacturing operation within the company have been addressed and are no longer significant problems. Last year number of production exceeded 30,000 units. However, under capacity and overstock that often occur in remanufacturing process are have been managed well so that the return flow runs smoothly. Thus, adoption of these practices enables the companies to ensure that its internal remanufacturing processes run as expected.

4.3 Remarketing of recovered products: managing the supply side.

Similar to supply side, demand forecasting is also conducted based on historical sales data of the company and new product sales of the OEMs. Finished remanufactured machines are sold back to OEMs on several forms: completed products, semi completed products with "dummy parts", kept as stock and sold as complete components. "Dummy parts" are parts that are used temporary as because the company does not have stock the parts. These parts are indicated with different color so that the OEMs can easily identify them and replace them with the original parts.

Production planning is carried out at very broad level based on historical data at product level but the remanufacturing processes are carried out at component level. Hence, the production planning is rarely to be accurate. Beside safety stock of cores to anticipate lack of incoming cores, the company also adopts production leveling or production smoothing.

Contradictory with Liang et al. [18] contending that price estimation should be integrated with cores sorting and disassembly planning, the company does not either organise specific effort for assessing the residual value of cores and sales price. During sorting the effort is devoted on minimising cost and maximising residual value, a generic strategy followed by remanufacturers.

Like in supply side, the demand side also hedges the uncertainties through safety stock. Even though some literature suggests the adoption of lean concept in remanufacturing to eliminate stock, the concept is difficult to adopt as there are two obstacles involved: the need for high investment and highly varied employees' background.

The demand system is managed through an information system for organising forecasting and communicating with OEMs (as they are suppliers and customers) and component suppliers. In addition, it is also utilized for organising daily production through feedback from OEMs.

5 DISCUSSION AND ANALYSIS

There has been dynamic interaction between supply and demand which is summarised in Table 2. Complexity of interaction is not only about quantity but also time and specification. To match them is difficult because the difference between supply and demand is not only about the quantity but also about the timing and product specification. Four scenarios that most probably could occur are displayed in Table 2. Unbalanced condition leads to either stock out or overstock which reduce th financial condition of the company. The goal of the company is to attain the shaded area that indicates the indicating the match between demand and supply of recovered products.

Table 2: Matching demand and supply

Demand / Supply	High	Low
High	Match	Overstock
Low	Stock Out	Match

Broadly speaking, profitability is dependent on three major factors: acquisition price of cores, remanufacturing cost and selling price of remanufactured cores. Based on the information obtained to date from this research, the relationship between acquisition prices, remanufacturing cost and the selling price of remanufactured products in unclear. Both acquisition and selling price are determined based on negotiation with OEMs so that they cannot be controlled entirely by the remanufacturer. Conversely, remanufacturing cost is the only activity that the company can manage. Accordingly, the company does not have much option except minimising remanufacturing cost to gain more profit; a strategy that can be categorized as efficient strategy [19] in reverse supply chain strategy typologies.

Every process in the company is subject to bottlenecks but the most potential ones are the availability of cores and the demand for recovered products. Both of the constraints are more difficult to manage compared to others as they involve external parties. Availability of cores can be managed with buffer stock but this method cannot be applied for demand problems.

The company experiences several disturbances that make forecasting to be less accurate: competition among remanufacturers and hedging from OEMs by choosing other remanufacturing companies to undertake their product recovery. Some OEMs can also dictate the company as they control the supply of cores and also the buying process. Even though on one side it offers benefit as supply can be easily matched with demand; however on the other side the position of the company is not good as it has low bargaining power regarding the determination of price and quantities of cores. Considering the high dependence on supply and demand from the same party – OEMs – the company should attempt to minimise this dependence either by developing its own remarketing channel or developing its own product acquisition channel [8]. With these strategies, the company could manage its supply and demand more independently and reduce intervention from others.

Current studies found evidence that independent remanufacturers are more sustainable compared to OEMs in remanufacturing business as they do not have to bear cannibalisation cost which has to be taken into account seriously by OEMs [20]. The only problem that should be addressed by independent remanufacturers is how to acquire cores to be further processed. As the acquisition is in the early stage of product recovery, it is the major factor that determines the profitability of product recovery activities [8] and also the main bottleneck of the overall process. Failure to manage this constraint will result in decreasing number of output of the overall system. Hence, a well-managed product acquisition management is a key success factor to eliminate bottlenecks in remanufacturing operations.

Current studies found that remanufacturers find it difficult to be efficient as there is a lack standardised processes due to materials variability; similar evidence is found in the company showing that the company should builds safety stock in almost every process to anticipate unpredicted requirements. This model is very common in many remanufacturing companies which follow "push system" in which production only can be started once the cores have arrived at the facility.

Even though the company has been successfully managing its internal operation and manages its market, there are at least two obstacles and challenges remaining. First, the launch of new products and technologies from the OEMs forces the remanufacturing company to reconfigure different remanufacturing facilities supported with different labor skills [21]. Martin et al. [21] further contend that the specific uses of asset to remanufacture certain brands make them unable to be used for other products even when for the products are still in the same product category. This is true as indicated by one of the respondents in this research stating that remanufacturing market reduced to 85% due to various causes. One of the reasons was the increase interest in diesel engine car as a substitute for the petrol engine one.

Second, the obsolescence rate differs greatly from one brand to another requiring the company to adopt different remanufacturing strategies for each product category. For automotive products, the rate of obsolescence is relatively more rapidly compared to others focus on functionality like military products. For the latter category, products can be remanufactured 4-5 times and require less effort to balance between demand and supply. Company also spent larger amount of funding for parts inventory on quicker obsolete products.

6 CONCLUSION, LIMITATION AND SUGGESTION FOR FUTURE RESEARCH

The use of a company as a single study is a potential drawbacks in this study although a single sample still can provide significant contribution as contended in Eisendhardt and Graebner [12]. However, it can be high risk as the researcher can give wrong judgment for a single event and also overstate easily the available data [22].

Another suggestion is regarding measurements for remanufacturing performance. This study determined that the performance evaluation is conducted at basic levels such as waiting time for cores to the next activity, number of throughput and capacity utilization. Those methods contain some deficiency as the methods do not capture the relationship between the elements in the reverse supply chain. Developing a robust methodology addressing the overall elements in the remanufacturing operations from product acquisitions to the remarketing process would be useful both for managers and academia. Several current studies could be used as a good start for this analysis. For example, Wu and Closs [10] following the suggestion from Beamon [23] suggesting the use of total system cost and order fulfill rate to assess purchasing performance, Guide and Daniel [24] proposes return volume, return stability, recovery processing time as parameters and material recovery rate.

The next stage of research will investigate the connection between residual values of cores with expected sales price. As suggested on Teunter and Flapper [24], quality variability of cores determines how much profit remanufacturer can expect; hence, the lower the value of cores, the lower the expected price. It is important to investigate this issue as sales price is highly important because sales price directly affects the financial performance of a company.

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A Simulated Annealing Algorithm for Balancing a Disassembly Line

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Abstract

Disassembly is used both in recycling and remanufacturing. The highest productivity rate is provided by a disassembly line and hence is the best choice for automated disassembly processes. In this paper, we consider a disassembly line balancing problem (DLBP) with multiple objectives that concerns with the assignment of disassembly tasks to a set of ordered disassembly workstations while satisfying the disassembly precedence constraints and optimizing the effectiveness of several measures such as minimizing the number of disassembly workstations, minimizing the total idle time of all workstations by ensuring similar idle time at each workstation, maximizing the removal of hazardous components as early as possible in the disassembly sequence and maximizing the removal of high demanded components before low demanded components. Since the complexity of DLBP increases with the number of parts of the product, an efficient methodology based on the simulated annealing (SA) is proposed to solve the DLBP. The proposed method is tested on a numerical example taken from the literature and the computation results show the functionality of the method.

Keywords:

disassembly line balancing, simulated annealing, metaheuristics

1 INTRODUCTION

Environmentally conscious manufacturing and product recovery (ECMPRO) is an obligation to the environment and society. ECMPRO related problems include a wide range of issues such as product design, reverse and closed loop supply chains, remanufacturing and disassembly. Gungor & Gupta [1] and Ilgin & Gupta [2] provide an extensive review of product recovery. Disassembly is used both in recycling and remanufacturing by allowing selective separation of desired parts and materials. Disassembly operations can be performed at a single workstation, in a disassembly cell or on a disassembly line. Although a single workstation and disassembly cell are more flexible, the highest productivity rate is provided by a disassembly line and hence is the best choice for automated disassembly processes, a feature that will be essential in the future disassembly systems. Therefore, a disassembly line should be designed and balanced so that it can work as efficiently as possible. The disassembly line balancing problem (DLBP) requires the assignment of disassembly tasks to a set of ordered disassembly workstations while satisfying the disassembly precedence constraints and optimizing the effectiveness of several measures. DLBP is a multi-objective problem that was described in [3] and has mathematically been proven to be NP-complete [4], making the goal to achieve the optimal balance computationally expensive. Although some researchers have formulated the DLBP using mathematical programming techniques [5,6], it quickly becomes unsolvable for a practical sized problem due to its combinatorial nature. For this reason, there is an increasing need to use metaheuristic techniques such as genetic algorithms [4] and ant colony optimization [7-9]. In this paper, a new approach based on the simulated annealing algorithm is proposed to solve the multi-objective DLBP. See [10] for more information on DLBP. The four objectives to be achieved are: (1) minimize the number of disassembly workstations, (2) minimize the total idle time of all workstations by ensuring similar idle time at each workstation, (3) remove hazardous components as early as possible in the disassembly sequence and (4) remove high demand components before the low demand components. Simulated Annealing (SA) is a stochastic neighborhood search method based on the process of annealing of solids that is developed for solving combinatorial optimization problems. It has the capability of jumping out of a local optima and move towards the global optima. This capability is achieved by accepting some of the neighborhood solutions that are worse than the current solution with a small probability. The acceptance probability is determined by a control parameter that is the temperature which decreases during the SA procedure.

The rest of the paper is organized as follows. In Section 2, problem definition and formulation is given. Section 3 describes the proposed SA approach for the multi-objective DLBP. The computational experience to evaluate its performance on a numerical example is provided in Section 4. Finally some conclusions are pointed out in Section 5.

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2 PROBLEM DEFINITION AND FORMULATION

Problem assumptions include the following: A single product type is to be disassembled on a disassembly line; the supply of the end-of-life product is infinite; the exact quantity of each part available in the product is known and constant; a disassembly task cannot be divided between two workstations; each part has an assumed associated resale value which includes its market value and recycled material value; disassembly tasks are to be assigned to a sequence of workstations without violating precedence relationships among the tasks; and complete disassembly is performed on the product. In this paper we deal with the multi objective DLBP that is deterministic, single-product DLBP with straight layout. Notation used in the mathematical formulation is given as follows:

CT	Cycle time; maximum time available at each workstation
d_k	Demand; quantity of part *k* requested
h_k	Binary value; 1 if part *k* is hazardous, else 0
IP	Set (k_1 , k_2) of parts such that part k_1 must precede part k_2
j	Workstation count (1,…, *NWS*)
k	Part identification (1,…, *n*)
n	The number of parts for removal
N	The set of natural numbers
NWS	Number of workstations required for a given solution sequence
NWS^*	Minimum possible number of workstations for complete disassembly
PRT_k	Part removal time required for k^{th} part
PS_k	k^{th} part in a solution sequence
ST_j	Station time; total processing time requirement in workstation *j*
x_{kj}	Task assignments to work stations; 1 if part *k* is assigned to workstation *j*, else 0

Based on concept and assumptions made in [4], the mathematical formulation of our DLBP is given as follows:

$$\min f_1 = NWS \tag{1}$$

$$\min f_2 = \sum_{j=1}^{NWS} (CT - ST_j)^2 \tag{2}$$

$$\min f_3 = \sum_{k=1}^{n} (k \cdot h_{PS_k}), \quad h_{PS_k} = \begin{cases} 1, \text{hazardous} \\ 0, \text{otherwise} \end{cases} \tag{3}$$

$$\min f_4 = \sum_{k=1}^{n} (k \cdot d_{PS_k}), \quad d_{PS_k} \in N, \forall PS_k \tag{4}$$

Subject to:

$$\left\lceil \frac{\sum_{k=1}^{n} PRT_k}{CT} \right\rceil \le NWS^* \le n \tag{5}$$

$$\sum_{j=1}^{NWS} ST_j \le CT, \quad j = 1, 2, ..., NWS \tag{6}$$

$$\sum_{j=1}^{NWS} x_{kj} = 1, \quad k = 1, ..., n \tag{7}$$

$$x_{aj} \le \sum_{j=1}^{NWS} x_{kj}, \quad \forall (a, k) \in IP \tag{8}$$

In the multi-objective optimization formulation given above, equation (1) aims to minimize the number of workstations in the disassembly line. Equation (2) aims to minimize the total idle time across all workstations and aims to make the idle times at all workstations similar to each other (where $f_2 = 0$ represents perfect balance), equation (3) aims to remove hazardous components as early as possible and equation (4) aims to remove high demand components before low demand components in the disassembly process. Constraint (5) guarantees that the number of work stations with a workload does not exceed the permitted number. Constraint (6) ensures that the work content of a workstation cannot exceed the cycle time. Constraint (7) ensures that all tasks are assigned to at least and at most one workstation (the complete assignment of each task). Equation (8) imposes the restriction that all the disassembly precedence relationships between tasks should be satisfied.

3 PROPOSED SIMULATED ANNEALING APPROACH

In this paper, a simulated annealing approach is proposed to solve DLBP. Due to the combinatorial nature of the problem, especially for large-sized problems, it cannot be easily solved by traditional mathematical techniques or exact solution methods such as branch-and-bound, dynamic programming. For this reason, a fast and effective algorithm such as simulated annealing is developed to solve the problem. Simulated annealing is an iterative random search technique that has been applied to many optimization problems in a wide variety of areas, including the assembly line balancing (ALBP) [11-17].

Simulated annealing is a stochastic approach used for solving many combinatorial optimization problems by inspiration from the physical annealing process of metals. Simulated Annealing gets its name from the physical annealing of solid that is heated to a very high temperature and then cooled at a slow rate, spending a relatively large amount of time near the freezing point of the solid.

The proposed approach starts with an initial solution that is defined as the current solution. Then, a neighbor solution is obtained from the current solution. The cost of the neighbor solution is calculated and compared with the cost of the current solution. If the objective function value is superior to that of the current solution, the neighboring solution becomes the new current solution. If the neighboring solution provides an objective function value inferior to that of the current solution, the neighboring solution may still become the current solution with a probability if a certain acceptance criterion is met. Otherwise the current solution remains unchanged. A distinctive feature of Simulated Annealing is that inferior solutions are sometimes accepted as the current solution to try and so, prevent getting trapped at local optima.

A configuration is a solution to a given problem. In the proposed SA algorithm, elements of the solution string are integers. Each element represents a task assignment to work station. For example, if there are 8 tasks to be assigned to workstations then the length of the solution string is 8. Fig. 1 illustrates assignment of tasks to workstations as an example.

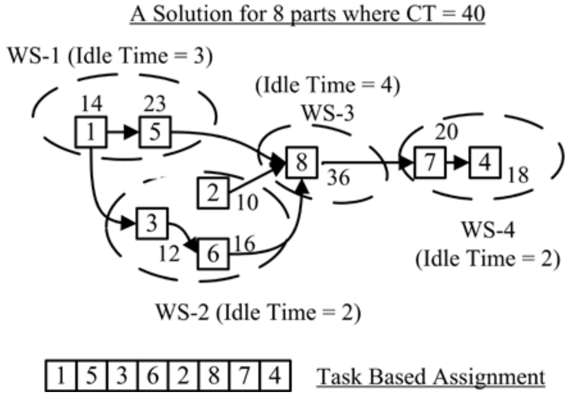

Fig. 1: Assignment of tasks to workstations

A new solution obtained from a current solution by using a specific move is called a neighborhood solution. In the proposed SA algorithm, interchanging two tasks (SWAP) or inserting a task to a different work station (INSERT) is implemented as a moving strategy such that the new neighboring solutions are ensured to be feasible. By guaranteeing feasibility in each operation, the necessity of the repair function is prevented. In SWAP, two randomly selected tasks from two randomly selected workstations are exchanged and in INSERT, a randomly selected task from a randomly selected workstation is inserted into another randomly selected workstation while satisfying the precedence constraints. Examples for SWAP and INSERT operators are given in Fig. 2 and Fig. 3 respectively.

Additional notations used in the paper are as follows:

T_0 : Initial temperature

$i_{\max}$: Maximum number of iterations

S_0 : Initial Solution

F_0 : Fitness values vector of initial solution

S_c : Current solution

F_c : Fitness values vector of current solution

S_{best} : Best solution found so far

F_{best} : Fitness values vector of best solution

i : Iteration number

S_i : Solution found at each iteration

F_i : Fitness values vector calculated at each iteration

At each iteration, it is desired to escape from local optimum points by increasing the temperature level. The following cooling schedule is used in this study [15]:

$$T_i = T_0 \big/ (1 + \ln(i)) \tag{9}$$

Flow Diagram of the Proposed Approach is given at Fig. 4.

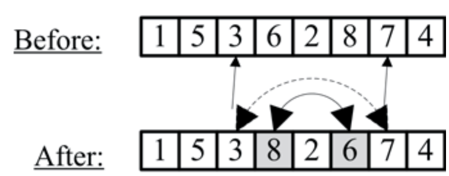

Fig.2: SWAP Operation

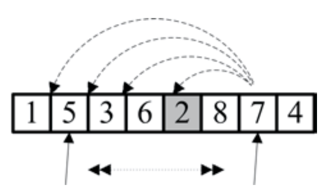

Fig.3: INSERT operation

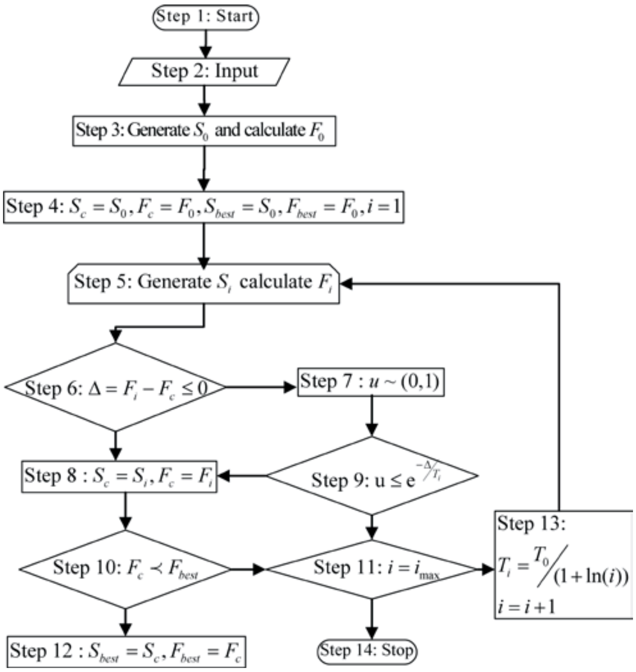

Fig. 4: Flow Diagram of the Proposed Approach

The steps of the proposed approach are given below:

Step 1: Start.

Step 2: Input DLBP data (Table 1), precedent relationships (Fig. 5) and SA parameters (T_0 , $i_{\max}$).

Step 3: Generate initial solution (S_0) by selecting the best solution found by GAs and heuristics such as Greatest Ranked Positional Weight, Greatest Number of Successors, Longest Processing Time, Smallest Task Number and Smallest Upper Bound, repair generated solutions if necessary, calculate the fitness values of the initial solution and set to F_0 vector.

Step 4: Set initial solution (S_0) to current S_c and best solution S_{best} , initial fitness values vector F_0 to current F_c and best fitness value vectors F_{best} and set iteration i to 1.

Step 5: Generate a neighbor solution S_i by applying INSERT or SWAP with the probability of .5, repair the solution found if necessary and calculate its fitness values and set to F_i vector.

Step 6: Checking fitness values f_1 , f_2 , f_3 , f_4 according to the priorities defined, if the fitness values in F_i vector of the solution S_i is less than or equal to the fitness values in F_c vector of the current solution S_c , go to step 8.

Step 7: Generate a uniform random number u and go to Step 9.

Step 8: Accept the neighbor solution found as current solution. Set solution S_i to current solution S_c and F_i to current fitness values vector F_c . Go to Step 10.

Step 9: If $u \le e^{(-\Delta/T_i)}$ where $\Delta = F_i(2) - F_c(2)$ go to Step 8, otherwise go to Step 11.

Step 10: Checking fitness values f_1 , f_2 , f_3 , f_4 according to the priorities defined, if the fitness values in F_c vector of the solution S_c is less than the fitness values in F_{best} vector of the current solution S_{best} , go to step 12.

Step 11: If maximum number of iteration criterion is satisfied go to Step 14, otherwise go to Step 13.

Step 12: Accept the neighbor solution found as the best solution. Set current solution S_c to best solution S_{best} found so far and F_c to best fitness values vector F_{best} .

Step 13: Adjust the cooling schedule as given in equation (9), increase iteration number and go to Step 5.

Step 14: Stop.

4 NUMERICAL RESULTS

In this section a numerical example from literature [18] is used to illustrate the effectiveness of the proposed SA. Here the objective is to completely disassemble a 25 part cellular phone while satisfying several precedence relationships. Disassembly line operates at a speed which allows *CT*=18 seconds for each workstation to perform its required disassembly tasks. This example consists of the data for the disassembly product as shown in Table 1 and Figure 5. The proposed algorithm was coded in MATLAB and tested on Intel Core2 1.79 GHz processor with 3GB RAM. All parameters of the algorithm are obtained experimentally. The preliminary experiment is performed to improve the solution quality and to determine the parameters of the proposed algorithm: T_0 and $i_{\max}$. According to the results of the statistical analysis, effective levels of the parameters T_0 and $i_{\max}$ are determined as 500 and 30000, respectively. All of the SA solutions found the optimal number of workstations $F_{best}(1) = 9$ [18]. From the literature , the minimal value for the measure of balance is $F_{best}(2) = 9$ [8]; it is also achieved by SA. The hazardous part measure averaged 85.5 (ranging from a best result of $F_{best}(3) = 81$ and a worst result of $F(3) = 90$). The high demand part removal measure averaged 918.5 (with a best result of $F_{best}(4) = 853$ and a worst result of $F(4) = 934$). A typical SA solution using the cellular telephone instance is given in Figure 6. Computational experience with the algorithm on the benchmark data set has shown that the algorithm performs remarkably well.

Table 1: Knowledge base of cellular telephone instance

Task	Time	Hazardous	Demand
1	3	Yes	4
2	2	Yes	7
3	3	No	1
4	10	No	1
5	10	No	1
6	15	No	1
7	15	No	1
8	15	No	1
9	15	No	1
10	2	No	2
11	2	No	1
12	2	Yes	4
13	2	No	1
14	2	No	1
15	2	No	1
16	2	No	1
17	2	No	2
18	3	No	2
19	18	Yes	8
20	5	No	1
21	1	No	4
22	5	No	6
23	15	Yes	7
24	2	No	1
25	2	Yes	4

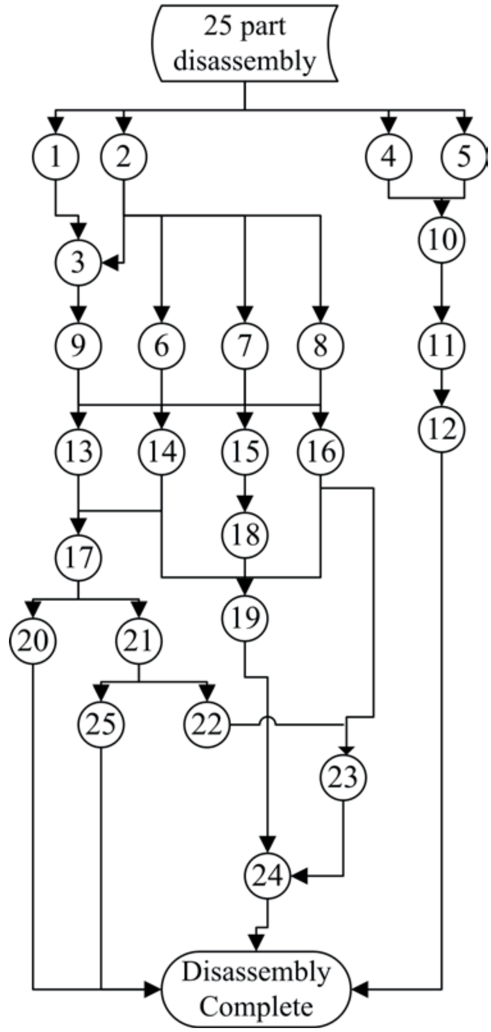

Fig. 5: Cellular Telephone Precedence Relationships

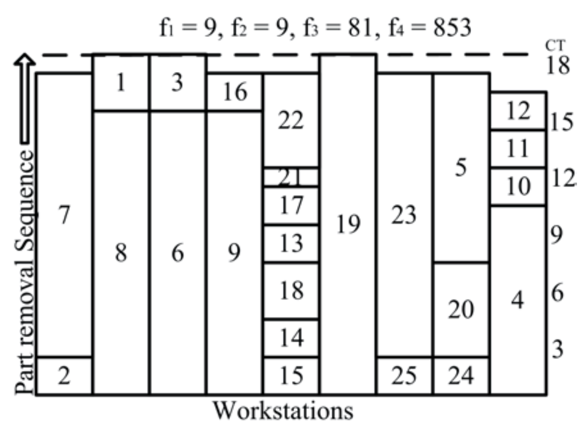

Fig. 6: A typical solution using the cellular telephone instance

5 CONCLUSIONS

The main objective of this paper was to introduce a SA approach to solve the DLBP with multiple objectives. To the best of knowledge of the authors, there is no published study that uses SA to solve DLBP. Here, SA was proposed to solve the problem which aimed to minimize the number of disassembly workstations, minimize the total idle time of all workstations by ensuring similar idle time at each workstation, maximize the priority of removing hazardous components as early as possible in the disassembly sequence and maximize the priority of removing high demand components before low demand components. Approach started with a good initial solution created by heuristics and GAs. A repair function was used to ensure feasibility where necessary. A move was created and evaluated iteratively by checking disassembly constraints until stopping criteria were met. A case study on the disassembly of a 25 part mobile example was used to ascertain the performance of the proposed approach. The SA approach was able to find (near) optimal solution(s) very fast. Computational experience with the algorithm of disassembly line balancing problem showed that algorithm worked remarkably well to obtain (near) optimal solutions.

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A Study of Mist Spraying System by Urban Transportation

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Abstract

The heat island phenomenon is severer for urban people according to global warming and urbanization in recent years. Especially, in the central part of the city, a large amount of inflow of the car and its congestion cause the temperature rise by the operation of air conditioners and the vehicle exhaust emission discharge etc. and it produces an extremely unpleasant environment for people who walk in the town. In this study, we propose micro mist spraying system by urban transportation, for example, the bus. It sprays the mist intensively on the central part and main streets. It offers a comfortable city life environment for the pedestrian. Through the introduction of this system, the temperature rise in the central part of the city is expected to be reduced by a comparatively easy method.

Keywords:

heat island phenomenon, global warming countermeasures, mist spraying system, urban transportation

1 INTRODUCTION

Recently, global warming is acknowledged as a problem. Especially, in the city part, the state whose temperature is higher than its surroundings, so-called the heat island phenomenon, have been generated by the following factors. It is estimated that the temperature rises at 3-4°C because of urbanization in the big city[1][2]. The following reasons are thought as causes of the heat island phenomenon.

1) Change of land uses

In the farmland, the green belt, and the waterside space etc., the absorption of heat according to the evaporation of moisture suppresses the rise of the temperature. On the other hand, in the city area, the ground level is covered with asphalt and concrete and the moisture is a little. The heat given from the ground level to the atmosphere increases, and the temperature rises.

2) Effect of building and road

In the city area, buildings absorb direct light from the sun, a part of reflected light from ground and a part of infrared rays discharged from ground to the atmosphere. The road asphalt also accelerates the temperature rise of the ground level. In addition, the velocity of the wind in the vicinity of surface of the earth is weakened because of the building and the heat of the ground level tends not to be carried to the sky. Therefore the heat island phenomenon is promoted.

3) Artificial rejection heat

Heat has been exhausted by various industrial activities and social activities of the city. It is estimated that the rejection calorie in the central part of the big city in daytime exceeds 100W per 1m^2. Especially, in the central part of the city, a large amount of inflow of the car and its congestion cause the temperature rise by the operation of air conditioners and the vehicle exhaust emission discharge etc. and it produces an extremely unpleasant environment for people who walk in the town.

For instance, the difference normal temperature in the summer of 2010 (from June to August in 2010) and average year in Japan was +1.64°C. After 1898 when Japan had begun taking statistics, it became the highest record as a temperature of summer[3]. In the whole country, the person who had been carried to the hospital by heat disorder exceeded 40,000 people. In addition, the death toll exceeded 400[4]. Such a severe situation cannot be disregarded.

As measures against the heat island phenomenon[5], the cooling method using the heat of vaporization of water is proposed and executed[6][7][8]. In present watering and mist spraying systems, however, cooling is planned for very limited place. Moreover, a large-scale construction of water service pipes is sometimes needed for them. Therefore it is difficult to introduce them into a central part of the existing city in full scale.

In this study, we pay attention to urban transportation, for example, the bus in the central part of the city. We propose the bus with micro water mist spraying function. It sprays the mist intensively on the central part and main streets in the city. It offers a comfortable city life environment for the pedestrian.

2 COOLING EFFECT BY MIST SPRAYING

When the plant does the transpiration, the water in the plant becomes steam. At this time, surroundings are

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deprived of heat of vaporization because the liquid is changed into the gas. This is called a transpiration effect. In a word, it deprives of surrounding heat when the liquid water is changed into the steam. The green belt is cooler than the city because the effect of the transpiration by the plant is large. In the green belt, a cool and comfortable temperature is kept by the transpiration effect.

A traditional method using this transpiration effect is watering ("Uchi Mizu" in Japanese)[6]. It is a mechanism that the water evaporates by watering the garden, and surroundings become cool. Mist spraying is similar to watering. In the comparison with watering, it is easy for water to evaporate and to obtain the transpiration effect because it artificially discharges particles of water. Because the mist evaporate immediately after being discharged, it gives a cool sense to the surrounding people.

Although the artificial generation of mist and its cooling effect by imitating the transpiration by the plant had been known so far, there was a big problem that the floor and the skin got wet because the particle of the mist was large. A new technology that overcame this problem was developed and called by the trademark in Japan such as "dry mist" that means very small particles of the mist and has no wet sense[7][8]. It was introduced actually and popular in World Exposition 2005, Aichi, Japan. The question that the mist spraying rather becomes sultry and oppressive is expected. In Japan, however, there are only several hours per one year when the relative humidity is 70% or more and the temperature 30°C or more and the transpiration becomes insufficient in the big city. It is also proven that the decrease in the temperature by the transpiration of the mist offers the comfort, though the humidity goes up somewhat[8]. Actually, the mist spraying system begins to be introduced into the place in which a lot of people gather, surrounding of skyscraper in the big city etc.[9][10]

3 MIST SPRAYING SYSTEM USING TRANSPORTATION

In this study, as one example of the heat island phenomenon reduction system, we propose to ease people's heat on the main street in the central part in the city by installing the mist spraying system on the bus and especially reducing the high temperature and dryness on the street.

The advantages of installing the mist spraying system on the bus are as follows.

1) Constructional characteristic of bus

The weight of a general bus is about 10t, it becomes only a weight increase of about 100kg (does not come up to as many as two adults) even if the water of 100ℓ is loaded, so it doesn't influence the performance of the bus at all. Therefore, transportation and mist spraying of volumes of water are possible. Moreover, there no problem in the point of the power supply to the generator of the mist

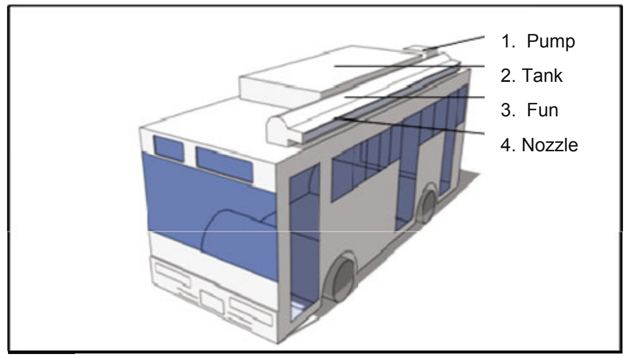

Fig. 1: Outline of mist spraying device by bus

Fig. 2: Image of mist spraying on the street

because the battery of the bus originally has large capacity for cooling inside of the bus etc. In addition, if water-supplying facilities are installed in the bus terminal etc., the water supply becomes easily possible during bus driver's break time, and a huge tank will not be necessary to be loaded on the bus for the mist spraying for a long time (during half a day or one day). Moreover, it is convenient that the cool breeze that contains the mist is supplied from overhead to the pedestrian because the height of the bus is about 2.5m. The heat of the passenger and the pedestrian etc. in the bus stop is expected to be eased by spraying the mist from a left side and the ceiling part of the bus as Fig. 1 and Fig. 2 show.

2) Selection and concentration of sprayed place

In the central part of the city, in general, the bus is running in the main street, and commercial establishments such as a department store and large-scale building are clustered, and people's traffic is active regardless of holiday or weekday. Therefore, the cooling effect by the mist spraying can be offered to a lot of pedestrians in the central part of the city. Moreover, a large amount of the mist will be sprayed in the route and time zone with a lot of passengers getting on and off because it can be said that the operation interval of the bus indirectly shows the number of people walking around bus routes. In a word, the mist spraying is controlled at the place and the time where the people do not exist, and it leads to the saving of the water charges for the mist spraying.

3) Advantage on road

In Japan, the bus often runs in a left-hand lane that is the nearest to the pavement. Therefore, it is easy to bring the cooling effect by the mist spraying to the passenger who waits the bus at the bus stop and the pedestrian in the pavement. Moreover, the bus waiting for the light to change can spray the mist to the pedestrian who is waiting too for a comparatively long time. In congestion of the road, the longer the sojourn time of the bus in a route becomes, the longer the time of mist spraying becomes on the road, and the effect of easing the temperature rise caused by the vehicle exhaust emission of the car is expected.

Of course, the bus has to be remodeled, and cost at which the tank of water and the spraying device are set up on the ceiling or below the floor of the bus is necessary. On the other hand, and large-scale construction on the road for the mist spraying, e.g., the construction of many water service pipes that becomes the cause of congestion is unnecessary. The reduction in costs of the vehicle mist spray system by mass production will be expected if the manufacturers of the car and the mist spray device cooperate for technological development in the future.

4 A NUMERICAL EXAMPLE

The surrounding of Sakae Station that is the central part of the Nagoya City is taken up as a numerical example. There are large-scale commercial establishments (three department stores) and a lot of office buildings in this area. It is understood that it centers on Sakae Station (a blue round sign in Fig. 3) and the city buses (red lines in Fig. 3) are running almost in the main street like the lattice when paying attention in the loop of the Nagoya city highway (about 1.7×2.2km) as shown in Fig. 3.

For example, the number of routes on which the buses are running arround Sakae Station is about 30 [11].

1)Amout of sprayed mist in central part of the city

It is assumed that a bus can spray the mist at 30 ℓ per hour.

The mist are sprayed in specified time zone(10:00-18:00).

By caluclation, the total amount of the water that can be sprayed in a day is less than 5t. Because the water that can be sprayed is very little compared with the specified area, the effect on easing the heat island phenomenon in the whole area is weak. From Fig. 4, however, the effect on the person who is actually walking in some main streets can be expected.

2)Initial Cost for installation

The total number of the city bus in Nagoya is about 1000, and it is assumed that the mist spraying system is introduced into 500 buses (1/2 of the total number). If the device of mist spraying on the market can be easily introduced, the initial cost per one bus for installation is 1.25 million yen or more by a simple calculation. Then the total initial installation cost of 600 million yen or more is needed for introducing the mist spraying system to 500 buses. Although this cost is certainly large amount of money, it is a little sum in comparison with the annual budget in Nagoya City for "the maintainance of the environment urban tree-plantation" (about 26 billion yen) and "Traffic" (about 78 billion yen).

Fig. 3 : Outline of bus routes in Nagoya city (Sakae Station surrounding)

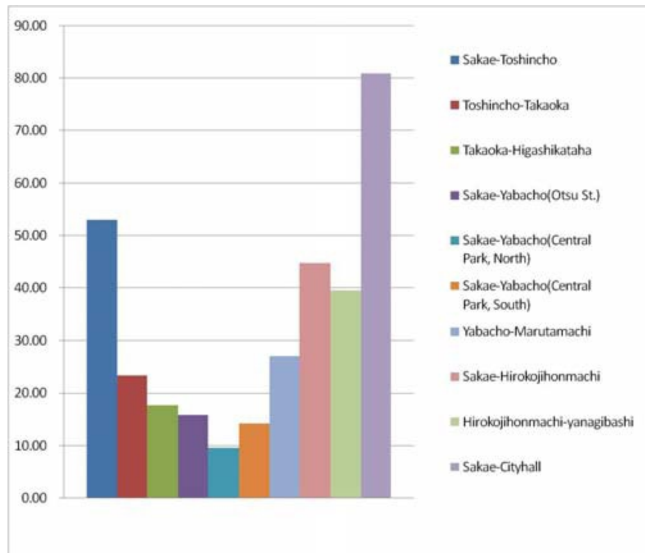

Fig. 4 : Volume(ℓ) of the sprayed mist per 100m and a day in main streets

3)Water Charges

If it is possible to continue mist spraying by 500 buses in the city for eight hours per day, 500×8×30=120kl of the tap water is necessary for one month. The water charges of one month (30 days) in Nagoya City are about 1.2 million yen/month [12]. Even if the mist is sprayed unconditionally at cool cloudy or rainy day, it is thought that the system can be executed because of lower cost than the related budget in Nagoya.

5 CONCLUSION

The mist spray system proposed in this study is especially intended to offer the comfort to the pedestrian in the central part in the big city. It is expected that the proposed system is more flexible than past system that can spray mist only in the decided place and needs the large-scale construction of water service pipes on the roads. However, the volume of water is insufficient to cool the highly heated road. For example, using the watering system by the recycled water together with the propesed system might be also effective to aim at a large cooling effect. Moreover, the country and the local government should positively reinforce the policy of cooling the entire city while advancing the green roof and wall and the maintenance of the waterside, roadside trees, and parks executed so far.

It is expected that the proposed system is not only a measure of heat island phenomenon but also a measure for educational campaign to local residents about heat island phenomenon and the promotion of regional revitalization worth positively executing.

It is important that an efficient and low-cost mist spraying system for vehicle will be developed.

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Carbon sink Evaluation for Biochar Production Process

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Abstract : We have proposed consideration of Carbon sink and CO_2 emissions derived from electric power and fuel energy, the following A and B facilities were to be an objection .The scenario was prepared in order to get four kind by two cutting method and two carbonizing method were combined. Energy consumption of each scenario were calculated for its machinery specification of A and B company. This study revealed the following results.

1)The Vertical grating furnace exhausted 2.4 times more CO_2 emission than the Repeat rolling furnace..The carbonization process had a big influence to the exhaust CO_2 emission.

2) The exhaust CO_2 emission of cutting processes were nearly equal.

3) The Carbon sink effect was about three times more than CO_2 emission in the running of a carbonization.

Keywords: carbon sink, building waste woods, waste wood pallets, carbonizing method , CO_2 emission.

1 INTRODUCTION

Recently, it has become an important issue to prevent global warming by capturing gases(GHG) and establishing sound material cycle societies.

The biomass carbonization stands as one of the recycling technologies and the resultant coal is called biochar. The definition of carbonization is not straightforward. Carbonization means heating organic material under no or scarce oxygen atmosphere, or "smothering" in daily terminology[1)]. Kawamoto et.al. reported that the half-life of charcoal due to atmospheric ozone exceeds 50,000 years unless heat reacted with oxygen[2)]. Based on this knowledge, Ogawa, Okimori, et, al[3)]. proposed that using char from biomass, or "biochar", in agriculture fields etc. is an effective way of carbon sequestration. In addition, because biochar is not decomposed in soil, its carbon sink effect is increasingly getting attention in recent years[4)]. The authors have proposed to take the CO_2 emissions into account which are derived from electric power and fuel consumption during the carbon sink or the carbonization process[5)].

In order to evaluate carbon sink effect at the design stage, this study verified the matching characteristics between the trial calculations and actual results obtained from the main machinery. Scenarios were also prepared in order to comparatively investigate CO_2 emissions in carbonization.

2 OUTLINE OF INVESTIGATED FACILITIES

This study covers the following A and B.

Company A has managed civil engineering and construction works for many years. Using waste

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woods and pallets from its own works, Company A has continued carbonization by Repeat rolling furnace.

Manufctured bio-char are shipped as agricultural planting materials or moisture controlling material for houses. Unlike the conventional humidity control method of buildings , Company A has devised unique method of setting the charcoal into the ceiling in order for the better ventilation. Using waste woods pallets collected from approximately 40 firms, Company B has continued carbonization by Vertical grating furnace. Generally speaking, imported machinery and industrial goods are loaded on wood pallets. These wood pallets are of different standards and cannot readily be re-used. There were no effective means to recycle those one way pallets from overseas, and huge amount of them were piled up causing headaches to importers. Company B has introduced its own carbonizing furnace and collected wood pallets as valuable material. The biochar produced is sold to companies which supplied the pallets. Companies buy the coal and use it in their own firm's water purification equipment and as deodorant[6]. causing. Company B indicated that the distributed re-cycling system can be realized with a carbonization furnaces at the system.

3 AMOUNT OF CO_2 EMISSION FROM EACH CARBONIZATION PROCESS

3.1 Targets of Investigation

Figure 1 shows the carbonization flow and system boundary targeted in this study. Mainly facilities of Company A and Company B are shown in Table 1.

3.2 Calculation method: After examining the flow diagram and specifications of the target facility, the process were divided into segments. The output

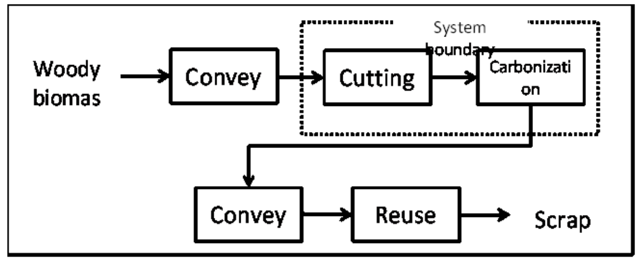
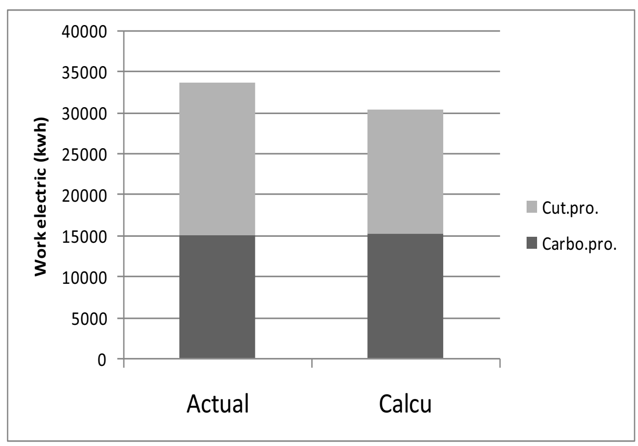


Fig.1 Carbonization flow and system bounary

Table.1 Abstract of A・B Co.

	Aco.	Bco.
Cutter	Hunmermill (Elec.)	Gearsys(L.oil)
Furmace	Rollingf'ce	Gratingf'ce
Contr. Ex-gas	–	LPG

elec.=electric, sys.=system, fce=furnace



Cut.=cutting, pro.=process, carbo.=carbonizing
Calcu.=calculation

Fig.2 Comparison of mean electric power・actual&caluculation electric power in A company

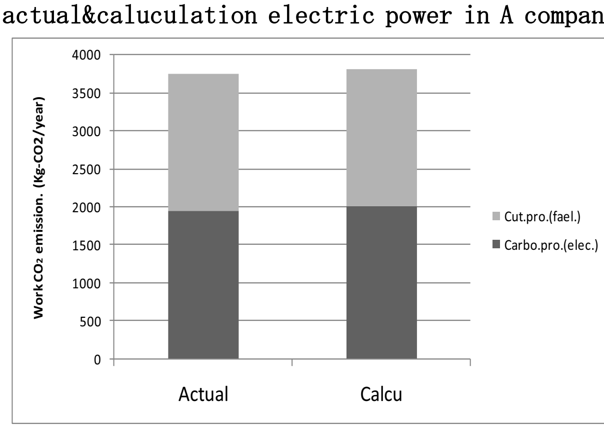


Fig.3 Comparison of mean ・actual & caluculation CO2 emission in B Company

throughput etc. of each machine were checked. The working time was set from the actual operating data to calculate the power and fuel consumptions. For machines and inverters with unknown outputs estimations were made using the actual operating data. Amount of CO_2 emissions were estimated using emission intensity of Environment ministry[7).

3.3 Calculation Results: In case of Company A, there was no difference between the calculated and actual values in the carbonization process, but there was a difference in the cutting process (see Figure 2).The error between the calculated and actual value was about 10 %. The cause of the error is assumed not to have taken the ancillary equipment such as conveyors into account. For Company B, the calculated and the actual values matched well both for electricity and fuel(see Figure 3). About 70 % of electricity was used by the fans and exhaust gas

Processor, and the carbonization furnace was not the main energy consumer as previously expected (see Figure 4).

4 CARBON SINK ASSESSMENT WITH SCENARIOS

4.1 Creating Scenario

Four different scenarios were prepared as shown in Figure 5. As the preliminary materials and their moisture content are assumed as waste woods and 15 % respectively.The amount of processing are set during 2.1～105 t/month with 21day. Uptimes are set to be 8h, and conteneous and carbon yield are set to be 8% and 20%. The CO_2 emission were estimated using emission intensity provided by the Environment ministry. The number of carbonizing furnaces were selected according to the required.The operating number of cutter・carbonizing furnace are shown in Table 3.

4.2 Calculations

Calculation of energy use for scenario is discussed using the data of equipment used by Company A and B as previously described.

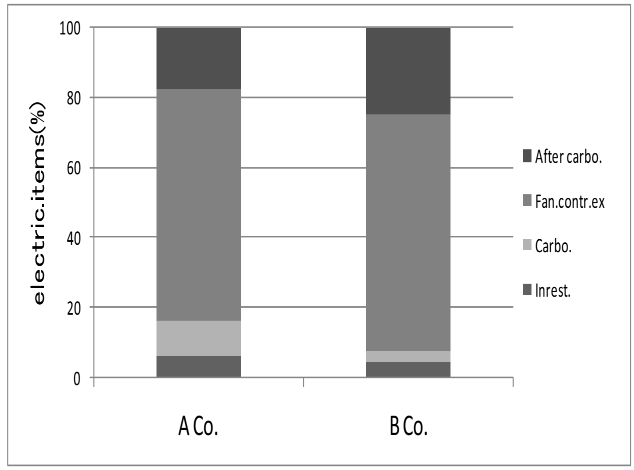


Fig.4 Electric. Items of A and B Co.
Contr.=control ex=exhaust invest.=investment

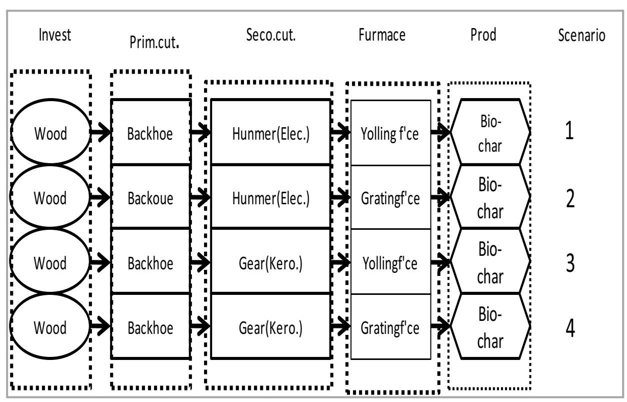


Fig.5 Evaluation scenario

Table.2 Caluculation object

		scenario1	scenario2	scenario3	scenario4
Cut.pr.	Elec.	O	O	–	–
	L.oil	–	–	O	O
	H.oil	O	O	O	O
Carbo.pr	Elec.	O	O	O	O
	P.oil	O	–	O	
	L.oil	O	O	O	O
	LPG	–	O	–	O
	G.gsol.	O	–	O	–

Table.3 Cutter・Carbonizing f'ce Operating number

		Wastewoodtreat(t/mouth)					
		2.1	10.5	21	42	63	105
Cutter	Scena.1~4	1	1	1	1	1	1
carb.f'ce	Scena.1	1	1	1	1	1	1
	Scena.2	1	1	1	2	3	5
	Scena.3	1	1	1	1	1	1
	Scena.4	1	1	1	2	3	5

4.3 Calculation results

Figure 6 shows the CO_2 emissions for different scenarios. The emission of scenario 1・3 was about 2000kg-CO_2 and that of scenario 2・4 was about 3200kg-CO_2. The CO_2 emission of scenario 2・4 was 1.6 times higher than scenario 1・3. In the cutting process, the CO_2 emission were nearly equal in all scenarios. The carbonization process of scenario 1・3 exhausted about 1030kg-CO_2 and that of scenario 2・4 exhausted about 2500kg-CO_2, therefore scenario 2.4 exhausted 2,43 times more CO2 than scenario 1・3. The scenario 1・3 used Repeat rolling furnace, and scenario 2・4 used Vertical grating furnaces. Vertical grating furnace has smaller throughput than the Repeat rolling furnace and more than one of the former were installed. The amount of carbon sink for different working hours per day are depicted in Figure 7. In each case, the equivalent CO_2 (CO_2 fixed value) of containing biochar[8] carbon is about three times more than the amount of CO_2 emission for driving facilities, demonstrating the clear effect of carbon sinks.

5 COMPARISON AMONG THE RESULTSOF 4 SCENARIOS

5.1 Amount of CO_2 emissions of each scenarios

The amount of CO_2 emission by scenario 1・3 with Repeat rolling furnace was 2.5t/h. That of scenario 2・4 using Vertical grating furnace was 0.16t/h. Therefore, plural number of furnaces corresponding to product volume were employed in scenario 2・4. From this result, scenario 1・3 using Repeat rolling furnace were of higher carbon sink effect than scenario 2・4. The CO_2 emissions per 1t of waste wood varies with changes in carbon yield rates. Although the difference exists in the cutting process, at the amount of wood waste in this study, the difference is negligible as the CO_2 emission in the carbonization processes is a lot bigger. We have found that the variation of cutting equipment hardly changes the overall performance.

5.2 Evaluation of carbon sink

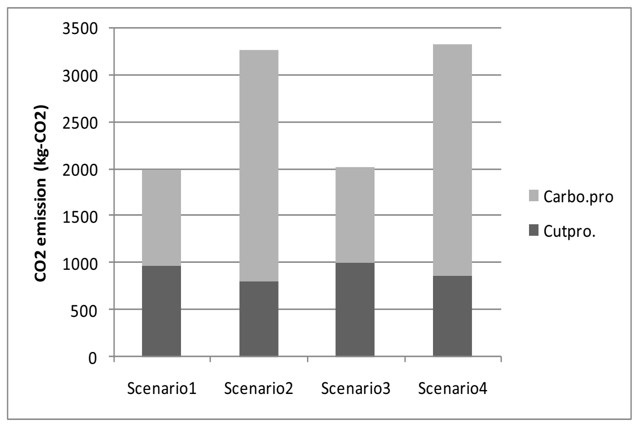


Fig.6 Each scenario CO2 emissions (42t/month)

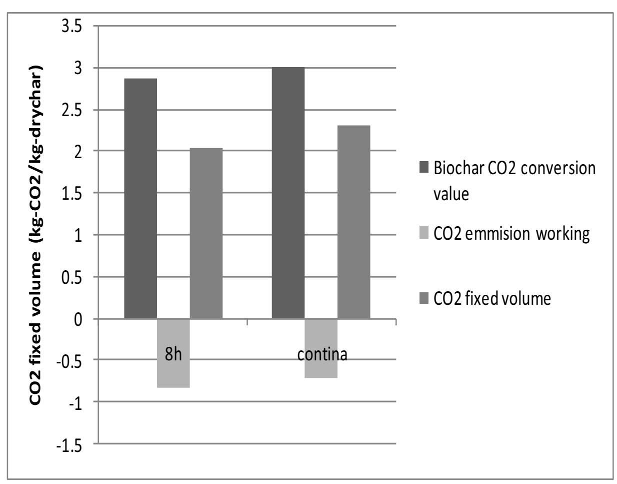


Fig.7 Carbon sink value (scenario 2, carb.yield 8%)

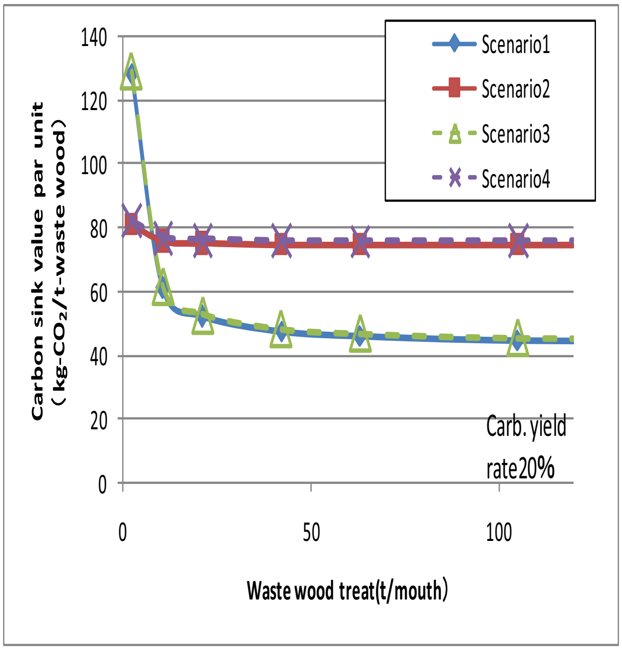


Fig.8 Each scenario CO_2 emission per waste wood

Carbon sequestration in coal made by biomass, can reduce the total amount of carbon in cycle[8]. Figure 9 shows the results of the amount of carbon sinks. The amount of carbon sink was higher in scenario 1・3. The higher carbon yield rate provided greater amount of carbon sink.

6 STUDY

Regardless of charcoal yield rate, the greater the product volume is, the smaller is the CO_2 emission per 1kg of waste wood. However scenario 1・3 of Figure 8 indicates, excessively small waste wood transaction (t/month) extremely increased CO_2 emissions per Ikg of waste wood . It is important to maintain it comparable to it processing power. For higher rate of biochar yield, the CO_2 emission per 1kg dry charcoal decreased. For all scenarios, amount of CO_2 emissions derived from carbonization process are greater than those derived from cutting process.

Scenario 1・3 has small difference between CO_2 emissions derived from carbonizing process and cutting process. It is interpreted as the result of the single Repeat rolling furnace operating efficiently. In addition, C02 emissions derived from cutting step were smaller than those from carbonization process, and continuous operation results show less CO_2 emissions. However, the long run introduce other problems such as increased labor costs, and whether continuous operation is advisable or not remains to be solved. About the carbon sink, as shown in Figure 10, volume of fixed C02 per 1kg dry charcoal stays high for the processing amount of 42t/month or above.

In regard to the carbon sequestration method in the earth or other places (carbon sink) evaluation of carbonization process was performed as below. The sequestration effect of using biochar as soil improvement material etc. without combustion was defined by following formula with the consideration of CO_2 emission in biochar production.

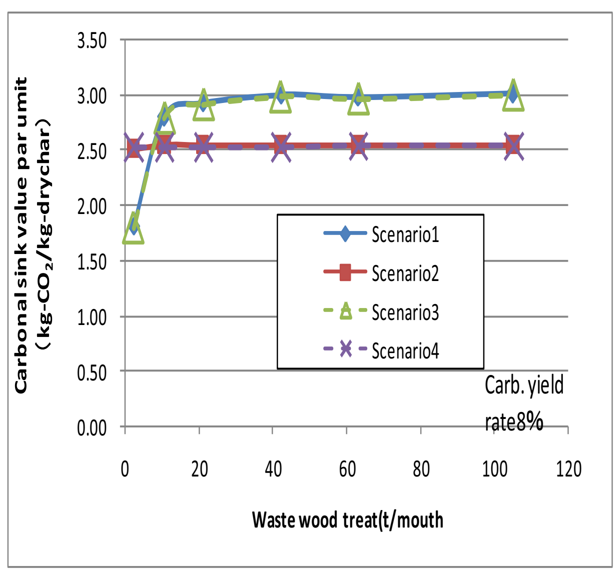


Fig.9 Each scenario carbon sink value per biochar(carb.yield rate 8 %)

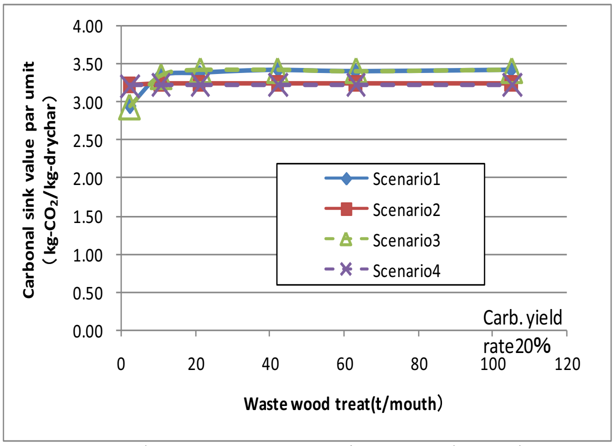


Fig. 10 Each scenario carbon sink value per biochar (carb. yield rate 20 %)

$$C_S = C_C - C_E \qquad (1)$$

Note C_S:Carbon sequestration(kg−CO_2)

C_C:CO_2 equivalence of biochar(kg−CO_2)

C_E:CO_2 emission by carbonization(kg−CO_2)

7 CONCLUSIONS

For the carbonization process of construction waste wood, the CO_2 emission derived from electric power and fuels were studied in relation to the carbon sink. We compared 4 different scenarios. This study revealed the following results.

1) The carbon sink effect was higher for Repeat rolling furnace in scenario 1・3 than Vertical grating furnace in scenario 2・4 . The throughput of Vertical grating furnace is 1/15 of the Repeat rolling furnace. In order to operate the Vertical grating furnace for the same volume as the Repeat rolling furnace, more sets of the former furnace are necessary causing higher CO_2 emissions. As for the rate of charcoal yields, the case of charcoal yield rate 20 % showed 1.6 times better carbon sink effects than the 8 % case.

2) The exhaust CO_2 emission of cutting process were nearly equal. Changing the type of cutting machine does not significantly influence the amount of CO_2 emission.

3) The CO_2 converted value of biochar (CO_2 fixed value) was about 3 times more than CO_2 emission by the carbonization. Therefore, carbon sink effect was verified.

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In-use Stock Analysis of Telecom Infrastructure in Japan

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Abstract

Information and communications technology (ICT) has penetrated in our lives, and telecom infrastructure has spread throughout the world. Many kinds of materials are stored in many ICT facilities, and material flow/stock analysis can provide a picture of future waste management. In this study, the in-use stock of the telecom infrastructure was estimated by the bottom-up method. As a case study, the in-use stock of major telecom facilities was estimated. It was found that the main material was concrete. Then the in-use stock of telecom poles was estimated by using nighttime light image data. A total of 3.4 million tons of materials were found to be in stock with geographical information.

Keywords:

material stock, telecom infrastructure, bottom-up analysis, nighttime light image

1 INTRODUCTION

The explosive penetration and rapid innovation of ICT have been accompanied by an increase in the demand for materials, and consequently by an increase in processing, deployment and waste treatment activities. This has raised concern about natural resource depletion and the waste treatment activity, known as the e-waste problem. An understanding of material stock is needed if we are to devise the most appropriate collection system and then accelerate the recycling of resources.

Material Flow Analysis (MFA) has been used to analyze the social material stock. Stock estimation methods can be classified roughly into top-down and bottom-up methods. The top-down method reveals social stock using statistical data such as input-output tables. The bottom-up method involves estimating the amounts of material included in products by multiplying the number of end products by their compositions. Recently, we developed an novel method for estimating in-use stock of materials by using nighttime light image data provided by satellites [1]. The radiance of nighttime light has a strong correlation with human activities such as energy consumption and GDP [2, 3]. It has been revealed that the nighttime light and the in-use stock of copper are closely correlated. The merit of this method is that the data covers the entire world, and geographical information can be added. The telecom poles are used to accommodate street lamps and so a close correlation could be expected.

In this study, the bottom-up method was used to estimate the in-use stock in the telecom infrastructure. In addition, the method using nighttime light was employed to obtain geographic information in a concrete pole case study.

2 METHOD

2.1 Bottom-up method

Bottom-up analysis was achieved with a model of the wired telecom infrastructure, which includes telecom poles, cables and conduit lines. The number of telecom facilities was obtained from published data for 2008 [4].

Data regarding the composition of these communication telecom facilities were obtained from our suppliers. The telecom poles consist of concrete poles, steel poles and wooden poles. The ratios of each kind of pole were assumed to be the same as those in Atsugi in Kanagawa prefecture.

2.2 Estimation of in-use stock by using nighttime light image data

The in-use stock of telecom poles was examined by nighttime light. The numbers of telecom poles were estimated from a formula for approximating the number of poles and the nighttime light radiance for each prefecture. Then the stock of each material was estimated by multiplying the estimated number and the composition.

The nighttime light images were processed at the National Geophysical Data Center of the National Ocean and Atmosphere Administration using Defense Meteorological Satellite Program / Operational Linescan System data collected by the US Air Force Weather Agency. The latest 2006 nighttime data were used in this study. The numbers of telecom poles in nine prefectures were available as public data. The ratios of concrete poles, steel poles and

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wooden poles were assumed to be the same in all prefectures.

3 RESULTS AND DISCUSSION

3.1 In-use stock of telecom infrastructure

The in-use stocks of the wired telecom infrastructure, which were estimated by the bottom-up method, are shown in Fig. 1. The heaviest material was the concrete found in concrete poles followed by the iron in metal conduit lines, the plastic in plastic conduit lines and the copper in metal cables.

The iron and plastic in conduit lines was unexpectedly heavy because there is 620,000 km of conduit line in Japan, which is about 20 times longer than the Japanese coastline. Conduit lines are buried underground and so the huge stock is not obvious.

There are many types of telecom cables. This study used the compositions of representative cables but a more detailed estimation is needed.

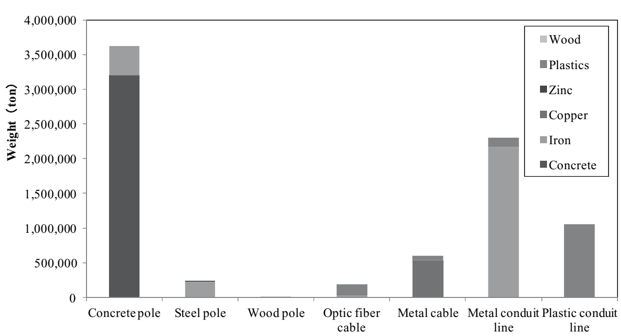

Fig. 1 : Material in-use stock in wired telecom networks

3.2 In-use stock of telecom pole with geographic information

The relationship between the net nighttime light radiance and the number of telecom poles in nine prefectures was studied. The correlation value was 0.49 when a straight-line approximation was assumed. The statistical and estimated numbers of poles in Tokyo were 340 thousand units and 360 thousand units, respectively, and a comparable correspondence was obtained for other prefectures.

The estimated material stock of telecom poles are shown in Fig. 2. A total of 3.4 million tons of materials were found to be in stock with geographical information. A lot of materials are stocked in Hokkaido, Aichi and Osaka. Additional data are needed for a more precise analysis and validation. Telecom poles are heavy and a shorter transportation distance is preferable. This estimation could be helpful when planning systematic recycling of end-of-life telecom poles.

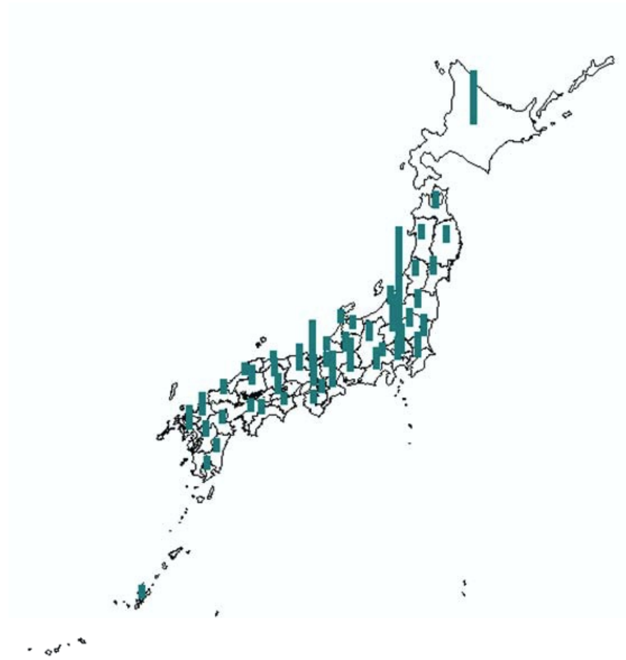

Fig. 2: Estimated material stock of telecom poles

4 SUMMARY

The in-use material stock of the telecom infrastructure was estimated with the bottom-up method. A rough estimation was obtained, and the heaviest material stock was the concrete in poles. The nighttime light images could add geographical information to the in-use material stock analysis. The relationship between the radiance of nighttime light and telecom poles is not particularly close but it can be used for a primary estimation. This method can be applied to other telecom facilities and other types of in-use stock analysis.

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Involvement of France Telecom Group for a Sustainable Future

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Abstract

The France Telecom Group has made the commitment to pursue its efforts concerning the impact of its business activities on the environment. Its goal by 2020 is to reduce greenhouse gas emissions by 20% and energy consumption by 15% compared to 2006 levels. In addition, 25% of FT Group electricity used in Africa should be derived from solar energy by 2015. Telecommunication networks account for over 60% of the Group's total energy consumption. Reducing the consumption of these networks is all the more a big challenge as the usage and traffic volumes continue to rise. Four action plans have been launched. The first action is roll out optimized ventilation and variable speed ventilation systems in telecom centres in Europe and emerging countries. This cuts down the need for air conditioning by 80%. The second action is to expand the climatic temperature range in technical rooms, which translates in a reduction of air conditioning consumption from 10 to 50%. The third action is to carry on and widen deployment of photovoltaic installations while reducing the energy use of Radio Base Stations. The last action is SWAP of telecom equipment. This is to prevent potential ecological risks associated with the raw materials necessary to the business activities upstream and downstream, to organize the sorting of the group's waste and to prepare its processing or recycling. In addition to those measures concerning the group itself, France Telecom aims at helping its customers in being eco-citizens. The paper will deals with the main actions of France Telecom related first, to the appropriate information on carbon footprint measurement or eco-labeling for example and secondly, to the way for increasing the range of eco-designed products and services and putting intelligent solutions on the market support and encourage the eco-friendliness of France Telecom's customers on a daily basis.

Keywords: policy, GHG reduction, free cooling, solar BTS, eco-friendly, eco-citizens, SWAP of telecom equipment

1 INTRODUCTION

For the past 15 years, France Telecom-Orange has worked hard to include sustainable development and Corporate Social Responsibility principles in its corporate strategy. In the digital society, the Group is shouldering its responsabilities to nurture social ties and ensure the greatest possible number of people benefit from the new technologies. Because CSR is important when it comes to creating value both for stakeholders and the Group, Orange has built the question into the heart of its Conquests 2015 strategic plan. The central role confirms the Group's ambition to become a benchmark CSR player in the telecoms sector.

2 ENERGY, CLIMATE WARMING AND TELECOMMUNICATIONS

The Group is finding innovative solutions for a greener world. In this respect, its efforts are being towards minimising its energy footprint, managing the waste it generates, and reducing the impact of its products by promoting their eco-design.

Developping technological solutions enabling each and every one of us to live and act as an eco-citizen is also a strong line of development for the Group. France Telecom-Orange has adopted a proactive approach to managing risks and their potential impact, helping to preserve the environment and maintaining the trust of its stakeholders.

The Group is also deeply involved in Standardization Bodies dealing with ICTs and climate change in particular within ITU-T/SG5.

2.1 Reducing the Group's carbon footprint

Faced with the issue of climate change, France Telecom-Orange has made a proactive commitment: to reduce its greenhouse gas emissions by 20% and its energy consumption by 15% against 2006 levels, both by 2020: a real challenge given the current growth in uses and the continuing increase in data traffic.

The Group is also developing innovative solutions to enable its customers to measure and reduce their own carbon footprint.

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At last, optimizing waste management is another environmental priority for France Telecom-Orange.

2.2 Reducing the impact of products and services

Besides limiting its direct impact, France Telecom-Orange endeavours to reduce the environmental impact of the products and services offered to its customers throughout their lifecycle.

2.3 Contributing to eco-citizen progress

In the face of environmental challenges, information and communication technologies offer unique potential for progress.
This is why France Telecom-Orange is continually innovating to develop technological solutions giving everyone the means to live and act as an eco-citizen.

3 LOWER ENERGY CONSUMPTION BY NETWORKS

The networks and information systems, including data processing centres, account for over 66% of the Group's total energy consumption.

At the beginning of 2009, France Telecom-Orange committed to a vast energy action plan prioritizing:

- optimizing air-conditioning;
- optimizing data processing centres;
- increasing the use of renewable energy;
- improving monitoring of energy consumption.

France Telecom made its commitment official by the signing in 2010 of two codes of conduct to reduce its energy consumption in Data Centres and for Broadband.

In 2010, the plan was deployed in 11 new countries (Egypt, Jordan, Central African Republic, Austria, Madagascar, Kenya, Dominican Republic, Mali, Republic of Côte d'Ivoire, Niger and Armenia), in addition to the 10 countries that adopted the plan in 2009 (France, United Kingdom, Poland, Spain, Slovakia, Romania, Switzerland, Belgium, Senegal and Guinea).

The Group hopes to save 170 GWh by 2012 as a result of this project. To date, an estimate covering seven countries (including France, Spain and Poland, which account for 86% of the savings reported) shows that over 145 GWh have already been saved.

optimized ventilation on over 9,700 sites

Optimizing air-conditioning is the most effective lever for reducing energy consumption by networks. For example, optimized ventilation helps to reduce the energy consumption of the air-conditioning system by up to 80% compared with a classic system whilst at the same time eliminating refrigerants, which are harmful to the environment. This system received the Trophy for clean and economic technologies awarded by Ademe and the magazine Industries et Technologies in 2007.

more efficient data centres

Data centres (computer centres housing IT servers) account for 20% of the total energy consumption of the Group's networks and information system.

The "Green data centres" project in progress since 2007 helps to reduce the energy consumption of data centres by four types of action:

- improving the technical environment (choice of more efficient air-conditioning and electricity supplies, optimization of air circulation);
- replacing the oldest servers with servers that have up to four times the processing capacity, which will enable us to reduce their number;
- rationalizing information systems by limiting the number of applications in use to a minimum and measuring the power consumed for each of them by each user;
- consolidating and virtualizing servers, carried out as part of the Ecocenter programme, enables several applications to be concentrated on one physical server.

By 2010, over 15,000 virtualized servers were deployed in the Group, more than 13,000 of which were in France. This means that the number of physical servers had been reduced by 90% since 2007 and nearly 60 GWh of electricity had been saved, thereby avoiding almost 2,500 tons of CO2 emissions. By the end of 2010, the Ecocenter virtualization programme had been deployed in a number of countries including France, Poland, Spain, Belgium, Romania, Switzerland and Slovakia.

over 1,500 solar stations installed

For over 30 years, France Telecom-Orange has been involved in research into the use of renewable energies in its business. The fi rst photovoltaic facility was set up in New Caledonia in 1975.

Today, the Group is focusing particularly on powering base stations (antenna repeaters) with solar energy in Africa and southern European countries.

By the end of 2010, 1,554 solar stations had been installed, including 922 radio stations (BTS) in 14 African and Middle Eastern countries, together with the Dominican Republic and Armenia. 922 solar radio sites were in service by end 2010. Annual production of solar energy of all sites is estimated to be 8.6 GWh, corresponding to the equivalent of 45,000 tons of CO2 emissions and 16.8 million litres of fuel being saved.

An indicator will be introduced in 2011 to monitor the deployment of the renewable energy programme in

Africa-Middle East-Asia zone networks (now based mainly on solar energy) and all the technical base stations.

precise monitoring of energy consumption

In order to manage its energy action plans effectively, the Group has defi ned 12 key energy performance indicators that are checked quarterly throughout the Group.

In 2009, meters were installed on some large technical sites in France, Spain and Poland to improve the precision of energy consumption measurements.

In 2010, two studies were carried out to model changes in consumption:

· a study on changes in energy consumption in the French mobile network up to 2020;

· the development of a simulation tool to assess the effects of the energy action plan on electricity consumption in the light of the estimated changes in consumption up to 2015, and according to different scenarios.

An assessment of the Group's carbon footprint was undertaken using the Bilan Carbone®method .

Additional monitoring of goals per customer will be introduced in 2011

3 DEVELOPING ECO-DESIGN PROCESSES

As early as 2007, as part of a strategic partnership with Sagem, Orange embarked on an eco-design process for Liveboxes distributed under its own brand.

The lifecycle analyses performed orientated the work on reducing environmental impact towards specifi c areas: energy consumption, use of recycled materials, repairability and recyclability, and packaging.

The Livebox 2 launched on the French and Spanish markets at the end of 2009 benefi ted from the results of these lifecycle analyses, which showed the predominance of electricity consumption in the usage phase in the global environmental assessment. This new version was therefore equipped with a WiFi switch so that users could switch the WiFi signal on and off at their convenience, whilst still enjoying the other Livebox services. This WiFi button and the stop/go switch can decrease electricity consumption by up to 30%.

On the basis of these initial successes, Orange rolled out this process in 2009 by:

· incorporating eco-design in its product development process;

· creating a team of eco-design experts and progressively providing training in eco-designfor all those involved in the product innovation chain;

· launching a research project on the ecodesign of services and software applications.

In 2010, the France Telecom Group carried out a number of new lifecycle analyses, amongst them a videoconferencing service and an e-Music service. The Group continues to study the lifecycle analyses carried out in the information technologies sector and actively contributes to standardization bodies such as ITU-T and ETSI in order to develop a common methodology for assessing the environmental impact of ICTs..

Specific tools have been created to support the process:

· The eco-design guide: a manual to popularize and raise awareness of eco-design, distributed to Technocentre Project Managers;

· A lifecycle analysis library that is continually being enriched, helping to assess the environmental impact of products and identify avenues for improvement from the design phase onwards.

· An eco-design training module for Product Managers, introduced in France in 2010 and shortly to be translated and disseminated in other countries.

The Group is also participating in work undertaken within the GSMA and ITU-T to design a common universal charger for mobile phones, that will prevent the need to change chargers with each change of mobile and may lead to the separate distribution of handsets and chargers. The recent adoption of the ITU-T Recommendation L.1000 *will enable the deployment of new products that are energy efficient and reduce the carbon footprint of the ICT sector.*Such solution will make it possible for the entire sector to eliminate up to 51,000 tons of electronic waste resulting from the accumulation of different chargers, whilst also improving the service delivered to the customer.

4 PROMOTING ECO-RESPONSIBLE USES

In addition to eco-designing products and services, Orange encourages its customers to help preserve the environment in both their personal and business usage. To do this, the Group has produced clear information resources about the environmental performance of the products and services it offers.

a pioneering environmental labelling programme

In France, in 2008, Orange was the first European operator to introduce an assessment of, and publicly display, the environmental performance of the telephone handsets it distributes.

This innovative initiative, developed in partnership with an expert lifecycle analysis firm and the WWF, meets a twofold objective:

· to raise the customer's awareness of the environmental impact of the handset they wish to buy and, orientate their choice – if they so wish – towards the greenest handset in the desired category;

· to encourage manufacturers to produce more eco-friendly handsets.

The environmental labelling system developed by Orange analyses environmental impact according to fi ve criteria graded from 1 to 5

· CO2

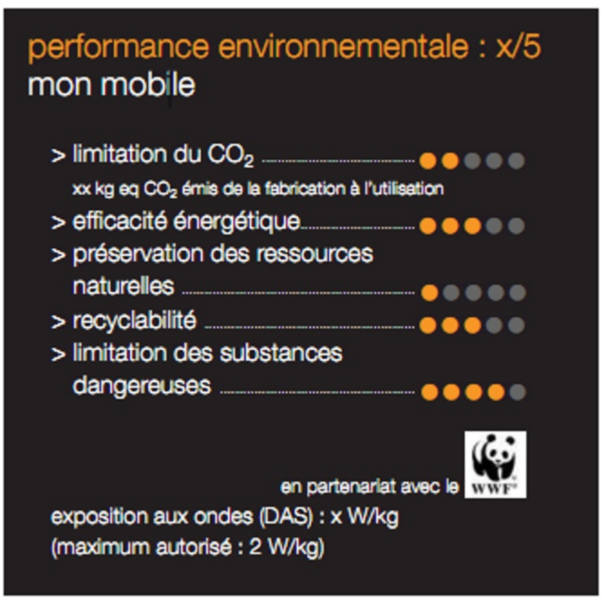
produced (quantity of greenhouse gases emitted during the main stages of a product's life: manufacture, transport and use);

· energy effi ciency (energy consumption during use of the product and devices enabling it to be reduced);

· the preservation of natural resources refl ects efforts made to limit the proportion of materials that are non-renewable or sensitive from an environmental, economic or societal point of view;

· recyclability (contribution of handset, its packaging and its documentation to limiting production of waste);

· eco-responsible design (effort made by a supplier to design its product to limit the use of potentially dangerous substances, ensure good traceability of metals and optimize the device's electricity consumption).



Almost all of Orange's suppliers of mobile and fixed handsets have now signed up to this initiative, which has been deployed in France, Spain and Romania and will be extended to all European countries by the end of 2010.

Most of Orange's suppliers have now signed up to this initiative, which is being progressively extended across the Group, with the aim of covering all European countries by the end of 2011.

In France, 92% of mobile handsets and 100% of DECT telephones distributed by Orange, together with over 80% of business handsets, have the eco-label.

In Spain, all telephones distributed by Orange with the exception of iPhones have eco-labels that may be consulted on the website.

Eco-labelling of mobile phones was launched in Romania in December 2010.

carbon calculators for business

Orange Business Services is developing very specific calculation tools to assess the potential greenhouse gas savings linked to remote working solutions and to enable companies to incorporate the carbon impact more easily in their investment decisions.

Lifecycle analyses are carried out by Orange Labs teams with the assistance of a specialist Swiss research company to measure the actual impact of solutions. They have already delivered very precise results on the Business Everywhere, Telepresence, Forfait Informatique, Flexible Computing and Business VPN solutions. This initiative is to be extended progressively to all "Green IT" solutions.

In 2010, on the basis of analyses performed, two new CO2

savings calculators were made available to Business customers:

· for the Telepresence solution: http://www.orange-business.com/content/co2/Telepresence/fr/Orange_TelePresence_vertical/Orange_TelePresence_vertical.html;

· for the Business Everywhere solution:

http://www.orange-business.com/content/co2/Teleworking/fr/Orange_Teleworking_vertical/Orange_Teleworking_vertical.html.

A tool for the Flexible Computing offering will come online in 2011.

an ongoing programme to raise customer awareness

Most countries regularly organize awarenessraising campaigns to encourage customers to adopt eco-citizen behaviour: opting for an e-bill, switching devices off when not in use, returning old equipment for recycling or keeping it for longer – these are all simple ways of helping to preserve the environment.

In France, Orange has set up a dedicated information website to encourage its customers to adopt six green habits: www.agi r- ref lexes ver t s .orange. f r. The Orange environment channel (http://actu.orange.fr/environnement/) also broadcasts environmental news with practical information so that viewers can take action on a daily basis.

In a number of European countries, specific schemes are also deployed to encourage customers to return their old mobile phones.

5 SUMMARY

Eco-citizenship is a core value in France Telecom-Orange's CSR strategy.

Initiated in 1996 with the signing of the ETNO Environmental Charter, the Group's eco-citizen commitment focuses on three complementary areas:

· setting an example as a company by reducing the environmental impact of the company's activities through an ongoing process of improving the performance of its various entities, focusing fi rst and foremost on combating climate change and optimizing waste management;

· reducing the impact of products on customers by developing eco-design procedures and encouraging and supporting customers to move towards eco-responsible uses;

· developing innovative products and services that contribute to the protection of the environment (and especially to the reduction of greenhouse gas emissions) and placing them at the service of society

The Group is also contributing to the standardization effort related to these areas .

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A case study analysis of the CO_2 emission reduction potentiality of the wireless harness within ICT equipment

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Abstract

We analyzed the change in the amount of CO_2 emitted when employing wireless technology based on life cycle inventory analysis. The ICT equipment targeted for the analysis was an automatic teller machine because it contains as many as 200 internal sensors. CO_2 emissions would decrease by 73% if a wireless system were used between the control boards and a main board as well as from the sensors to the control board. The results indicate that a wireless system can contribute to reducing the CO_2 emissions of ICT equipment.

Keywords:

ICT equipment, CO_2 emission, wireless technology, LCI

1 INTRODUCTION

ICT equipment including sensors incorporates a large number of cables. Some ICT equipment contains several kilometers of cable. Such ICT equipment requires a complicated wiring structure, and this makes the assembly process and maintenance costs high. Wireless technology is expected to provide a solution to the problem of reducing both the lifetime CO_2 emissions and the manufacturing and maintenance costs of ICT equipment with embedded sensors. There are several challenges we had to tackle during the implementation of wireless technology including data transport reliability, communication security and point-to-multi point packet transmission, which must also be similar to that of a wired system, and the power consumption of wireless systems must be minimized.

Advanced Telecommunications Research Institute International, Oki Electric Industry Co. Ltd., and Nippon Telegraph and Telephone Corporation have been collaboratively developing a wireless system for use in ICT equipment as part of the "Research and Development Project of Wireless Communication inside ICT Equipment" supported by the "Promotion Program for Reducing Global Environmental Load Through ICT Innovation (PREDICT)" of the Japanese Ministry of Internal Affairs and Communications[1][2]. Fig. 1 shows the concept of the wireless system inside ICT equipment.

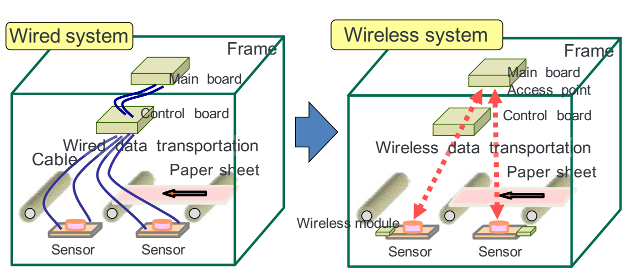

Fig.1: Concept of wireless system inside ICT equipment

This paper discusses the change in the amount of CO_2 emitted when employing wireless technology based on life cycle inventory analysis.

2 STUDY APPROACH

The ICT equipment targeted for the analysis was electronic equipment with functions allowing cash to be dispensed and deposited, because it contains as many as 200 internal sensors, and such machines are installed throughout the country.

The study compared the use of wireless and wired systems with ICT equipment. The comparison consisted of a quantitative assessment, similar to a life cycle inventory. Three systems were compared:

(1) An ICT equipment system employing wired communication.

(2) An ICT equipment system employing wireless technology between the sensors and control boards.

(3) An ICT equipment system employing wireless technology between the sensors and control boards, and between the control boards and a main board.

We assumed that the equipment would have a useful lifetime of 7 years and be used 12 hours per day. We used LCI data of a printed circuit board to estimate the CO_2 emitted when manufacturing wireless modules adjusted to

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the target size because the wireless module is under development [3]. Owing to data availability and time limitations, the scope of the research was limited in the following ways:

・The case study assessed the reduction in CO_2 emissions achieved by eliminating the need to manufacture cables and connectors, to connect a wire harness during the assembly process and to maintain the wire harness, and the increased CO_2 emissions caused by both the manufacture and power consumption of wireless modules.

・The comparison of the wireless and wired systems was limited to CO_2 emissions. Other parameters, such as water consumption or waste generation, were not included.

・ The study requires a number of estimates and assumptions. This means that the results should be interpreted as indicative rather than a precise measure of CO_2 emissions.

This study set out to evaluate the CO_2 reduction effect of wireless technology employed inside the ICT equipment. It was not meant to assess the overall life cycle impacts of the targeted ICT equipment or other ICT equipment.

3 RESULTS AND DISCUSSION

Fig. 2 shows the calculated ratio of CO_2 emission related to wired and wireless systems based on (1), (2) and (3). The CO_2 emission caused when manufacturing cables and connectors, and wireless modules exceeded 80%, 90% and 95% in systems (1) (2) and (3) respectively. This result indicates that the manufacture of cables and connectors, and wireless modules is more important than the wiring harness, the use of wireless modules and maintenance. Based on our analysis, we focused on the manufacture of cables and connectors, and wireless modules.

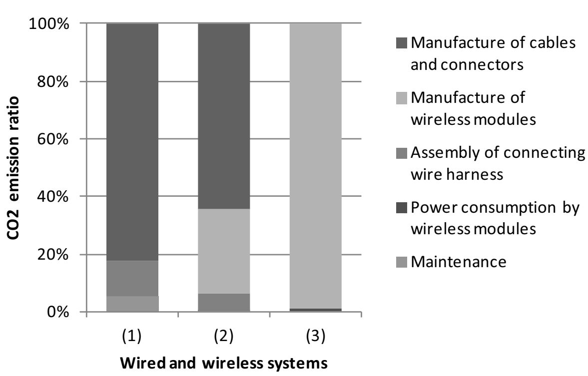

Fig.2: CO_2 emission ratio related to wired and wireless systems (1), (2) and (3)

Table 1: The change in CO_2 emission achieved by using the wireless system in the ICT equipment

	% change of CO_2 emission
{(2)-(1)}/(1)	+45%
{(3)-(1)}/(1)	-73%

Table 1 shows the CO_2 emission reduction ratio achieved by subtracting the CO_2 emissions produced when manufacturing the cables and connectors from the CO_2 emissions produced when manufacturing the wireless modules, divided by the CO_2 emissions of the manufactured cables and connectors. There was an estimated 73% reduction in CO_2 emissions when the wireless system was employed between the control boards and a main board as well as from the sensors to the control board. Although the study results are fairly case specific, they point to the fact that a wireless system can contribute to reducing the CO_2 emissions of ICT equipment. On the other hand, CO_2 emissions would increase by 45% when using a wireless system from the sensors to the control board. This result does not indicate that the wireless system had a negative effect as regards CO_2 emissions in this case because this comparison was limited to the manufacture of cables and connectors, and wireless modules as described above. The results also suggest that reducing CO_2 emissions during the manufacture of wireless modules, such as by downsizing the parts or minimizing their number, would be effective when employing a wireless system.

In a further study, we aim to enlarge the target ICT equipment to discover enhanced applications for this wireless technology.

4 CONCLUSIONS

The approach described in this study is intended to support the process of evaluating the CO_2 reduction effect of a wireless system. We found that wireless technology can contribute to a reduction in the CO_2 emitted by ICT equipment. However, the contribution that wireless technology can make will be limited by the component specifications and operating conditions of ICT equipment.

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Green ICT toward Low Carbon Society

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Abstract
Information and communications technology (ICT) itself produces CO2 emissions due to consumption of electrical power to operate equipment and systems. On the other hand, ICT usage can contribute to a reduction in CO2 emissions due to a marked improvement in the efficiency of production, consumption and business, also that of traffic alternatives, and a reduction in traffic volume. This is because that ICT is considered to be the first technology that has increased benefit while decreasing proportional consumption of resources and energy. ICT exploitation can readily contribute to solving the climate change issue. It is thus important to further promote shifting to an ICT-oriented society. This paper describes Green research and development activities for reducing the environmental impact of society by reducing the impact of ICT installations in telecommunication centers, datacenters, and customers' offices and homes (Green of ICT) and by reducing the impact of society as a whole by providing various kinds of ICT services (Green by ICT).
Keywords:
Green of /by ICT, CO2 emissions, LCA

1 INTRODUCTION

ICT contributes to tackling global warming issues. ICTs produce CO2 emissions due to consumption of electrical power to operate equipment and systems. On the other hand, ICT usage can contribute to a reduction in CO2 emissions. By using ICT, the movement of people and products can be reduced, the energy efficiency can be improved, and the efficiency of production and consumption can also be improved. This paper overviews of Green ICT toward low carbon society and NTT's current R&D efforts to reduce the environmental impact of society by leveraging ICT with cutting edge technology[1].

2 ICT & CLIMATE CHANGE

The relationship between economic growth (GDP) and environmental impact (CO2 emissions) is shown in Fig.1. The agricultural and industrial revolutions sped up economic growth, but the ICT revolution has enhance economic growth without increasing environmental impact, and has actually shown that it can reduce impact instead. Dr. Yoshio Tsukio, an emeritus professor of Tokyo University, has remarked about this: "Of all the technologies that mankind has obtained to this point, ICT is the first one that has increased benefit while decreasing proportional consumption of resources and energy."
Figure 2 shows the world distribution of CO2 emissions and the estimated CO2 reduction effect by ICT. According to GeSI SMART2020 [2], the use of smart grids, smart construction, smart distribution and smart motors, etc., will lead to a total global reduction of 7.8 billion tons (15% of the current world total) by 2020. We believe that further use of ICT will help to achieve a 50% reduction in CO2 emissions by 2050.

Ministry of Internal Affairs and Communications (MIC) also estimated the ICT effect on the CO2 reduction in Japan [3]. Regarding Green of ICT, until 2020, the ICT

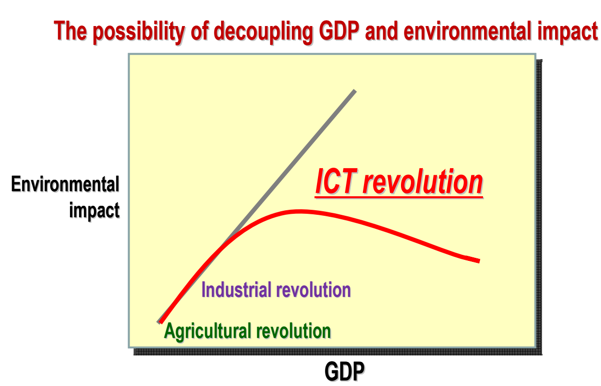

Figure 1: Relationship between GDP and environmental impact

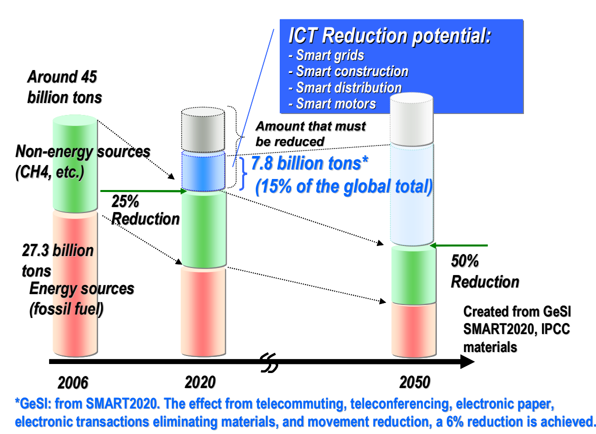

Figure 2: CO2 reduction potential by ICT

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power consumption will be suppressed and the CO2 emission will be reduced by 30 million tons. On the other hand, regarding green by ICT, ICT can potentially reduce CO2 emissions by up to 155 million tons in 2020. Eventually, 125 million tons of CO2 will be reduced in total. This amount is equivalent to around a 10% reduction in total emissions relative to 1990 levels in Japan. Based on these forecasts, we can say that ICT is the most promising technology to solve the climate change issue.

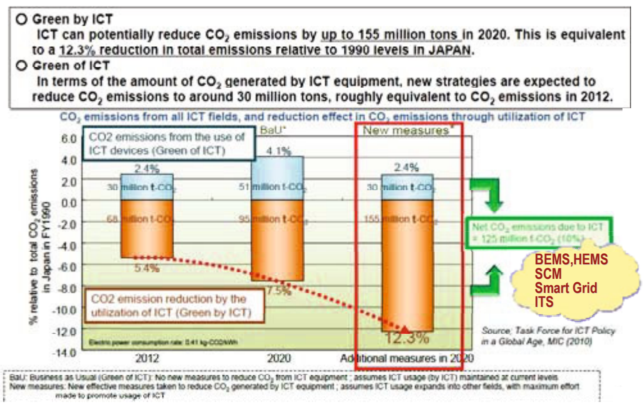

Figure 3: MIC's estimation of reduction in CO2 emission by utilizing ICT in Japan

3 NTT'S GREEN VISION

The NTT Group has endeavored to protect the environment through the three priority activities of mitigating global warming, reducing waste, and reducing paper consumption. In November 2010, we added the conservation of biodiversity to these priorities, and drew up THE GREEN VISION 2020 [4]. In THE GREEN VISION 2020, the NTT Group proposes the three approaches of "Green of ICT", "Green by ICT", and "Green with Team NTT". "Green of ICT" refers to efforts to reduce the environmental impacts of our own business activities. "Green by ICT" refers to our efforts to reduce CO2 emissions across society through providing ICT services. "Green with Team NTT" refers to efforts by group employees and their families to work with local communities to help protect the environment.

Figure 4: NTT's Green Vision

4 NTT'S R&D TOWARDS REDUCING ENVIRONMENTAL IMPACT

4.1 General appearance

Figure 5 shows the broad range of R&D themes of NTT relating to green ICT. The fastest-growing and arguably most attractive segment in energy saving, energy efficiency, and alternative energy lies in software, hardware, network architecture, and networking equipment. This is the heart of green ICT. Specific technologies include next-generation networks (NGN), network architectures, and smart grids; electrical generation, electric supply systems, air conditioning, access technology, cloud computing, and promising new energy-saving equipment such as optical packet routers, and so on.

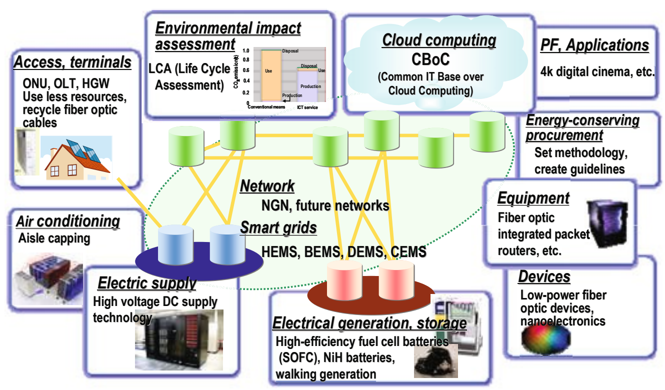

Figure 5: NTT's R&D themes relating to green ICT

4.2 Green of ICT

We NTT Group offer a full range of network services. Until fairly recently, each service was implemented as a separate network to optimize efficiency and for security reasons. This meant that multiple network facilities were constructed, which of course greatly increased power consumption. NTT Group has been transitioning toward network integration where multiple services are supported on the same network – NGN. Network integration permits more efficient use of network facilities and reduces overall power consumption. NTT also rolled out Gigabit Ethernet Passive Optical Network (GE-PON), a faster and less expensive optical access system that accommodates faster delivery of Internet services and lower charges to subscribers. By enabling multiple subscribes to share the same line, the system is more energy efficient and cost effective than previous schemes. In addition to the power savings achieved by modifying the ONU itself, we are also working on functional capabilities that will dramatically improve the energy efficiency of next-generation access network systems; namely, a sleep function that cuts power to unneeded parts of the ONU when there is no traffic, and an adaptive link-rate function that adjusts the link rate between the OLT and ONU depending on traffic volume.

An overview of R&D to reduce CO2 emissions is shown in Fig 6. We are working on more energy-efficient telecom buildings by conserving energy, through high-voltage DC (HVDC) power supplies and air conditioning, while at the same time, creating new energy sources, such as fuel cells and high-efficiency solar cells. In recent years, we have seen a dramatic increase in power consumption per equipment rack, along with thicker cables to supply the greater current required. Deployment of the new HVDC system in data centers thus promises to reverse these trends by reducing current and CO2 emissions. We are also seeking to improve the energy efficiency of households, by connecting residential DC power supplies to the smart grid, based on dispersed power generation and storage batteries.

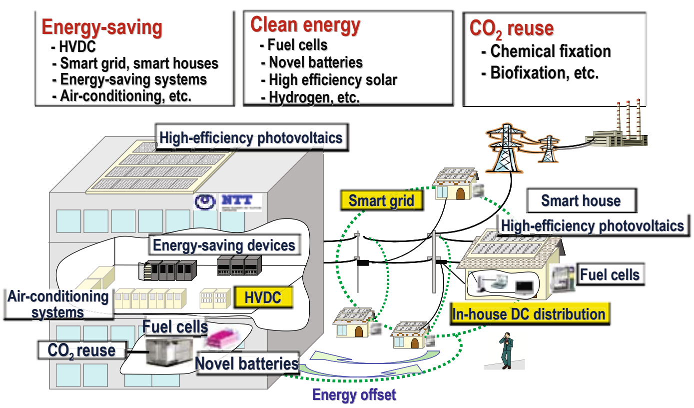

Figure 6: Overview of R&D to reduce CO2 emissions

As for the facility resource savings, some objectives of NTT's service life prolonging and repair technology initiatives are shown in Fig 7 In order to provide telecommunications services, NTT Group owns substantial telecom equipment and facilities including everything from telephone poles and vast stretches of communications cable to switching systems. These facilities must be periodically upgraded when they reach the end of their useful service life or as new services become available. When upgrading facilities, we must always consider how to minimize our environmental impact by reducing the use of new resources and by suppressing waste.

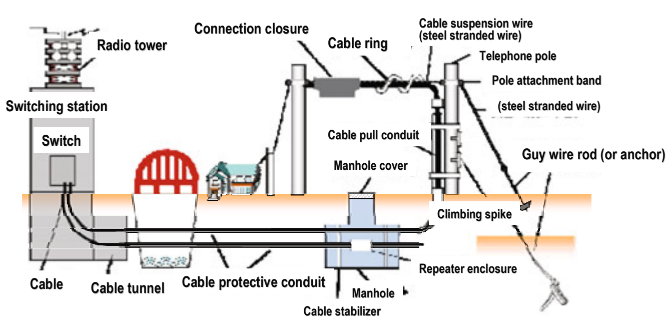

Figure 7: Telecommunication Infrastructure

4.3 Green by ICT

ICT has a beneficial effect on the environment in two basic ways: ICT itself can be engineered to reduce its impact on the environment (Green of ICT), and through the use of ICT, the environmental impact of society as a whole can be reduced (Green by ICT). We can expect that as the number of broadband users continues to grow, the electricity needed to power all the additional computers and network equipment—which all produce CO2 emissions—will also continue to grow, and this trend is likely to continue for the foreseeable future. This clearly constitutes a negative impact of ICT services on the environment. Yet at the same time, ICT services have certain beneficial effects on the environment: they can reduce the need for travel and can streamline distribution and manufacturing. The tradeoff—i.e., the balance of positive and negative factors—of the impacts of ICT on the environment are illustrated in Fig. 8.

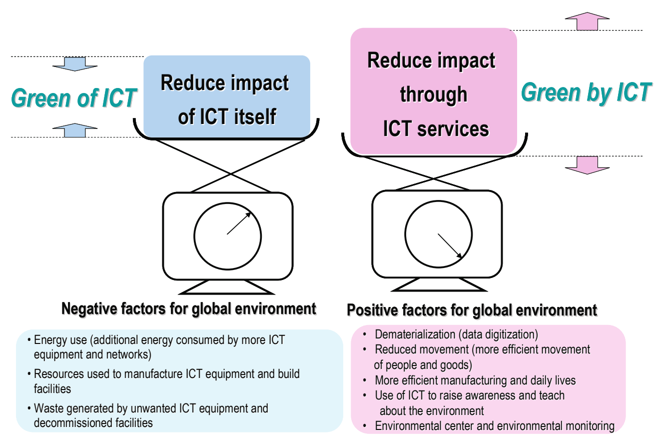

Figure 8: Effects of ICT on the environment

Assessing the relative impacts of these effects of ICT on the environment requires a method of quantitative accounting to measure the positive and negative factors. Life cycle assessment offers a procedure for quantitatively evaluating the environmental impact of products and services over their entire life from manufacturing and use until the product is finally retired and taken out of service, and this is the approach that we use to quantitatively assess the environmental load of ICT services including ICT equipment and networks. Generally, we model the way things were done in the old days before a particular ICT service was available and then compare the load of the old approach with that of the new ICT service. The way quantification is taken in the environmental impact assessment is shown in Fig.9.

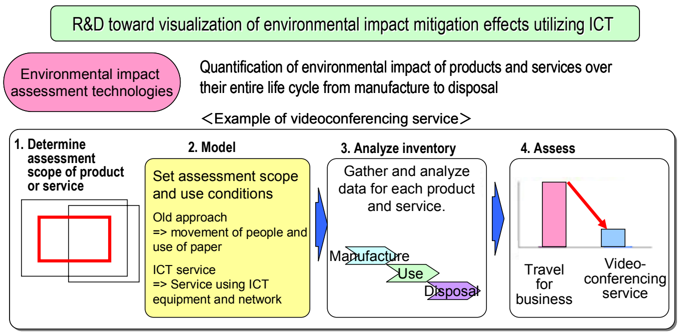

Figure 9: Environmental Impact Assessment Quantification

The environmental impact reduction effects with utilizing ICT are categorized as the eight effects of reduction :

(1) in materials consumption,
(2) reduction in electric and energy consumption,
(3) reduction in human movement,
(4) reduction in materials movement,
(5) efficiency in office space,
(6) reduction in materials storage space,
(7) work efficiency, and
(8) reduction in waste disposal.

Using the methodology, we can estimate CO2 emissions reduction in tele-conferencing with LCA in comparison with conventional means, or a trip to a conference. If 12 conferences are supposed to be held between Tokyo and Osaka a year, emissions will be reduced by 35% using ICT.

5 SUMMARY

This paper gave a brief overview of Green ICT toward low carbon society and introduced some important green R&D initiatives in NTT. Followings are the future challenges of R&D;

Regarding Green of ICT:

- Much Lower power consumption of ICT equipment,
- Creation of applicable clean energy in the ICT sector, and
- Waste recycling in the ICT sector,

Regarding Green by ICT:

- Increasing ICT services which could contribute in reducing energy consumption,
- Standardization of environment impact assessment methodology.

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Indium Recovery and Recycling from an LCD Panel

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Abstract

Environmental problem turns one of the most important issue in the world. Recently, more and more people concerned about environment and their health. Especially, waste management and resources recycling issues are important problems equal to global warming, disruption of ecosystem and other problems. The markets of electric appliances and electronics devices are highly developing, therefore wastes from those items are supposed to be rapidly increasing. Rapid rise of industrial production leads to growing demand of resources, so securing of resources is very important for manufacturer in the future. So there are strong needs to recover and recycling of resources from used products and waste from materials. Thanks for its advantages such as "flat screen", "lightweight", and "low power consumption", LCD panels are utilized in many final products such as LCD TV, mobile phone etc. And the production of final products with LCD are growing rapidly, too. Therefore, in the recycling technology of LCD panels, we should focus on how we collect the materials from LCD panel effectively. Especially, indium is very important. Because indium is a one of rare metal, and essential materials for transparent electrode of LCD panel. To avoid the shortages of indium for LCD production in near future, securing indium resources is important for LCD panel manufacturers. We are developing technologies that work to recover indium resources from LCD panels.

In particular, the simple and energy-saving ion exchange method is proving to be effective approach. We have constructed demonstration equipment that can process 240kg of waste LCD panels per day. We have achieved a recovery rate of 94%, using glasses discarded from LCD panel manufacturing plant.

Keywords:

Indium, LCD panels, rare metal, transparent electrode

1 INTRODUCTION

Liquid Crystal Display (hereinafter, LCD) panels are recognized as an environmentally friendly displays, because of its advantage of "low energy consumption" and "light weight" . And it has become widely used in various kinds of electronic products such as televisions, personal computers, monitors, cameras, cell phones, PDAs and game machines. The productions of LCD panels are highly increasing.

Recently people are more concerned about environmental problems.And in accordance with grows of production volume, LCD products is required to pay more attentions to safety, environmentally friendly design, and recyclability.

This situation requires establishment of the LCD panel recycling technology.

Especially, indium is focused. Because indium is rare metal and also it is essential material for transparent electrode of LCD.

Because the market of LCD panels is highly growing, it is very important for manufacturers to secure the indium resource. Therefore we have developed the technology which makes efficient use of indium, recovering indium from waste LCD panels.

2 THE AGENDA FOR INDIUM RECYCLING TECHNOLOGY

2.1 Indium resources in LCD panels

Indium tin oxide (hereinafter, ITO) is known as a transparent electrode material, and has the advantage of electrical properties, optical properties and process-ability.

Indium is utilized in various kinds of applications, such as LCD displays, solar cells and touch panels.

The demand for indium which is main component of ITO is growing, because ITO target materials for use in transparent electrode have become widely used.

We expect the demand for indium to keep increasing because of growth in the LCD TV production.

Fig. 1 shows a cross section of a TFT-LCD panel which is one of the LCD display types. The LCD panel is consist of the display element, and it is composed of polarizers, glass substrates, color filters, TFTs, transparent electrodes, alignment films, liquid crystals and seal materials. ITO is used in the transparent electrodes.

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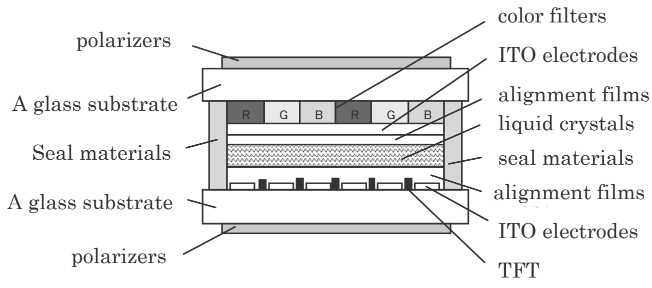


Fig. 1 The cross section of a TFT-LCD panel

Fig. 2 shows a material flow in an LCD plant. Indium used in LCD manufacturing.

In ITO target process, only 10% of indium are utilized, and the rest(90%) are unused and collected in the recycling system.

The residual parts are deposits on equipments and inclusions of LCD panels.

We have been already recycling deposits on equipments from 2005, but we did not find solutions for “Low cost” and “High efficient indium recovery technology” at that time.

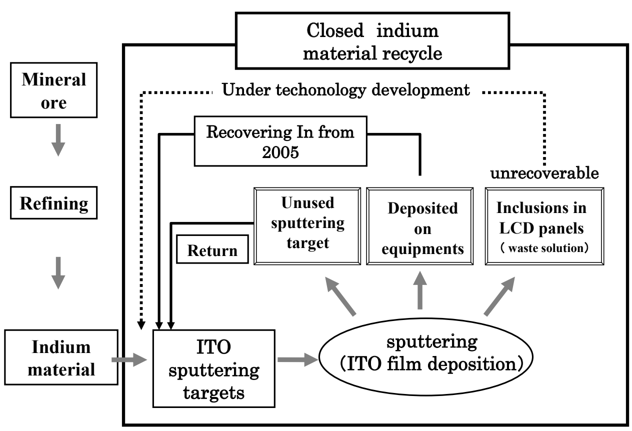


Fig. 2 The material flow in a LCD plant

2.2 Conventional Indium Recover and recycle technologies

Some conventional examples include dissolving an ITO sputtering target with hydrochloric acid and nitric acid, and then isolating and recovering the indium by removing impurities through a hydroxide method, a sulfide method, a cementation, solvent extraction or electro-winning. Indium that has been isolated and recovered by an above method is then refined by electrolytic refining method or similar methods.

However, the conventional methods require a large quantity of an alkaline agent in order to control the pH, when isolating and recovering the indium.

A large amount of metallic resources such as zinc is used in case of cementation process, and waste solvent is difficult to dispose in case of solvent extraction.

These conventional technologies are mainly for recovering unused indium from an ITO sputtering target and the indium deposited on sputtering equipments, and very little attention has been given to the recovery of indium from the glass substrates of used products or waste materials in the manufacturing process.

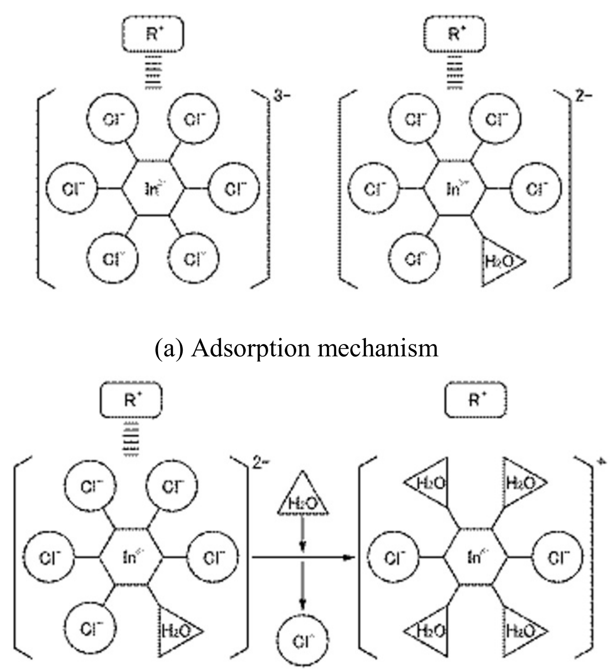
We have developed the indium recycling technology which is simple and environmentally friendly process by using the anion-exchange resin which can adsorb indium.

3 THE INDIUM RECOVERY AND RECYCLING TECHNOLOGY

3.1 The adsorption mechanism of indium

As shown in Fig. 3(a), indium that is present in an acid solution that has hydrochloric acid as a primary component becomes an indium chloro complex made from indium and hydrochloric acid and that behaves as an anion, and adsorbs specifically to the anion-exchange resin.

The anion-exchange resin to which indium has been adsorbed is then brought into contact with water to dissolve the indium.



(a) Adsorption mechanism

(b) Desorption mechanism

Fig. 3 The adsorption and desorption mechanisms of indium

As shown in Fig. 3(b), the indium chloro complex becomes an indium aquo chloro complex due to the conversion of the ligand from chloride ion to water molecules brought about by the drop in the chloride concentration that accompanies the desorption of hydrochloric acid, in the process becoming cation that is repelled by the anion-exchange resin and is desorbed.

Because indium adsorbs and desorbs onto anion-exchange resin through the use of complex form, this method has the advantage of the degradation-free anion-exchange resin.

3.2 Indium recycling process flow

Fig. 4 shows the recycling process flow which uses the adsorption mechanism onto the anion-exchange resin.

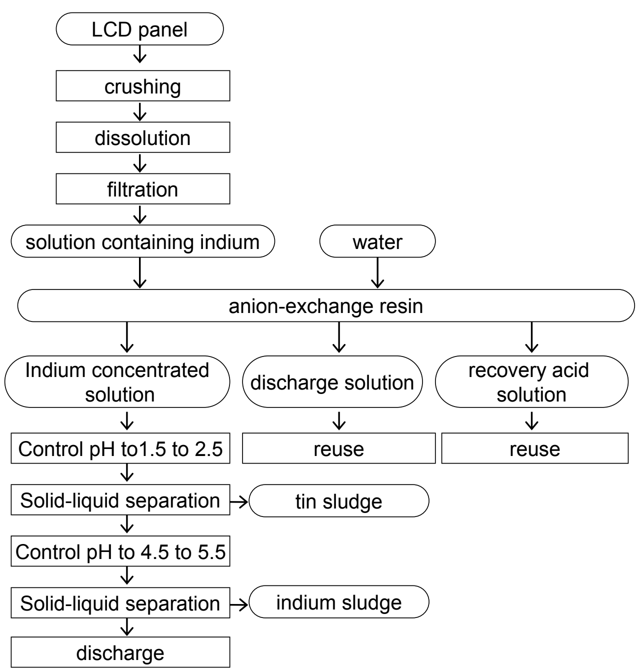


Fig. 4 The recycling process flow which uses the adsorption mechanism onto the anion-exchange resin

Indium dissolution process

At first the LCD panels is crushed to pieces not more than 10 mm, and the ITO conducting film in the LCD panels is dissolved with an acid whose primary component is hydrochloric acid. Then impurities such as glass and film in the solution are removed by filtration or the like.

Table 1 Composition of the acid solution containing indium

The solutin containing indium (mg/L)			
In	Al	Sn	Cl
7.9×10^2	1.3×10^2	4.3×10	3.4×10^4

Table 1 shows the composition of the acid solution containing indium thus obtained. It contains indium and tin which are transparent electrode materials and aluminum which is a TFT electrode material.

Indium adsorption process

The acid solution containing indium and impurities that make up the LCD panel thus obtained is passed through a column packed with the anion-exchange resin. By the above mentioned mechanism indium is absorbed to the anion-exchange resin along with acid and tin, and impurities such as aluminum pass through the column without adsorption. In this way, indium and tin can be separated from the impurities.

Then an alkaline agent such as sodium hydroxide is added to the solution that contains the impurities that have been passed through the column to control the pH to about 8, thereby precipitating the impurities as a sludge of hydroxide. The sludge is removed from the solution by a solid-liquid separation, and the solution can be discharged.

Indium recovery process

In the indium recovery process, water is passed though the column packed with the anion-exchange resin that was processed in the indium adsorption process. By doing this, the acid that has adsorbed to the anion-exchange resin can be eluted off. First the acid recovery solution with a high acid concentration is fractioned off and recovered while measuring the acid concentration of the recovery solution that has passed through the column using a conductive meter or the like. The acid recovery solution that has been recovered can be reused as the acid for dissolving the LCD panels. Once the acid concentration has increased to a value that has larger than a fixed value, the indium concentrated solution is recovered.

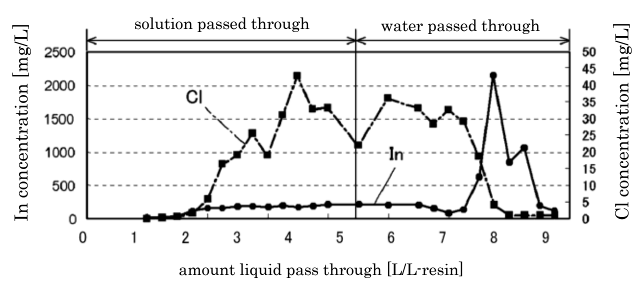


Fig. 5 The behavior of indium in a hydrochloric solution

Table 2 Composition of the indium concentrated solution

The indium concentrated solution (mg/L)			
In	Al	Sn	Cl
2.1×10^3	5	6	8.4×10^3

Fig. 5 shows that the highly-concentrated indium solution is obtained from 7.5 L/L-resin to 9.0 L/L-resin. Table 2 shows the composition of the indium concentrated solution. Aluminum which don't adsorbs onto the anion-exchange resin is removed and indium and tin which adsorb onto the resin is highly-concentrated. Table 3 shows the material balance of indium, the volume, the indium concentration, the mass, the content ratio of the original solution, the acid recovery solution, the indium concentrated solution and the discharged solution are shown. The indium recovery rate of the indium concentrated solution is 86%.

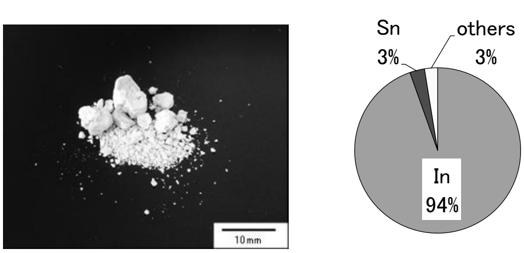
The residual indium is contained in the acid recovery solution and the discharged solution. The acid recovery solution can be reused, so 3.7% contained in it is recoverable. Then overall indium recovery rate is 90%.

Table 3 The material balance of indium

	Volume (L)	Indium		
		Concentration (mg/L)	Mass (mg)	Material balance
The solution containing	18	6.1×10^2	1.1×10^4	
The recovered acid solution	18	6.2×10	1.1×10^3	10%
The indium concentrated	7	1.4×10^3	9.4×10^3	85%
The discharged solution	13	4.3×10	5.5×10^2	
Total			1.4×10^4	

Since the indium concentrated solution contains indium and tin, first an alkaline agent such as sodium hydroxide is added to the indium concentrated solution to control the pH in the range of 1.5 to 2.5. As a result, the tin precipitates as tin sludge in the form of tin hydroxide and can be separated from the solution.

Once the tin sludge has been removed, the pH of the indium concentrated solution is controlled in the range of 4.5 to 5.5. By doing this, it is possible to obtain a high purity indium sludge made of indium hydroxide. Fig. 6 shows component fraction of the indium sludge. We have recovered high grade indium sludge which contains 94% indium.



Indium sludge

Fig. 6 Component fraction of the indium sludge

4 CONCLUSION

More and more rare metals are used in electrical and electronics equipment to add new functions. Rare metals are essential resources for highly functionalized electrical and electronic equipments. But there are some concerns about future securing of the resources. In consideration of this, we have developed recovering indium from the LCD panels which production rapidly increasing. We have achieved a recovery rate of 94%, by demonstration experiment using LCD panels discarded from the manufacturing plant.

ACKNOWLEDGEMENT

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A Product Attribute to Impact Algorithm to Streamline IT Carbon Footprinting

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Abstract
In an effort to reduce the cost of life cycle assessment analyses, a research consortium of industry, academia and governmental/non-governmental organizations was convened in 2010 to look for ways to streamline environmental assessment in the IT sector. The resulting methodology, referred to as product attribute to environmental impact algorithms (PAIA), aims to 1) streamline the LCA process through statistically-based data triage and 2) map the characteristics (or attributes) of ICT products to their environmental performance. First developed for laptops and now extending to LCD modules and desktops, PAIA links a set of product attributes (type of display module, type of memory) to a bill-of-materials and process and finally maps to the resulting global warming impact at the product class level.
Keywords:
ICT, LCA, product carbon footprint, streamlined LCA, life cycle assessment

1 INTRODUCTION

Traditionally, information technology (IT) has been designed to meet the cost, quality, and performance demands of the marketplace with little concern over environmental performance. However, as corporate pressure for "carbon footprinting," or life cycle assessment (LCA), of products for consumer-facing indices continues to mount, firms have a growing need for tools that assess environmental performance in a way that can inform design improvements. This pressure has generated interest on the part of original equipment manufacturers (OEMs) to create a platform that provides a "level playing field" from which products can be measured. However, executing quantitative measurement and identifying the primary drivers of environmental impact presents particular challenges within the IT industry due to the complexity and dynamics of products and supply chains.

This work is motivated by the information technology (IT) industry's ongoing investigation into the environmental impact of their products. IT products are complex and experience high turnover both in their manufacturing and assembly process flows as well as the supply chains used to procure materials and components. In the time it takes to develop accurate inventories of materials, energy, and emissions for a particular product, these data may no longer be relevant for that product. However, developing tools to assess environmental performance is critical to addressing the impact of these products.

2 OBJECTIVES

This work builds tools that map product characteristics into insight on environmental impact through analysis of generic IT products. The tools, or product attribute to impact algorithms, developed in this work will relate IT product characteristics to environmental performance and thereby help the industry develop efficient, resource-sensitive, and actionable sustainability strategies.

A core group of key partners along the electronics supply chain has been assembled to accomplish this work, leveraging existing industry and literature data. Through analysis of generic industry products and the development of impact mapping algorithms, this work will 1) identify and learn about the most intense drivers of impact in the environmental footprint of products, 2) catalog the specific challenges presented by calculation of energy and carbon-intensity for ICT products, and 3) quantify the underlying variation and uncertainty in these calculations.

3 FRAMEWORK

This approach is based on previous work in streamlined LCA such as work done by Sousa et al [1]. The approach aggregates comparable, relevant data with temporal and spatial uncertainty and variation [2-4]. These methods are also informed by relevant industry standards in such as the British Standards Institute, International Standards Organization, efforts by the International Electrotechnical Commission, and World Resources Institute/World Business Council on Sustainable Development's Greenhouse Gas Protocol [5-7].

In summary the steps to involved in the project are:

1. High level triage assessment based on available literature including uncertainty/variation. The significant research activity in this stage is quantifying the sources of uncertainty from grid mix variation, to supplier location and bill of materials weight ranges.
From this we perform statistical assessment that provides an understanding of the confidence in what drives global warming potential impact (driving down from life cycle phases to particular components with the product class of interest).
2. In conjunction with step 1 we identify important candidate attributes of the product. These attributes include elements such as screen size, hard drive capacity, processor type. It is important to recognize that these attributes include ostensible (or knowable) attributes that can be determined by examining the product

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specifications, but also contextual attributes based on, for example, the location of product manufacture. Preliminary results have indicated that knowledge of only ostensible attributes does not provide sufficient resolution of product class impact.
3. We use the first two steps to refine targeted data collection using OEM data/feedback and supplier surveys were possible. These significant activities are mapped to attributes and then impact.

The major analysis performed in this work are:
1. Statistical contribution analysis to identify hotspots within the carbon footprint. These are based on the most significant contributors to total impact. Quantitative metrics are provided to understand the significance of each phase or module's contribution to impact.

2. Statistical regression analysis to map to attributes to activities and impact. These regressions are based on existing data found in literature, industry data and disassembly data provided by the research team.

3. Based on elements of the analysis that we'd like to discriminate between, which at this point are at the product class level only, we determine the desired resolution between product classes. The quantitative metric for this analysis is the "false signal rate" or the percent of the time we will chose the environmentally non-preferable product based on the variation in the results. For example, a 13" screen produced in a facility without extensive abatement equipment will have a higher impact than a 14" screen produced in a facility with extensive abatement equipment. False signal rate calculations then drive further resolution, based on most significant contributors to variation between items we'd like to discriminate (activities, classes of product). For these analyses Sobol and Spearman coefficients are determined and activities are resolved to the extent possible until the desired false signal rate can be achieved.

3 APPROACH

This partnership investigates the environmental impact of ICT products through targeted and efficient analyses to determine the following:

- *What are the critical drivers of environmental performance for particular electronics products (focused on greenhouse gas emissions)?*
- *How do changes in product characteristics drive changes in the product's environmental performance?*
- *How much do these critical drivers vary and how uncertain are they (e.g. from one supplier to another or from one manufacturing approach to another)?*

This effort develops energy and carbon footprints that feed into product attribute to impact algorithms, or PAIAs, for several IT product categories including laptops, desktops, and monitors, by leveraging existing industry and literature data. The following steps are undertaken to accomplish the goals of this partnership:

Develop methods to create proxies for each generic product: Establish the bill of activities (BOA) for each product, including information such as materials used and the amount of each material, production and assembly location, use profile, etc. This can be done through an *averaging* approach where the BOA results from characterization of each OEM's product or through a *sampling* approach by dividing the product into sections of roughly equal weight/number of parts and each firm contributing a fraction of the final parts or subsystems. During this step, the involved parties will also establish the product characteristics to be tracked, for example processor, monitor size, memory, hard drive capacity, and other specifications.

Assemble data: Identify and aggregate sources of data through a review of the academic research in ICT life cycle assessments, available life cycle inventory databases, and existing industry analyses of products within sectors of interest.

Convert BOA to footprint: Quantify the environmental footprint of each generic product by leveraging existing data. In some cases approximate methods of scaling known data may be possible, but this method's appropriateness will vary depending on process and component type.

Generate product attribute to impact algorithms: Develop models connecting product characteristics to the BOA and then to the resulting environmental impact for each product proxy. These PAIAs relate environmental performance to both design characteristics and consumer-perceived attributes.

Quantify uncertainty and variation: Based on the relationships between parameters established in the previous step, the magnitude and impact of uncertainty and variation within the environmental footprints will be quantified. Some of the uncertainties included are: geographical variation in production facilities efficiency and electricity grid mix, variability in distances and modes in supply chains, and uncertainty in secondary data.

4 CONCLUSION

Thus far this approach to determining carbon impact of IT products has shown that uncertainty is large but can be accommodated depending on the goals of the assessment. Screening is possible and providing a robust mechanism for screening within standards is critical. Attribute-based models do appear possible, but cannot be based on product attributes alone, some contextual information is required.

Because data deep within the supply chain are still scarce, collaboration within the relevant parts of the industry is critical. Joint action is required to get deep supply chain data and avoid effort duplication.

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Simplified Approach for Estimating Life Cycle Eco-Impact for Information and Communications Technology Products

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Abstract
The International Electronics Manufacturing Initiative (iNEMI) Eco-Impact Estimator team has been working on developing a simplified life cycle assessment (LCA) tool that could more efficiently assess impact on human health and the environment (eco-impact) for information and communications technology (ICT) products. The resulting work is a methodology that follows the International Standards Organization (ISO) 1404x methodology for conducting an environmental LCA, while employing simplified approaches to estimating environmental impact of products. In this paper, there is an overview of the team's research around existing tools/methodologies/data in the industry, a high-level overview of the methodology, and a status report on tool development.

Keywords:
ICT, Telecommunications, modular design, LCA, LCI, carbon footprint, estimating, life cycle assessment

1 INTRODUCTION

The International Electronics Manufacturing Initiative (iNEMI) set an objective to find or develop a tool that could be used to more efficiently assess an ICT product's impact on human health and environment (eco-impact). iNEMI formed the Eco-impact Estimator Work Group (WG) to research and define a simplified methodological framework, and then develop a tool based on this framework for more efficiently estimating such eco-impact information.

2 OBJECTIVES

The objective for the project is to define a set of industry acceptable practices to more easily calculate the approximate eco-impact for different types of ICT equipment. The allowed approximations would produce an accuracy that is commensurate with the information's intended use in defining eco-impact within the ICT industry. The ensuing estimator tool will then utilize this methodology to provide a simplified means for calculating the significant eco-impacts of a particular product type over its life cycle stages. The methodology will also provide users with a unified format for requesting LCA information from suppliers. Key elements within these product types will be defined based on their relative importance in contributing to the overall eco-impact.

3 REVIEW OF EXISTING METHODOLOGIES

The WG researched the current LCA standards, methodologies, tools, and databases for relevance to the project objectives, as LCA approaches vary in method of analysis and data requirements. The most common LCA methodologies are based on "Process-Sum", "Economic Input-Output", or hybrid models that use multiple methodologies to provide targeted benefits while overcoming certain inadequacies. Standards such as ISO 14040/14044 can provide the framework for an LCA methodology deployed on ICT products. The British Standards Institute (BSI) PAS-2050: 2008 is a publicly available specification that can also be referenced regarding the greenhouse gas emissions (GHG) of goods and services [1].

Currently available LCA software tools offer distinct but somewhat different capabilities for conducting eco-impact assessments for ICT products. The drawback is that these tools require a high level of LCA expertise and modeling experience and considerable effort to develop and collect the input data necessary to perform the assessment.

In an effort to reduce the extensive resources needed to perform a full LCA on ICT products, simplified LCA-based tools are required to offer an easier approach to quantifying eco-impact. They can also be simplified further to assess just a few key eco-impacts associated with ICT products such as global warming potential and freshwater usage for the manufacturing and use stages.

Another challenge for the ICT industry is in selecting existing databases that can provide global value, while allowing that data to be corroborated with current information from the ICT sector. Periodic updates are necessary to assure that the databases remain valid. Finally, the databases should be made publicly available and not include any proprietary information, such that it can be open to external peer review and continual improvement.

The WG concluded that it would be necessary to develop a more useful LCA estimating methodology and tool. Because global warming potential is one of the most commonly evaluated eco-impact indicators, the WG decided to start with developing a LCA methodology framework for estimating this particular eco-impact. The remainder of this document describes the framework for this methodology.

4 METHODOLOGY FRAMEWORK - BASICS

The WG determined that the basis for an LCA estimator methodology framework to calculate approximately the eco-impact of ICT products includes the following attributes:

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- Integrate simplified processes to more easily derive eco-impact information.
- Categorize targeted products and their assets to provide and define key elements within ICT product types.
- Provide a simplified means of evaluating, summarizing and communicating eco-impact results.
- Demonstrate scalability, transparency, and update capabilities.

The scope included the total life cycle: from resource extraction through disposal. Individual stages were separately evaluated. This scope was in-line with ISO 14040/44. The WG did not intend for this estimator to be used to make comparative assertions between competing products, for comprehensive scenario analysis of the variants of a particular product system (e.g., with different energy sources, suppliers, material options, etc.), or for in-depth weak-point analysis of a product system.

The estimator was designed to be capable of evaluating a functional unit set to be the product unit as defined by the product manufacturer. In addition, the functional unit is defined as a specified unit of end-use capacity or to deliver a certain type of end-use value or service over a given time period.

The system boundary typically defines which processes belong to the product system as defined in the functional unit. Setting the system boundary means deciding which activities to include and which to omit for the different stages of the LCA. As a rule, all relevant activities must be included. Omission of certain processes can only be justified if they are insignificant to the outcome of the LCA study.

For a more simple LCA analysis, the WG included the following into the framework:

- Greenhouse gases associated with Global Warming Potential (GWP) over 100 years
- End-of-life product processing within the boundaries of the system.

Excluded in the framework were eco-impacts associated with:

- Carbon offsetting operations,
- Research & development
- Employee transportation from home to/from work,
- Services related to a product or system, such as advertising, canvassing and marketing, and
- Impacts of customer transportation to a product sale outlet.

Several cut-off criteria are typically used in LCA practice to decide which inputs are to be included in the assessment, such as mass, energy and environmental significance. For all of these inputs, the WG defined the cut-off criteria as the exclusion of total cumulated flows of less than 5% of the benchmark flow (per the French Standard: BP X30-323) [2].

Uncertainty and sensitivity analysis can be conducted based on the standard ISO 14040:2006.

5 CLASSIFICATION AND CATEGORIZATION OF ICT PRODUCTS

ICT products can be classified into distinct categories with common attributes that produce certain levels of eco-impact regarding their component makeup, assembly, usage, and design life. Upon analysis by the WG, these major classification categories were as follows:

- LAN (local area network) and Telecom
- PCs (personal computers)
- Printers
- Monitors
- Handhelds

These classifications were then sorted by the WG into component categories comprised of similar materials and manufacturing processes. The components were then analyzed with regard to their respective contributions to the eco-impacts associated with raw materials extraction and processing, intermediate materials manufacturing, and component / subassembly manufacturing.

Table 1 contains the eco-impact categories and their corresponding indicators for conducting an LCA on ICT products. As mentioned previously only the first eco-impact category, Global Warming Potential – 100 years, as measured by greenhouse gas emissions in units of carbon dioxide equivalents (kg CO_2e), was included by the WG in the initial phase of development for the LCA estimator tool.

Table 1: Eco-impact Categories for ICT Products

Impact Category	Category Indicator	References
Global Warming	kg CO2 equivalent	Latest IPCC report.
Water Use	m^3 water	ReCiPe 2008
Human Toxicity	kg 1,4-dichlorobenzene equivalent	USES 2.0 model
Resource Depletion	MJ surplus energy	Ecoindicator 99
Ecotoxicity	kg 1,4-dichlorobenzene equivalent	USES 2.0 model
Eutrophication	2,4-Dichloro-phenoxyacetic acid eq.	EPA TRACI
Smog	kg PO4 eq.	Stoichiometric procedure
Ozone Depletion	kg N eq.	EPA TRACI
Acidification	kg ethylene eq.	UNECE Trajectory model

Land Use	kg NOx eq.	EPA TRACI
Energy Use	kg CFC-11 eq.	WMO model/EPA TRACI

6 LIFE CYCLE STAGES – INCLUSIONS / EXCLUSIONS

The following life cycle stages and their LCA eco-impact inventory assessments were defined by the WG for the framework in estimating an ICT product's eco-impact:

- Manufacturing / Assembly of ICT Products, which ***included***:
  - Raw materials extraction and transport to facilities
  - Component manufacturing and transport into final assembly
  - Final assembly and test processes
  - Industry average values for the primary/secondary ratio of base materials
  - Packaging materials for final transport

  Considered in this stage, but ***excluded*** due to negligible effects, are:
  - Office buildings for staff design, research & development staff
  - Business travel for staff
- Transport, Distribution and Installation of ICT Products, which ***included***:
  - Transport and distribution from the manufacturing facility to the customer's premises or points of purchase for end-use customers
  - Installation

  Considered in this stage, but ***excluded*** due to negligible effects, are:
  - Distribution center buildings for storage and warehousing of products
  - Ancillary and site materials necessary for specialized installation of ICT products at customer premises
- Use and Servicing of ICT Products, which ***included***:
  - Use of the ICT product as it is intended by the manufacturer
  - Operating period can be defined as a unit of time
  - Energy used to cool the ICT product within the facility or enclosure intended for its installation
  - Servicing of product by trained service technicians
  - Warranty repair / replacement (unless the average amount over the operating life is not substantial enough to require inclusion)

  Considered in this stage, but ***excluded*** due to negligible effects, are:
  - User activities associated with maintaining the primary applications of the ICT product
- End-of-Life Treatment of ICT Products ***included***:
  - Various options for materials and parts recycling into secondary products or secondary materials that can be integrated into the intermediate materials manufacturing step and thereby offset to some degree raw materials
  - End-of-life treatment in appropriate recycling facilities offering current technologies for handling and processing.
  - Disposition to landfill for the materials that were not recycled into primary or secondary materials/ products

  Considered in this stage, but ***excluded*** due to negligible effects, are:
  - De-installation, removal of ICT product from its place of use

7 MODELING THE "MANUFACTURING" STAGE

Based on the selection of Global Warming Potential as the targeted eco-indicator for this study, the LCA "Manufacturing" Stage of ICT Products is modeled below.

7.1 Summing the eco-impacts for components

The parameters and metrics for assessing the eco-impact of components that comprise ICT products / assets are summarized in Table 2 They represent the significant eco-impact contributors (per the defined boundary conditions and cut-off criteria) based on the analyzed datasets – internally available from within the ICT industry (e.g., integrated circuits) and externally available from other industry sectors (e.g., bulk metals and plastics).

Table 2: ICT Component Parameters and Metrics

Component Category / Parameter	Metric
Printed (circuit) wiring boards	
Board area	Per square meter
Board layers	Total number of layers
Placement locations	Single sided; double sided
Board surface finish	Selection by type of surface finish
Integrated circuits (ICs)	
IC package type	Classification by package type
IC Input / Output (I/O) Count	Number of I/Os
Semiconductor package type	Classification by package type
Semiconductor Package I/O Count, weight	Number of inputs / outputs and weight (grams)
Electromechanical devices	
Classification by device type	e.g., fans, motorized devices,

	speakers (coil driven), relays, etc.
Classification by device weight	e.g., weight (kg) of single fan unit, triple fan unit, etc.
Optional: Breakdown of electro-mechanical device into its respective material components and then assessment by weight	e.g., metals: copper wire, zinc plated steel, aluminum; plastics: PVC, nylon, polycarbonate, etc.
Metallic components	
Metal / metallic mechanical materials, weight	Classification by material type and weight (kg)
Polymeric components	
Polymeric mechanical materials, weight	Classification by material type and weight (kg)
Displays	
Display device type, area size	Classification by device type/ technology and display area
Power supplies	
Power supply type, size, rating	Classification by device type and size / rating – per unit
Large capacitors	
Large capacitor type, size	Classification by type and component size
Batteries	
Battery type, weight	Classification by cell type and weight
Cables	
Cable type, size, weight, length	Classification by cable type, weight or length
Specialized components	
Specialized component type	Classification by group, type and component characteristics – e.g., optoelectronic devices, radio frequency devices, disk drives, camera devices, etc.

An associated algorithm is based on the Life Cycle Impact Assessment (LCIA) data available for the above parameters. For example, a linear regression equation of the following type can be developed for the component category of printed circuit boards.

$$GWP_{PWB} = A_B\,[\alpha + (\beta\, S_F) + (\gamma\, B_L)]$$

Where: GWP_{PWB} is the total Global Warming Potential (100 years) for the printed wiring boards in the product / asset; expressed in kg CO2e

A_B is the area of the PWB; expressed in square meters
α is the "intercept" constant for this linear regression equation

β is the "PWB surface finish type" constant for this linear regression equation

S_F is the PWB surface finish type (e.g., HASL → S_F = 1; ENIG → S_F = 2)

γ is the "PWB layer" constant for this linear regression equation
B_L is the number of layers in the PWB

Life cycle impact assessment data is available from databases that exist worldwide. They vary in features, content, region and license type.
The WG determined that some databases might not contain data that would be relevant to electronic components. However, nearly all of them have data on plastics and metals, which are important for the electromechanical and cabling portions of electronic products. In terms of electronics, a little over half of the databases surveyed have data surrounding electronic components. The most widely used databases appear to be also tied to the most widely used software tools out on the market.

7.2 Summing the Eco-Impacts for the manufacturing stage

For the manufacturing stage the LCA eco-impacts reflect the total of the ICT components' manufacturing, transport of components and intermediate materials to final product manufacturing locations, product assembly & testing, and product packaging. Because shipments of intermediate components are very low in weight and often shipped in bulk, the summation of the total material transport impact was treated by the WG as an overall factor applied to the total eco-impact of the product for this LCA stage.
The eco-impact for final product packaging was based on the packaging types used to ship the finished products to their intended distribution facilities and end-use locations.
Assembly and testing of the intermediate materials, components, and subassemblies into finished products and assets included processes such as surface mounting technology, thru-hole mounting technology, mounting of ICT product / asset, surface treatment for cabinets, and testing of the ICT product. These parameters were treated by the WG as a collective summation of the total assembly and testing processes, and defined as an overall factor applied to the total eco-impact of the product for the manufacturing LCA stage.

8 MODELING THE "TRANSPORT" STAGE

The parameters for assessing eco-impact of the transport, distribution and installation of ICT products / assets LCA stage were modeled as listed in Table 3.

Table 3: ICT "Transport" Stage Parameters and Metrics

Parameter	Metric
Location of final product assembly / EMS	Nodal point – by region

Location of product integration center / warehouse	Nodal point – by region
Location of final product installation	Nodal point – by region
Transport mode	Selection of modal mix
Transport mode GWP factors	kg CO2e per kg of shipped product weight per km traveled Additional factors to be considered include: ▪ Transportation equipment used ▪ Fuels used ▪ Load factor of the means of transport used ▪ Empty return rate of the means of transport used
Final product shipping weight	kg

The total eco-impact associated with the installation of an ICT product is highly dependent on its type. For small ICT devices that are designed for consumer use and transport to consumer premises can be considered negligible to the total eco-impact of the Transport LCA Stage.

For network servers and telecom products, the ancillary materials, parts, and resources necessary to complete an installation at a customer's premises may be more significant.

For the Transport LCA Stage the summation of eco-impacts then included these above-mentioned parameters.

9 MODELING THE "USE" STAGE

The parameters for assessing eco-impact of the use of ICT products can be modeled as listed in Table 4.

Table 4: ICT "Use" Stage Parameters and Metrics

Parameter	Metric
Location where product is used	By region or country
Power consumption	Kilowatts (kW)
Power usage per annum	Kilowatt-hours per year
Product operating life	Time period product is expected to be used

The power consumption of the product should be based on its typical configuration and feature set deployed. For external cooling necessary to transfer heat, control humidity levels, and cool the surrounding equipment area, there should be an apportionment of the energy needed to maintain typical temperature and humidity requirements of the equipment being assessed for the region it is deployed.

For power usage per annum, this can be an average daily power usage based on a typical pattern of usage that includes sleep modes and other power saving features. A use profile can be estimated or derived from studies on actual product usage by end users.

The product operating life can be its design life, typically in years or the average time a product is used. The eco-impact associated with servicing of the ICT product is highly dependent on its type. For small ICT devices that are designed for consumers can be considered insignificant to the total eco-impact of the Use LCA Stage.

10 MODELING ECO-IMPACT FOR THE "END-OF-LIFE" STAGE

The parameters for assessing eco-impact of the end-of-life of ICT products can be modeled as listed in Table 5.

Table 5: ICT EOL Stage Parameters and Metrics

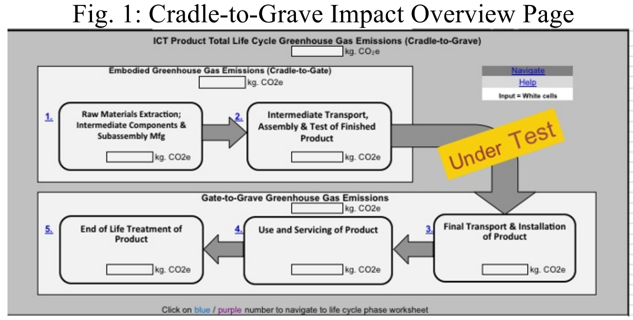
Parameter	Metric
Product constituent materials - weight	Weight (kg) of constituent materials, e.g., circuit boards, frames / chassis, metals, polymers, etc.
Disposition of product constituent materials - percentage	Percentage (%) of constituent materials receiving end-of-life treatment, e.g., full recycling, incineration / energy recovery, landfill disposal

The parameters presented in this table can provide a simple means of evaluating the End-of-life LCA Stage. Key to this are the factors that represent the eco-impacts associated with these different treatment schemes. Proper (environment-conscious) end-of-life treatment was only considered by the WG in this analysis. It is possible for more sophisticated approaches taken to develop end-of-life treatment models (e.g., European Life Cycle Data System). However, in the experience of the WG the eco-impacts of the End-of-life LCA Stage are rather small relative to the overall LCA, and thus may not warrant such sophisticated treatment.

12 TOOL DEVELOPMENT

The WG is currently in the development and test phase of the tool based on the Eco-Impact Estimator methodology with an expected completion date of April 2012. Figure 1 displays the summary page.

Fig. 1: Cradle-to-Grave Impact Overview Page



Modules under development include bare PCB, large IC and other electromechanical components, final assembly and test, transport (Figure 2), use (Figure 3) and end-of life.

Fig. 2: Transport View

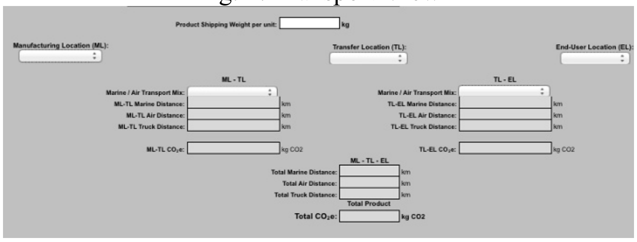
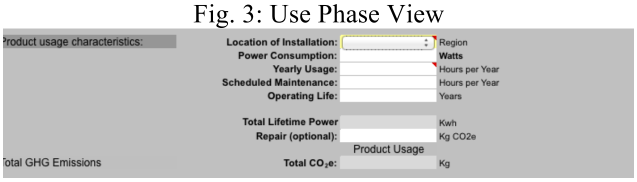


Fig. 3: Use Phase View



Other aspects of tool development include prototype testing, comparison of test results with known LCA results, and development of data collection and maintenance guidelines. In addition, uncertainty studies will be performed to understand the level of uncertainty compared to LCAs that are performed using the commonly used tools in industry.

13 CONCLUSION

The Work Group (WG) concluded that there were insufficient methods, tools and processes available to provide a simplified LCA tool that could be used to more efficiently evaluate and produce eco-impact information for ICT products. They then developed a framework that defines a process for more easily estimating the eco-impact of ICT products over their full life cycle. Since carbon footprint is one of the most widely analyzed eco-impact indicators, the WG decided to initially estimate greenhouse gas emissions in terms of carbon dioxide equivalents towards the Global Warming Potential – 100 years. The team is currently in the phase of developing the tool, and is testing/comparing results with known LCAs, performing uncertainty analyses, and is developing data maintenance strategies prior to deployment. Additional eco-impacts such as water use and resource depletion can be incorporated as potential future work.

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Progress and Challenges in EcoDesign of Semiconductor Products

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Abstract

Considerable effort has been devoted to implementing design for environment principles in the manufacturing of semiconductors. These efforts have resulted in considerable progress that is demonstrated by among other things significant reductions in greenhouse gas emissions, amount of waste disposed, and amount of energy used in manufacturing processes. In addition, the products themselves have become considerably more energy efficient, and no longer contain lead, halogenated compounds and other materials of concern. Considerable challenges in further reducing the overall lifecycle impact of semiconductors remain however. Products become more complex and powerful over time, requiring additional layers and manufacturing steps which naturally drives an increased need for energy and resources in the manufacturing process. As computing power of the products increases, their energy use may increase as well and the list of material inputs needed may grow. In addition, while many semiconductor manufacturers have completed studies that identify the environmental impacts of their supply chain, efforts to reduce those impacts are still in the very early stages. This paper will evaluate historic trends in the overall energy and environmental impact of semiconductor manufacturing processes focusing on historical water and energy use, emissions of greenhouse gases and other air pollutants, and trends in waste reduction and recycle. It will also identify likely future trends in these areas and key drivers of those trends, and discuss potential solutions that can help reduce the environmental impact of future manufacturing processes. This will include new approaches being evaluated for water and energy conservation and techniques for reducing emissions and discharges of greenhouse gases and other pollutants. It will also evaluate historic trends in energy use and environmental impacts of the finished products and identify key challenges for reducing these impacts going forward. The paper will also review information on the overall lifecycle impact and identify those portions that are the largest contributors along with discussion of future efforts to reduce those impacts.

Keywords: semiconductors, manufacturing, perfluorocompounds, emissions

1 INTRODUCTION

The manufacture of semiconductors requires significant inputs of energy, materials, and water. Reducing these inputs and the overall environmental impact of semiconductor manufacturing and product use has been a key objective of manufacturers for many years. At Intel Corporation, design for environment principles have been used to incorporate environmental thinking into the development of manufacturing processes before they are ever introduced to the factory floor. This approach has produced considerable environmental gains, such as reduced use of certain hazardous chemicals, improved energy and water efficiency and reduced emissions and discharges of key pollutants of concern. Considerable focus has also been placed on reducing the environmental impact resulting from the use of processors in finished products. Energy efficiency has improved considerably in recent generations of products and materials such as lead and halogen compounds have been eliminated from semiconductor packages.

Despite this progress, continuing to reduce the environmental impacts of semiconductors over time presents significant challenges. The first challenge comes in developing a clear definition of environmental impact. There are many parameters that can be measured to assess the environmental impact of manufacturing operations or product use. These include energy, water and raw material inputs required to produce the product, emissions and waste products generated during manufacturing, and energy used by and materials contained within the finished product. Determining whether overall impact is increased or reduced when some of these indicators show improvement but others do not is an inexact science. Another significant challenge is introduced by the fact that semiconductor devices become increasingly complex over time. Although much progress has been made in reducing the impact of manufacturing operations, newer more complex products require more steps to produce, which can drive *increases* in resource use and environmental impacts. Further, while the direct environmental impact of manufacturing operations is generally well understood, insufficient data is available to fully comprehend overall life cycle impacts of the manufacturing process. Various efforts have been made to estimate the supply chain impact of the manufacturing operations, including one by the authors of this paper [1]. However, the complex nature of the semiconductor supply chain, and the lack of standards and consistent approaches in estimating impacts throughout the chain, make it difficult to judge whether this portion of the environmental impact is improving or not.

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This paper will look at various environmental and resource impacts over time in semiconductor manufacturing at Intel. The goals of the paper are to show trends in the overall environmental impact of manufacturing representative Intel products over the years, and identify future challenges in both understanding and reducing that impact. This paper will also look at some of the key environmental impacts of finished products.

2 DEFINING ENVIRONMENTAL PARAMETERS

2.1 Product History

To assess the environmental impact of the manufacture and use of semiconductor products, it is helpful to consider the way in which products have changed over time. Few manufactured products have changed more than microprocessors in recent decades. The 4004 microprocessor introduced by Intel in 1971 was the world's first commercially available processor. It contained 2,300 transistors and had a circuit line width of 10 microns. In contrast, Intel processors manufactured in 2010 contained about 1 billion transistors and had a circuit line width of 32 nanometers, a reduction in basic feature size of greater than 99%. This dramatic shrink in circuit size has enabled placing far greater numbers of transistors on a given area of silicon, which dramatically increases chip size and computing power.

Over the past 40 years, the manufacturing processes required to make these chips changed substantially as well. Hundreds of individual manufacturing steps are required to make a modern microprocessor, and each process generation requires the introduction of new materials not used previously. The increased complexity of the product and the manufacturing process drives the need for more material and energy inputs, and hence drives a tendency toward increasing overall environmental impact, or at least reducing the gains that have been made through design for environment principles.

2.2 APPROACH

One of the challenges in defining the environmental impact of a product or process lies in defining the key parameters to measure. Microprocessor manufacturing requires inputs of energy, water, and numerous chemicals and gases and other raw materials. In addition, the process results in the generation of wastes and discharges that must be tightly managed. There is no set formula for determining overall environmental impact from this divergent set of environmental indicators. Intel's approach to assessing overall environmental performance is based on measuring the environmental parameters it has determined to be the most significant from its manufacturing operations. For this paper, the parameters include energy and water use, chemical waste generation, scope 1 greenhouse gas impact, and emissions of volatile organic compounds (VOCs), hazardous air pollutants (HAPs) and perfluorocompounds (PFCs). Many years of sound data is available for each of these parameters and they represent some of the most important resource inputs to the process (energy, water) and some of the discharge parameters that are most important for environmental regulatory purposes (air emissions, waste disposal). The total environmental impact results are from Intel operations worldwide.

Once the parameters are defined, the next challenge is assessing whether or not the results represent improvement in environmental performance real value of those parameters has increased or decreased over time. The semiconductor industry in general and Intel specifically have grown substantially over the last few decades. As a result, the total impact of some parameters will have increased over time simply due to the presence of more factories producing more products. This is not necessarily an indication that environmental performance has degraded, or that manufacturing has become "less green." Conversely, if a similar assessment were done over a period of time when business was declining, the decrease in environmental impacts would not necessarily reflect improved environmental performance. For this paper, the authors have attempted to assess the environmental impacts (resources used, wastes/emissions generated) of producing a single unit of a representative product. This is similar to the approach used in a previous Intel paper which assessed the environmental impact of manufacturing a Pentium Pro chip compared to a Pentium 4 chip [2]. A similar approach was also used in a recent paper by Williams & Deng which evaluated the environmental impacts of semiconductor manufacturing [3]. These impacts are not actually measured at the individual product level, of course, but Intel does track total area of silicon (cm2) processed each year, which allows overall environmental data to be normalized per/cm2 of silicon. This is then multiplied by the chip (or "die") size of the individual product to estimate the total impact of manufacturing that product.

The fundamental question this analysis is trying to address is whether or not the environmental impact of manufacturing a given product has been reduced over time. Intel manufactures a variety of semiconductor products for use in desktop, server and mobile devices. Die sizes can be substantially different among these categories of products. Server chips for example, are typically substantially larger than chips for mobile products, but they are also typically substantially more powerful. Therefore, to assess the environmental impact of manufacturing products of different generations, it is necessary to compare products that perform similar functions and are aimed at similar market segments. This study will evaluate the environmental impact of desktop microprocessors for the last several generations of Intel products. A given processor is typically produced on more than one process generation. Typically a processor is initially manufactured on one circuit width (e.g. 65nm) and is later converted to the next circuit width (e.g. 45nm).

That conversion significantly reduces the die size of that product, and therefore will significantly reduce the environmental impact as calculated by the method described above. Since the purpose of this study is to attempt to compare impacts of products over successive generations, it was important to be consistent in determining which version of the product to measure. The results shown are based on the initial version of the product, with its original circuit width and die size. Environmental data were collected from the year that product began manufacturing and were attributed to the individual product as described above.

3 IMPACTS

3.1 Manufacturing, design for environment

Intel has made considerable effort over the years to reduce the environmental impact of its manufacturing operations. These actions have been driven both by the desire to demonstrate leadership on environmental matters, and the desire to maintain operating flexibility by ensuring resource consumption does not strain local limits, and avoiding the more burdensome requirements that sometimes exist when certain emission thresholds are exceeded. The concept of "design for environment", which is now often referred to as "ecodesign" has been a major part of Intel's strategy for many years.

The fast changing nature of the semiconductor manufacturing process actually presents an opportunity to utilize ecodesign principles. Approximately every two years, Intel introduces its newest generation manufacturing process with a smaller circuit width, which reduces die size and increases chip speed. This conversion requires the replacement of a substantial number of manufacturing tools, and revisions to the chemical "recipes" of many others. Intel's design for environment program enables it to set environmental goals for these new processes as they are being developed. In this way, environmental targets can be set which reduce the impact of new manufacturing tools and process steps.

Reducing emissions of VOCs was one of the earliest environmental goals Intel established through this process. New air pollution regulations in the U.S. in the 1990s set strict permitting requirements for facilities whose emissions exceeded the definition of "major source". Intel was concerned about the potential for permitting delays to impact the ability to make rapid changes, so emissions reduction goals were established that would allow all manufacturing operations to remain below this threshold. Maintaining emissions at these lower levels helped avoid potential permitting delays and enable more flexibility to make changes in operations.

Another early example dealt with emissions of PFCs. PFCs are compounds that are essential to semiconductor manufacturing, but which are known to have global warming potential. Though unregulated until recently, Intel and others in the industry entered into a voluntary agreement in the 1990s to dramatically reduce emissions of these compounds. In both examples, the objectives were achieved by considering environmental issues in the initial design of the manufacturing process. As the process was being developed, alternate chemistries were introduced, processes were optimized to reduce material use, and highly efficient treatment systems were developed. Similar actions were taken to reduce energy and water use, facilitate waste recycling and to reduce emissions and discharges of other pollutants of concern.

3.2 Results

Table 1 below shows the trends in Intel wide environmental impact for the different environmental parameters over the last 10 years. Obviously, Intel's manufacturing has grown substantially over that time, and the nature of its products has changed. Therefore, while absolute values are certainly important, they may not provide a complete picture of whether or not environmental progress has been made.

Table 1: Environmental Data, Intel Wide

	2000	2004	2008	2010
Energy, Bkwh	3.7	5.0	5.7	5.2
VOCs, tons	271	232	211	182
Water Use, Bgal	5.7	6.0	7.7	8.1
Scope 1 GHGs, Mmetric tons	2.4	1.4	1.1	1.2
PFCs, Mmetric tons	2.2	1.0	0.7	0.5
HAPs	24.6	31	18.6	20.5
Chemical Waste, ktons	9.8	20.2	28.5	31.3

It is also useful to look at the data on some kind of production normalized basis to see if the operation is becoming more or less efficient from an environmental perspective. For this analysis, the last 5 generations of leading edge microprocessors aimed at the desktop market were evaluated. The specific products included are shown in Table 2. For each product, the table also shows the year for which the environmental data was collected and applied to that product. For example the Pentium 4 device was being manufactured on the 180nm process in 2000. Therefore, Intel wide environmental data from 2000 was used as the basis for calculating the impact of manufacturing P4 chips.

Table2: Desktop Processor Products [4]

Product	Circuit width, nm	Die size, mm2	# of cores/ transistors	Year
Pentium 4	180	217	1/55M	2000
Pentium D	90	206	2/376M	2002
Core 2 quad	65	286	4/456M	2004
Core i-5	45	296	4/774M	2006
Core i-7	32	246	4/1B	2008

Figures 1 through 3 below show the impacts calculated for manufacturing each of the selected products.

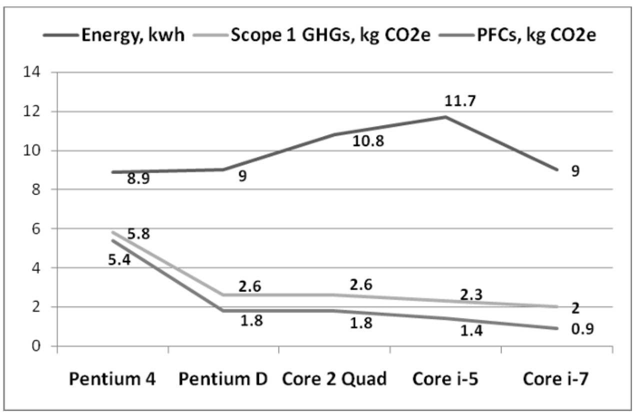

Fig. 1: Energy & Greenhouse Gas Impacts

The recent Williams & Deng paper estimated energy required to produce some of the same products, with different results. The energy data used in this paper included all Intel energy consumption, not just that used in the actual manufacturing fab. This may be a source of difference between these estimates. It is also not clear whether the studies were evaluating the same generation of product. If the 32nm version of the i-5product (which has a die size roughly 1/3 of the original) were included in this analysis, it would have been estimated to require just 3 kwhrs to produce. This is also a source of difference between the values in this chart and some of the values shown for the P4 product in the earlier Intel paper by Yao, et. al. To make comparisons consistent, this paper focused on the product as it was initially manufactured.

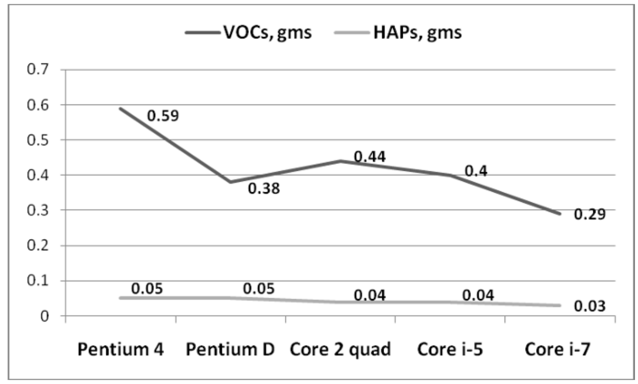

Fig. 2: Air Emissions Impacts

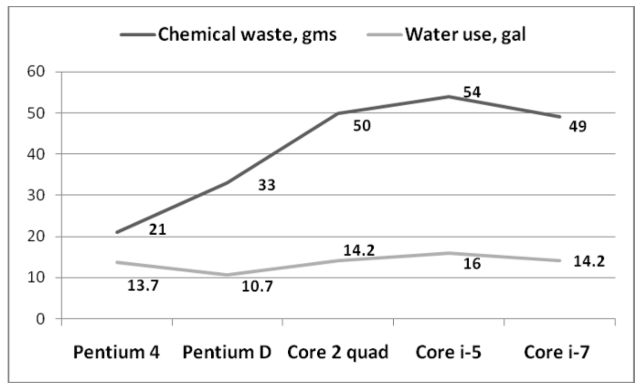

Fig. 3: Waste & Water Impacts

The results show considerable progress in reducing impacts on many of the parameters. Others, such as water and energy use have remained relatively flat, although it should be noted that the complexity and number of steps required to produce new products increases with each generation. In that case, it can be argued that keeping impact levels flat still has required considerable focus on environmental improvements. Also, it must be acknowledged that there are limits to any discrete list of parameters to measure. For example, while chemical waste generation per product has increased substantially, the amount of waste recycled has grown substantially as well. In the time frame reflected, waste recycle rates at Intel have gone from less than 50% to about 80%, so the amount of waste being disposed of has stayed roughly flat. Clearly, there is environmental benefit in increasing recycling amounts, even as actual amounts generated have grown. Intel has also substantially increased its use of renewable energy over this time, both through renewable energy purchases and the installation of onsite solar photovoltaic panels at many of its facilities. Since 2008, Intel is the largest purchaser of renewable energy in the US purchasing over 2B kW-hrs or 85% of its US electricity consumption This is also clearly environmentally beneficial, though is not reflected in the energy use figures above.

On the other hand, each new generation of products requires new chemicals and raw materials not previously used. The comparative life cycle assessments of different chemicals and materials are not fully understood, so it is difficult to say whether such changes represent increased or decreased environmental impacts.

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3.3 Product Use

Assessing the environmental impact from the use phase of the product requires a different set of parameters than the manufacturing phase. The actual use of a microprocessor does not directly consume water, or generate emissions or discharges. Therefore, the most relevant parameter to measure is product energy use. As microprocessors have become increasingly powerful over time, designing them for improved energy efficiency has become critical. One of the challenges in comparing energy efficiency of different generations of products is driven by the fact that newer processors perform more functions including some that may have previously been performed by other chips in the system. There are also of course differences in power use among different operating states (e.g. sleep, idle).

Much of the focus in improving processor efficiency has been on improving power management which involves enabling processors to more quickly enter idle or sleep modes and reducing consumption during those modes. These measures should reduce the total energy consumed over time. Measuring that requires making assumptions about the use patterns, and what portion of computing time is spent in various operating modes. As industry standards for such measures differed, Intel developed a model it referred to as the "day in the life" model to estimate typical usage patterns[5].

Using this approach, the average annual consumption of several different platforms based on different generations of Intel processors was measured. The focus of these studies was the platform as a whole, not the processor specifically, as the processor over time has assumed additional functions previously performed by other chips.

Table3: Annual Electricity Consumption, kwh

Pentium 4 based platform	216.5
Pentium D based platform	196.1
Core 2 Duo based platform	144.4

This analysis shows decreasing energy consumption of a typical platform over successive generations of microprocessors. A more recent analysis has been done on newer generation products, using the Typical Energy Consumption (TEC) energy use model included in the Energy Star Program Requirements for Computers. Using this model, Intel estimates that an average platform based on its 45 nm products will consume 194 kwhrs per year, compared to 107 kwhrs per year for a platform based on the new 32nm products. While not directly comparable to the above table due to the different use models assumed, this appears to support the notion that newer generations of products have continued to make improvements in energy efficiency. As another example of improved computing efficiency, it is estimated that Intel technology will enable the billion PCs and servers installed between 2007 and 2014 to consume half the energy of the first billion, with 17X the compute capacity.[6]

While energy consumption is the most measurable parameter for addressing the environmental impact of product use, it is not the only way in which ecodesign has been incorporated into new products. Certain chemicals such as lead and halogenated flame retardants have been removed from new products. It is difficult to develop a metric to precisely quantify the environmental benefits of such actions. However, these improvements were made in direct response to environmental concerns raised by customers and government agencies and are therefore widely accepted to represent improvements in ecodesign.

4 FUTURE/REMAINING CHALLENGES

Semiconductor products will continue to become more complex with each successive generation, as they always have. The manufacturing process to make these chips will therefore require additional steps, which has a tendency to increase the amount of energy, water and raw materials needed and the amount of wastes and discharges generated. Continuing to reduce the overall environmental impact of manufacturing will therefore require further breakthroughs in resource use optimization and in treatment technologies.

Semiconductor fabs that manufacture new generation products are becoming larger and more complex. Considerable work is being done through the International SEMATECH Manufacturing Initiative (ISMI) to attempt to make both the manufacturing tools and the fabs themselves more energy and water efficient. These efforts will be very important in managing the resource consumption of future fabs. The use of new materials also poses challenges for future manufacturing. Often times this results in the generation of new wastes, which may require the development of new treatment technologies. At the same time, the conversion to larger wafer sizes in the future represents an opportunity for improvements. Previous work has demonstrated that converting to larger wafer sizes can produce economies of scale that reduce environmental impacts, and offer an opportunity to make process changes to reduce those impacts [7].

As noted previously, the semiconductor industry has a large and complex supply chain. Previous studies have attempted to estimate the impact of this supply chain, with some concluding the impact was as large as or larger than the manufacturing operation itself. Tools for making these estimates are currently fairly crude, so developing a better understanding of supply chain impact is necessary before considerable improvements can be made.

5 SUMMARY

Measuring the "greenness" of a product or operation is difficult. There are many parameters that can be measured, and determining which are the most important (or the tradeoff among them) is an inexact science. This assessment is further complicated by the changing nature of products themselves. In some cases, the absolute amount of material inputs or wastes generated from the manufacture of a product may have increased over time, but that product may be performing many more functions, some of which may even have displaced other products. In such cases, it can be difficult to say whether the new or old version of the product is "more green".

In evaluating some of the environmental parameters that are widely measured for semiconductor factories, we can see evidence that years of focus on ecodesign and green manufacturing are producing positive results. In many cases, these parameters show reduced environmental impact. While this is not always the case, it can also be argued that keeping resource use and pollutant discharges flat, while making increasingly complex products and increasing the total number of products manufactured, also requires considerable environmental improvements. As products and the factories that make them continue to grow in complexity, meeting these challenges will be essential to continue the progress that has been made over the past few decades.

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Ecodesign Strategies in Micro, Small and Medium Enterprises (MSMEs) of the Electronic Sector: a Brazilian Standpoint

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Abstract
Ecodesign is a proactive management approach that guides product development processes towards the reduction of environmental impacts throughout a product's life cycle, without compromising other essential criteria. However, the ecodesign concept is not equally disseminated between MSMEs and large companies, especially in Brazil, where MSMEs play an important role in the economic scenario. Thus, this paper aims to present preliminary results of a survey conducted in Brazilian MSMEs of the electronic sector, focused on the adoption of Ecodesign strategies. The major part of the surveyed companies already know the ecodesign concept, but do not take into account when developing a product. Although some of them have claimed to be interest in developing ecodesign projects over the next two years, it would be necessary the establishment of top-down regulations/requirements in order to suit the proactivity of the national electronics industry.

1 INTRODUCTION

Ecodesign can be defined as a strategic design activity whose purpose is to conceive and develop sustainable solutions. It generates sets of products, services and knowledge that enable consumers to achieve sustainable results. Ecodesign can also be seen as a proactive management approach that guides product development towards the reduction of environmental impacts throughout a product's life cycle, without compromising other criteria such as performance, functionality, aesthetics, quality and cost [1-7]. Due to its great potential, therefore, design is one of the most influential factors in the development of sustainable production systems and products [8].

According to Vercalsteren [9], ecodesign is a growing concern in large industrial companies. These companies consider the implementation of ecodesign as a means to preserve, besides the environment, their competitiveness and image in the market. On the contrary, ecodesign is a concept too far off micro, small and medium enterprises (MSMEs) daily business currently, as well as it already is for some large sized companies, and they still have to be convinced of the advantages and possibilities of ecodesign [9,10].

A study on strategies for ecodesign dissemination to MSMEs [11], carried out in 2000, stated that: (1) some of them have experience with ecodesign in single demonstration projects, but they rarely lead to implementation of ecodesign in product development processes; (2) ecodesign is not a management issue for them: strategic goals regarding environmental product policy are very rare; and (3) when ecodesign is practiced by them, the focus is on the environmental redesign of products rather than the development of new product concepts (eco-innovation).

In Brazil, most of the MSMEs are considered 'family business' and employees more than 60 million people; they are 4.5 million small businesses, accounting for 98% of industrial, commercial, and service undertakings, more than 60% of urban jobs, and around 21% of the GDP as well as being responsible for 12,4% of all exports on a direct way [12]. These numbers show the relevance of MSMEs for the Brazilian economic scenario and the amount of work that must be done in environmental concerns.

Thus, considering the mentioned above, this paper aims to present the ecodesign benefits and drivers, some international and national initiatives founded during a initial literature review and to start a discussion on what should be done for Brazilian MSMEs to keep themselves alive in the market, while give their contribution to the environment.

2 ECODESIGN IN MSMES

MSMEs face difficulties to stay competitive in the market: they present organizational, decision-making and individual specificities, as lack of resources, poor organizational maturity, short-term time horizon, lack of quantitative data and others [1]. Due to their specificities many research works are being conducted on ecodesign strategies within MSMEs, some concerned on the development of environmental friendly products itself, while others were more concerned on the utilization of ecodesign at strategic level. Tukker, Ellen and Eder [2]

M. Matsumoto et al. (eds.), *Design for Innovative Value Towards a Sustainable Society*,
DOI 10.1007/978-94-007-3010-6_154,

published a report project focused on ecodesign strategies for dissemination to SMEs; Vercalsteren [3] presented the experiences obtained in the integration of ecodesign and life cycle concept in the development of products in Belgian SMEs; Van Hemel and Cramer [4] pointed out the barriers and drivers for ecodesign in SMEs; the German Institute Fraunhofer IZM [5] promoted a ecodesign awareness raising campaign for electrical and electronics SMEs in Europe; Le Pochat, Bertoluci and Froelich [6] dealt with the integration of ecodesign into the enterprises' organization, conducting changes in SMEs. These works are just examples, and many others may be found in the literature, for other countries and regions, as shown below for the Brazilian context.

2.1 The Brazilian Context

In Brazil, the studies on ecodesign issues follow the international trend. Some of the research works have analyzed the use of ecodesign strategies within furniture industry at strategic level [7], while others have tried to indicate the potential use of the strategies within SME companies [8].

Mazza, Fortes and Moraes [9] pointed ecodesign as a strategy for increasing competitiveness of micro enterprises clothing in Fortaleza (northeast Brazil), and Silva [10] evaluated the environmental sustainability of micro and small enterprises suppliers of the productive chain of oil and gas of the basin of Campos (southeast Brazil).

The work of Costa and Gouvinhas [11] represent a diagnosis on the use of ecodesign strategies within 49 Northeast and Southeast Brazilian SMEs and their internal and external drivers, and the 'roadblocks' for their implementation. This work has demonstrated that legislation and government regulations were the main external drivers for companies to adopt Ecodesign strategies within their product development while environmental and production cost reduction and the opportunity for new markets were considered to be the main internal driver for Northeast and Southeast regions respectively. The main roadblocks were the lack of market demand for environmental friendly products and the perceived view from companies that the development of 'green' products will bring commercial drawbacks to them.

In an effort to answer the question "how to do ecodesign?", Pigosso and Rozenfeld [12] presented a proposal of an ecodesign maturity model that aims to guide companies into the effective implementation of ecodesign practices into the product life cycle management in accordance with their strategic objectives and drivers. This model is composed by three main elements: (1) 'the application method', that presents the way in which companies can use the model for process improvement and contains a scheme of continuous improvement (like PDCA – plan cycle) based on Business Process Management (BPM) approach; (2) 'the ecodesign practices', which correspond to the best practices currently adopted by companies and developed by universities for the integration of environmental concerns into the product development process, and it is composed by management practices (those that deals with the management of ecodesign), operational practices (related to technical design issues) and ecodesign methods and tools that support the application of management and operational practices; (3) 'the maturity levels', which represent the company evolution level in applying the environmental issues into their business processes.

3 METHODOLOGY

The seven companies surveyed and presented in this article are part of a survey conducted in Brazilian companies in the electronics sector. These organizations represent the test phase of this survey, i.e., the selection of institutions that responded critically to the questionnaire will be sent to other companies in the survey.

To this was done a detailed literature review and after this preliminary step, the pilot questionnaire was prepared that, after critical analysis of three experts on topics of research, was submitted to ten organizations. It was requested that the questionnaires were answered by officials and criticized by the environmental departments of companies, because they have more ownership in these sectors in information organizations.

The questionnaire was initially structured with questions that aimed to characterize the sample. The second part was directed at the identification and adoption of Ecodesign by industries. Some questions were composed of two response options (Yes and No) and others have multiple alternatives, allowing the company to tick more than one option, according to its need. The respondent is directed to the next question according to the answer to that question.

This type of research has a descriptive and explanatory second [13] and is being increasingly used in the manufacturing sector [14]. Figure 1 illustrates the flow of methodological research.

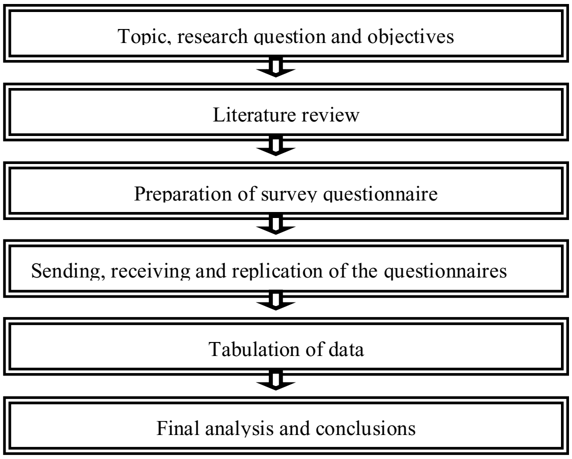

Fig. 1: Methodological research flow

According to Forza [15], the survey has significant advantages such as low investment, ease of access, it does not require the physical presence of the researcher, favors the confidentiality of corporate information and promotes the impartiality of the available data in relation to the researcher and research subject.

After receiving the final versions of the questionnaire by the seven companies, the data were tabulated and analyzed by the software statistica 7.0. statistical tools were applied in order to build an initial overview of the adoption of environmental procedures for electromedical sector companies in Brazil.

4 ANALYSIS OF RESULTS

The companies surveyed represent a sample of Brazilian Medical Equipments Manufacturers, a sector responsible for more than 4 billion dollars in 2009 [16], located in the South (1) and Southest (6) regions. This sample comprises small (42.9%) and medium enterprises (57.1%) well-established in the market, and most of them have between 25 and 50 years of operation (71.4%). The main clients of the surveyed companies are national MSMEs (57.1%), large national companies (28.6%) and international MSMEs (14.3%). Six of the seven companies are exporters and the exports account for up to 24.9% of revenues, directed to South and Central America and Africa. All of them have certified Quality Management System for Medical Devices according the ISO 13485 standard, and the major part (85.7%) also are certified for ISO 9001 standard.

Respondents of these organizations are postgraduates (57.1%), graduated (28.6%) and high school level (14.3%). Six respondents are managers and one is project coordinator; 42.9% of them have up to two years of employment, 42.9% work in the company for 5 years and 1 day to 10 years and 14.3% of them are in the company between 2 years and 1 day and 5 years.

Table 1: Reasons why companies do not adopt Ecodesign

	Companies						
Reasons	**1**	**2**	**3**	**4**	**5**	**6**	**7**
There is no alternative solution for the product	X	X		X			
Conflicts with functional requirements of the product			X				
Not yet required by the customers			X	X	X	X	X
Lack of clear environmental benefits					X		X
Commercial disadvantage				X		X	X

Regarding the questions about Ecodesign: the survey was initiated by the question which sought to identify the knowledge about the concept; 71.4% of the respondents know the concept but do not use it in their companies and 28.6% of them answered that do not know what Ecodesign is. Considering this information, we can notice that most of the companies are familiar with the Ecodesign definition, but still do not apply it for their products, although six of them have a systematic process for product development (PDP). Most of the surveyed companies do not take environmental issues into account during the PDP, but three of them intend to develop projects based on Ecodesign in the next two years. The reasons why companies do not perform environmental changes in the products are presented in Table 1.

One contradiction is the fact that all the studied companies stated they do not carry out changes in the products to minimize environmental impacts, but 57.1% of them claimed to have a qualified team to develop environmentally friendly products; 42.9% of the sample stated the opposite, which suggests that companies may need external help to identify opportunities for environmental improvements in its products.

It was noticed that one company does not take into account environmental improvements in its products due to the conflicts that could interfere in products functionality, perhaps because of product specificities, which demands appropriate studies. Five companies have pointed out the lack of demand from their customers as one driver for not conducting Ecodesign projects. Thus, one can conclude that the initiative for changes in the products of an environmental nature must come from customers demand, which characterizes a purely commercial motivation. The lack of clear environmental benefits were identified in two companies; one of them has a skilled team for Ecodesign and the other has not.

5 SUMMARY

Despite of the benefits, drivers, and all national and international efforts, research works on the application of ecodesign strategies in SMEs seems to be very shallow. Considering the relevance of SMEs for the Brazilian economic scenario, there is a lot of work to be done in environmental concerns.

All the surveyed companies are taking part of a pilot project named AMBIENTRONIC, an initiative of the Center for Information Technology 'Renato Archer' (CTI) that aims to improve sustainability levels in Brazilian enterprises from the electrical and electronics sector, supported by three Brazilian Ministries: Science and Technology, Environment, and Development, Industry and Foreign Trade; this could be the reason why these companies know the Ecodesign concept, but this sample could not be representative if all Brazilian Medical Equipments Manufacturers or Electronics Manufacturers were taken into account.

About the certifications: the Medical Equipment sector need to fulfill some specific requirements defined by the Brazilian Health Surveillance Agency (ANVISA). Thus, this information could justify the high level of adoption of Quality Management Systems by the sample but could not represent the reality of other sectors.

About the reasons why companies are not using Ecodesign:

Ecodesign is not yet required by the customers

An important and consistent information obtained with this survey indicated that most companies do not practice ecodesign because it is not required by customers. This shows the importance of top-down regulations/requirements in order to suit the environmental profile of national products.

There is no alternative solution available for the product

As three companies have pointed out that there is no alternative solution for their products. This could means a lack of investment/training on Ecodesign, and represents an opportunity for innovation and technological maturity for these companies.

Commercial disadvantage

The Brazilian companies follow the international MSMEs trend and still have to be convinced of the advantages and possibilities of Ecodesign. External drivers like customers requirements or encouragement/incentives by the government could increase the adoption.

Conflicts with functional requirements of the product

One of the surveyed companies has pointed out that the application of Ecodesign could be the cause for conflicts with functional requirements of the product. However, it should be noted that ecodesign actions in electronics product probably will not result in a conflict with the functionality of the product as a whole.

The survey of Brazilian MSMEs Medical Equipment Manufacturers has indicated that the companies have their own product development processes and are inserted in the international market, with exports to countries in South/Central America and Africa. These companies are participating intensively in the Ambientronic Project (ABIMO - CTI/MCT), training in technologies for sustainability (Ecodesign, LCA, compliance with European directives such as RoHS, WEEE, etc.) Thus, these companies have knowledge but do not invest significantly in the ecodesign of their products. Some relevant points may explain this scenario, as the lack of strategic vision of the competitive advantages that this technology could add to their products and innovations fear that this may have conflicts with the many safety requirements required for the electronics sector regulatory agencies (health). But this survey has also shown that the main factor that contributes to the lack of investment in these companies is the fact that ecodesign is not a requirement for the customers, and it is directly related to the target market served by these companies. Another important factor is that, despite of the recommendations established in the Brazilian National Solid Waste Policy (PNRS) for the development of environmentally friendly products, there is no regulation defined yet for the PNRS to leverage this technology out to MSMEs Electronics Manufacturers. Thus, in this context, Ecodesign appears as an important opportunity for the technological innovation in Brazilian MSMEs, creating competitive advantages to their products and opening new business opportunities with local and international markets, while preserving the environment .

It is important to highlight that the results shown in this paper are related to a small sample of the electronics sector, and then, in order to consolidate information about the national scenario, and analyze the needs and opportunities of ecodesign in MSMEs, further surveys will be conducted, considering other MSMEs of Medical Equipments and, especially, other Electronics Manufacturers.

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A study on a system design approach to promote better circular use of Electrical and Electronic Equipment

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Abstract

Electrical and electronic equipment (EEE) are popular in recent world and have large impacts on environment. In Japan, there are legislations for designated products. But, collected amount comparing to produced amount is not sufficient. Whatever the proper end-of-life strategies is, the first step is to collect the used product as much as we can. This paper discusses the key factor to enhance collection rate and to prolong product life based on sensitivity analysis and tries to figure out what can be proper strategies to reduce environmental impact of e-waste with high technology progress speed.

Keywords: e-waste, inverse supply chain model, collection rate, reuse rate, sensitivity analysis

1 INTRODUCTION

Electrical and electronic equipment (EEE) are popular in recent world and have large impacts on environment. In Japan, there are legislations for designated products and the ratio of recycled material out of collected amount of product is high enough. However, on the other hand, collected amount comparing to the produced amount is not sufficient. Basically, for 4 designated home appliances, the rate is about half and for laptop PC, mobile phone, and so on, the rate is much lower. Whatever the proper end-of-life strategies is, the first step is to collect the used product as much as we can. Therefore, a countermeasure to enhance the collection rate needs to be discussed.

Thus, one objective of this paper is to clarify what is the key factor to reduce the environmental impact of EEE production. And the other objective is to propose a better way of circular use of WEEE which can reduce environmental impact of product, by combining reuse and upgrade of components properly. Consideration based on system design aspect will be helpful in finding how the end-of-life options can be combined. In the paper, laptop PC is selected as the example of analysis. Since production amount of laptop PC is considerable and the collection rate is low, a countermeasure should be discussed. The report from Ministry of Environment tells the product reuse should be promoted to reduce environmental impact. In addition, it is evident that if reuse of some of the components is implemented, environmental impact of laptop PC can be reduced. However, component reuse cannot be a motivation for consumers. A replacement service, so-called upgrade, of low-performance components is necessary. Without ensuring that the product is always up-to-date, no one would like to use the products during long time. Of course, there is no official upgrade business of laptop PC components. Thus, to predict the feasibility of the business and its impact on environmental impact reduction, an approach based on system design methodology is necessary. As the first step of the analysis, inverse supply chain models not including and including component reuse and upgrade are drawn. The paper also combines quantitative analysis with the models and tries to know the key factors to decrease the environmental impact. Then, the paper tries to propose a way to enhance better circular use of EEE and reduce the environmental impact.

2 COMPONENTS TO UPGRADE AND REUSE

2.1 Case study; laptop PC

Laptop computer is a popular electric product widely spread in society. However, the official end-of-life option of laptop computer is material recycling. In current social system, since the laptop PC is not so difficult to storage in home, consumers have not so strong incentive to take back used laptop PC to recycling facility. In implementing the reuse of laptop computers, there are many obstacles such as difficulty in assuring the reliability, etc. As well as other electric and electrical products, laptop computer consists of many parts such as screw, plastic panel, etc. And a certain group of parts corresponds to a certain function of a laptop computer. In this paper, 'component' is defined as a physically connected group of parts having a certain function. One of the difficult problems is the difference of the speed of technical progress in each component. Although some components can still be used, some components don't have updated performance. In such case, consumers might not want to use the product with insufficient performance.

2.2 Laptop PC components

Firstly, the authors actually disassembled a laptop computer and investigated which parts can be grouped as components. As a result of disassembly, 7 components have been defined. Those are hard disk drive (HDD), AC

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adaptor, liquid crystal display (LCD), CPU board, battery, CD/DVD drive and main body. Table 1 shows the defined components and corresponding functions. Some components such as HDD have been modular-designed already, but some of the components such as CPU board and main body cannot be called as modules. However, these groups of parts correspond to certain functions of a laptop computer almost one by one. Thus, the groups of parts can be recognized as 'components' with particular functions. There are some other options of components categorization. However, the purpose of this paper is to consider the end-of-life strategies such as reuse or upgrade corresponding to the components. Therefore, components should have one-on-one relations between performances .

2.3 Environmental impact of component production

Then, the next step is to calculate CO_2 emission during the manufacturing stage of each component based on existing surveys. For the components that can be disassembled to material level, equation (1) and database [1] on CO_2 intensity of materials were applied to calculate the CO_2 emission. However, print circuit board is a common part consisting electric product and it is difficult to disassemble print circuit boar further. So, we treated print circuit board as a single material. CO_2 emission to fabricate print circuit board was decided based on an existing survey [2]. For components that cannot be disassembled, other surveys [3-5] are referred. As the result, environmental impact of production of seven components are estimated as Table 1.

Table 1 CO_2 emission of component production

Component name	CO_2 emission of production ($kg\text{-}CO_2$)
Battery	3.81
HDD	2.72
CD/DVD	1.08
CPU	2.59
AC adaptor	4.07
Main body	2.43
LCD	12.49

2.4 Performance change of components

In the former section, environmental impacts of component productions were estimated. The next step is to know the value of components. Based on the internet survey, prices of spare parts, and so on, price of the product has been distributed to 7 major components and initial price of each component was estimated. However, at the end of product life, the component values must be different. Since the performances of the components rapidly progresses in EEE, high performance product at the time of purchase will be no more updated product after some years of usage. This is so-called obsolescence. To know the obsolescence very simply, it was assumed that the value of components are proportional to values of performances. Table 2 shows the comparison of components performances in 2004 and 2008 [6].

Table 2 Performance progress of laptop PC components

Date	Battery capacity and life	HDD storage capacity	Drive (speed)	CPU board (clock)	AC adapter capacity	LCD (pixels)
May 2008	7.5Ah	120GB	Max *8 DVD	2GHz* 2	16V 3.75A	1400 *1050
May 2004	7.0 Ah,	40GB	Max *8 DVD	1.3GH z	16V 2.5A	1400 *1050

Without any performance obsolescence it is expected that value of products for user may decrease. For example, because the products become very popular, so-called commodity product, the prices of the products often decrease. In this case, the average price of the example laptop PC in 2008 decreased to about 2/3 of the same class high-end mode in 2004l. [7] Considering these factors, the paper proposes an equation to calculate value change of laptop computer components through lifecycle. Table 3 indicates the estimated initial value and calculated decreased value of the components. And Fig.1 shows the value decrease rate which is calculated by dividing decreased value by initial value of components.

Table 3 Initial and decreased value of components

Component	Original component price	Decreased component value
Battery	25000	15555
HDD	18000	4000
CD/DVD drive	45000	30000
CPU board	66000	14300
AC adaptor	10000	6667
Main body	10000	6667
LCD	60000	40000

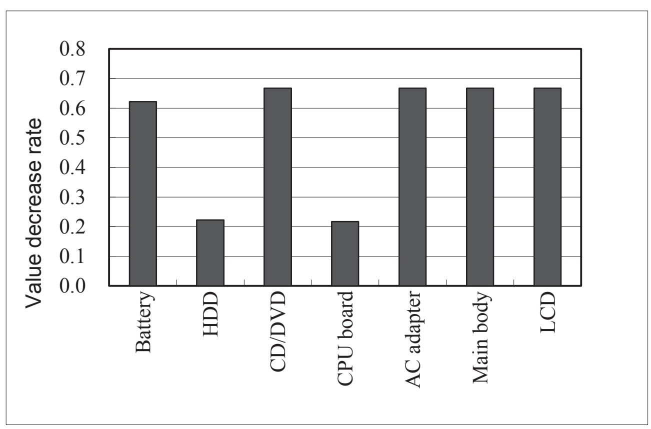

Fig. 1 Value deterioration of components

2.5 Upgradable and reusable components

Based on the value deterioration shown in Table 3 and Fig.1 and environmental impact of component production shown in Table 1, upgradability and reusability of components has been considered. In this paper, simply, it was defined that components with high rates of deterioration and relatively small environmental impacts are upgradable. And components with low rates of deterioration and large environmental impacts are reusable. By these simple criteria, it was decided that HDD and CPU board are upgradable and LCD is reusable.

3 CONSIDERATION ON FACOTORS TO EFFECT ENVIRONMANTAL IMPACT OF EEE

3.1 Social system of e-waste recycle

In Japan, social system to recycle used EEE has been established. As it was mentioned in the beginning, although the recycling rate is high enough, collection rate is not enough. A countermeasure is necessary. The next Fig.2 shows the simple inverse supply chain diagram of the social system for recycling in Japan including non-collected e-waste.

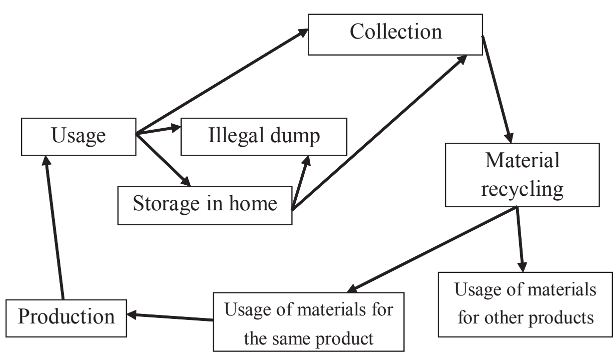

Fig.2 Inverse supple chain of e-waste

3.2 Virtual social system with component reuse and upgrade

On the other hand, if component reuse of used EEE becomes available, the CLD of e-waste management will be like Fig.3. And this paper is to consider this virtual chain of e-waste management with component reuse and upgrade. Thus, Fig.3 is the target inverse supply chain model of e-waste to be analyzed. In this inverse supply chain model, these assumptions are included.

1) Upgrade means ownership of the product belongs to the original owner and some components are upgraded.
2) Reuse means ownership of the product doesn't belong to the original owner and a retailer reuses the entire product or some components.
3) Consumers consider to purchase new laptop PC after certain years of usage.
4) A certain percentage of consumers bring back their used PC to retailers and consider they should upgrade components or purchase the whole products.
5) If the consumers decide to upgrade components, they upgrade those components and use the laptop PC for same length as 3).
6) When consumers don't decide to upgrade components, they decide to purchase new PC and use the new laptop for the same length, too.
7) Retailers reuse reusable components of used PC that have not been upgraded.
8) Based on the afore-mentioned analysis, upgradable components are HDD and CPU-board. And the reusable component is LCD.

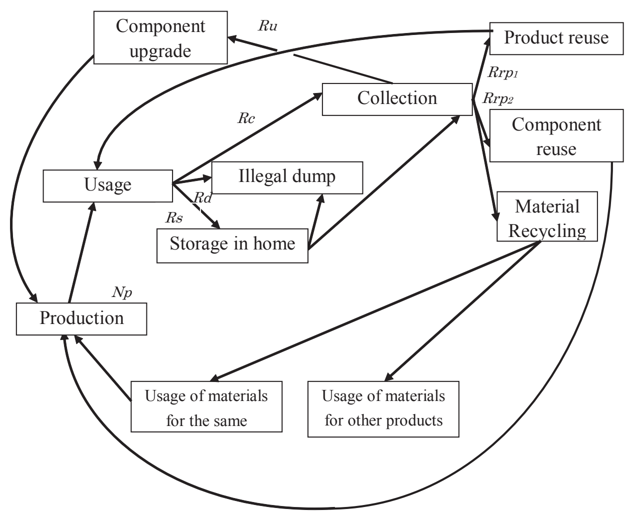

Fig.3 Inverse supply chain of e-waste including component reuse and upgrade

3.3 Definition of parameters

As shown in the figure, there are some key factors to affect the loop quantitatively. Thus, the paper defines these parameters that affect the loop, as shown below and in the figure.

Rc: collection rate, ratio of collected products among produced products

Np: produced number, produced number of products

Ru; upgrade rate, ratio of products that are going to be upgrade

Rrp_1: product reuse ratio 1, ratio of product reused as it is.

Rrp_2: product reuse ratio 2, ratio of product reused as components

Rd: dumped rate, ratio of product that are illegally dumped

Rs: storage rate, ratio of product that are stored in home after usage

Ruc_i: component upgrade rate, ratio of product in which components i is upgraded.

Of course there are some relations between the factors and the relation can be expressed by equations (1). In case that the total number of production is same every year, total environmental impact of laptop PC production can be expressed by equation (5).

$$Rc+Rd+Rs=1 \quad (1)$$

$$E_{total}=Np*(1-Rc)*Ep+Np*Rc*(Ruc_1*Ec_1+Ruc_2*Ec_2)+Np*Rc*Rrp_2*(Ep-Ec_3) \quad (2)$$

E_{total}: environmental impact of total production
Ep: environmental impact of product
Ruc_1: upgradable rate of HDD
Ec_1: environmental impact of HDD production
Ruc_2: upgradable rate of CPU board
Ec_2: environmental impact of CPU board production
Ec_3: environmental impact of LCD production

4 SENSITIVITY ANALYSIS OF FACTORS

4.1 Relations between performance progress and upgrade rate

In addition, based on the scenarios 4), 5), 6) and 7) in section 3.2, some assumptions can be made. In this paper, it is assumed that if the performance progress of a certain component in a year is high enough, the component can motivate consumers to upgrade all the upgradable components. And if all the components have relatively low performance progress rate, it means that the product has an enough performance to reuse as an second-hand product. Based on these qualitative analyses, equation (3) and (4) are assumed. And equation (5) is defined.

$$Ruc_1=Ruc_2=Ru \quad (3)$$

$$Ru+Rrp_1+Rrp_2=1 \quad (4)$$

$$Ec_{12}=Ec_1+Ec_2 \quad (5)$$

4.2 Affect of factors on environmental impact

Based on the equations from (1) to (5), it is possible to calculate total environmental impact of production and factors. Table 3 shows the list of parameters for sensitivity analysis. For each parameter, "low" is set -10% of the mid value and "high" is set to +10% of the mid value. Using these parameters set, the paper tries a sensitivity analysis of these parameters based on L8, 2 levels orthogonal array [8]. And Fig.4 shows the result of sensitivity analysis of 5 parameters shown in Table 4. Since the number of the product is common constant to all the cases, it can be eliminated from the calculation.

Table 4 List of parameters

Variable	Meaning	Low	High
Rc	Collection rate	0.45	0.55
Ru	Component upgrade rate	0.27	0.33
Rrp_1	Product reuse rate	0.27	0.33
Ec_{12}	Environmental impact of upgradable component production	*1.1	*0.9
Ec_3	Environmental impact of reusable component production	*1.1	*0.9

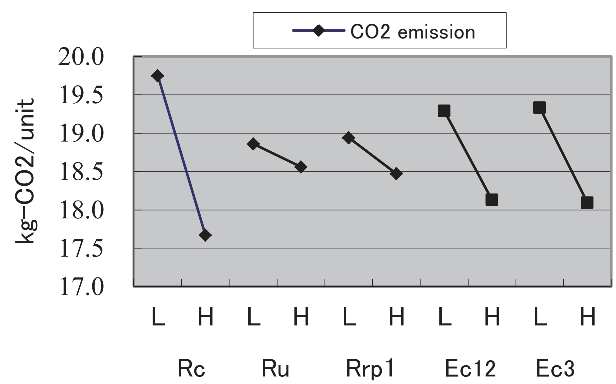

Fig.4 Effect of factors on total environmental impact

5 DISCUSSION

Although this is a very simple calculation based on assumption, Fig.6 suggests some findings about effects of parameters. The figure suggests, enhancing the collection rate is most effective to reduce overall environmental impact. And comparison of "upgrade" and "component reuse" tells that enhancing component reuse rate is a little more effective to reduce overall environmental impact, if it is possible by same efforts. In addition, reducing the environmental impact of production by "reduce design" is rather effective.

Of course, in a practical case, all these efforts should be carried out simultaneously. And in such cases, cross-effect of these parameters should be examined. For example, upgradable design will be effective in enhancing the upgrade rate, and it will be an incentive for consumers to bring back used products for consumers. Therefore, enhancing the upgrade rate will increase the collection rate, simultaneously. Upgradable design may of course affect the product reuse rate and component ruse rate.

In the aspect of environmental impact, impact of disassembly, assembly, collection and delivery at upgrade and reuse should be taken into account, next.

In addition, other factors to affect consumers' behavior should be considered. For example, consumers might not use upgraded products as long as the original product. They might not use second-hand product as long as the new products, either.

6 CONCLUSION

In this paper, firstly through the disassembly experiment, parts of the laptop computer were grouped into 7 major components. Those are battery, HDD, CD/DVD drive, CPU board, AC adapter, main body and liquid crystal display (LCD). The paper estimated the environmental impact of production for 7 components. By investigating the speed of performance progress of the components indicated by specifications, another aspect to characterize components has been discussed. The result of the calculation clarifies value deterioration of components Using these two sets of data, components suitable for upgrade and components suitable for reuse are identified. In this case study, HDD and CPU board are upgradable and LCD is reusable.

Then, a consideration of inverse supply chain was carried out and the paper assumed inverse supply chain model of used laptop PC with and without reuse and upgrade. Based on the model and simple assumptions, effect of each parameter which identifies the supply chain model quantitatively was tested. Using a sensitivity analysis method, it was concluded that enhancing the collection rate will be most effective to reduce overall environmental impact of the products.

Of course, many points should be considered next, including the reasonability of assumptions, cross-effects of parameters, other aspects to affect consumers' behavior and so on.

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The Research on Integrating TPI Database with CAD API Technique for Environmental Design

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Abstract
The purpose of this research is to introduce a numerical environmental assessment tool into computer aided design, and than makes designers accomplish design and inspection simultaneously. A new computer tool "EcoCAD" was developed according to the purpose. Its PCB-, electric component- and display component- environmental assessment on demand is based on the TPI (Toxic Potential Indicator) of Fraunhofer IZM and follows the UN's GHS' MSDS (Material Safety Data Sheet); and than incorporate into the SolidWorks API (Application Programming Interface) technique. Furthermore, EcoCAD can provide the corresponding suggestion with regard to the overall assessment (still in developing). A test MP3 player design case was successfully demonstrated the useful effect of EcoCAD in design and assessment process, and it indeed can reduce the R&D cost and manpower.

Keywords:
environmental design, toxic potential indicator (TPI), application programming interface (API), SolidWorks.

1 INTRODUCTION

Beyond doubt, the LCA is very necessary for the companies; however, it is very inconvenient for the companies' designers. The LCA information collection of a product keeps within the whole life of the product, including raw material, refined material, design, manufacture, transportation, maintenance, disposal, etc. The scope of information collection is wide and it results in complex inventory and assessment. Some software tools are helpful to the LCA project; nevertheless, it often embarrasses the R&D plan of the companies. Practically, the companies have to employ another group of engineers to carry out the LCA project. It could spend a lot of time and get no benefit to business strategy at present. Therefore, an idea "Environmental Assessment on Demand in Product Design" is conducive to resolve the problem. In other words, if the designers can construct their 3-D models and make environmental assessment in the mean time, a wide margin of increased efficiency would be obtained and the companies would save much R&D cost.

In this research, we would like to realize the above-mentioned idea and tried to establish a new tool for environmental design. The primary object of the tool is expected to support the most designers to implement environmental design; hence we used an existing business CAD software as a mother platform, and we adopted an easy-comprehend approach for the environmental assessment. The integration of business CAD software and environmental assessment is the emphasis of the research. Therefore, we planned to apply the Fraunhofer IZM's TPI (Toxic Potential Indicator) approach to the popular CAD software "SolidWorks" through API (Application Program Interface) technology, and the new tool could provide varied specific functions for advanced electric components and products.

2 BRIEF INTRODUCTION TO TPI

2.1 Developments and Applications of TPI

The TPI was developed by the German Fraunhofer IZM due to the environmental screening assessments of electronics through the indicators of hazardous substances [1-4]. The Fraunhofer IZM also built up a friendly calculator for the easier assessment [5]. Schischle et al [6-7] explained the calculation process and outsiders finally comprehend the TPI. Yen and Chen [8-9] and Fujino at al. [10] developed their respective exclusive TPI calculation according to their countries.

2.2 Basic Calculation for TPI

The TPI is numerical to quantify the hazardous potential of substances, and it is an assessment of a "worst-case-scenario" as a screening approach [1-4]. For the TPI assessment, the complete BOM (Bill of Material) is necessary, or else the assessment could be inexact. If we would like to know the TPI of a product, we can sum up

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the TPI of each component of the product, so

$$TPI_{Product} = \sum [TPI_{Component}] \quad (1)$$

where $TPI_{Product}$ is the total TPI of the product, and

$TPI_{Component}$ is the TPI of the component.

Both $TPI_{Product}$ and $TPI_{Component}$ are non-dimensional. In one of the components, there could be more than two materials; therefore we should sum up all the materials' TPI as following

$$TPI_{Component} = \sum [TPI_{Material}] \quad (2)$$

where $TPI_{Material}$ is the TPI of the material and it is non-dimensional as well.

Because a material could be also composed of more than two substances, we have to do the sum of the TPI of all the substances as following

$$TPI_{Material} = \sum [TPI_{Substance} \times m_{Substance}] \quad (3)$$

where $TPI_{Substance}$ is the TPI of substance and its unit is mg^{-1}, and then $m_{Subsance}$ is the mass of substance and its unit is mg.

The TPI is derived form three legally defined values: R-phrases/R-values, MAK (the German acronym for the "maximum workplace concentration") and WGK (the German acronym for the "water hazard classes"). If we would like to know those three values of a substance, we can search the MSDS (Material Safety Data Sheet) database of GHS (Globally Harmonized System). GHS is to use harmonized criteria for classifying and labeling of hazardous chemicals, the international adoption of GHS has been endorsed by UN (United Nations) and many international organization. As for the way to reach the values R-phrases/R-values, MAK and WGK can be obtained in the articles of Nissen et al.

3 DEVELOPMENT OF ECOCAD FOR ENVIRONMENTAL ASSESSMENT ON DEMAND

A TPI value of a substance or a component could be easily obtained through consulting MSDS database and manual calculation, but it definitely is a big problem to obtain total TPI information of a product in a short time. For a modern advanced electric product, the TPI assessment is difficult to finish in fast, especially for various electronic components. For the purpose of environmental assessment on demand during CAD stage, the TPI approach was incorporated into the CAD software platform. The new proposed integrated tool was named as "EcoCAD," and it was developed for most electric and electronic products.

3.1 Link between TPI database and CAD by API

TPI focuses on substances and its unit is mg^{-1}, therefore EcoCAD must collect mass of each component. Further, EcoCAD was expected to allow designers to obtain the TPI value by directly pointing each component model. SolidWorks API provides some API commands to support those requirements. Each TPI value of material (or single substance) is reached by the preceding approach and Taiwanese MSDS. Originally SolidWorks 2009 has restored many internal materials for CAD designers, and this working sheet can actively make links with the TPI database after launching EcoCAD. Moreover, designers can add other new materials which are not in SolidWorks 2009. Currently EcoCAD is still in Chinese Traditional, and has five working sheets including "Single Part," "Substance Attributes," "Special Substances," "Overall Information" and "Respective Information." Some working sheets are specially introduced.

3.2 General TPI evaluation for products

Most components (non-electric/electronic components, such as plastic or metallic components) can be evaluated in "Single Part." The SolidWorks API technique is introduced for constructing an automatic rapid measuring/evaluating function, such as the object commands "GetPathName" and "swPartGetMassPropel." After finishing modeling under the "Single Part" environment of SolidWorks, a designer can click the label of a 3-D model locating on the SolidWorks' hierarchical tree diagram and then push the button "Execute," immediately he can obtain all the TPI information of the model as shown in Fig.1.

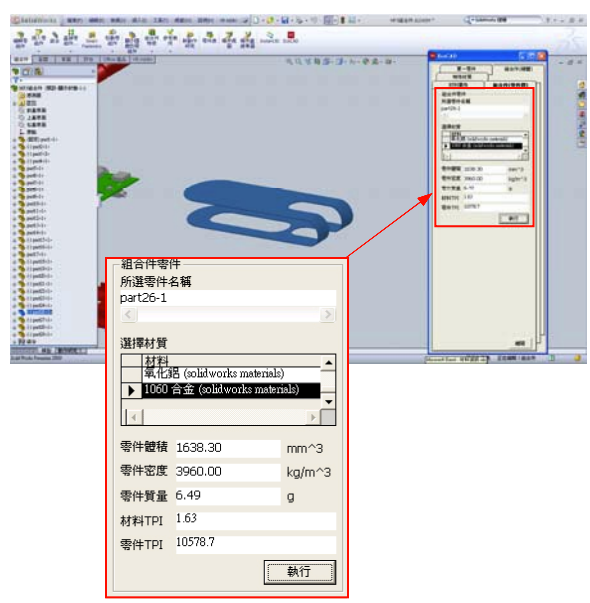

Fig. 1: TPI evaluation on an aluminium-alloy component

3.3 Special TPI evaluation for 3C products

The PCBs, electric/electronic components and LCD components of 3C products would make higher TPI value due to some negative-impact substances. Therefore the working sheet "Special Substances" is developed for evaluating them, as shown in Fig.2 to Fig.4.

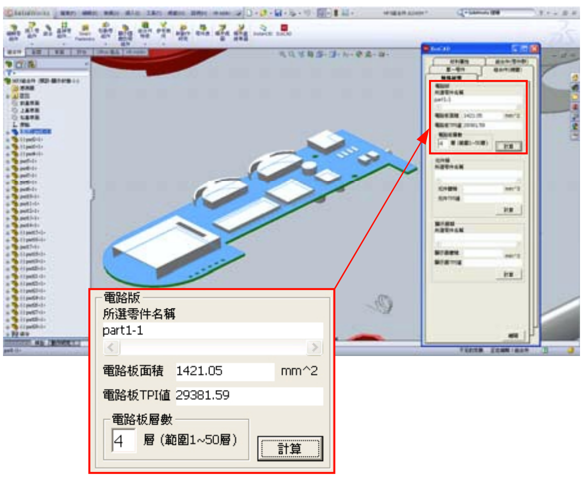

Fig. 2: TPI evaluation on a PCB

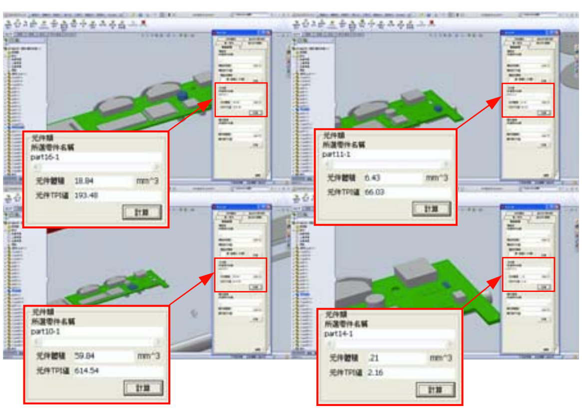

Fig. 3: TPI evaluation on electric/electronic components

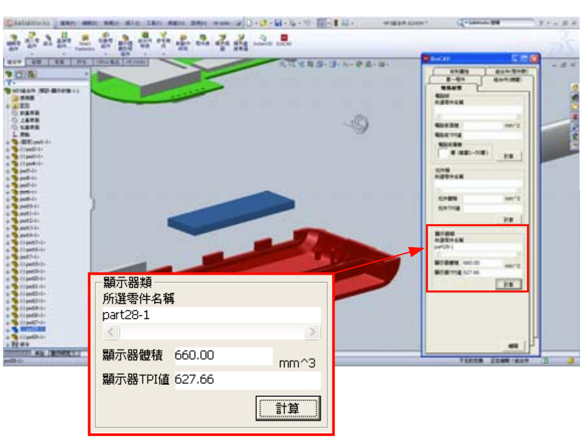

Fig. 4: TPI evaluation on LCD components

4 TEST DESIGN CASE

In this part, a design case will demonstrate the effect of EcoCAD and test its reliability. A MP3 player is very adequate to the demonstration because it comprises various components. The CAD model of that MP3 player could be entirely simulated and constructed in SolidWorks 2009, and that model contains all the components including a case, a metal cover, a PCB, some electric/electronic components and a LCD (Battery is not involved). Those components are constructed according to the expected real size, and Table 1 shows the result of TPI evaluation.

Table 1: TPI evaluation result of a MP3 player

<table>
<tr><th>Components</th><th colspan="2">TPI</th><th>Volume</th></tr>
<tr><td>Case</td><td colspan="2">0</td><td>3,631.37 mm^3</td></tr>
<tr><td>Metal Cover</td><td colspan="2">10,578.70</td><td>1,638.3 mm^3</td></tr>
<tr><td>PCB</td><td colspan="2">29,381.59</td><td>1,421.05 mm^2</td></tr>
<tr><td rowspan="4">Electric/Electronic Components (4 components in this case)</td><td>193.48</td><td rowspan="4">Total: 876.21</td><td rowspan="4">85.32 mm^3</td></tr>
<tr><td>614.54</td></tr>
<tr><td>66.03</td></tr>
<tr><td>2.16</td></tr>
<tr><td>LCD (Gray Level STN)</td><td colspan="2">627.66</td><td>660 mm^3</td></tr>
<tr><td>Total</td><td colspan="2">41,464.16</td><td>—</td></tr>
</table>

5 CONCLUSION AND FUTURE WORKS

This research realizes an idea "Environmental Assessment on Demand," and the proposed tool "EcoCAD" has been successfully demonstrated by a real product design case. EcoCAD will be very practical because it makes a designer know well the environmental performance of his developing product during the CAD modeling stage, and its suggestions can inspire the designer to modify the original design. Much practical TPI information of components, as PCB, electric/electronic component and LCD, has been built in EcoCAD. Although EcoCAD is still in developing, it could be regarded a model because it not only make the gap between design and evaluation connected, but also integrate them completely. The authors believe that it is indeed conducive to the enterprises which have less R&D human power, as the small and medium-sized enterprises in Taiwan or other countries in Asia. The R&D staff of enterprises can comprehend the performance of their developing product in advance; they also can find out the problem and reach the solution through EcoCAD, especially when meeting the component with higher TPI.

The proposed idea could be extended to other environmental regulations or criteria. For example, the issue "Carbon Emission" or "ErP Directives" are connection with LCA; therefore a suitable LCA database could be applied to link up with a business CAD software platform. The result of evaluation is definitely beneficial to proof, examination or verification. An idea "Eco-design Chain" will be constructed which can reduce the waste of time and human power. Of course, it needs a lot of works to realize the idea. In fact, the authors right now are making their efforts to make the dream come true.

ACKNOWLDGEMENTS

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Eco-innovation by Applying Design-Around concepts on Eco-ARIZ method

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Abstract

The study applied ARIZ method on sustainable design, and inserted design-around concepts on Eco-ARIZ. It started from collecting enough data of the patents, and analyzed the related data. The prior data must match with the first part "Formulation of system conflicts" of Eco-ARIZ tool, and transform into the information of Eco-ARIZ. Then, it must find the independent claims from the patents, and use the contradiction removing concepts with the design-around concepts to solve. After solving, it can help designers to find the possible resources from substances or fields in the environment. Finally, it can use Ideal Final Result (IFR) to check the innovative idea(s). An example is illustrated to demonstrate the capabilities of the proposed paper.

Keywords: TRIZ, ARIZ, Design-around

1 INTRODUCTION

The 21st century is the era of competition where structures of products have become more and more complex. To avoid willful infringements by competitors, companies would make patent applications to protect their products prior to introducing them. No company would be able to exist in this fully competitive world if there were no patents. A patent is a powerful tool for protection, which protects its own objects or methods. A product can only remain its competition in the market when appropriate patent claims are used to protect it.

Altshuller developed TRIZ in 1946 by summarizing the results of numerous patent analyses. Altshuller proposed many innovative design tools, such as the contradiction matrix and invention principles, substance-field analysis (Su-Field), idealization analysis, and the algorithm for inventive problem solving (ARIZ). These methodologies improve efficiency in finding innovative concepts and in generating creative ideas during the product design process.

Chang and Chen [1-3] proposed the design-around and extension method, and collected 40 examples of eco-innovation using TRIZ inventive principles, which covered several product and process designs. Zhang presented a method which can help designers design around existing patents and recreate on the basis of the patents of competitors [4]. Jiang *et al.* used contradiction matrix and inventive principles to design around existing product patents, and recreated a belt conveyor [5]. Liu *et al.* presented an innovative design process which can reduce the design cost, shorten the development cycle and lower the risk about patent infringement [6].

Eco-ARIZ was firstly presented by Chen and Chen [7], which combined eco-innovation concepts with ARIZ method. This study proposes a novel design method by combining design-around concepts and Eco-ARIZ.

2 INTRODUCTION OF DESIGN-AROUND CONCEPTS

Intellectual Property Right (IPR) is the important issue among countries nowadays, of which patents is the most common one. The authorized right from the patents is the type of right to exclude. With the exception of the patent owner, it is the right to exclude others from making, selling using or importing the invention or method in accordance to the above purposes. The patents are therefore the key to the competitiveness of a corporate. The design around in patents originated from USA to counter the infringement allegations of legitimate competitive behavior. Proper use of it can maintain the market competitiveness. On the contrary, a risk of failure exists.

In the patent field, design around is an important measure to enterprises for avoiding the occurrence of infringement, and is seen as a response strategy. It mainly takes a legitimate avoidance to a specific patent claim to change a product's design. The avoidance with the result may still exist with risks, but may act as an important mean for striking back.

The following four are the steps for the avoidance of an innovation patent:

(1) The establishment of a basic database using patent index for search,

(2) Using analytical skills to integrate valuable information,

(3) Using design around to avoid infringement,

(4) Assess the submission of the application.

First of all, various analytical and accessible messages can be found from different databases such as the Intellectual Property Digital Library (IPDL) of WIPO, the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), Japan Patent Office (JPO) and Taiwan Patent Search. The innovative methods commonly

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used include: (1) imaginative, associative search, or (2) the TRIZ method, which the latter further includes many tools. When the methods of above are used to obtain a solving plan or innovative thought, the application for a patent is then submitted according to the different patent laws among countries to enhance its competitiveness. In other words, the improved product which may be exposed to infringement can avoid falling into the claims of the original patent owner.

According to the developments by case law, the United Stated summarized the principles of patent design around based on a law perspective:

(1) The elements and their functions by the plaintiff claims are deleted for carrying out design.

(2) A specific element in the claims is selected and replaced by different elements; it does not just have minor changes.

(3) A specific element of the plaintiff claims is selected, and physical changes are made to achieve a different type of technical mean.

(4) Design a functional structure with different means plus function(s) of the plaintiff.

(5) Design a function expression with a disclosed structure or equivalent object which differs with the plaintiff function.

Finally, a non-infringement report is written by a patent agency or patent attorney. The report is evaluated from a legitimate view to see if it meets with the three primary conditions: All Element Rule, Doctrine of Equivalent/ Reverse Doctrine of Equivalent and Prosecution History Estoppel. It is examined by an outside patent attorney to determine if it is a legal design around behavior. If the patent case is determined as a patent infringement by court, it may avoid aggravated punishment from willful infringement.

3 INTRODUCTION OF ECO-ARIZ

This section briefly describes the procedure of Eco-ARIZ. Eco-ARIZ was revised from ARIZ-85C by Fey [8]. The procedures of Eco-ARIZ are simplified shown as below:

3.1 Part1 Formulation of system conflicts

Step 1.1 Describe the problem completely.

Step 1.2 Simplify and find the Primary Function (PF).

Step 1.3 Determine whether the problem is suitable for using Eco-ARIZ to resolve it or not.

Step 1.4 Determine the Major Components (MC) of the eco-system.

Step 1.5 Choose and match the components of system conflicts.

Step 1.6 Draw the diagrams of the models of the system conflicts in pairs (SC-1 and SC-2).

3.2 Part 2 Analysis of the system conflicts and formulation of a mini-problem

Eco-ARIZ and ARIZ-85C [8] both have the same character in part2, which presents two different solution procedures according to whether the auxiliary tools (AT) contained in the system have any conflicts or not. In this study, AT is one component in the independent claims. It only introduces the situation that system contradiction (SC) includes AT in the part2.

Step 2.1 SC includes AT.

Step 2.2 Eliminate AT.

Step 2.3 Build the analytic conditions of SC-3.

Step 2.4 Perform a Su-Field analysis of SC-3.

Step 2.5 Formulate an eco-mini-problem.

3.3 Part 3 Analysis of the available resources

Step 3.1 Specify the conflict domain (CD).

Step 3.2 Specify the operation time (OT).

Step 3.3 Define the possible resources of the Su-Field model in step 2.4.

3.4 Part 4 Development of conceptual solution

Step 4.1 Select one of the X-resources for modification from step 3.3

Step 4.2 Formulate an eco-Ideal Final Result (IFR) for the selected X-resource

Step 4.3 Formulate a physical contradiction macro

Step 4.4 Resolve the physical contradiction macro

Step 4.5 Formulate a physical contradiction micro

Step 4.6 Resolve the physical contradiction micro

Step 4.7 If the eco-mini-problem has not been solved

4 ECO-ARIZ WITH DESIGN-AROUND CONCEPTS

The five principles for patent design around were mentioned in Section 2. These principles are combined with Eco-ARIZ. The patent claims are consisted by independent and dependent items which includes many elements (e.g., A, B, C…). Furthermore, the dependent items belong to a certain element (or element combination) of the independent item (e.g., A1, A2,…, B1, B2,…, C1, C2…). When the designer uses design around concepts, avoiding the independent items (e.g., A=A1+A2+A3+A4 ==> A'=A1+A2+A3) is needed. The independent items which are avoided would definitely avoid the dependent items. This is a very important principle in design around method.

The method is applied to patent search and analysis at the very beginning. The required information from formulating system conflicts, i.e. the first part of Eco-ARIZ, can be achieved from prior art.

Part 2 - Analysis of the system conflicts and formulation of a mini-problem. This part has two different solving branches in Eco-ARIZ. However, as elements will definitely exist in the independent items of the claims, the other situation is therefore not considered (the part which does not include AT). In the patent case a certain element of the independent item is used as an auxiliary tool (AT) and removed. Further on, SC-3 is established which Su-Field is used to draw the problem model. The standards are used to solve this model while creating a mini-problem.

Part 3 - Analysis of the available resources. The related information for this part can be found from the abstracts of prior art patents, including the space of the issue, the time when contradictions were created and possible components or fields.

Part 4 - Development of conceptual solution. A component from above is selected for innovation, which the ideal final result (IFR) is established and a conceptual solution is inspected. A solution can be found if it meets to IFR; if it fails to meet with IFR, other methods are then used to conduct reanalysis.

5 CASE STUDY

Screws are common connected between two components in products. Products are usually directly destroyed in recycle at their end-of-life (EOL), because the disassembly cost by human is high and the disassembly efficiency is too low. In the case study, the screws are designed as a patent forms as follows:

Claims:

A connected tool, which contains a hut, a spindle, and threads…………

The hut, the spindle, and threads are the components of the independent items. Choosing one of the components as AT, and use Eco-ARIZ to remove the contradictions.

Part 1- Formulation of system conflicts

The information can find from the prior art, *e.g.,* primary function (PF), major tool (MT), auxiliary tool (AT), major components (MCs) and the contradictions about the problem.

(1)PF: Connecting ability.

(2)Contradictions: Screws are popular connecting tools, but they pollute the environment without recycling.

(3)HA: The harmful action is polluted the environment.

(4)UA: The useful action is easy for using and low cost.

(5)Major component: Screws.

Part2- Analysis of the system conflicts and formulation of a mini-problem

Choose one of the components in the independent items (e.g., the spindle). Removing the spindle (AT) and formulate SC model and find the related Standards to resolve.

Mini-problem: Avoiding to use the spindle enables easy maintenance of the X-resource at low cost (UA) with limited environmental pollution (HA) but without decreasing connecting capability (PF)

Part3- Analysis of the available resources:

(a)CD: Screws.

(b)OT: After the products are recycled.

(c) Define the possible resources (substance or field):

Resources of the CD: Screws

Resources of environment:

The components which are connected by screws; or the mechanical field.

Part4- Development of conceptual solution

(1) Choose the spindle to innovate.

(2) IFR: Find the ideal fasteners with low pollution.

Formulate the solution

The screws are common made by single material and manufacturing process. The innovative idea is to divide the spindle into outside case part and inside empty part.

(1) Outside case part: The part is composed of plastic and strong material.

(2) Inside empty part: The part can be filled with many micro particles.

The novel fastener are composed of the two part, and it is easy to disassemble or assemble by stuffing or separating the micro particles.

6 SUMMARY

The study combined the design around concept in patents with Eco-ARIZ to let the designer add the design around concept during the product design process. This can avoid infringement after the product is introduced.

The results after design around are sometimes successful; the design around result is not patent characteristic and may involve infringement. However, this does not indicate that design around is a failure and may further fall into another invention.

The study also provides a case in regards of Eco fasteners. After combining the design around concept with Eco-ARIZ, an innovative smart fastener was created which were different the smart fasteners using shape memory alloy and shape memory plastic.

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A Low Carbon Product Design Method Based on Process-Scenario Design

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Abstract

The wave of GHG emission reduction requirement slammed on the industrial society. Product manufacturers as well as service providers faced pressure of GHG emission reduction through all their activities. Thus, methodologies that reduce GHG emission at each life cycle stage are developed, suggested, in some case, even adopted and applied in companies. However, though only few methods forecasting GHG emission at the down-stream of life cycle are suggested, those methods are still limited by some obstacles such as allocation problems, complexity problems, uncertainty problems.

In this study, a process-scenario based low carbon product design method is suggested. The suggested method consists of an allocation method including allocation criteria development and allocation factors identification, the process inventory with inter-lifecycle information, and a scenario creation method. This method let a product/service designer/developer estimate GHG emission of a product alternative and find an alternative reducing GHG emission of a product' life cycle.

The suggested method may be used in product design process or service design process or even at the gate of waste treatment process. Further researches are required to increase accuracy and preciseness of inventory database, representativeness of allocation factors and validity of scenario expected.

Keywords:

GHG emission, low carbon, product design, process-scenario design,

1 INTRODUCTION

Huge tide of green growth swept over Korea as well as world recently. Each national government faced the demand of green growth and is trying to reduce their greenhouse gas (GHG) emission with introducing or preparing to introduce a regulation of GHG emission limitation. At the same time, companies also have been paying sharp attention to rapidly changing market environment.

All projects and plans related in green growth are based on that those projects and plan may reduce GHG emission. Then, in order to reduce GHG emission, first, those who want to reduce GHG emission should know GHG emission accurately, and, second, conduct GHG emission reduction measures.

To estimate GHG emission, GHG emission internationa standards such as PAS 2050 [1], ISO 14064-1,2,3 [2,3,4] are already established and ISO CD.2 14067 [5] is underdeveloping. Moreover, GHG emission estimation methods in detail are suggested in IPCC guideline[6], which gives GHG emission estimation methods to stakeholders such as national governments and organizations.

Although GHG estimation methods are given by standardization organizations or public institutions, GHG emission reduction method is hardly to find such methods, which implies that a GHG emission reduction method is difficult to be agreed by stakeholders, in addition, it is impossible that a standard covers all products and services doubtlessly. Only some ecodesign standards such as ISO/TR14062 [7] or IEC 62430 [8] give a way to reduce GHG emission as a part of ecodesign measure.

This research introduces a low carbon product design method based on process-scenario method, the proposed

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method cosists of 1) process-scenario definition of life cycle product/service system, 2) design alternatives development and its interaction consideration 3) GHG emission estimation and the best design alternative selection 4) application of the proposed method.

2 RESEARCH QUESTIONS

In order to clarify the purpose and goals of this research, here gives research questions.

2.1 Question 1: What kind of GHG emission reduction method do we need?

As mentioned above, it is impossible that a GHG emission reduction method covers all the products/services, so that it is needed to find some constraints to develop a GHG emission reduction method. This question is to clarify intended use of the proposed method.

2.2 Question 2: How to decide a definition of life cycle product/service system

It is not a question about system boundary, but about system structure. As a matter of fact, system boundary setting is quite important if GHG emission estimation is only required. However, this research is to reduce GHG emission through products/services' life cycle, so that, design alternatives should be described with components of system structure.

2.3 Question 3: How to connect a component to another component of a product/service system with considering characteristics of interrelation and interaction among components and life cycle stages?

If an alternative is replaced by another, the change is not only the name of alternatives, but also components of product/service system. Even if only a small component is changed, the change may cause big change through product/service's life cycle. Therefore, a method considering interconnection should be developed.

2.4 Question 4: How to estimate GHG emission of alternatives?

This is not an even LCA study. This is a research on GHG emission reduction method development. Thus, given alternatives are not produced products or in serving. It is required that an estimation method of GHG emission changes followed by alternative changes, and existing LCA methods are not enough.

3 METHOD

3.1 Overview and constraints

The proposed method is developed to use in product design and development stage. Therefore, a prerequisite is that nothing is confirmed yet until designer makes decision.

The proposed method is to predict GHG emission of an alternative at time t of its life cycle time line theoretically. Whenever time t is, with the method may predict GHG emission of selected alternative from time t to its afterward. The method can be applied to the product and the service equally.

3.2 Life cycle product/service system definition

In view of an LCA study, a product/service system consists of material/energy flows and processes. The proposed method analyzes the system a little differently. The method supposed that a product/service system consists of processes and paths. And both scenario and design method may consist of processes and paths, to avoid confusion between scenario and design alternative the definition of those are given below.

Process

ISO 14044 defines process as ' set of interrelated or interacting activities that transforms inputs into output.'

Path

The path may be defined as a connection between two processes, however, the path is needed a decision making, and in the method, the decision making is based on design alternative selection. And a path change may cause another path at another process or stage.

Scenario

A scenario is defined as a set of series interconnected with processes and paths through entire life cycle

Design alternative

A design alternative is defined as a set of fixed scenario.

3.3 Interconnecting method

A process is interconnected with other through paths. An inventory may be used for arrange the information and data of the process itself. The inventory should include the information of input and output flow, its characteristic and interconnected processes information.

3.4 GHG emission estimation method

In order to GHG emission estimation, the method adopted Song and Lee's [9] method

4 CONCLUSION

The research raised questions about low carbon product design system. And, to answer questions developed a low carbon product design system based on process-scenario system. The proposed method is required an empirical study.

5 ACKNOWLEDGEMENT

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Low-Carbon Product Ecodesign using a TOE Performance Indicator

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Abstract

Low carbon product ecodesign method considering TOE as a performance indicator of a product is proposed here. The amount of life cycle GHG emissions and unit cost of each material of a product are integrated into TOE. Applying the appropriated conversion for TOE is the crucial work. The proposed method mainly consists of two elements: i) gathering life cycle GHG emissions data of a product and ii) integrating the GHG emissions and economic cost data into TOE. The multiple regression method used to estimate the energy contribution parameter during product's use stage and the recycling rate calculation based on GHG emissions are two supplementary methods to complete TOE evaluation.

The key used of TOE value is to compare the reduction effect between reference and alternative product. The proposed ecodesign method was verified through a case study by assessing an existing product and an alternative with urban railway vehicle where 6 cars in a single formation. The case study confirms that the proposed method is a viable alternative to the ecodesign of a product, as it yields a quantitative assessment of the improvement alternatives.

Keywords:

eco-design, greenhouse gases, eco-efficiency, TOE, railway vehicle

1 INTRODUCTION

It is imperative to reduce and prevent greenhouse gas (GHG) emissions from the whole life cycle stage of a product. In order to meet the heightened interest in environmental issues, such as sustainable development and low-carbon green growth, ecodesign can be envisaged as a viable solution. Previous research [1, 2, 3, 4, 5] on ecodesign with indicators such as eco-efficiency and a combination of LCA and LCC has reached a level that can be easily understood and applied by designers to a great extent; nevertheless, it remains insufficient in that the research has mainly focused on stage-by-stage studies on eco-materials, environmentally-friendly disassembly, recycling and re-manufacturing, and energy efficiency improvements at the use stage. Therefore, the development of techniques is necessary that enable simulation of the overall effects, such as the amount of energy consumption at the use stage and recycling and recovery rate at the disposal stage depending on the chosen material at the design stage.

The objective of this paper is to propose a low carbon product ecodesign method that minimizes GHG emissions over the entire life cycle stages of a product. A specific objective is to develop a life cycle embedded GHG emission estimation method to reduce a product's GHG emission using the Ton of Oil Equivalent (TOE) performance indicator. The applicability of the proposed low-carbon product eco-design was evaluated using a railway vehicle.

With the TOE-performance indicator, a designer can compare the life cycle GHG emissions of the alternative materials and make the right choice regarding the proper alternative material.

2 LOW CARBON PRODUCT ECODESIGN

2.1 Concept of life cycle GHG reduction ecodesign

The ecodesign procedure suggested by ISO/TR 14062 and IEC 62430 consists of four stages: product planning, conceptual design, detailed design, and mass production. The life cycle embedded GHG emissions of a product can be reduced by applying an ecodesign procedure to the product, including its end-of-life (hereafter, EoL) stage. The environmental impact at the production stage and at the disposal stage may vary depending on the material involved.

In this study, the end-of-life vehicle treatment process of the automobile industry for railway vehicle treatment and the recycling technology of a composite material considered as a lightening product are reflected in the recycling scenario.

2.2 Life cycle embedded GHG emissions calculation

The life cycle embedded GHG emissions of a product can be quantified by the method proposed by [6]. In this research, the embedded GHG emission of manufacturing and distribution stage are not included in the calculation of the product's life cycle embedded GHG emissions due to the difficulties of gathering information of those stages.

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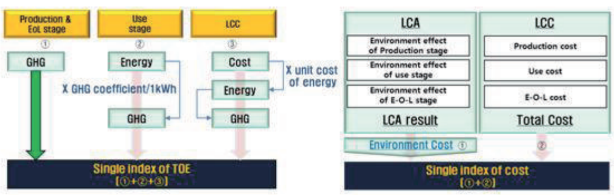
In the case of a product that uses energy, multiple regression analysis is used. The product recycling scenario is created by surveying the current technology used in the automobile industry.

2.3 Concept of the TOE-performance indicator

Fig. 1(a) shows the concept of integration assessment method with TOE. Fig 1(b) shows an existing method that integrates the results of LCA and LCC into the cost. As can be seen in Figures 2, the proposed integration assessment with TOE is simpler than the existing assessment method. And the results from the proposed method are more objective, it means more credible, than the current method and can be directly applied to the CDM(Clean Development Mechanism) project because the results shows the amount of GHG mitigation.



(a) (b)

Fig.1: Comparisons of the integration assessment method

Eq. (6) is the definition of a TOE performance indicator (TPI) that is used to assess the performance, the amount of the GHG mitigation of a product between the reference and alternative product. When the value of TPI is less than 1, the alternative has lower GHG emission as such the product designer can choose the alternative in his design, while greater than 1, the reference product is better than alterative.

$$TPI = \frac{TOE_{alternative}}{TOE_{reference}} \leq 1 \qquad (1)$$

$TOE_{reference}$ and $TOE_{alternative}$ can be calculated from Eq.(2) ~ eq.(6).

$$TOE_{reference} = TOE_{material} \pm TOE_{energy} \pm TOE_{cost} \qquad (2)$$

$$TOE_{alternative} = TOE_{material,alternative} \pm TOE_{energy,alternative} \pm TOE_{cost,alternative} \qquad (3)$$

Here:

$TOE_{material}$ refers to the TOE value from the amount of GHG emission of the material

TOE_{energy} refers to the TOE value from the amount of energy at the use stage of the product

TOE_{cost} refers to the TOE value from the cost amount of each material

$$TOE_{material} = \left(\sum_n GE_n + \sum_n GE_{EoL_n}\right) \times \frac{0.22TOE}{0.424tCO_2 - eq.} \qquad (4)$$

$$TOE_{energy} = 0.00022 \times \sum Use\_stage_{energy} \qquad (5)$$

$$TOE_{cost} = 0.00022\left(Cost_{material} \times \frac{1}{Unit\_Cost_{Electricity}}\right) \qquad (6)$$

Here, 0.00022 is the conversion coefficient for 1kWh into TOE, as suggested by the IPCC. Eq. (9) is employed to convert the potential CO_2 of the material used in the reference product to be generated at the manufacture and disposal stages into TOE, while Eq. (6) is used to compare the environmental and economic effects when an alternative is selected for the purpose of product improvement, with consideration also given to the disposal stage.

2.4 Concept of the GHG basis recycling rate

According to the ISO 22628 standard [7], the recycling process consists of four stages: pretreatment (m_p), dismantling (m_D), metal separation (m_M), and a non-metal residue treatment (m_{Tr}, and m_{Te}). M_v is the vehicle mass. The recycling rate based on weight is calculated as shown in Eq. (7).

$$R_{cov} = \frac{m_p + m_D + m_M + m_{Tr} + m_{Te}}{M_v} \qquad (7)$$

The recycling rate based GHG emissions can be calculated using Eq.(8)

$$R_{CO_2} = \frac{\sum CO_{2,EoL}}{\sum CO_{2,initial}} \qquad (8)$$

3 LIFE CYCLE GHG EMISSION CALCULATION

3.1 Reference product, functional unit, and system boundary

An electric railway vehicle was used in a case study to verify the applicability of the proposed low-carbon product ecodesign method.

Functional unit

The functional unit (f.u.) of the product is 6 cars in a single formation. In this research, it is assumed that each car is composed of the same components and materials.

System boundary

System boundary includes all stages of the product except the production, maintenance stage and energy for the end-of-life process due to the lack of information and considering the scope of this study, which only compares the CO_2 contribution between the reference material and an alternative material, as mentioned above.

All material information was gathered within 95% of the total weight of the product.

3.2 Reference product information

A railway vehicle is mainly composed of two parts, a car body and a bogie system. The reference product in this study is one formation of railway vehicle which consists of six cars as such the total weight of the reference product is 215.3 ton/ f.u. (35,715 ton/ car x 6 cars).

3.3 Estimation of the amount of embedded GHG emissions

Fig.2 shows the amount of GHG emissions of the initial material and the amount after the EoL treatment. The components and materials are classified by the EoL process according to the ISO 22628 standard. The total amount of GHG emissions was 83.5 ton CO_2-eq./car of initial material and 74.1 ton CO_2-eq./car after the EoL treatment. The efficiency of the EoL process of each material in the automobile industry and the data from national statistics for the landfill requirements of each material are reflected in the recycling scenario.

Classification	component	Initial weight (kg)	GHG (kgCO_2-eq.)	EoL treatment scenario				GHG after EoL treatment (kg CO_2-eq.)			
				Reuse	Recycling	Recovery	Disposal	Reuse	Recycling	Recovery	Disposal
Pre treatment	Coolant	4.5	25.6	100%			0%	-25.6			
	Oil	8	8			70%	30%			-20.6	0.21
	Lubricant	5	5	10%		85%	5%	-0.5			0.02
	tank	600	2,030		90%		10%	-1,827			0.42
	--	--									
	Sub-total	**617.5**	**2,061**					**-26**	**-1,827**	**-21**	**1**
Dis mantling	RSW2 & A2	2,220	5,960		95%		5%		-5,662		0.78
	Cast iron	508	716		95%		5%		-680		0.18
	Bogie frame	1,660	1,860		95%		5%		-1,767		0.58
	J. box ass'y SC450	315	353		95%		5%		-335.4		0.11
	Bearing steel	49	0		95%		5%		-0.3		0.02
	SM45C	42	113		95%		5%		-107.4		0.01
	SCP1	66	0.38		95%		5%		-0.4		0.02
	SS400	4	9		95%		5%		-8.7		0.0
	--	--									
	Sub-total	**19,730**	**34,756**					**-36**	**-30,322**	**-2,181**	**12**
Shredd ing	Interior Panel										
	Glass fiber	575	2,640	60%			40%	-1,584			1.61
	NOMAX	104	1,340				100%				1.27
	Phenol	173	669				100%				2.12
	Carbon steel	43	115		95%		5%		-109.3		0.02
	Floor										
	PLY WOOD	1,603	2,000			80%	20%			-1,810	19.47
	Carbody block	5,190	18,900		90%		10%		-17,010		3.63
	--	--									
	Sub-total	**15,367**	**46,702**					**-2,590**	**-34,573**	**-2,609**	**33**
Total		**35,715**	**83,519**					**-2,650**	**-66,722**	**-4,811**	**46**
								-74,139			

Fig.2: Initial amount of GHG emission and after the EoL treatment of the materials (1 car)

3.4 Energy consumption prediction of a railway vehicle

In this study, multiple regression analysis is used as a means of predicting the energy demand under various energy consumption factors. The contributing factors for energy consumption were simplified into four factors: the vehicle weight, number of passengers, operation distance, and number of stations.

Table 1: Operation data from railway operation bodies and the regression results

Operation company	Line	Vehicle weight (ton)	No. of Passenger (1000person)	Running distance (km)	No. of Station (ea)	Electricity (real) (MWh)	Electricity (estimation) (MWh)
Daegu	#1	6,786	61,488	2,918,412	30	36,001	32,168
Seoul Metro	**#1**	6,009	167,287	20,504,140	10	54,512	46,371
	#2	30,023	719,439	91,945,303	50	263,840	253,662
	#3	18,865	257,198	52,790,887	31	143,993	148,341
	#4	16,788	298,894	53,328,581	26	124,273	138,750
Seoul Metropolitan Rapid Transit	**#5**	19,973	597,357	18,591,288	51	114,474	121,405
	#6	11,152	213,896	6,878,704	38	59,283	60,222
	#7	16,740	110,519	3,540,108	42	89,128	82,421
	#8	4,330	216,343	6,285,506	17	25,548	23,877
Coefficient		**4.73**	**0.01**	**0.001**	**163.44**	**-8796.70**	R^2=0.98 R^{*2}=0.96

To predict the energy consumption of a railway vehicle during the operation stage, data from Korean operation companies (Seoul Metro and Seoul Metropolitan Rapid Transit Corp.) over the past three years (2006~2008) were collected for the multiple regression analysis and shown in Table 1.

Using the estimation of energy consumption as shown in Eq. (9), the energy consumption of the reference product was estimated as 212,370 MWh for 25 years.

$$\text{Energy consumption} = 4.73X_1 + 0.01X_2 + 0.001X_3 + 163.44X_4 - 8796.70 \quad (9)$$

Where,

X_1 (weight, ton) = 214.3 (6 cars/formation)
X_2 (number of passenger, thousand) = 213,896
X_3 (distance, km) = 6,878,704
X_4 (number of station) = 38
Life years: 25 years

3.5 Recycling rate calculation

The calculation result of the recovery rate of the railway vehicle using Eq. 7 was 97%.

The recycling rate based on embedded GHG emission of material was calculated following the proposed calculation formula in Eq. 8. To calculate the GHG emissions during the EoL stage, the on-site treatment efficiency of an automobile EoL treatment company was used for the recycling scenario. Regarding the energy recovery, the average heat capacity of each composition specifically from the Korean shredder company, was used. For the landfill data, the emission factors by the IPCC were used. As a result, the recycling rate based on the GHG emissions was determined to be 89%.

4 APPLICATION

4.1 Contribution analysis of GHG emissions

Lightening technology for a railway vehicle is important because various synergetic effects can be gained, such as fatigue reduction, a longer lifespan of the rails through a reduction of the vertical load, and energy savings. From the results of the GHG emission analysis of each material, aluminum for the car body and the FRP for the bogie frame were chosen as the alternative materials.

Aluminum and a composite of fiber-reinforced plastic can reduce the weight by 15% and 35% each compared to steel from the UIC report (UIC, 2010) and the results of KRRI research (KRRI, 2008).

Evaluation of the GHG emissions of the material

The GHG emissions from the aluminum body and the composite bogie frame, which were applied specifically to reduce the weight, were compared with those of a stainless steel car body and the bogie frame at the material stage. The results show that the embedded GHG emissions of the alternatives were higher than that of the existing materials.

Estimation of electricity consumption at the use stage

The lightening effect of a railway vehicle after adopting the alternatives of an aluminum car body and a composite bogie frame resulted in a total reduction of 5.4%, accounts to -1,376 MWh/25yr, f.u. approximately, compared to the existing vehicle.

Converting cost into the TOE

To include the effect of the material cost gap into the evaluation, as the material cost of the alternatives is higher than that of the existing material, stainless steel, the total cost of each material applied to the railway vehicle was converted into the TOE. As a result, it was confirmed that the TOE of the alternative material was higher than that of reference material. The details of the procedure and the results are shown in Table 2.

Table 2: TOE calculation results from the cost of each material

Classification	Reference (Stainless steel)		Alternative		Remarks
	Car body (steel)	Bogie frame (steel)	Car body (Aluminum)	Bogie frame (composite)	
Wt (kg)	5,190	3,320	4,412	2,158	
Unit cost (1000₩/kg)	1.09	1.09	3.96	2.0	Ungureanu et.al & ALSTOM's report
Total price (1000won)	5,57.1	3,618.8	17,471.5	4,316.0	
Electricity (kWh)	80,816	51,697	249,593	61,657	Industrial price 70₩/kWh
tCO_2-eq.	34.27	21.92	105.83 (71.56↑)	26.14 (4.22↑)	0.424tCO_2/MWh
TOE	17.78	11.37	54.91 (37.13↑)	13.56 (2.19↑)	Coefficient 0.00022TOE/1kWh

Recycling rate comparison

The total amount of recycled GHG was -84,668 $kgCO_2$-eq. per car compared to the initial embedded GHG emission of 98,799 $kgCO_2$-eq. The recycling rate in terms of GHG was approximately 86%, representing a reduction of 3% as a result of using the alternative material. However, the recycling and recovery rates based on ISO 22628 (ISO, 2003) were identical, at 91% and 95%, respectively.

4.2 Life cycle GHG emission and TOE

The TOE comparison results of each stage are shown in Table 3.

Table 3: Embedded GHG emissions of a railway vehicle over its life years (25 years)

Classification		Raw material		Use	End-of-life	Total	Remarks
		CO_2	cost				
Reference Product	$tonCO_2$-eq.	501.1	56.2	90,044.9	-444.8	90,157.4	
	TOE	260	29	46,721	-231	46,779	
Alternative Product	$tonCO_2$-eq.	592.8	132.0	89,461.5	-508.0	89,678.3	-479
	TOE	308	68	46,419	-264	46,531	-249

From the result of TOE performance indicator, which shows a value of less than 1, a designer can adopt this material as an alternative as a lightening material at the design stage. It can be confirmed from the results that the energy consumption at the running stage accounts for most of the total consumption, which suggests the need for technology to improve the running energy.

$$\text{TOE performance indicator} = \frac{46,530}{46,779} = 0.99 \leq 1 \qquad (10)$$

5 SUMMARY

5.1 Ecodesign for life cycle GHG emission reduction of product through TOE

To create designs to improve the eco-performance of a product, the environmental and economic benefits from the use of alternative materials are evaluated in an objective manner to assist the designer's decision-making process. In this paper, through a case study of a lightening material as an alternative product, a simple way to predict the amount of embedded GHG emissions after a change of the materials is suggested with the concept of TOE. It was confirmed that this low-carbon product eco-design concept can be applied to other products which are similar in their characteristics to a railway vehicle.

5.2 Consideration of the recycling rate calculation method

For current circumstances, a low-carbon product, and a low-carbon society, a CO_2-basis recycling rate calculation method is preferred to the weight basis recycling rate calculation method. From the verification with the case study, it was also confirmed that the CO_2 basis recycling calculation method is applicable to other products.

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Development of Diagram for Estimating Value of Wastes and Waste Heat in Association with Technology

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Abstract

A new methodology was presented, by which the value of organic wastes and waste heat is quantitatively estimated with associating technologies. The diagram proposed is the relationship between production cost per year and thermal energy utilized per year. Based on energy cost line of heavy oil and the cost line of final product such as hydrogen, the values of organic waste organic and waste heat can be determined by the drawing in the diagram. It was shown the diagram gives us the effect of selected technology on the values of organic wastes and waste heat or the judgment of recycling.

Keywords:

Value of organic wastes, Waste heat, Recycle technology, Energy cost

1 INTRODUCTION

Lack of fossil resources and increase in carbon dioxide are actualized from 1990s, and the necessity of the construction of a sustainable society is strongly mentioned in 21st century. A reliable and effective way based on present activity for realizing it is save energy. The principle of save energy is the suppression of energy required to the production and consumption processes. To do so, many efficient manufacturing processes have been developed. For example, the power plant by fossil resources progresses to a combined cycle with both gas and steam turbines. However, the thermal utilization is restricted by Carnot cycle, and more than 50% of the original chemical energy is obliged to discard as a waste heat. On the other hand, the biomass waste can be utilized to reduce the fuel material and CO_2 emission. The utilization of biomass waste (organic waste) is effective if the energy consumed by recycling is small below a certain level. Namely, the recycling or regenerating technologies are crucial to utilize organic wastes. Furthermore, the value of recycling is significantly varied with the regenerating products.

In industrial factory, the heat recovery is designed to save energy by pinch technology method, which determines an optimum heat exchange sequence for maximum heat recovery based on *T*-*Q* diagram [1, 2]. This method is powerful and leads to drastic energy save. However, the method is just applied to heat recovery, namely the value of waste heat is not improved to the valuable materials except heat. To build up a sustainable development in industrial sector, waste materials and heat should be effectively and reasonably recovered as a various valuable forms. Unfortunately, the waste materials were judged to be little value by now. The essential point to utilize waste materials and heat is whether the recycling is performed without excess energy input, and the value of waste is changed by the final regenerated product as mentioned above. Therefore, the method for estimating the value of wastes linked with regenerating technology is desired to design the efficient recycle and regeneration systems. Otherwise, the environmental policy should be performed with quantitative technological proof, but there is little way to judge and select proper environmental technology. From this viewpoint, we proposed a new method for estimating the value of waste organic materials and waste heat with associating technologies. The method is worked using a diagram consisted of the relationship between production cost per year and thermal energy of wastes exhausted per year. In this study, the outline of proposed diagram was explained, and the usage of the diagram for judgment of recycle, selection of the technology was examined in order to verify the possibility as an effective chart for treating of wastes.

2 OUTLINE OF PROPOSED DIAGRAM

2.1 Precondition

The objects treated in this study were organic wastes and waste heat, and the usage of the diagram was schematically explained in the case that the organic wastes and waste heat exhausted in chemical factory was

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regenerated into hydrogen or combustion energy. The following assumptions were set to drawing the diagram.

1) The costs of organic waste and waste heat are zero.

2) Additional energy to produce regenerated product is counted by heavy oil.

3) Only running cost is considered.

4) The regenerated hydrogen or thermal energy is used on site (no transportation to other site).

2.2 Basic equations for regeneration of organic wastes

The energy balance of the conversion process from wastes to product is represented by eq.1.

$$Q_m + Q_R = Q_P \tag{1}$$

Q_m [kJ/year]: Thermal energy of M mol of organic wastes emitted

Q_R [kJ/year]: Thermal energy required for production

Q_P [kJ/year]: Thermal energy of product

Where, Q_m and Q_R are calculated by eq.2 and 3, respectively.

$$Q_m = M\left(\Delta H_{R\bullet 298} + \int_{298}^{T} C(T)\mathrm{d}T\right) \tag{2}$$

$C(T)$ [kJ/(mol·K)]:Molar heat capacity

$\Delta H_{R\bullet 298}$ [kJ/mol]: Standard enthalpy of formation

$$Q_R = Q_W + Q_S \tag{3}$$

Q_W [kJ/year]: Thermal energy of waste heat utilized

Q_S [kJ/year]: Thermal energy of input from external

On the other hand, when the organic wastes and waste heat are utilized as a thermal energy, Q, by combustion, the energy balance is expressed by eq.4.

$$Q_m + Q_W = Q \tag{4}$$

Based on these equations, the diagram was constructed.

2.2 Drawing procedure of diagram

As a simple example, we schematically show the drawing procedure for estimating the values of organic wastes and waste heat when regenerating into hydrogen. Fig.1(a) shows the basic line in the diagram. The vertical axis is production cost per year, and the abscissa is thermal energy utilized per year. At first, the cost line of heavy oil is drawn. The slope is equal to the energy cost (yen/kJ). When one uses other energy resources, they can easily draw the line from the energy price. On the other hand, the hydrogen production cost from virgin organic resources is also drawn. Since the hydrogen is a typical bulk material from the steam reforming of methane, the production cost is represented by a linear line in proportional with methane energy price. On the basis of this graph, the procedure for estimating values of organic wastes and waste heat is summarized below.

i) Calculate the thermal energy of organic wastes, Q_{m}, from elemental composition and water content by eq.2, and then plot the value on the horizontal axis. Next, calculate available thermal energy of waste heat, Q_{W}, in the factory, and plot the sum values of Q_{m} and Q_{W} on the horizontal axis (Point “W” in Fig.1(b)).

ii) Calculate the amount of hydrogen produced from M mol of organic wastes by material balance. From this stoichiometric relation, calculate the thermal energy (reaction enthalpy) required to produce hydrogen from M mol of organic wastes, Q_{T}, and plot on the horizontal axis (Point “T” in Fig.1(b)). And then, determine production cost of hydrogen at Q=Q_T on the production cost line (Point “P” in Fig.1(b)).

iii) Q_{T} is the value at ideal state. Since there are some heat losses in actual process, actual amount of thermal energy required to produce hydrogen, Q_{A}, is the value divided by Q_{T} to process efficiency. Based on this result, calculate the additional thermal energy for producing hydrogen, Q_I (= Q_A − Q_m − Q_W). And then, plot $-Q_I$ value on the horizontal axis (Point “I” in Fig.1(b)). From these procedures we can obtain additional thermal energy for hydrogen production from organic waste and waste heat.

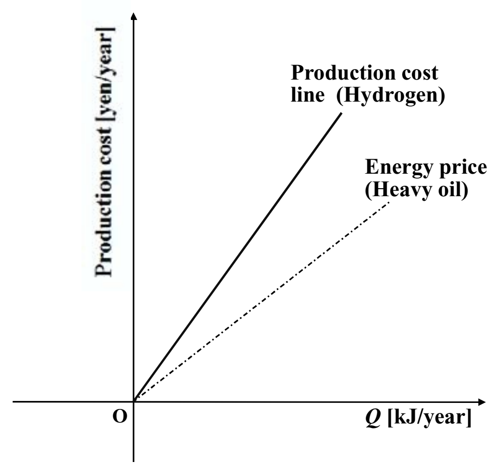

Fig.1(a) Basic concept of the proposed daigram

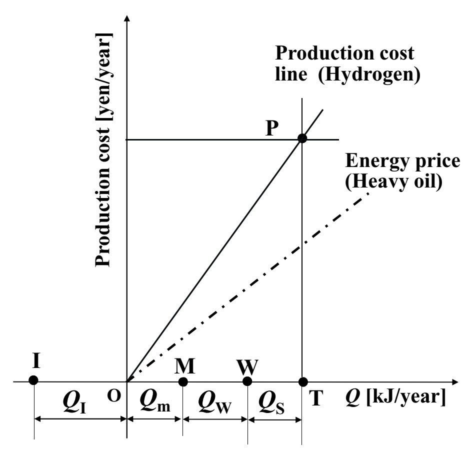

Fig.1(b) Procedure of drawing diagram (1)
Plot of thermal energy of wastes

iv) Next, move parallel to the energy price line of heavy oil from the origin to point "I" (lines IK), and then determine the interception of vertical axis (point "K" in Fig.1(c)). The value of point K is the additional energy cost for the hydrogen production.

v) Finally, draw the horizon line through point "K", and determine point "J" on lines PT (Fig.1(c)). From these procedures, the value of organic waste and waste heat is given by lines PJ. Where, since the lines WJ is equivalent to the process efficiency of hydrogen production, we can obtain the organic wastes value and waste heat value, respectively, by drawing lines MN parallel to lines WJ. PN and NJ are the organic wastes value and waste heat value, respectively (Fig.1(d)).

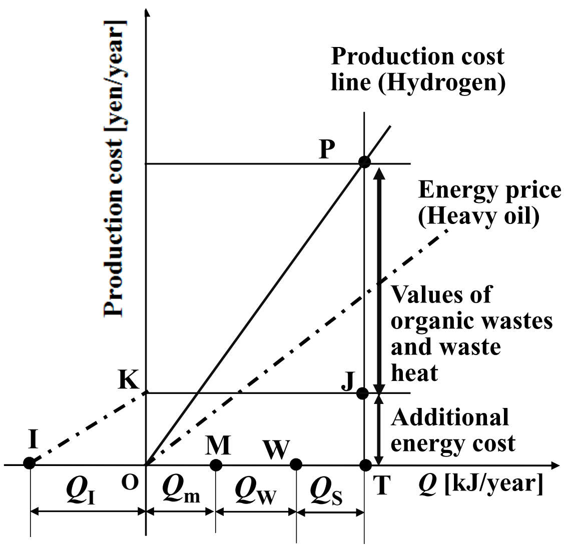

Fig.1(c) Procedure of drawing diagram (2)
Determination of value of wastes

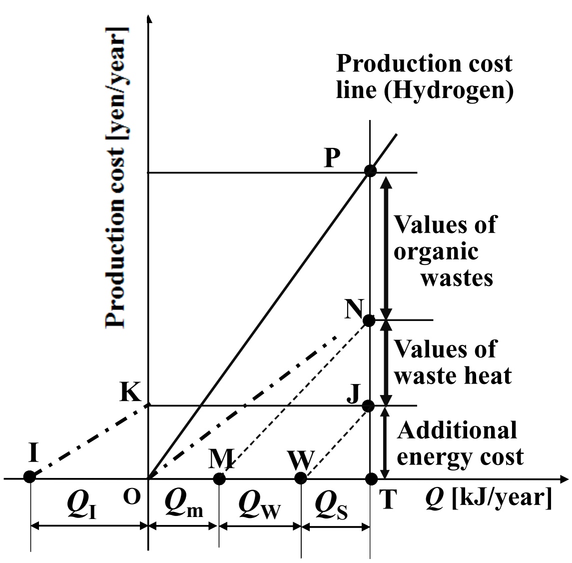

Fig.1(d) Procedure of drawing diagram (3)
Division of organic wastes and waste heat values

3 APPLICATION OF PROPOSED DIAGRAM

3.1 Change in values of organic wastes and waste heat by utilization way

There are several options for organic wastes utilization. In the previous section, the methodology for determining the values of organic waste and heat when producing hydrogen was shown. Another popular option is the thermal recovery by combustion. In this case, the value of organic wastes and waste heat is lines WC in Fig.2. Comparing lines PJ and WC, the value of organic wastes and waste heat is higher for hydrogen production. When energy price of heavy oil significantly increases, the value of hydrogen production decreases (lines PJ decreases) on the contrary, the value of combustion increases (lines WC increases). Thus, the proposed method gives us the change in the value of organic waste and waste heat by utilization option, and indicates a proper selection in consideration with energy price.

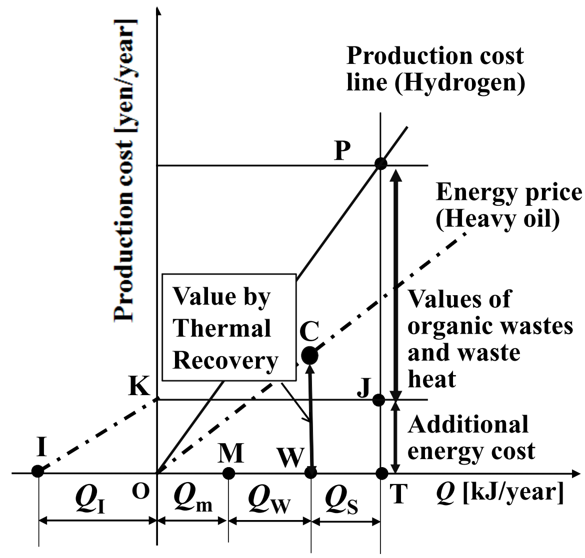

Fig.2 Change in the values of wastes
by regeneration product type

3.2 Change in values of organic wastes and waste heat by technology

As one easily supposes, the values of organic wastes and waste heat significantly change by the conversion technology adopted. Fig.2 shows the diagram for hydrogen production using a poor technology. Now, the hydrogen is produced by steam reforming of organic materials via endothermic reaction, so a poor technology means bad process efficiency. Herein the lines OI becomes large, and then the additional energy cost (lines JT) increases. Consequently, the lines PJ decrease, and the values of organic wastes and waste heat reduce. At that time, the individual values of organic wastes and waste heat is determined by lines PN and NJ, respectively, in the same manner in Fig.1(d). Since the value of waste heat can be assumed to be equivalent to that of additional heavy oil energy, the value of organic wastes significantly decreased as shown in Fig.3. If point "N" is over point "P", the value of organic wastes is negative, the recycle of organic wastes is meaningless by the selected technology, indicating that only waste heat should be recovered as thermal energy. Furthermore, if point "J" is over point "P", the recycling of organic wastes and waste heat makes no sense. Thus, point "P" is pinch point of recycling, and we can judge the effect of recycling in relation to recycle technology.

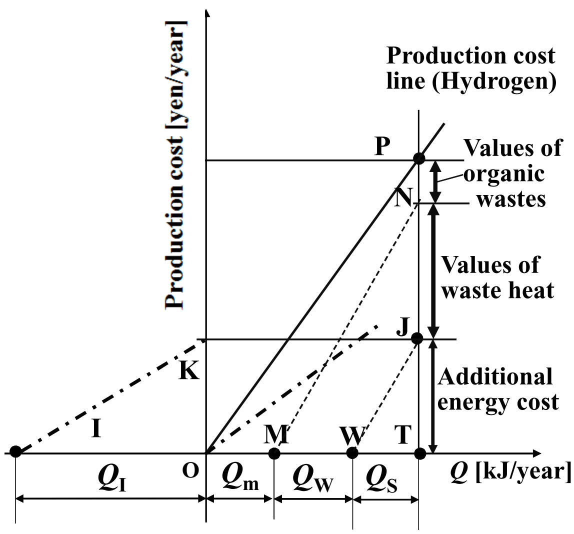

Fig.3 Change is value of wastes by hydrogen conversion technology.

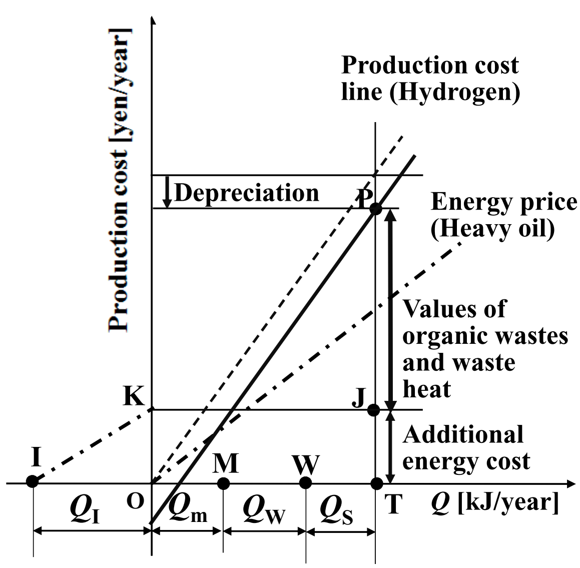

Fig.4 Diagram for estimating value of wastes in consideration with construction cost.

In the previous discussion, plant construction cost for converting organic wastes ignored in the above discussion. Fig.4 shows schematically the treatment of construction cost in the proposed diagram. Calculate the annual construction cost by introducing the depreciation, and then the original production cost line shift down to parallel by annual cost. By this drawing, we get a pinch point including construction cost (Point "P" in Fig.3). The values of organic wastes and waste heat are determined in the same manner described above.

4 SUMMARY

To build up sustainable society, waste materials and heat should be recovered effectively and reasonably. To design the recycling or regenerating way, we proposed a new method to estimate the value of organic waste organic and waste heat with associating technologies. The diagram proposed is the relationship between production cost per year and thermal energy utilized per year. Based on energy cost line of heavy oil and the cost line of final product such as hydrogen, the values of organic waste organic and waste heat can be successfully estimated by the drawing in the diagram step by step. Since the conversion process is expressed as a thermal efficiency, the difference in technology can be expressed by the slope in the diagram. The slope of bad technology is large, and the value of waste is reduced. On the other hand, the diagram can be utilized as a pinch analysis for evaluation of recycling criteria with a proper technology. Thus, the proposed method provides us a quantitative value of organic waste organic and waste heat in association with regenerating (recycling) technology. It is expected that the diagram give a clue to link environmental technology and policy making easily.

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A New Diagram for Evaluating Relationship between Technological and Environmental Actions

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Abstract

A new index, environmental space life, and a new diagram based on its index were proposed for considering low carbon emission life. The index is defined as a consumption time of product on the basis of a space, which can represent flexibly as an independent variable when treating LCA data. Using the proposed diagram, CO_2 emission profiles of several electric products in our home and automobiles were compared. It was found that the suppression effect of CO_2 emission is different by the duration of use for each product, and that the duration of use is a crucial factor to low carbon emission. The abscissa of the diagram represents the environmental action, and the effect of technological innovation and environmental action are quantitatively compared by changing the unit of space. Thus, the proposed method would give us a clue to introduce a low carbon emission society.

Keywords:

Estimation of CO_2 emission, Environmental action, Life cycle of industrial products

1 INTRODUCTION

In recent years, much attention is paid to the construction of low carbon emission society and many technological innovations are developing. To use properly such technologies and construct an environmentally benign life, it is required to develop some tools for both analysis and synthesis of the life from the viewpoint of environment. Life cycle analysis (LCA) is very useful method to evaluate the CO_2 emission of products [1]. For example, it is shown that electric eco-products significantly reduce the CO_2 emission by the analysis of eco-efficiency index [2]. Thus, the evaluation of each item is established, but the methodology for synthesizing the low carbon emission action is not yet sufficient. By extending effectively the results of LCA to our environmental action in the life, an additional quantitative synthesis method to relate between life design and CO_2 emission is desired. To realize it, we proposed a new index, environmental space life, for CO_2 emission. This index is defined by the amount of CO_2 emission per time and space. In this paper, a new diagram is proposed based on the environmental space life, and then the CO_2 consumption rates of several industrial products for public welfare were compared. Furthermore, the methodology, by which the effects of technological innovation and environmental action on the suppression of CO_2 emission were quantitatively compared, was presented, and then the possibility of the proposed method for designing low carbon emission life was examined.

2 DEFINITION OF A NEW INDEX

The LCA is accumulated the amount of CO_2 emitted from material to waste for individual product. The data is useful to show clearly the CO_2 loading of each product. However, the CO_2 emission is caused by the consumption of energy and products. As you know, the CO_2 does not increase, if the consumption rate (= CO_2 emission rate) is within the absorption rate of CO_2. This indicates that our action in the society is a crucial factor to reduce the emission rate of CO_2. In this sense, previous environmental indices are somehow weak to design the CO_2 emission rate in our life. Then, we introduced a new index, environmental space life, to represent the consumption time of products per a certain space as defined by eq.1.

$$\text{Environmental space life} = \frac{\text{Consumption time of product [year]}}{\text{Space}} \quad (1)$$

The index represents life time of products utilized in a certain space. The space and time in the index can be selected flexibly based on the way of products use. The definition of space in the eq.1 is broad, and we can select the number of person etc. as a dimension of space. The index can be defined at several levels, elemental level, compound level, product level etc. The advantageous feature of the proposed index is summarized as follows: (1) Easy and fair comparison of CO_2 load among various

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product utilizations, (2) Consumption rate can be controlled by setting a proper space, and (3) The quantitative target of environmentally friendly action is indicated. Especially, items (2) and (3) are significant. For example, we can reduce large amount of CO_2 per time derived from a certain product by considering the utilization space. Also, the introduction of proposed index gives us the effective connection between technology and policy making. Furthermore, the index can be applied to natural green resources such as wood and plant, and the CO_2 absorption life time and space can be estimated.

3 A NEW DAIGRAM FOR DESIGNING THE ENVIRONMENTAL ACTION

3.1 Outline of a new diagram

Fig.1 shows the outline of the proposed diagram for designing environmental actions. The diagram is based on the relationship between the accumulated amounts of CO_2 emitted during the use of product and the environmental space life. The value of vertical axis is calculated by LCA. On the other hand, the abscissa is the value which multiplied the environmental space life defined above by a certain space. From this, the slope represents the CO_2 emission rate in a certain space during the use of a product. Using this diagram, we can draw the CO_2 emission events of product. As shown in Fig.1, the amounts of CO_2 emitted from resource mining to production and discard is plotted as a value of interception of vertical axis. Next, the space (occasionally the number of person) is set, the CO_2 emission rate is calculated by the LCA data, and drawing the line to the durable time of the product. Finally, the average emission rate of CO_2 with depreciation is drawing as a line from original point to end point of use.

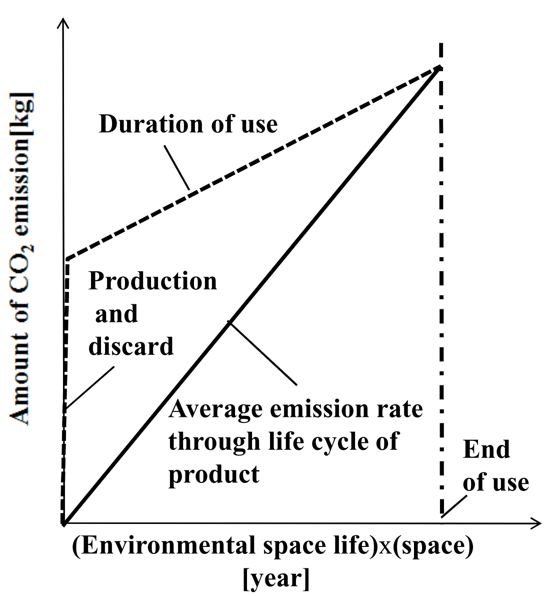


Fig.1 Outline of proposed diagram

Thus, the diagram is merely refined LCA data to the space velocity of product consumption, but this treatment gives us the indication of the environmental action and its quantitative effect. Furthermore, since the diagram suggests the amount of CO_2 emission rate per unit space and time, we can design the CO_2 emission by selecting a proper combination of space and time. We can say the idea of the proposed diagram based on the index, environmental space life, is useful.

3.2 Comparison of CO_2 emission among the products

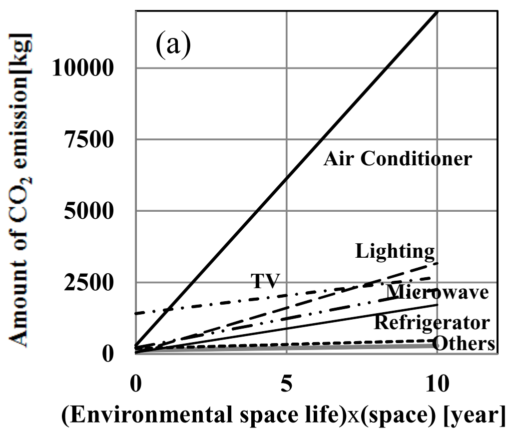
In the present life style, automobile and electric products are inevitable items. As we know, the CO_2 emissions from public welfare section must significantly reduce, but it is difficult to conduct end-of-pipe treatment such as CO_2 collection in the power plant. Therefore, we must try to minimize the consumption rate of energy in our house and office. To assist this action, various save energy products are supplied by technological innovation. Indeed, such products are effective to reduce the CO_2 emission in the life cycle, but we do not know the quantitative way to use these products properly for minimizing CO_2 emission. To overcome this situation, it is required to the comparison of the CO_2 emission rates between these products including the usage at same index. The diagram proposed here could be satisfied the above requirement. Table 1 summarizes the calculation conditions. Based on LCA data referred, the amounts of CO_2 emitted during production & discard and the CO_2 emission rate during use, respectively. The data are average value per a household. Using these data, Fig.2 (a) and (b) show the CO_2 emission profiles of the various electric products and automobile.

Table 1 LCA analyses of automobile and electric products

	Calculation conditions (household basis)	CO_2 emission		Data ref. No.
		Production & Discard [kg]	Duration of use [kg/year]	
Automobile				
Gasoline(10km/L)	10000km/y 1 car[1)]	8350	2040	[3]
Hybrid(30km/L)		6070	772	[3]
Hybrid EV(30km/L)		9711	219	[3]
Sum of main Electric products		2682	2337	
Items of electric products				
Refrigerator400L (2006)	1 unit	210	204	[4]
Air conditioner (2006)	3 units	291	1167	[4]
Lighting	500W 2 years life	47	312	[4]
TV (2009)	2 unit[2)]	1406	127.1	[4]
Electric Carpet (2010)	1 unit	23	177	[4]
Laundry	1 unit	342	141	[4]
Microwave	1 unit	189	28	[4]
Rice cocker	1 unit	50.1	166	[4]

* All the data is calculated besed on Japanese average household (2.55 persons) (Japanese sensus 2010)
1) BPO report (2009.10.23) http://www.garbagenews.net/archives/1123030.html
2) Automobile Inspection & Registration Information Association report (2011.8.23) http://www.airia.or.jp/publish/pdf/happyou/2011_08setai.pdf

First, we selected main electric products in the house and total CO_2 emission profile is calculated. At that time, the life is assumed to 10 years, and the CO_2 emission during use is calculated by year-average consumption of electricity of typical household. As shown in Fig.2(a), each electric product is relatively low CO_2 emission for production process, but we need many kinds of electric products. The CO_2 emission rate by air conditioner is very large, indicating that the usage of air conditioner is a key point to reduce CO_2. On the other hand, the CO_2 emission rate of automobile intensely large as compared with each electric product (Fig.2(b)). At that time, the duration time is set to 10 years. The major factor is the CO_2 emission during production of automobile. The total CO_2 emission of main electric products is smaller than that of gasoline car for production process, but both are comparable at the duration of use. On the contrary, the CO_2 emission of hybrid car was smaller than that of total electric products. From these results, the technological innovation of automobile is fairly effective. On the other hand, the suppression of CO_2 emission related to electric products is crucial to consider electric supply including natural energy and the usage of electric products. The upgrade frequency



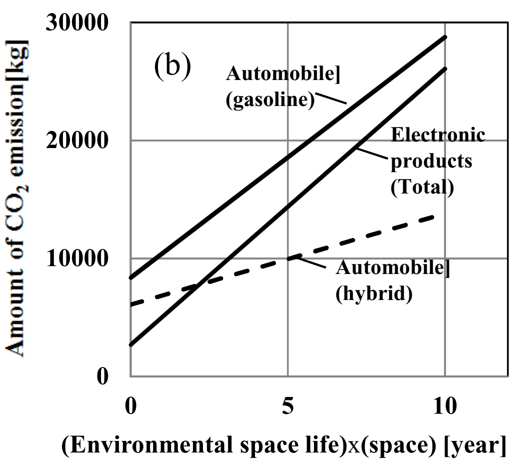


Fig.2 CO2 emission profiles
(a) Electric products, (b) Automobile

of product is also important. If the average upgrade frequency of electric products is half of that of gasoline car, both CO_2 emissions are almost equivalent.

3.3 Comparison of effects of technological innovation and environmental action

From Fig.2, it is supposed that technological innovation and individual environmental action are very significant and has a large effect to reduce CO_2 emission. So, we consider our actions influence the CO_2 emissions by use of the proposed diagram. Fig.3 shows the effects of technological innovation and environmental actions were compared quantitatively for automobile for an example. The lines for automobiles in the figure were calculated at the following conditions: The mileage is 10000 km/year, one person utilizes a car, and fuel consumptions are 10 km/L and 30 km/L for conventional and hybrid cars, respectively (see Table 1). As shown in the figure, the hybrid car dramatically decreases CO_2 emission. On the other hand, hybrid EV car emits largely CO_2 during production, but its emission rate during use is significantly low. Hybrid EV car suppress the CO_2 emission over 1 years against gasoline car, and over 7 years against hybrid car. From the figure, we understand quantitatively our actions as follows: hybrid EV car should be utilized more than 7 years, and hybrid car can reduce CO_2 emission to half against gasoline car by using 6 years. Thus, the diagram instantly indicates our environmental action about usage of the products.

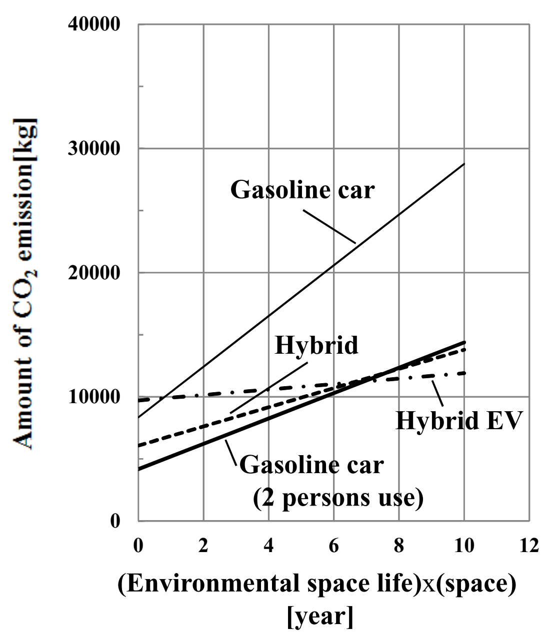


Fig.3 Effects of technological innovation and environmental action on CO_2 emission.

Next, the effect of our action to the reduction of CO_2 emission is estimated quantitatively by the diagram. The abscissa of the figure represents the value which multiplied the environmental space life defined above by a certain space as above stated. Now, the number of person utilized the car is selected as a space. For example, when the conventional car is utilized by two persons, the CO_2 emission rate during the use becomes to half (bold solid line). In that case, the accumulated amount of CO_2 emission suppressed lower than that of the hybrid car utilized by one person till 7 years. Comparing these slopes during use, both slopes are comparable, indicating that the environmental action of two person's use is almost same effect of technological innovation of hybrid car. Thus, the proposed diagram gives us a quantitative effect of our environmental action, and clearly shows the target of our action or a story of low carbon emission by combination of technological innovation and environmental action.

3.4 Usage of diagram

As an application example of the proposed diagram for determining the indication of low carbon emission life was summarized in Fig.4. We use many products with CO_2 emission. We should make an effort to keep within a limit of CO_2 emission in the home to construct low carbon emission life. First, the CO_2 emission profile is drawn at basic space condition such as one person and one room etc. If accumulated amount of CO_2 emission after some years is over the upper limitation of CO_2 emission (dotted line), the line slope shifted smaller within the upper limitation (bold solid line). After this work, we read the value of abscissa, and consider the space to satisfy that value.

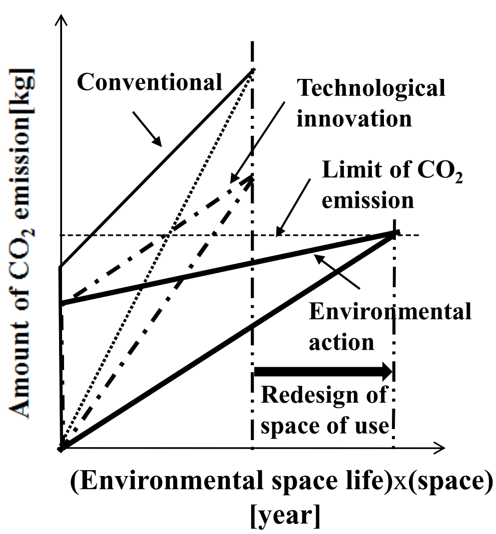


Fig.4 Determination of environmental action

Thus determined space leads to our environmental action and suggests quantitatively the social system design. The method proposed here was just shown its basic concept and a further study is required to use effectively, but it is expected that the proposed methodology will a clue to solve the combination of technology and social action for low carbon emission society.

4 SUMMARY

A new index, environmental space life, and a new diagram based on its index were proposed for considering low carbon emission life. The index is defined as a consumption time of product on the basis of a space. Using this index, the diagram was constructed by the environmental space life vs. the amount of CO_2 emission. In the diagram, the change in the amount of CO_2 emission is drawn by a linear line with interception of CO_2 emission value accompanied at production and discard. The average slope represents the technological performance. Using this diagram, CO_2 emission profiles of several electric products in our home and automobiles were compared. It was found that the suppression effect of CO_2 emission is different by the duration of use for each product. Since the abscissa of the diagram represents the environmental action, the effect of technological innovation and environmental action are quantitatively compared by setting a proper space parameter. In other word, the environmental action for reducing the CO_2 emission down to the target is shown quantitatively by the drawing the diagram. Thus, the proposed method would give us a clue to introduce a low carbon emission society.

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Incorporating Reuse and Remanufacturing in Product Family Planning

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Abstract

Frequent product model replacement, which is a typical option for manufactures to fulfill the ever-changing consumer requirements and defend their shares in today's technology dominated market, can be a big obstacle to enhancing reuse and remanufacturing. In this study a product family planning method taking advantage of the differences in technological lifetime of components and preference of product functionality, quality and environmental performance among consumers is proposed to promote reuse and remanufacturing. Based on the predefined requirements of product improvement and component attributes each of which possesses a limited number of levels over the planning time horizon, the product line-ups and model changing plan are generated using Generic Algorithm (GA) to minimize the total environmental impacts. Then, a case study of product family planning of personal computers (PCs) demonstrates an implementation of the method

Keywords: Reuse, Remanufacturing, Product family planning, Life cycle, Environmental impacts

1 INTRODUCTION

Faced with threats of various environmental issues such as resource depletion, climate changes and pollutions, there is a growing awareness of environmental protection around the world. It is recognized that the manufacturing industry which though created today's well life of human beings is the major contributor to environment problems. As the green competence is becoming more and more important in today's market, It is crucial for manufacturers to not only satisfy traditional requirements such as maintaining low manufacturing costs and high product quality, but also comply with environmental regulations (e.g. EU's WEEE/RoHS directives), and fulfill expected responsibilities (e.g., Corporate Social Responsibility and Extended Producer Responsibility)[1]. In order to achieve a sustainable development, it is important to "close the loop" of product life cycle and consider the technical and economic implications of several possible alternatives to direct disposal, including reuse, remanufacturing, and recycling. Closed-loop manufacturing, which enables material circulation potentially reduce the environmental impacts over a product's and lower the cost of compliance with laws about product end-of-life treatments. Among the alternative options, reuse is most preferred as it generally has the lowest cost and creates the least environmental burden. Products of long market lifetime and relatively short use lifetime are suitable for implementation of reuse strategies, because demand for reclaimed components can be secured and thus reuse rate can be high.

However, it is apparently difficult to implement reuse, remanufacturing for many products like, most typically, the consumer electronics, because 1) the diverse customer needs increase product variety and reduce product component commonality, leading to very limited reuse approaches of particular components, and 2) their product model changes frequently due to the changing customer requirements and rapid technology development. This means a tradeoff between reusability, functional variety and improvement. As a possible solution to this issue, we proposed a product family planning method taking advantage of the differences in technological lifetime of components and preference of product functionality, quality and environmental performance among consumers to promote reuse and remanufacturing. In the following section, the optimization problem of product family planning in this research is formulated. Methodology to solve the problem, including the methods for identifying the relationship between customer satisfaction, functional or quality attributes and structural elements (i.e. module, component) of product and evaluating multiattribute utility of the product family plan and a GA and Life cycle simulation-based optimization algorithm, is presented in Section 3. The proposed procedure is applied to personal computers as an illustrative example.

2 FORMULATING THE OPTIMIZATION PROBLEMS OF PRODUCT FAMILY PLANNING IN THIS RESEARCH

The goal of this research is to develop a decision model that aids design and manufacturing engineers in planning of product family over generations. The product system is composed of several product models respectively in order to cover the market. The purpose of product line-up formulation and model change planning is to determine the model change timing of major structural

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elements so as to maximize the reduction of environmental load by means of reuse while satisfying functionality and quality requirements of consumers of the targeting market segments, while ensure certain profitability. We aim to, on one hand, strike a compromise between the extension of a product's market life and frequent model changes in response to the changing customers needs by the possibly frequent model changes of components which are sensitive to the change in customer satisfaction while longer model change intervals of components which are not [2], and on the other hand maximize component sharing over the both generational and space product families while considering product variety.

3 METHODOLOGY

3.1 A QFD-based method to model relationships between customer requirements, functional or quality attributes and structural elements of product

QFD [3] which is an effective tool to identify and translate customer requirements into technical specifications for product planning is used to model relationships between customer requirements, functional or quality attributes and structural elements of product. The process is conducted as followed:

1) Customer requirements are surveyed, analyzed and summarized. The projection of customer requirements to technical specifications, such as engineering parameters which characterize the functionality or quality of product, is established using QFD. The goal is to transform the linguistic and vague information about customer requirements into specified and numerical parameters which could be dealt by engineering processes.
2) For some products, there are no one-to-one correspondences between the technical specifications and the structural elements. In such case, QFD is conducted again to formulate the relationships between technical specifications(i.e. engineering parameters) and product's structural elements (i.e. modules, components) to understand the impacts of changes in product functionality or quality on its physical structure. Thus, candidates of structural elements to be redesigned in correspondence to changes in functionality or quality requirements are identified.
3) After the above steps, the relationships between customer satisfaction, functional or quality attributes and structural units of product are modeled. Given the diversity in customer needs, the QFD process should be repeated until all the target market segments are characterized.

3.2 Multiattribute Utility Function of the product family plan

A product family is denoted by a set consisting of a few selected product profiles. There are multiple market segments, each containing homogeneous customers, with a size, MK_i where *i* denotes the *i*th market segment. Various customer preferences on diverse products are represented by respective utilities, U_{ij} where *j* denotes the *j*th product in the product family. U_{ij} is assumed to be a function of weight of customer requirements, relationship between customer requirements, functional or quality attributes and structural elements of product, and the performance values of the attribute levels of the product, i.e.

$$U_{ij} = \sum_{m=1}^{M}\sum_{k=1}^{K}(w_{im} r_{mk} pv_{klm} x_{jkl}), pv_{klm} \in PV_{klm} \equiv \{pv^*_{klm} \ | l = 1, \ldots, \mathrm{L}_k\} \quad (1)$$

where w_{im} is the importance of the *m*th customer requirement, r_{mk} is the relationship between the *m*th customer requirement and the *k*th component of the product established by the QFD processes, pv_{klm} is the performance value of *l*th model of the *k*th component regarding the mth customer requirement , x_{jkl} is a binary variable such that $x_{jkl} = 1$ if the *l*th model of the *k*th component is adopted for the product and $x_{jkl} = 0$ otherwise, and L_k is the number of model choice of component *k*.

3.3 Mathematic description of the product family planning problem

This research addresses the product family planning problem with the goal of maximizing profit of the manufacturer and minimize environmental impacts of product manufacturing and disposal during a given time period.

For a certain technical period *T*, i.e. 6 years in our case study of PC, a model change plan of product family is denoted as $Zch \equiv \{Z_v \ | v = 1, \ldots, V\}$, where Z_v is the product family profile during the *v*th period of *T* and V, number of unit period of the technical period *T*. $Z_v \equiv \{Z_{in,v} \,|\, i = 1,\ldots,I, n = 1,\ldots,N_i\}$ where $Z_{in,v}$ represents model of the nth product targeting the ith market segment , and $Z_{in,v} \equiv \{pv_{inkm,v} \,|\, m = 1,\ldots,M, k = 1,\ldots,K\}$ where $pv_{inkm,v}$ is the performance value of the selected model of component *h* of product during the *v*th time period , and $pv_{inkm,v} \in \{pv^*_{klm} \ | l = 1, \ldots, \mathrm{L}_k\}$.

A baseline product family plan during the technical period, which represents the general product planning strategies of major competitors in the marketplace denoted with a set of product profile $Zch_{base} \equiv \{Z_{base,v} \mid v = 1, \ldots, V\}$, is first formulated. During period v the demand of product n from consumers of market segment i is projected using the multinomial choice model with product utility as input [4], i.e.

$$D_{in,v} = \sum_{i=1}^{I} \frac{e^{U_{in,v}}}{\sum_{i=1}^{I}\sum_{n=1}^{Ni} e^{U_{in,v}} + \sum_{j=1}^{J_{base}} e^{U_{ij,v}}} \times MK_i \tag{2}$$

Every product is associated with certain engineering and production costs, denoted as $C_{manu,in,v}$ (or $C_{basemanu,in,v}$ for the baseline product family). The manufacturer must make decisions to select what products (component models) to offer as well as their respective prices, $p_{in,v}$ (or $p_{base,in,v}$ for the baseline product family). If collection, reuse and recycling options are implemented, the respective costs are denoted costs of collection $C_{col,v}$, disassembling, inspection, refurbishment and residue disposal for reuse ($C_{reuse,in,v}$), processing and residue disposal for recycling ($C_{recyc,in,v}$), while recovered values from reusing and recycling as $V_{reuse,in,v}$ and $V_{recyc,in,v}$. Thus, the profits of the manufacturer during time period v are calculated as

$$Pf_v = \sum_{i=1}^{I}\sum_{n=1}^{N_i} \begin{Bmatrix} D_{in,v}(p_{in,v} - C_{manu,in,v}) \\ -\sum_{g=1}^{v-1} ret_{in,v-g+1} D_{in,g} r_{col}[C_{col,v} + (C_{reuse,in,g} - V_{reuse,in,g})x_{reuse,in,g} \\ +(C_{recyc,in,g} - V_{recyc,in,g})x_{recyc,in,g}] \end{Bmatrix} \tag{3}$$

where $ret_{in,v-g+1}$ is the retirement rate of product at age of v-g+1, r_{col} is the collection rate, $x_{reuse,in,g}$ and $x_{recyc,in,g}$ are binary variables such that $x_{reuse,in,g}=1$ and $x_{recyc,in,g}=1$ if reuse and recycling are implemented.

The environmental impact of product manufacturing, processing for reuse and recycling and direct disposal are denoted as $EI_{manu,in,v}$, $EI_{reuse,in,v}$, $EI_{recyc,in,v}$ and $EI_{disp,in,v}$, while environmental benefits (i.e. raw material saving) of reuse and recycling as $EB_{reuse,in,v}$ and $EB_{recyc,in,v}$. Then, environmental impacts of product manufacturing and disposal and environmental benefits of reuse and recycling during time period v are calculated as

$$EI_v = \sum_{i=1}^{I}\sum_{n=1}^{N_i} \begin{Bmatrix} D_{in,v} EI_{manu,in,v} \\ +\sum_{g=1}^{v-1} ret_{in,v-g+1} D_{in,g}[r_{col,v}(EI_{col,v} + EI_{reuse,in,g}x_{reuse,in,g} \\ +EI_{recyc,in,g}x_{recyc,in,g}) + (1-r_{col,v})EI_{disp,in,g}] \end{Bmatrix} \tag{4}$$

and

$$EB_v = \sum_{i=1}^{I}\sum_{n=1}^{N_i}\sum_{g=1}^{v-1} \begin{matrix} ret_{in,v-g+1} D_{in,g} r_{col,v} \\ (EB_{reuse,in,g}x_{reuse,in,g} + EB_{recyc,in,g}x_{recyc,in,g} \\ +EI_{recyc,in,g}) \end{matrix} \tag{5}$$

Thus, the optimization problem is defined as

$$\max f = w_{econo}\frac{\sum_{v=1}^{V} Pf_v}{\sum_{v=1}^{V} Pf_{base,v}} + w_{env}\frac{\sum_{v=1}^{V} EB_v}{\sum_{v=1}^{V} EB_{base,v}} \times \frac{\sum_{v=1}^{V} EI_{base,v}}{\sum_{v=1}^{V} EI_v}$$

s.t. $w_{econo} + w_{env} = 1$

$$\sum_{l=1}^{l_k} x_{inkl,v} = 1, \forall i \in (1,\ldots,I), \forall n \in \{1,\ldots,N_i\}, \forall k \in \{1,\ldots,K+1\}, \forall v \in \{1,\ldots,V\}$$

$$x_{inkl,v} \in \{0,1\}, \forall i \in (1,\ldots,I), \forall n \in \{1,\ldots,N_i\}, \forall k \in \{1,\ldots,K+1\}, \forall v \in \{1,\ldots,V\} \tag{6}$$

where w_{econo} and w_{env} are respectively the weight of economic and environmental goals. That is, find a family planning solution other than the baseline one which is the reference model and, therefore, is not optimized.

3.4 GA AND LIFE CYCLE SIMULATION-BASED OPTIMIZATION

GA (Genetic Algorithm) is used as the optimizing algorithm in this research for its excellence in solving combinatorial optimization problems [5,6]. A product family plan on the planning horizon is represented by a chromosome consisting of a string. Each substring represents the product family profile during each time period. A fragment of a substring represents the product model and each element called gene, indicates the component model choice. The value assumed by a gene, called allele, represents an index of component model of certain performance value.

A life cycle simulator [7,8] is developed and run based on the generated product family plan by GA. During the each time period, the simulator first calculates the demand for each product in the product family, and then the profit from product sale and environmental impacts of product manufacturing. Next, the retired products are generated. By comparing the product models of the retired products with those in production, whether reuse can be implemented or not is judged. Components of the retired products can only be reused or remanufactured if they are functionable and fulfill certain quality requirements, and their models are still in production. Based on the judgments, the cost, environmental impacts and benefits of end-of-life treatment of the retired products are calculated. The simulator repeats this cycle until it reaches the end of the planning horizon. Then, the simulation results are used to calculate Eq.(6) to evaluate the fitness value of each individual chromosome within the population of each generation.

4. CASE STUDY

The proposed method has been applied to the personal computer product family planning problem. As computers are highly modularized product, we simply use a set of key components as functional or quality attributes. Assuming that three market segment are identified and characterized based on VOC, the customer requirements and their respective weight according to preference of different market segments, quality attributes and their relationships with customer requirements are presented in Table 1.

Table 1 Relationships between customer requirements, functional or quality attributes and structural elements of product based on QFD

Weight / Market segment			Customer requirements	Quality attributes							
				CPU MHz	Memory capacity	Hard disk drive capacity	Size of display	Tower size	Mouse type	Keyboard type	Price
S1	S2	S3									
3	9	6	CR1:smaller size	1		1	3	6			
9	6	3	CR2:display performance	6	9						
6	6	9	CR3:business performance	9	9	9	6		3	6	
9	6	3	CR3:game and media performance	9	9	9	9		9	3	
9	6	6	CR4: easy operation				6		9	6	
1	6	3	CR5: energy saving	6			6				
3	6	9	CR6:price								9

Available attribute levels and their performance values regarding different customer requirements are listed in Table 2. Among them, "price" is treated as one of the attributes to be assumed by a product. Every PC is thus described as a viable configuration of available attribute levels. The performance values of attribute levels with respect to each customer requirement are evaluated by AHP analysis [7]. The firm plan to develop a product family which consists of three product models for the target market and a baseline product family planning is first formulated as a reference. Components of retired products can only be reused (or remanufactured) if their models are still in production. For simplicity in this case study, old components are reused only once. LCA method and Ecoindicator99 are used to quantify the environmental impacts of manufacturing reconditioning, recycling and disposal of product and components. A standard markup of 20% is used to calculate the selling prices of products.

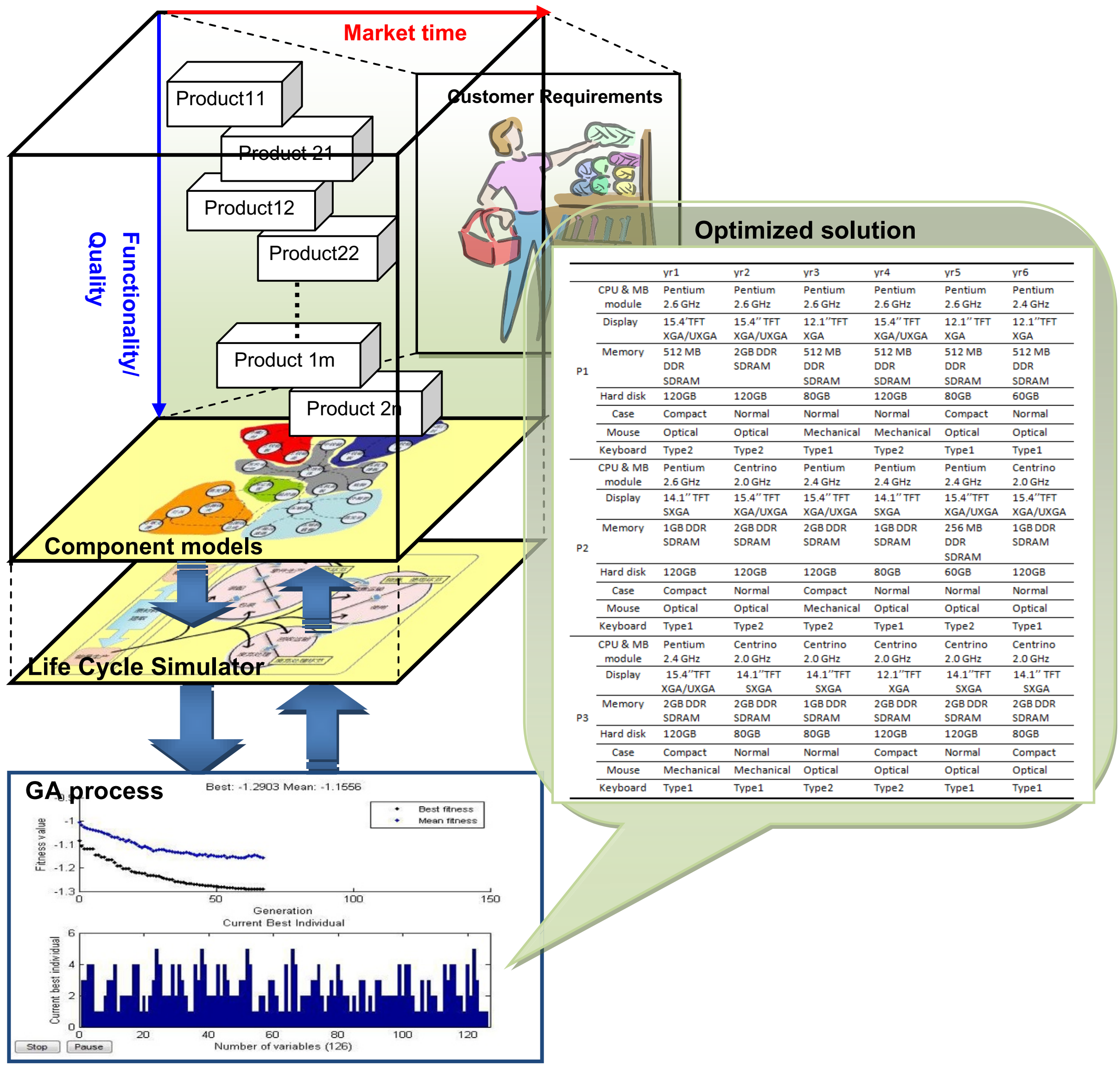
By GA and Life Cycle Simulation, an optimized the product family plan during the technical period is then generated (Fig.1).The optimized plan is projected to achieve about 30% better performance (a weighted sum of economic and environmental index) than the baseline plan.

5. CONCLUSION

This paper has presented a decision model for product family planning with consideration of manufacturers' profit, and environmental impacts. GA and Life Cycle Simulation are employed to solve the multi-objective optimization problem. The proposed planning method is applied to PC. The result verifies the effectiveness of the method. However, there are several issues that need to be studied further. Especially, some constraints need to be introduced to the GA model to ensure the profitability and technological feasibility of the product configuration, for instance, high performance CPU module should not match up with small memory capacities. This is a major problem to be addressed in our future study.

Table 2 Functional/quality attribute levels and their performance values

Component	Code	Description	Performance value, pv						
			CR1	CR2	CR3	CR4	CR5	CR6	CR7
CPU and mother board module	Comp11	Pentium 2.8 GHz	0.17	0.44	0.52	0.52		0.07	
	Comp12	Pentium 2.6 GHz	0.17	0.17	0.21	0.21		0.08	
	Comp13	Pentium 2.4 GHz	0.17	0.17	0.11	0.11		0.08	
	Comp14	Centrino 2.0 GHz	0.17	0.08	0.07	0.07		0.25	
	Comp15	Centrino 1.8 GHz	0.17	0.08	0.04	0.04		0.25	
	Comp16	Centrino 1.6GHz	0.17	0.06	0.04	0.04		0.26	
Display	Comp21	12.1” TFT XGA	0.81		0.06	0.05	0.08	0.79	
	Comp22	14.1” TFT SXGA	0.11		0.47	0.47	0.46	0.11	
	Comp23	15.4” TFT XGA/UXGA	0.09		0.47	0.47	0.46	0.10	
Memory	Comp31	128 MB DDR SDRAM		0.05	0.06	0.04			
	Comp32	256 MB DDR SDRAM		0.07	0.07	0.05			
	Comp33	512 MB DDR SDRAM		0.11	0.11	0.19			/
	Comp34	1GB DDR SDRAM		0.22	0.22	0.23			
	Comp35	2GB DDR SDRAM		0.56	0.55	0.49			
Hard disk	Comp41	40GB	0.33		0.09	0.06			
	Comp42	60GB	0.33		0.07	0.08			
	Comp43	80GB	0.29		0.15	0.23			
	Comp44	120GB	0.10		0.70	0.63			
Case	Comp51	Compact					0.6		
	Comp52	Normal					0.4		
Mouse	Comp61	Mechanical			0.3	0.2			
	Comp62	Optical			0.7	0.8			
Keyboard	Comp71	Type1			0.5	0.25	0.4		
	Comp72	Type2			0.5	0.75	0.6		
			Market segment						
			S1	S2	S3				
Price	Pr1	<=$800	0.10	0.15	0.35				
	Pr2	$800-$1100	0.15	0.20	0.30				
	Pr3	$1100-$1500	0.5	0.45	0.25				
	Pr4	$1500-$2000	0.2	0.15	0.08				
	Pr5	>$2000	0.05	0.05	0.07				



		yr1	yr2	yr3	yr4	yr5	yr6
P1	CPU & MB module	Pentium 2.6 GHz	Pentium 2.6 GHz	Pentium 2.6 GHz	Pentium 2.6 GHz	Pentium 2.6 GHz	Pentium 2.4 GHz
	Display	15.4'TFT XGA/UXGA	15.4'' TFT XGA/UXGA	12.1''TFT XGA	15.4'' TFT XGA/UXGA	12.1'' TFT XGA	12.1''TFT XGA
	Memory	512 MB DDR SDRAM	2GB DDR SDRAM	512 MB DDR SDRAM	512 MB DDR SDRAM	512 MB DDR SDRAM	512 MB DDR SDRAM
	Hard disk	120GB	120GB	80GB	120GB	80GB	60GB
	Case	Compact	Normal	Normal	Normal	Compact	Normal
	Mouse	Optical	Optical	Mechanical	Mechanical	Optical	Optical
	Keyboard	Type2	Type2	Type1	Type2	Type1	Type1
P2	CPU & MB module	Pentium 2.6 GHz	Centrino 2.0 GHz	Pentium 2.4 GHz	Pentium 2.4 GHz	Pentium 2.4 GHz	Centrino 2.0 GHz
	Display	14.1'' TFT SXGA	15.4'' TFT XGA/UXGA	15.4'' TFT XGA/UXGA	14.1'' TFT SXGA	15.4''TFT XGA/UXGA	15.4''TFT XGA/UXGA
	Memory	1GB DDR SDRAM	2GB DDR SDRAM	2GB DDR SDRAM	1GB DDR SDRAM	256 MB DDR SDRAM	1GB DDR SDRAM
	Hard disk	120GB	120GB	120GB	80GB	60GB	120GB
	Case	Compact	Normal	Compact	Normal	Normal	Normal
	Mouse	Optical	Optical	Mechanical	Optical	Optical	Optical
	Keyboard	Type1	Type2	Type2	Type1	Type2	Type1
P3	CPU & MB module	Pentium 2.4 GHz	Centrino 2.0 GHz	Centrino 2.0 GHz	Centrino 2.0 GHz	Centrino 2.0 GHz	Centrino 2.0 GHz
	Display	15.4''TFT XGA/UXGA	14.1''TFT SXGA	14.1''TFT SXGA	12.1''TFT XGA	14.1''TFT SXGA	14.1'' TFT SXGA
	Memory	2GB DDR SDRAM	2GB DDR SDRAM	1GB DDR SDRAM	2GB DDR SDRAM	2GB DDR SDRAM	2GB DDR SDRAM
	Hard disk	120GB	80GB	80GB	120GB	120GB	80GB
	Case	Compact	Normal	Normal	Compact	Normal	Compact
	Mouse	Mechanical	Mechanical	Optical	Optical	Optical	Optical
	Keyboard	Type1	Type1	Type2	Type2	Type1	Type1

Fig.1 Optimization of the product family plan

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Simulation model to derive recycling routes of reused desktop PCs

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Abstract

It is necessary to construct an information network system that is constituted by the consumer, producer, administrator, etc. to plan an optimum recycling system. We constructed an algorithm that deduces the preferred recycling routes of desktop PCs based on dispersive product information from the viewpoint of material resources. This model was constructed by applying a multi-agent system. Through the agents and the ascribed criteria that affect the products' and waste parts' databases, it is possible to derive an ideal recycling map.

Keywords:

recycling model, multi-agent system, simulation system, desktop PC, recycling route

1 BACKGROUND

Global environmental problems like global warming cannot be solved through individual environmental measures, but by transforming the entire society toward recycling. In Japan, the Law for Promotion of Effective Utilization of Resources, which is also applicable to personal computers (PCs), came into effect in April 2001. Although the use of recycled material has been increasing since then, the legal system alone might not lead to the realization of optimum resource circulation. In the process of recycling and waste disposal treatment, the lack of essential information flow might lead to fragmented local optimization efforts, thereby preventing the construction of a holistic recycling system. Hence, it is necessary for consumers, producers, administrators, and other parties to construct an information network system and realize an optimum recycling system.

Efforts on computerization of disposal treatment and recycling treatment are being made in many fields, for example, digitizing manifests and chasing systems for illegal dumping of hazardous wastes. Based on the principles of an ecosystem, where every creature is a resource for other creatures, the studies on industrial ecology [1] suggest that every product becomes a resource for other products. Such a paradigm is being pursued and promoted vigorously.

Recycling of the PC is mandated by the above-mentioned law in Japan. As per this, the collection and recycling of PCs sold to home users is compulsory. However, the PC–recycling process requires much cost and labor because most of the parts are treated only as material resources. In Japan, a used–PC market exists, but the number of PCs circulating in them is small. The perception in this market is that if all the available parts for recycling are used, then the specifications of the refurbished PCs become too diverse to be accepted by the customers. Conversely, if specifications are made for refurbished PCs, then their supply will decrease and the number of parts to be disposed will increase.

2 OBJECTIVE

In this paper, we present an algorithm that can determine the preferred recycling routes for desktop PCs based on the dispersive information available on reusable parts from the viewpoint of material recycling. This model was constructed using a multi-agent system (MAS). Applying the MAS to the lifecycle (production, use, reproduction, and disposal) of a desktop PC, we simulated recycling routes for the PC parts. By this method, we envisage that the simulated condition of the refurbished–PC market clarifies an optimal recycling plan. Figure 1 shows a model of the refurbished–PC market. Figure 1 a) indicates the ordinary market, where recycling of used parts of aged PCs are not done, thereby causing an increase in the number of recyclable parts. Figure 1 b) indicates a model of the refurbished–PC market, where CPUs (including the motherboard) are reused in 4–5-year-old PCs, and hence most of the available PC parts are used. Our study shows that most of the refurbished PCs with definite specifications can be made by adhering to certain market rules and by introducing some new parts in the recycling process. By supplying information on the waste parts and criteria that affect the products to the agents, an ideal recycling map can be calculated. Further, it is thought that the circulation of secondary parts circulation emerged, the quantities of the material to be recycled and disposed as waste could be largely reduced.

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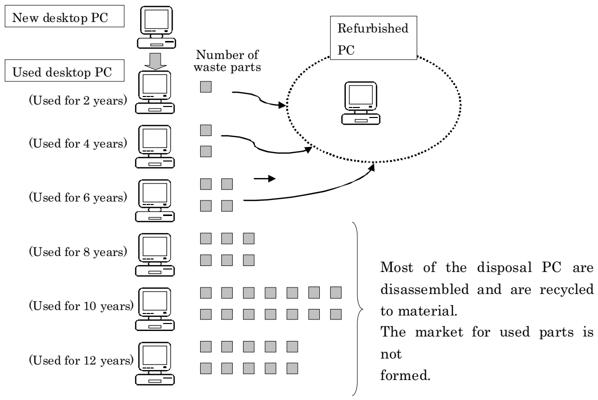
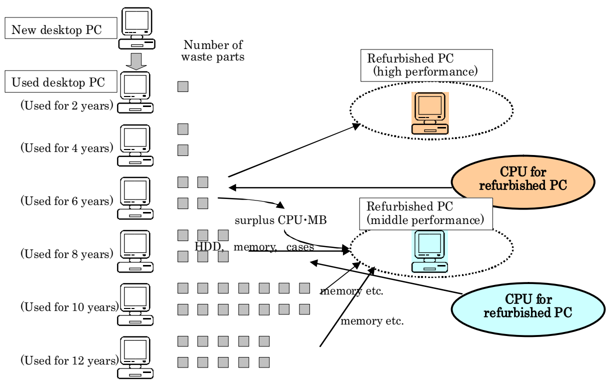


a) Conventional PC recycling



b) Formation of refurbished–PC market

Fig. 1 Models of PC recycling markets

3 RESEARCH MODEL

3.1 Multi-agent model to deduce recycling route

Generally, information on the products' designs, their disposal, and recyclability has the following characteristics.

- Data (design data, material data, etc.) are huge.
- Data always fluctuate according to the substitutes of a new product and so on.
- Data disperse in each site.

We used a multi-agent model that used the data on these characteristics to derive an effective recycling route. We applied a large number of agents to each criterion of the product information of the PC, which was found dispersed in the information network space. Figure 2 shows the actions of the agents in the PC–part cyclic process. As we could not cope with the various changes that occurred in the information on the product and recycling when individual agents used complicated action rules, we set simple action rules for them. It is, however, difficult to make a decision on whether the result provided by the MAS is the most optimum. Under a fluctuating situation of product information, the maintenance of the recycling cycle is more important than the derivation of an optimum value for a certain point in time. Therefore, the principal objective of this study is to clarify the condition of the agent in which the circulation of recycling is continued.

3.2 Modeling of desktop PC

The general desktop PC comprises of a CPU, memory, motherboard, HD, chassis, and power supply unit. As shown in figure 3, we took up four main parts of a PC and assigned each part with a character, and modeled a product through the expression of a string of characters. Each process step in the lifecycle of a product – production, disassembling, disposal, and recycling – can present many permutations and combinations of calculations (e.g., composition, division, and substitution of characters). Therefore, an easy-to-apply, multi-agent model was considered as appropriate.

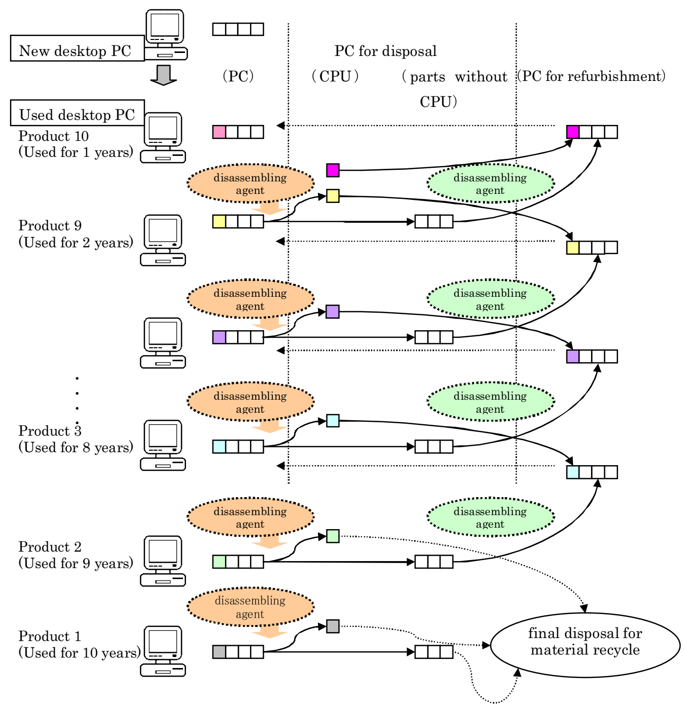


Fig. 2 Movement of agents in PC recycling process

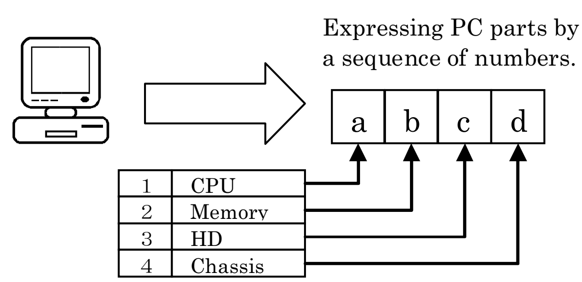


Fig. 3 Numerical model of desktop PC

3.3 Initial condition and calculation parameters

Specifications of standard PC

The initial number of PCs manufactured from 2000 to 2010 was set to 100, and they were classified according to their ages in steps of one year (the series Product 1 to Product 10 was in a descending order of age). PCs were broken down at each time step with a constant probability (initiated when the rate of trouble rises in an old PC), and at random. One character of a string was expressed (the PC part) and was changed to the other character (expressed as the trouble part) at random for every time step. The CPU has a performance attribute of 100–1000 (the calculation of performance of a CPU increases with the increase in this number). Other parts have performance levels of -20 to +20. We modeled them so that the total of the performance levels of each part expressed the total performance of the PC. Table 1 indicates the changes in the standard specifications of the desktop PC at different years of production. The performance of the PC improves year-by-year in this way, however, the replacement of a part in a PC is relatively easy if their ages are almost the same.

Table 1 Specifications of standard desktop PC

	2010 year model	2008 year model	2006 year model	2004 year model	2002 year model	2000 year model
CPU	2.80 GHz	2.53 GHz	3.06 GHz	2.66 GHz	1.7 GHz	1.0 GHz
Mother board	HM55 Expres s	Intel G965	Intel 945G Expres s	Intel 865G	Intel 845GV	Intel 815E
Memory	2 GB ×2	1 GB ×2	512 MB ×2	512 MB	512 MB	128 MB ×2
HD	500 GB	500 GB	320 GB	160 GB	80 GB	60 GB

Specifications for agent

As an initial condition, we prepared 1000 agents. Five-hundred agents were assigned the role of assembling and the other 500 agents, disassembling. Furthermore, each agent was assigned performance attribute an attribute of PC-age for his or her work. The discarded PC is disassembled, and the part that is not out of order is reused. The agents who were able to work (assembling or disassembling) survived and multiplied. The agent who did not have work at some step perished.

Specifications of CPU for refurbished PC

In the conventional PC–recycling market, the PC is disassembled and the young part is reused; but as there is no demand for the aged part, its material is recycled. Therefore, to reduce the quantum of PC parts that will be disposed off and to create a market for the reuse of aged parts, we specified the use of a new CPU (including the motherboard) along with the aged parts to produce refurbished PCs with mid-performance rating.

4 RESULTS

4.1 Differences in number of products with use of new CPU for refurbished PCs

Figure 4 shows the number of products in the market for different ages of refurbished PCs that were not replaced with a new CPU. Figure 5 shows the number of products in the market for different ages of refurbished PCs that were replaced with a new CPU (performance attribute of 500) in the market. This indicates that the market for Product 5 was formed. Simultaneously the number of the reused PC of Product 7 increased as secondary circulation. Figure 6 shows the number of products in the market for different ages of refurbished PCs that were replaced with a new CPU (performance attribute of 700) indicating the formation of a market for Product 7. However, the secondary circulation except Product7 was not formed in figure 7.

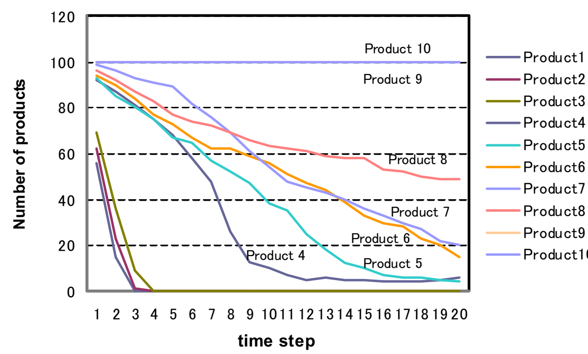


Fig. 4 Transition in number of products (without a new CPU)

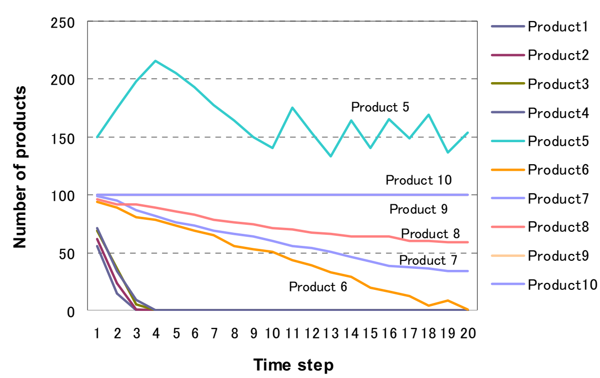


Fig. 5 Transition in number of products with new CPU and performance attribute of 500.

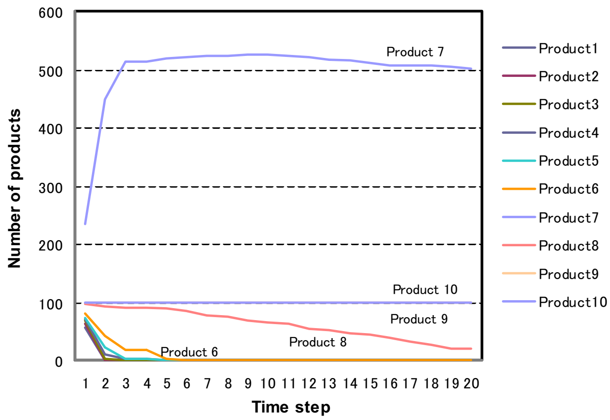


Fig. 6 Transition of number of products with new CPU and performance attribute of 700

Figures 7 and 8 show the number of products for 20 steps with and without the use of a new CPU for refurbishment for different performance attributes. Figure 7 shows that the Product 5 has a market and that the use of a new CPU to refurbish the PCs increases their market, recyclability, and reuse of the other parts.

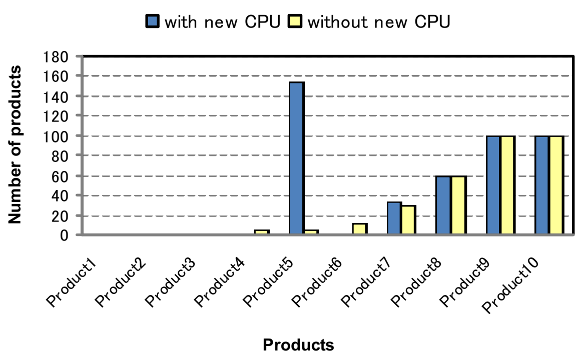


Fig. 7 Products number of 20 steps (with renewal CPU of 500 performance, and without renewal CPU)

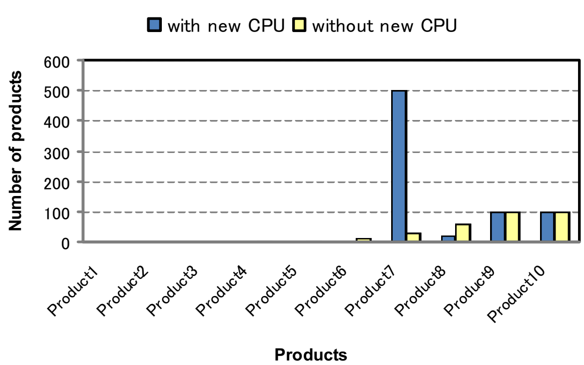


Fig. 8 Products number of 20 steps (with renewal CPU of 700 performance, and without renewal CPU)

4.2 Difference in number of parts for disposal with use of new CPU for refurbished PCs

Figures 9 and 10 show the comparison of the number of parts in the market for PCs with performance attributes of 500 and 700, respectively, with and without the use of a new CPU. A decrease in the number of parts for disposal is observed when the new CPU is used for refurbishing the PC with a performance attribute of 700.

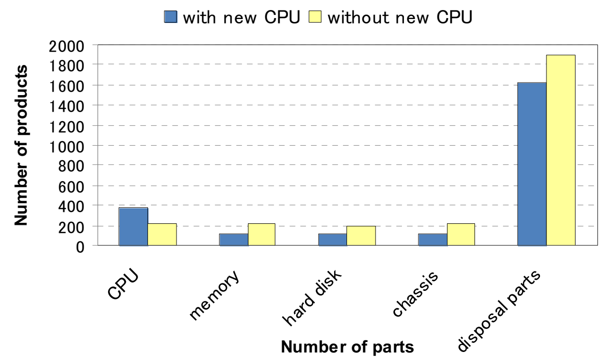


Fig. 9 Parts number of 20 steps (with renewal CPU of 500 performance, and without renewal CPU)

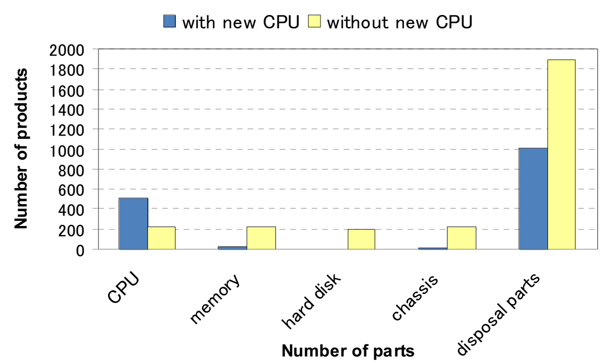


Fig. 10 Parts number of 20 steps (with renewal CPU of 700 performance, and without renewal CPU)

5 CONCLUSIONS AND FUTURE WORK

Based on our model computations, we found that when CPUs (including the motherboard) are suitable for refurbishment of 4–5-year-old PCs that were introduced in the recycling market, most of the PC parts that were available for reuse were utilized. Further, it was found that the circulation of secondary parts circulation emerged, and the quantities of the material to be recycled and disposed off as waste could be largely reduced. Thus, we were able to show the emergence of a global structure (the formation of a refurbished–PC products market) that could not be described by individual agents. This circulation system can also be applied to products in other fields for the creation of a refurbished-products market. In this manner, we can contribute to the creation of a sustainable society.

We intend to focus on the following problems in the future:

- Clarification of the mathematical conditions that establish the circulation of recycling.
- Detailed evaluation of the environmental impact of recycling using lifecycle assessment (LCA) data.
- Construction of a model based on the consideration of costs of the parts.
- Examination of the economic parameters that contribute toward the circulation of recycling.
- Modeling to evaluate the influence of extension of life of products.
- Modeling of the geographical factors in the disposal of products.
- Evaluation of the energy consumption of PCs.

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A New Graph-based Selective Disassembly Sequence Planning for Green Product Design

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Abstract
Selective disassembly is used to access and remove specific product components for reuse, recycling, or remanufacturing. Early related studies developed various heuristic approaches for selective disassembly. In this study, a new graph-based method using disassembly sequence structure graphs (DSSGs) was developed for selective disassembly sequence planning. Fastener constraints, minimum number of removals, and minimum number of reorientations are all considered. Unlike prior graph-based methods, in which target components are disassembled by choosing a path through a total disassembly graph that contains all parts in the product, the developed method creates DSSGs that only contain the components and fasteners which must be removed to disassemble the target components. Thus, using the developed DSSGs greatly reduces computational time and resources needed.

Keywords:
selective disassembly sequence planning, disassembly sequence structure graph, green product design

1 INTRODUCTION

Due to increasing environmental awareness and concerns, green design is playing an increasingly important role in industrial manufacturing. In particular, product end of life is becoming an important issue in green design. Now, end of life objectives such as component reuse, remanufacturing, and recycling constitute some of the most important reasons for disassembling products, while in early disassembly studies, researchers focused primarily on finding optimal assembly or disassembly sequences to reduce manufacturing cost and increase product value.

Early disassembly research focused more on finding complete optimal assembly or disassembly sequences for a product. However, selective disassembly sequence planning is particularly important for green designs, because, generally, specific components need to be removed from the products to reduce energy use and environmental impacts.

Prior studies have utilized advanced algorithms to find optimal selective disassembly sequences. Srinivasan et al. presented a wave propagation (WP) method to solve selective disassembly problems [1, 2]. WP allows disassembling one or more components, as well as total selective disassembly. WP considers minimal removals as the goal, designers are able to obtain disassembly sequence which has minimal objects. Although their evaluation function is simple, it might not satisfy the demands of many realistic product design problems.

Ant colony optimization (ACO) and genetic algorithms (GA) are also utilized to solve selective disassembly sequence planning problems [3, 4]. More details like geometric constraints or disassembly directions are able to be considered to make the evaluation more realistic. However, their methods are more suitable for single target component removal.

Smith and Chen [5] developed a rule-based recursive algorithm which takes more details into consideration. In their study, fastener's geometric information is considered to make the evaluation more practical. Although Smith and Chen's method can effectively find a near-optimal heuristic solution while greatly reducing computational time, their method is also only suitable to solve single target disassembly sequence planning problems.

Some prior research used different graphical methods to help present disassembly information, like geometric information, component information, and constraint information. For example, weighted hierarchical attributed liaison graph (WHALG) shows the layer relationship between product components and the module relationship [6]. A module can also be divided into single objects or smaller modules.

A Disassembly Tree (DT) decomposes a product into different clusters or layers by component functionality [7, 8]. An AND/OR graph is also used to show the relationships between components [9]. Components with OR relationship means the disassembly solutions have more than one choices. A Disassembly Graph (DG) shows all possible disassembly sequences for disassembling a product [10, 11].

The graphical methods mentioned above are all designed

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for total disassembly or single-target component removal. Users disassemble parts according to the route they choose in the graphs. Thus, parts which are not disassembled during the selective disassembly process are also presented in the graphs. In this paper, a new graphical method, Disassembly Sequence Structure Graph (DSSG), is presented for selective component removal. Instead of constructing a graph for total disassembly sequence planning, DSSG shows only necessary parts which need to be disassembled for reaching target components for selective disassembly. Thus, using DSSG can reduce computational time and recourses greatly.

This paper integrates DSSG and the rule-based recursive method for obtaining near-optimal heuristic selective disassembly sequences. Fastener constraints, disassembly directions, minimum disassembly reorientations, minimum number of removals are considered in the method.

2 DEFINITIONS OF GEOMETRIC RELATIONSHIPS

In this section, Smith and Chen's disassembly models [5] are modified to satisfy the requirement for constructing a DSSG. A fastener here is a connector like a screw, bolt, washer, spring, etc, which usually is not a major design element in a product. A component here is a design element usually possesses certain functionality. A part here is a collective term for a fastener or a component. A query part is a component or a fastener which is currently under disassemblability checking.

2.1 Disassembly matrix for components

A disassembly matrix for components, *DC*, is defined to record the immediate touched fasteners, in the fastening directions, and the immediate touched components fastened with the query components by certain fasteners, in their fastening directions.

The *DC* has six columns, which represent six principal directions *+x, -x, +y, -y, +z*, and *–z*. If any of the six directions does not have any constraint, the corresponding column will be recorded "*0*". Here, a fastener is represented by an alphabet letter and a component is represented by an Arabic numeral. For the 2D example in Figure 1, the *DC* of component *1* is: $DC_{11} = 0$; $DC_{12} = 0$; $DC_{13} = a, h, 5$; and $DC_{14} = 2$. The complete *DC* of the example in Figure 1 is as follows.

$$DC=\begin{bmatrix} DC_1\\ DC_2\\ DC_3\\ DC_4\\ DC_5\\ DC_6\\ DC_7\\ DC_8\\ DC_9 \end{bmatrix}=\begin{bmatrix} 0 & 0 & a,h,5 & 2\\ 6 & b & a,1 & c,3\\ 0 & 0 & 2,4,7 & c,d,e\\ f,g & 5,8 & 0 & e,3\\ g,4 & 0 & h & 1\\ 8 & b,j,2 & 0 & d,7\\ 0 & 0 & i,6,9 & d,3\\ f,4 & j,6 & i & 9\\ 0 & 0 & i,8 & 7 \end{bmatrix}$$

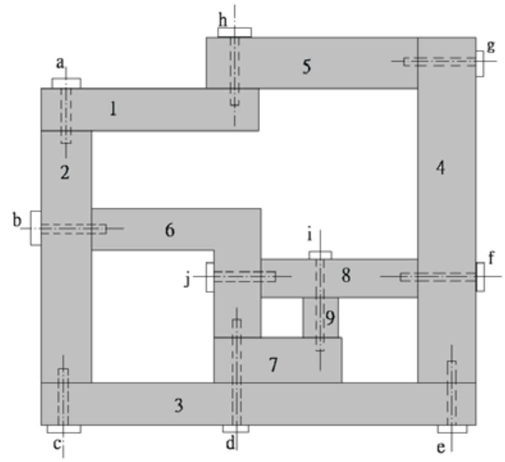

Fig. 1: Example Assembly

2.2 Disassembly matrix for fasteners

A disassembly matrix for fasteners, *DF*, is defined to record the disassembly directions of each fastener. The corresponding directions for disassembling a fastener are recorded "*0*". Other directions are "*-1*". The *DF* of the example in Figure 1 is as follows.

$$DF=\begin{bmatrix} DF_a\\ DF_b\\ DF_c\\ DF_d\\ DF_e\\ DF_f\\ DF_g\\ DF_h\\ DF_i\\ DF_j \end{bmatrix}=\begin{bmatrix} -1 & -1 & 0 & -1\\ -1 & 0 & -1 & -1\\ -1 & -1 & -1 & 0\\ -1 & -1 & -1 & 0\\ -1 & -1 & -1 & 0\\ 0 & -1 & -1 & -1\\ 0 & -1 & -1 & -1\\ -1 & -1 & 0 & -1\\ -1 & -1 & 0 & -1\\ -1 & 0 & -1 & -1 \end{bmatrix}$$

2.3 Motion constraint matrix for components

A motion constraint matrix for components, *MC*, is defined to record the "first-level parts" of a query component which are not recorded in *DC*, and record the fasteners which constraint the motion of the query component in two directions of a principal direction. The definition of "first-level parts" is different from which of Smith and Chen [5]. Here, first-level parts are the parts would intersect with the shadow of a query component or fastener in given principal directions. For example, in Figure 1, the *MC* is as follows.

$$MC=\begin{bmatrix} MC_1\\ MC_2\\ MC_3\\ MC_4\\ MC_5\\ MC_6\\ MC_7\\ MC_8\\ MC_9 \end{bmatrix}=\begin{bmatrix} a,h,4 & a,h & 0 & 6\\ a,c,j,4,7 & a,c & b & b\\ c,d,e & c,d,e & 0 & 0\\ e & e,1,2,6,7,9 & g,f & g,f\\ h & h & g & g,i,8\\ d,4,9 & d & b,j,1 & b,j,3\\ d,i,4 & d,i,2 & 8 & 0\\ i & i & f,j,5 & f,j,3,7\\ i,4 & i,6 & 0 & 0 \end{bmatrix}$$

2.4 Motion constraint matrix for fasteners

A motion constraint matrix for fasteners, MF, is defined to record the first-level parts of a fastener in its disassembly direction. The MF of the example in Figure 1 is as follows.

$$MF=\begin{bmatrix} MF_a\\ MF_b\\ MF_c\\ MF_d\\ MF_e\\ MF_f\\ MF_g\\ MF_h\\ MF_i\\ MF_j \end{bmatrix}=\begin{bmatrix} 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&0&0\\ 0&0&5&0\\ 0&2&0&0 \end{bmatrix}$$

Here, the union of two matrices is the union of the parts in the corresponding tuples. For example,

$MC_1 \cup DC_1 =$
$[MC_{11} \cup DC_{11} \quad MC_{12} \cup DC_{12} \quad MC_{13} \cup DC_{13} \quad MC_{14} \cup DC_{14}] =$
$[a, h, 4 \quad a, h \quad a, h, 5 \quad 2,6]$.

According to the definition, when the corresponding tuples in DC_n and MC_n are 0, component n can be removed from the corresponding directions. Likewise, when the corresponding DF_f and MF_f are 0, fastener f can be removed from the corresponding directions.

The modified *DC, DF, MC*, and *MF* can define a disassembly model more completely and efficiently. In addition, the modified matrices are more useful for our DSSG-based selective disassembly sequence planner.

2.5 Projection component matrix

A projection component matrix (*PC*) records, for each component and each disassembly direction, the number of components which would prevent the given component from moving in the given disassembly direction. The *PC* matrix is used to choose initial disassembly directions for removing given target components from a product. The *PC* for the example in Figure 1 is

$$PC=\begin{bmatrix} PC_1\\ PC_2\\ PC_3\\ PC_4\\ PC_5\\ PC_6\\ PC_7\\ PC_8\\ PC_9 \end{bmatrix}=\begin{bmatrix} 1&0&1&4\\ 5&0&1&1\\ 0&0&8&0\\ 0&7&0&1\\ 1&0&0&6\\ 3&1&2&2\\ 1&1&5&1\\ 1&2&1&3\\ 1&2&2&2 \end{bmatrix}$$

The *DC, DF, MC*, *MF,* and *PC*, as defined, can be used to efficiently create disassembly models for 2D or 3D products. In addition, the matrices can be used to build DSSGs for our multiple-target selective disassembly sequence planner.

3 DISASSEMBLY SEQUENCE STRUCTURE GRAPH (DSSG)

3.1 DSSG definition

A DSSG is an inverted tree. The root of the DSSG is at the bottom of the tree and the leaves are at the top of the tree. The root nodes of the DSSG represent target components. The leaf nodes of the DSSG represent parts (components and fasteners) which constrain the target components from being removed. Graphically, components are represented by squares and fasteners are represented by circles (as shown in Figure 2). A final selective disassembly sequence can be found by removing the leaf nodes to reach the root nodes (target components). To reach the target components, all of the parts in the DSSG need to be removed.

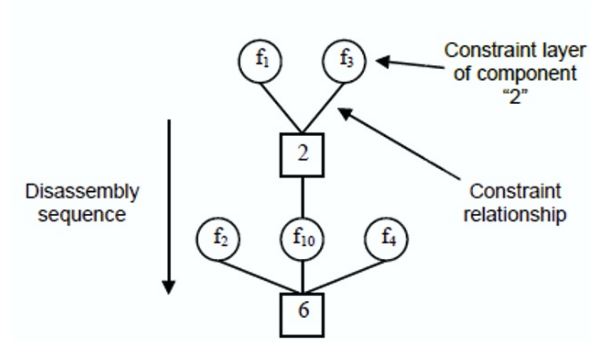

Fig. 2 : A DSSG Example

Nodes in the DSSG are arranged in levels and connected based upon the constraint relationships between parts. Parts which constrain a given part (node) are placed in the next higher level (constraint level) of the given part and are connected to the part as children. For example, in Figure 2, fasteners f_1 and f_3 are in the constraint layer of component 2, and they are the children of component 2. Similarly, component 2 is in the constraint layer of fastener f_{10}, and it is the child of fastener f_{10}.

3.2 DSSG construction

A DSSG is constructed by extracting information from the disassembly model matrices. The DSSG construction process begins by extracting information about the target component from the matrices. From the information returned, the root node and root node's constraint level can be built. The process continues by extracting information about the constraint level parts, in an iterative fashion. The target component is always the first part considered in the DSSG construction process. The process may result in more than one DSSG for removing a single target component. The different DSSGs describe different sets of parts which can be removed to reach the given target component.

After a DSSG is constructed, the DSSG can be analyzed to determine part disassembly order, to create a disassembly sequence. The DSSG is analyzed by querying parts (nodes) in the tree to determine if the parts can be removed. A query part is a part which is currently being considered for removal.

In a practical disassembly process, parts are removed using one-translation motions; parts do not change their disassembly directions when they are removed. One-translation motions make tool and part access easier for robots and disassembly workers. Therefore, in this study, DSSGs are constructed and analyzed assuming one-translation motions. With one-translation motions, a given part can only be disassembled in a certain direction after removing all parts that block movement in that direction. In addition, based upon practical experience, target component should be disassembled in the direction with the least number of obstacles.

As a result, the process for constructing a DSSG is based upon three rules. Rule 1 states that before a query component *n* can be removed, all fasteners attached to the component need to be removed. Rule 2 states that before a query component *n* can be removed in a pre-defined disassembly direction, all obstacles in the given direction need to be removed. In the algorithm, directions are expressed as *tuple_tags*. For a 3D product, *tuple_tags* (1, 2, 3, 4, 5, 6) correspond to the principal directions (+x, -x, +y, -y, +z, -z). Therefore, the pre-defined direction for removing component *n* is called *tuple_tag(n),* and the obstacles which need to be removed before component *n* are in $DC_{n(tuple\_tag(n))}$ and $MC_{n(tuple\_tag(n))}$. Rule 3 states that before a query fastener *f* can be removed in a given disassembly direction, all obstacles in the given direction need to be removed.

Evaluating Rules 2 and 3 requires the union of two rows in the disassembly model matrices. By definition, the union of two rows of the disassembly model matrices is the union of the corresponding row tuple elements. For example, for the product in Figure 1,

$MC_1 \cup DC_1 = [\ MC_{11} \cup DC_{11} \quad MC_{12} \cup DC_{12} \quad MC_{12} \cup DC_{12} \quad MC_{14} \cup DC_{14}] = [f_1,f_8,4 \quad f_1,f_8 \quad f_1,f_8,5 \quad 2,6]$.

Based upon Rules 2 and 3, if any union of corresponding row tuple elements from DC_n and MC_n is *0*, then component *n* can be removed in the corresponding direction. Similarly, if any union of corresponding row tuple elements from DF_f and MF_f is *0*, then fastener *f* can be removed in the corresponding direction.

The target component is the first query component *n* and the root node of every DSSG. The target component must be removed in a direction which has the smallest number of obstacles. The process considers all directions, *tuple_tag v*, for which PC_{nv} is a minimum. The process constructs DSSGs such that all fasteners which constrain a query component will be removed first, by Rules 1 and 3, and then, all obstacle components will be removed, by Rule 2.

As an example, the target component for the product in Figure 1 is component *7*. Since PC_7=[1 1 5 1], and PC_{71}, PC_{72}, and PC_{74} are minimum values, the process will consider removing component 7 in the +x, -x, and +y directions, respectively. The final three corresponding DSSGs for disassembling component 7 are shown in Figure 3.

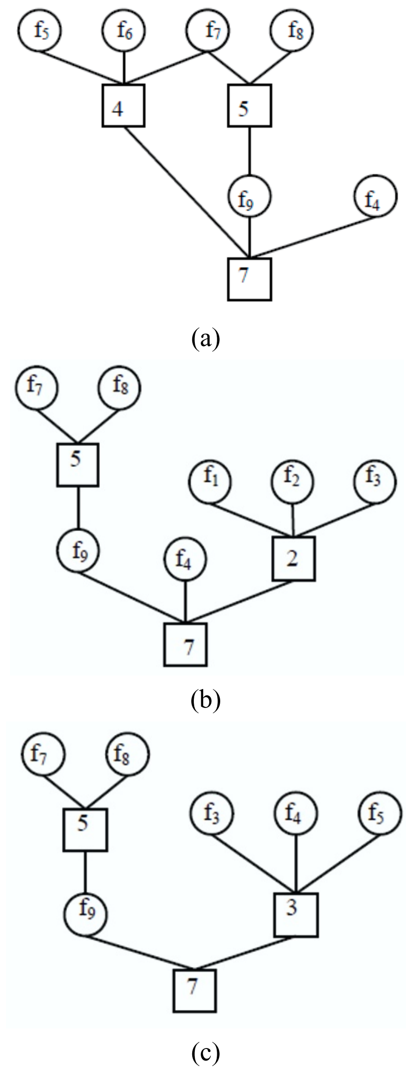

Fig. 3 : DSSGs for Disassembling Component 7

4 CONCLUSIONS

In this study, a new graph-based method was developed which uses DSSGs to solve the selective disassembly sequence problem. The method starts by creating a disassembly model for a given product. The model is composed of four matrices which contain disassembly constraint information. For given target components, DSSGs are extracted from the disassembly model. The process for constructing DSSGs is based upon three rules, which were developed by analyzing characteristics of disassembly processes and the disassembly model. Finally, disassembly sequences are generated and optimized by decoding the DSSGs using a GA.

Unlike prior graph-based methods, in which target components are disassembled by choosing a path through a total disassembly graph that contains all parts in the product, the developed method creates DSSGs that only contain the components and fasteners which must be removed to disassemble the target components. Using DSSGs, therefore, eliminates unrealistic and impractical disassembly sequence solutions. Using DSSGs also greatly reduces computational time and resources needed.

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Exploring the Life Cycle and Attachment Characteristics of Eco-Products

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Abstract
This research explores the life cycle and possible characteristics of attachment towards the product-user relationship. It is an introduction to the study of attachment characteristics of eco-products. In this research those attachment characteristics are related with physical sensation of touching and aesthetic elements (form, color and material). According the analysis of eco-products from Eco-Design Handbook, it was identified that leisure & recreation product category and domestic product category have potential attachment characteristics.

Keywords:
life cycle, attachment, eco-products

1 INTRODUCTION

Based on the studies of Mugge [1], in the literature on interpersonal relationship, it is proposed that an attachment is an emotion-laden-target-specific bond between two persons. [2]

Product attachment is defined as the strength of the emotional bond a consumer experiences with a specific product. [3]

The definition of product attachment suggests that when experiencing attachment to a product, a strong relationship or tie exists between the individual on the one hand and the object on the other hand.

The definition implies that the object to which as person experiences attachment triggers one's emotions. [1]

According to the study of Mugge and Hekkert the most reported emotions related with products were happiness, love, warmth, nostalgia, sadness, pride, security, comfort, excitement, and joy. [4]

From the viewpoint of eco-product and sustainability, one possible strategy to slow down product life cycles is by increasing the attachment people experience towards the products they use and own [5]

From the arguments of Yim [6], many eco-products have better environmental performance but fulfilling consumer needs is far beyond the consumers' satisfaction level.

Based on the previous studies [7,8,9] the most eco product in the marketing reported on the life cycle principles, where a little attention has been given the emotion aspects.

The implementation of emotion values, as the attachments aspects in the eco product can to contribute the balance of between product and users. The attachment characteristics can user stimulating the awareness of product longevity.

2 DESIGN OF RESEARCH

This research explores the relationship between the life cycle and attachment characteristics. To make possible this research, at the first stage, 233 of eco-products from The Eco-Design Handbook [10] were explored from life cycle viewpoint (pre-production, production, distribution, use and disposal phase).

In the second stage those eco-products were explored from attachment viewpoint. In this research the attachment characteristics are related with the physical (sensation of touching) and aesthetic (form, color and material) viewpoint. (Fig.1)

The products were classified into seven categories, furniture, lighting, fashion & textile, appliance, transport, leisure & creation and other domestic product.

The Eco-Design Handbook is a comprehensive publication catalogue and represents the green product to the consumer. It is a complete sourcebook for everyday use at home and in the office.

2 ANALYSIS OF ECO-PRODUCT (LIFE CYCLE VIEWPOINT)

The 233 eco-products (Fig.2), classified into seven categories were judged with values 0 and 1, based on the criteria of life cycle assessment. Based on the results of number of frequency of each product, the categories of products were characterized by the following basic principles of life cycle assessment (LCA): recycled materials, renewable materials, reduction material usage, economy of usage material, reduce energy, energy efficiency, functionality, multi function, clean production, zero emission, fuel consumption, reduction of waste production. (Table 1)

M. Matsumoto et al. (eds.), *Design for Innovative Value Towards a Sustainable Society*,
DOI 10.1007/978-94-007-3010-6_165,

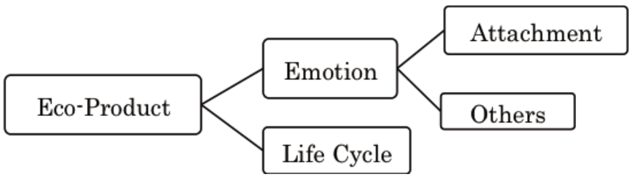

Fig.1: Exploring Attachment Characteristics

Table 1: Analysis of Eco-Product (LCA Viewpoint)

Product Categories	Basic Principles of LCA
Leisure and Creation	Zero emission
	Renewable material
	recycle
	Reduction material usage
Domestic products	Multi function
	Economy of usage material
	Reduce energy
	recycle material
Transport	Fuel Consumption
	Zero emission
Lighting	Renewable material
	Economy of usage material
Appliances	Functionality
	Energy efficiency
	recycle material
Fashion and Textiles	Renewable material
	Clean production
	Reduction of waste production
Furniture	Economy of usage material
	recycled material

3 ANALYSIS OF ECO-PRODUCT (ATTACHMENT VIEWPOINT)

Based on the research of product attachment [11,12,13], the authors explore four possible characteristics of attachment towards the product-user relationship. These characteristics are: aesthetic elements (color, form and material), nostalgia-memories, physically touched and function-practical.

Each 233 eco-products (Fig.1), classified into seven categories, were judged based on those characteristics with values from 1 to 4. (Table 2)

Table 2: Analysis of Eco-Product (Attachment Viewpoint)

Product Categories	Rank-Order	Attachment Characteristics
Leisure and Creation	1st	aesthetic elements
	2nd	Nostalgia-memories
	3rd	physically touched
	4th	Functionality-practical
Domestic products	1st	physically touched
	2nd	aesthetic elements
	3rd	Functionality-practical
	4th	Nostalgia-memories
Transport	1st	Functionality-practical
	2nd	aesthetic elements
	3rd	Nostalgia-memories
	4th	physically touched
Lighting	1st	Functionality-practical
	2nd	aesthetic elements
	3rd	Nostalgia-memories
	4th	physically touched
Appliances	1st	Functionality-practical
	2nd	physically touched
	3rd	aesthetic elements
	4th	Nostalgia-memories
Fashion and Textiles	1st	aesthetic elements
	2nd	physically touched
	3rd	Nostalgia-memories
	4th	Functionality-practical
Furniture	1st	Functionality-practical
	2nd	aesthetic elements
	3rd	physically touched
	4th	Nostalgia-memories

4 DISCUSSION

According the analysis of eco products from Eco-Design Handbook, it was identified that leisure & recreation product category and domestic product category have potential attachment characteristics. From the life cycle view, the leisure & recreation products category was characterized by the grouping of reduction material usage,

Lighting		
	1	Bernini
	2	Quentin
	3	Fish Lamp
	4	Flirt
	5	Lampshade
	6	Miss ceiling Light
	7	Milk bottle light
	8	Northern Fleet
	9	Loop
	10	Bogdan light
	11	cape light
	12	Comeback series
	13	Clips
	14	Corkscrew lamp
	15	Hand
	16	Table/floor light
	17	Light Wall 2
	18	Lumalight lamp
	19	e light
	20	Obinjo
	21	Mini desk lamp
	22	Tube
	23	PO9810
	24	Pharos floor lamp
	25	PO9902
	26	Post it Lamp
	27	Table lamps
	28	Sailbuoy Canvas
	29	The eye of the peacock
	30	Table floor light
	31	Table lamp
	32	Light columns
	33	Viva
	34	Valvestem candlestick
	35	Power glass
	36	Delight
	37	Wall bracket
	38	Helmut
	39	[illegible] MFL
	40	Pod Lens
	41	Outdoor light
	42	solar bud
	43	[illegible]
	44	Outdoor light
	45	[illegible]
	46	Freeplay Flashlight
	47	Aladdin Power
	48	L48 solar lantern
	49	SL Torch
	50	Solaris

Domestic Product		
	1	Morphy one project
	2	Bob
	3	Ecolo
	4	Malvinas
	5	Fruit holders
	6	wagga wagga
	7	spiralbaum
	8	sponge vase
	9	Tableware
	10	ceramic bowls
	11	the softvase
	12	Attila
	13	Cricket
	14	UNPAC
	15	Zago
	16	Bottle stopper and opener
	17	GlobalKnife
	18	Fold
	19	Cutlery tool
	20	Double cup
	21	Disposable cutlery
	22	Drinking glass
	23	Drinking vessel
	24	Wine rack
	25	Basket 2 Hands
	26	Barnacle
	27	Coffee cream bottle
	28	Elster
	29	Durex Avanti
	30	Earth sleeper
	31	Eco-ball
	32	Fingermax
	33	Juice cartons
	34	Kango
	35	Muscle Power toothbrush
	36	Magazine rack
	37	Mega solar
	38	Pin up clock
	39	Mega [illegible]
	40	[illegible] Thermos
	41	Pet Pod
	42	Rollerbag
	43	Stationery goods
	44	U-box
	45	Waste paper bin
	46	Basket
	47	Litter bin
	48	clock
	49	Talking alarm clock

Leisure & Creation		
	1	Wissel horse saddle
	2	Synchilla snap T
	3	NIGHTEYE
	4	Pod floating lounger
	5	Veloland
	6	Kayak
	7	Skystreme 729
	8	Terra grass armchair
	9	E tech
	10	Can o Worms
	11	Nature's choice trellis range
	12	Compost converter
	13	MicroBore
	14	Pedal Lawnmower
	15	Solar mower
	16	Glass sound
	17	V-mail camera
	18	Canon IXUS
	19	Digital Mavica
	20	Freeplay FPR2
	21	Magno Radio
	22	AE1000 free power radio
	23	Tykho
	24	Grundig 15 colour
	25	FLS range
	26	Smart wood Les Paul
	27	The Basic bass
	28	Savvy
	29	Xenium
	30	Rocket eBOOK

Transportation		
	1	Citymobil C1
	2	Ecobasic
	3	EV1
	4	Insight
	5	Daimler Chrysler
	6	G90
	7	ICVS
	8	Multupla Hybrid Power
	9	P2000 HFC Prodigy
	10	Prius
	11	Sparrow
	12	Smart car
	13	THINK City
	14	Triax
	15	VW Lupo 3L TdI
	16	NECAR 4
	17	Independence 3000 iBOT
	18	Hybrid bike
	19	Delite
	20	Nexus cycle
	21	Electrical Bike
	22	Strida 2
	23	Wind Cheetah
	24	Rattan bicycle
	25	Brompton
	26	Daedalus 88
	27	Gossamer Albatross
	28	The Pickup
	29	Ciro Magic
	30	Skoot
	31	Xootr Cruz
	32	Tricycle
	33	Plumber cart
	34	SRAM
	35	Leggero Twist

Appliances		
	1	IChef
	2	Aga
	3	Solar cooker
	4	Café Duo Hd
	5	Glass kettle
	6	Rondo
	7	POLTI Ecologico
	8	Karcher
	9	Cleaning
	10	Polti Vaporetto
	11	Oko Lavamat
	12	Titan
	13	Hoover Quattro
	14	Staber System 2000
	15	OZ23
	16	Planet DC
	17	Supercool
	18	Vestfrost
	19	Sycamore fan
	20	Wind
	21	Soft fan

Furniture		
	1	Spin & oasis Chair
	2	Agatha Dreams
	3	Chair
	4	Slick Slick
	5	Sprocket
	6	Bastian
	7	Blotter
	8	Body Raft
	9	Miss Ramirez
	10	Garden Bench
	11	Bucket Seat
	12	Model 290F
	13	Transit Chair
	14	Seating System
	15	Gallery
	16	Impression
	17	How Slow the Wind
	18	Marilyn, I can see your Knickers
	19	Origami Zaisu
	20	Mirandolina
	21	Box
	22	C1 Recliner and Footstool
	23	Cardboard Chair
	24	Conversation Chair
	25	The Porcelain Stool
	26	OTO
	27	Plyboo

Textile & Fashion		
	1	[illegible] 12x12
	2	TENCEL Fashion garment
	3	10939 [illegible] dress
	4	Levis Engineered Jeans
	5	New Nomads
	6	Sensor sportwear
	7	Titshirt
	8	Euro comfort
	9	Wool felt slippers
	10	DOMINO4
	11	The Inner Tube

Fig.2 : Seven Categories of Eco-Design Handbook

recycle, renewable materials and zero emission. However, the domestic products category was characterized by the grouping reduce energy, economic material usage and multi-function.

The relationship between the life cycle and attachments characteristics of leisure & recreation product category were the aesthetic elements with the renewable materials.

While that the domestic products category the relationship were the physical sensation of touching with unique or single material.

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Hazardous Potential Indicator for Material According to Globally Harmonized System

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Abstract

The industrial revolution has resulted in the rapid growth of product manufacturing, and this growth has made an important contribution to world economy. Because of the complexity of product manufacturing processes and their waste streams, products may post hazard to environment and human health. Typical small and medium-sized enterprises, which tend to have shorter product cycles, cannot afford staffing toxicologists or environmental specialists in the companies' product design divisions. These enterprises need an easy-to-use and time-efficient tool for environmentally conscious design. The potential indicator methodology in this study developed meets such a need. Unlike traditional LCA tools that require tremendous amount of inventory data, the standard Safety Data Sheets (SDSs) are sufficient to establish the indicators. The proposed Hazardous Potential Indicator (HPI) is suitable to all countries that implement the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Thanks to the GHS, consistent HPI results can be obtained on materials based on different SDSs. The potential indicator approach, based on applicable SDSs, is a simple and direct tool to help product designers compare and select components and materials to reduce the impact to the environment for the purpose of Eco-design.

Keywords:

Hazardous Potential Indicator (HPI), Globally Harmonized System (GHS), Safety Data Sheet (SDS), material assessment

1 INTRODUCTION

The use of chemicals to enhance and improve life is a widespread practice worldwide. But alongside the benefits of these products, there is also the potential for adverse effects to people or the environment. As a result, a number of countries or organizations have developed laws or regulations over the years that require information to be prepared and transmitted to those using chemicals, through labels or safety data sheets (SDS). While these existing laws or regulations are similar in many respects, their differences are significant enough to result in different labels or SDS for the same chemical in different countries. Through variations in definitions of hazards, a chemical may be considered flammable in one country, but not another. Or it may be considered to cause cancer in one country, but not another. Decisions on when or how to communicate hazards on a label or SDS thus vary around the world, and companies wishing to be involved in international trade must have large staffs of experts who can follow the changes in these laws and regulations and prepare different labels and SDS [1]. Based on these different SDS descriptions, the potential indicators will be subject to national laws and regulations, culture, language and habits, leading to the same substance in different countries may have different findings. In addition, the development and maintenance of chemicals classification and labeling system is a complex task, many countries did not even such a system, and it is really necessary to establish a universal system. The approach presented in this paper is so consistent with the spirit of the pursuit of global reconciliation system to establish the potential indicators.

2 GLOBALLY HARMONIZED SYSTEM

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is the culmination of more than a decade of work. There were many individuals involved, from a multitude of countries, international organizations, and stakeholder organizations. Their work spanned a wide range of expertise, from toxicology to fire protection to achieve this system. The work began with the premise that existing systems should be harmonized in order to develop a single, globally harmonized system to address classification of chemicals, labels, and safety data sheets [1]. The first version of the document was published by the United Nations Economic Commission for Europe (UNECE) in 2003. Since then, the GHS has been updated every two years as needs arise and experience is gained with its implementation. GHS truly provides much important information for the safe use of chemicals in the world.

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3 HAZARDOUS POTENTIAL INDICATOR

It is necessary to establish simple, convenient, easy possessed and recognized evaluation indicators for hazardous properties of chemicals. Providing safe, healthy and environmentally friendly products has gradually become the universal requirements for product features. Product designers also want to have a more convenient and consistent way as a reference benchmark with regard to the choice of materials. The study, based on years of accumulated research and practical application experience [2-6] and referring to GHS gradually reached a mature stage of practical application, proposed the new indicator named Hazardous Potential Indicator (HPI). The evaluation framework is based on three components: physical hazards, health hazards and environmental hazards according GHS, shown in Fig. 1. Each input variable is ranked with a standard scale factor- N_P, N_H or N_E- from 0 (negligible or zero impact) to 7 (extreme impact). Then, the use of the logarithmic aggregation calculation results in the HPI value of a substance from 0 to 100. These categories and their standard scale factors are shown in Table 1.

Table 1: Example for physical hazard classifications and standard scale factors

Hazard classification	Hazard category	Signal word	Hazard statement	Standard scale factor
Explosives	Unstable explosives	Danger	Unstable explosive	5
	Division 1.1	Danger	Explosive ; mass explosion hazard	4
	Division 1.2	Danger	Explosive ; severe projection hazard	3
	Division 1.3	Danger	Explosive ; fire, blast or projection hazard	1
	Division 1.4	Warning	Fire or projection hazard	0
	Division 1.5	Danger	May mass explode in fire	0
	Division 1.6	No signal word	No hazard statement	0

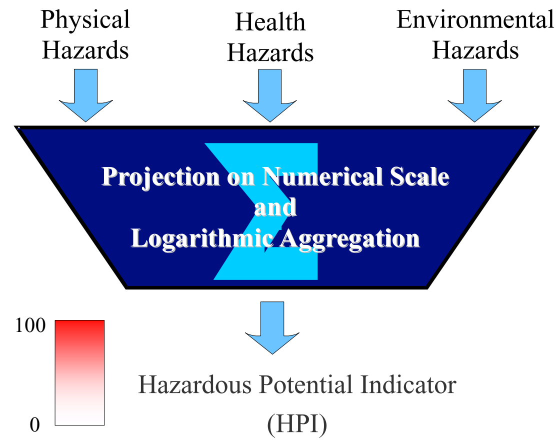

Fig. 1: HPI evaluation framework

4 CASE STUDY

The method for evaluation the hazardous potential of materials in this article is illustrated with a case study of mercury. After screening the SDS for mercury used in this study and using the hazardous substance declarations referenced such as Table 1, we can obtain its hazardous properties, as shown in Table 2. Using values shown in Table 2, we can calculate the HPI value of mercury and result in 26.81.

Table 2: Evaluation results for mercury

Hazard classification	Hazard category	Standard scale factor		
		N_P	N_H	N_E
Acute toxicity (inhalation)	3		5	
Skin corrosion/irritation	1		5	
Serious eye damage/eye irritation	1		4	
Skin sensitizer	1		2	
Toxic to reproduction	2		4	
Specific target organ toxicity following repeated exposure	2		3	
Long-term hazards to the aquatic environment	1			6.12

5 CONCLUSIONS

Enterprises need an easy-to-use and time-efficient tool for environmentally conscious design, and the HPI is sufficient to meet their needs. It is not a traditional LCA tool that needs a large quantity of inventory data, and SDSs found on GHS are sufficient to establish the indicator of hazard. On the whole, the HPI, based on applicable SDSs, is a simple and direct tool to help product designers compare and select components and materials to reduce the potential hazard of products.

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A Life Cycle Simulation for Part Agents that Proposes a Management of Parts Based on Consumer's Satisfaction

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Abstract
Management of individual parts throughout their life cycle is required to promote the reuse of parts. A part agent system is proposed and is being developed for this purpose. In this paper, a scheme is proposed so that part agent proposes the replacement of parts taking consumer's satisfaction into account. To evaluate consumer's satisfaction, consumer preferences are extracted based on the questionnaire and are implemented in part agent system. Life cycle simulation for parts and part agents is performed to show the effect of the scheme.

Keywords:
part reuse, life cycle simulation, part agent, consumer preference

1 INTRODUCTION

Reuse is an essential measure to build a sustainable society. In order to achieve an effective reuse of parts, management of individual parts throughout their life cycle is required. For that purpose, we are proposing a part agent system that consists of a network agents and radio-frequency identification (RFID) tags [1][2][6]. A part agent advises the user on replacement of the part taking into account the user preference. In this paper, we report the extraction of consumer preferences by analyzing the questionnaire and their implementation into part agents. The effect is evaluated through a life cycle simulation of parts and part agents.

In the next section, the concept of part agent is described. Extraction of consumer preference by analyzing the questionnaire is explained in section 3 and a life cycle simulator developed to evaluate the effect of preference is described in section 4. In section 5, the result of simulation focusing on user satisfaction is shown. Section 6 summarizes the paper.

2 PART AGENT FOR SUPPORTING LIFE CYCLE MANAGEMENT OF INDIVIDUAL PARTS

To realize the effective part reuse required for a sustainable society, we must consider the management of individual parts, each with different reuse history, throughout their life cycles to ensure appropriate maintenance and follow up on their reuse.

We have created a scheme of a "part agent" that manages a part and supports user maintenance in promoting parts reuse (Fig. 1). We propose to develop a part agent with a combination of a network agent and an RFID tag. It is assigned to a part to which an RFID tag is attached and programmed to follow its actual counterpart wherever it goes. We assume network proliferation that allows mobility of network agents. The part agent advises users on part reuse and promotes used-part circulation.

A part agent acquires information for managing its part by communicating with the network, where such function as a product database providing product design information, prediction of part deterioration, logistics information, and market information are provided. A part agent also communicates with local site functions such as sensors detecting part status, storage for individual part data, and part management and control. Subordinate network agents generated by the part agent establish the communication. Based on the information acquired, a part agent generates appropriate advice to users on part management. Based on the user's decision, it provides directions on product management and control.

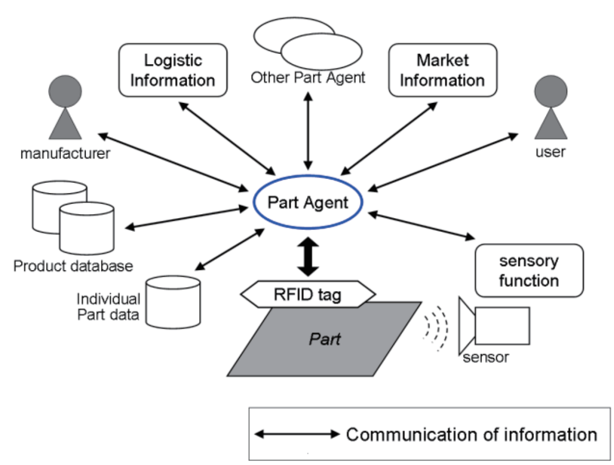

Fig.1: Concept of Part Agent

3 CONSUMER PREFERENCE

3.1 Consideration of consumer preferences

As consumers have various preferences on maintenance of products, part agents must propose maintenance activities that satisfy their preferences. Consumer may not accept proposals that dissatisfy them even if those proposals are environmentally preferable. This rejection disturbs the reuse of parts. On the other hand, proposals based on consumer preference will promote the reuse of parts because it will increase the opportunity of reuse; for example, when a consumer discards a part due to his preference, another consumer with a different preference may pick it up. For these reasons, we develop our part agent system taking consumers preferences into account.

3.2 Estimation of consumer preference

The level of satisfaction obtained by elements of products differs greatly by consumers. Preference designates the level of satisfaction that a consumer obtains from each element. We know how much a consumer is satisfied with a product by estimating his/her preference.

Table 1: L9 orthogonal array

	CPU	HDD	Memory	Price
1	Core i3-2120	500GB	2GB	60,000Yen
2	Core i3-2120	1000GB	4GB	100,000 Yen
3	Core i3-2120	2000GB	8GB	140,000 Yen
4	Core i5-2500S	500GB	4GB	140,000 Yen
5	Core i5-2500S	1000GB	8GB	60,000 Yen
6	Core i5-2500S	2000GB	2GB	100,000 Yen
7	Core i7-2600S	500GB	8GB	100,000 Yen
8	Core i7-2600S	1000GB	2GB	140,000 Yen
9	Core i7-2600S	2000GB	4GB	60,000 Yen

3.3 Inquiry of consumer preference

To estimate consumer preference for our system, we made a survey by questionnaire against 55 students. The questionnaire shows 9 PCs with different combinations of CPU, HDD, memory and prices and asks the respondent to sort them in the order he wants to purchase.

9 PCs presented in the questionnaire are selected according to L9 orthogonal array for 4 attributes with 3 levels (Table 1). Orthogonal array [3] is a method used in design of experiments that provides the requisite minimum number of experiments when estimations are required for combinations of parameters. In this case, the number of combinations of estimation to evaluate 4 attributes with 3 levels can be reduced to only 9 from 4th powers of 3.

3.4 Estimation of the effect of PC attributes on a preference

The result of questionnaire is evaluated using multivariate regression analysis [4] by scoring the order such that 9 points is given for the first preference, 8 points for the second and so on. Multivariate regression analysis is a method of multivariate analysis that analyzes quantitatively the effect of multiple independent variables against a dependent objective variable by fitting a multivariate equation. Weights of attributes of PC for the preference of a respondent are estimated using this analysis.

3.5 Extraction of preferences

Preferences are classified in multiple clusters and their mean values are used in life cycle simulation. We extract 5 preference clusters using K-means method [5].

Satisfaction of preference obtained the above analysis is discretized for each attribute values shown in the questionnaire. For example, satisfaction can be estimated for only 3 types of CPU that are Core i3-2120, Core i5-2500S and Core i7-2600S. To solve this problem, a quadratic function that fulfills the 3 values is created for each preference. Figure 2 shows preference functions derived for HDD.

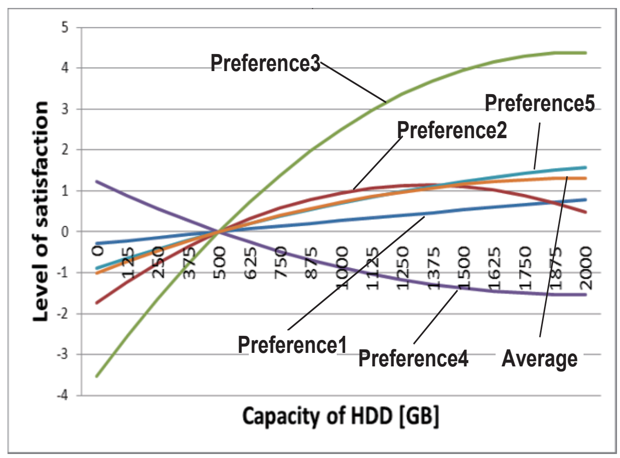

Figure 2: Preferences for HDD

These quadratic functions are combined into an equation shown below to represent overall preference.

$$s = \sum_{i=CPU,HDD,memory} (a_i x_i^2 + b_i x_i + c) + a_{price} x_{price} + C \quad \dots (1)$$

where s is the level of satisfaction of the preference, a_i, b_i and c_i are coefficients of the quadratic function for each attribute i that is either CPU, HDD or memory. The effect of price is simplified to be proportional to the price x_{price} with coefficient a_{price}. C is a constant term. Table 2 shows the coefficients derived.

This equation is used in the simulation described in the following sections to calculate the level of satisfaction for preference.

Table 2: Coefficients of eq(1) representing preferences

Preference	1	2	3	4	5	Average
Number of consumers	17	7	8	5	18	
a_{CPU}	-8.03E-08	-3.42E-07	-6.31E-08	-7.55E-08	-2.58E-07	-1.61E-07
b_{CPU}	1.83E-03	7.60E-03	1.48E-03	1.69E-03	6.32E-03	3.80E-03
c_{CPU}	-9.31	-3.82E+01	-7.62	-8.51	-3.33E+01	-1.97E+01
a_{HDD}	-2.61E-08	-1.59E-06	-2.08E-06	7.11E-07	-3.58E-07	-5.66E-07
b_{HDD}	5.88E-04	4.29E-03	8.13E-03	-2.80E-03	1.94E-03	2.29E-03
c_{HDD}	-2.88E-01	-1.75	-3.54	1.22	-8.83E-01	-1
a_{memory}	-9.48E-02	-2.94E-01	1.39E-02	8.33E-02	-2.31E-02	-6.46E-02
b_{memory}	1.09	3.36	1.25E-01	-9.00E-01	2.78E-01	7.91E-01
c_{memory}	-1.8	-5.54	-3.06E-01	1.47	-4.63E-01	-1.32
a_{price}	-6.45E-05	-1.25E-05	-1.20E-05	-3.33E-05	-1.62E-05	-3.16E-05
C	9.96	2.15	2.74	9.33	2.94	5.56

4 LIFE CYCLE SIMULATION OF PARTS WITH PART AGENTS

4.1 Objective of life cycle simulation

A life cycle simulator for parts and part agents is developed to estimate the effect of behavior of part agents that take the consumer preferences into account against the reuse of parts.

4.2 Models for the simulation

Life cycle simulator is developed based on the model shown in Fig.3. In the figure, blocks shows the classes of object and lines show the relation between them where simple lines show the attribution and lines with arrows show the inheritance. Elements of the model are described as follows.

World is the root element and controls the simulation. A **SimulatedObj** is an object in the simulation that is either a **Cast**, a **Part** or a **LCStage**. A **Cast** is an element that behaves actively according to an **Act** that describes its action and is generated based on the status of the **Cast** and a **Request** to the **Cast**.

A **Cast** is either an **Agent** that represents a part agent, or a **Human** that represents persons and organization. A **Human** is classified into a **User** that has a **Preference**, and a **Company** that is a **Producer**, an **Assembler**, a **Vender**, a **Transporter**, a **Repairer** or a **Disposer**.

A **Part** represents a part or a product in the simulation.

A **LCStage** represents a life cycle stage and is either a **Stage** or a **Transfer** that represents a path between life cycle stages. A **Stage** represents a life cycle stage that is an activity in the life cycle and is a **Production**, an **Assembly**, a **Sale**, a **Use**, a **Maintenance** or a **Disposal**.

5 PROCESS OF THE SIMULATION

5.1 Overview of the process

Life cycle simulator is developed so that the order of execution of processes does not affect the simulation results. For this purpose, the following steps are applied.

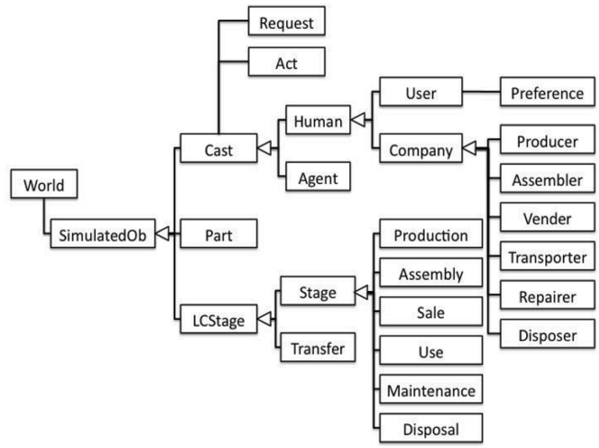

Fig.3: Model of elements in the life cycle simulation

- Process in a single step that represents a unit of time in the simulation is divided into two sub-processes that are Pre-Process and Action.
- In a Pre-Process sub-process, a plan is made on the action of each Cast according to its situation.
- In an Action sub-process, actions are executed in a random order for all Casts based on their plan.

Note that a single object does not control all the processes in the simulation but each object decides and executes its action by itself.

Fig. 4 shows the overall processes in the life cycle simulation. Arrows show requests of action from an object to another object. In a Pre-Process sub-process, each object makes a plan for the current step based on both these requests and its own status. Thus, the coordinated actions can be realized among objects.

5.2 Deterioration and failure of parts

Performance of a product deteriorates as it is used. It is

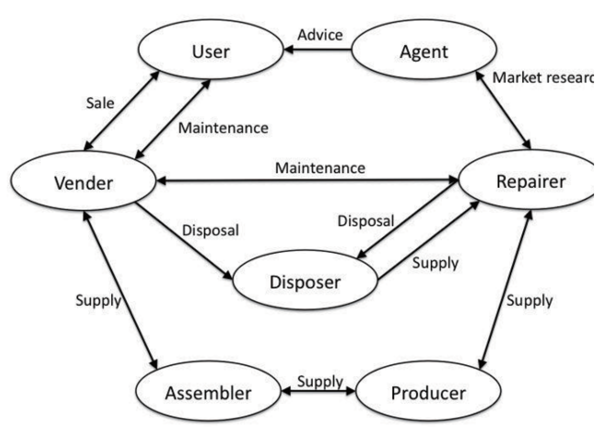

Fig.4: Relation among processes

assumed in this simulation that the level of performance decreases a fixed value when it is used for one step. The price of reused part C_{used} is assumed to follow the equation (2) where C_{new} is the price of a new part, S_{ini} is its initial performance and S_{pre} is its current performance [6].

$$C_{used} = C_{new} \times \frac{S_{pre}}{S_{ini}} \qquad \dots (2)$$

We use this simple assumption represented by this equation to determine the price of reused parts where performance level of a part decreases in proportion to its used time and its price decreases in proportion to decrease of its performance level.

We also assume in this simulation that failure occurs in one step according to a fixed rate of failure probability.

5.3 Conditions of simulation

A life cycle simulation is performed based on the conditions shown in Table 3.

Table 3: Conditions of life cycle simulation

Product	PC
Part	CPU, memory, HDD
Number of users	55
Price of PC	110, 000 Yen
Performance of CPU	11378
Price of CPU	18,000 Yen
Performance of HDD	1,000 GB
Price of HDD	5,500 Yen
Performance of memory	8 GB
Price of memory	3,000 Yen

Note that the performance of CPU is the maximum value measured for Core i5-2500 using a benchmarking software called Sandra and compared to Core 2 Duo (Penryn) with its value as 1000.

6 SIMULATION RESULTS

Figure 5 shows the level of satisfaction for consumers with preference 2. Note that the satisfaction level is zero while replacing parts.

Two cases of simulation are performed; multiple preference case where network agents propose replacement of parts taking into consideration preference of consumers and single preference case where they propose the replacement based on the average preference. Table 4 shows the total level of satisfaction for each case. The satisfaction for multiple preferences case is larger but it decreases in preference 2 where too many replacements may hinder the satisfaction due to the idle time for replacement.

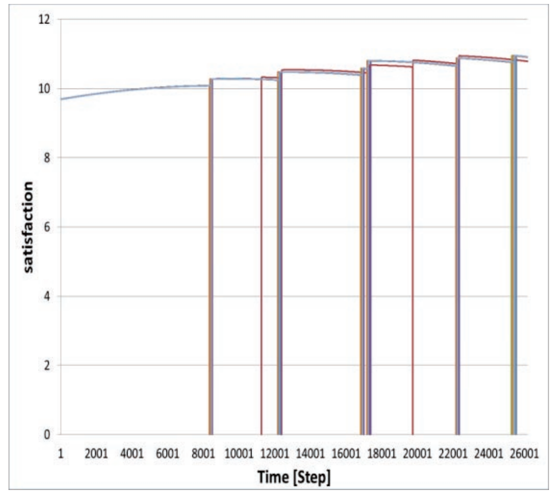

Fig. 5: Level of satisfaction for consumers with preference 2

Table 4: Effect of replacement based on preference

Preference	1	2	3	4	5	Average
Number of consumers	17	7	8	5	18	
multhple preferences	12.2	10.33	7.48	9.01	8.81	9.86
single preference	12.2	10.37	7.25	8.93	8.74	9.81

7 CONCLUSION

A part agent system taking into account consumer preference is developed. Consumer preferences are extracted based on the analysis of questionnaire and are implemented into part agents. The effect is evaluated through a life cycle simulation of parts and part agents. Further research is necessary to develop more effective function of part agent considering consumer preferences.

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Proposal of Design Environment for Life Cycle Scenario

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Abstract

To reduce environmental impact and resource consumption, life cycle design is required; especially planning a strategy of product life cycle in the early design stage is needed. On the strategy planning, rationales of designer's decision and design alternatives should be managed. This paper proposes a method of supporting for planning the strategy with representation scheme called life cycle scenario by managing design rationale and alternatives. We implemented a life cycle scenario description support system and verified the system by a case study.

Keywords:

life cycle design, life cycle scenario, design rationale

1 INTRODUCTION

In order to solve the environmental issues such as global warming, huge amount of waste, and exhaustion of resources, we need to construct sustainable manufacturing system by minimizing environmental impact and resource consumption. For this purpose, to design a product life cycle has been identified as the most important factor [1].

We are proposing a life cycle design methodology, which focuses on the design not only of a product but also of its life cycle [2]. In the early stage of the design process, information about products is limited, but the degree of design capability is large and they go down while the information increases [1]. Therefore, a product life cycle should be planned by determining the basic direction of the life cycle in early design stage. Then, the basic plan for a product life cycle, called 'life cycle strategy', should be implemented by designing the product and its process.

For supporting the examination of life cycle strategies, 'life cycle scenario' has been proposed, which outlines a product life cycle and represents how to manage the product through its whole life [3]. Describing the life cycle scenario efficiently supports the latter stage of life cycle design by clarifying design requirements for product and process design. However, the computational representation of the life cycle scenario has not been formalized yet, and, therefore, the computational support system for determining life cycle strategy with the life cycle scenario has not been developed.

In this paper, we propose a representation scheme of life cycle scenario, and develop a computational environment for determining a life cycle strategy.

2 APPROACH

In a life cycle planning process, designers have to solve trade-off problems by deriving several design solution candidates, plan a strategy with selection of a solution, and finally extract design requirements for product and process design. Therefore, we set the following five functions required to the system; (1) supporting description and examination for planning life cycle strategies in step-wise manner, (2) recording design rationale derived through the design process, (3) managing design alternatives, (4) extracting design requirements for product and process design, and (5) importing results from life cycle design support tools.

For the aspect (1), the formalization of life cycle scenario should be specified so as to plan a strategy in step-wise manner. Therefore, we propose a representational scheme for the life cycle scenario in Section 3.1.

For the aspect (2), designers plan a strategy by selecting a solution from various solution candidates with their rationales. Designers should declare the reason why they select the solution in order to enable them to be referred during or after designing. Therefore, we propose a method for recording design rationale in the scenario description process in Section 3.2.

For the aspect (3), in the life cycle planning process, designers may derive a lot of solution candidates. In order to examine the solution candidates, the management of design alternatives should be supported. For this purpose, we use Truth Maintenance System (TMS) [4], and propose a method for managing alternatives in Section 3.3.

For the aspect (4), the process for extracting design requirements should be supported for product and process design in order to realize the planned strategy as mentioned in Section 1. Therefore, the system should enable designers to describe the design requirements.

For the aspect (5), throughout the life cycle planning

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process, designers should make decisions on selecting a solution from design alternatives and on solving trade-off problems. For supporting the designers' decision, various support tools for life cycle design should be easily accessed, such as Disposal Cause Analysis Matrix [5], Life Cycle Planner [6], and the Life Cycle Simulation (LCS) [7]. The system should be able to import the result from these external support tools.

3 DESCRIPTION METHOD FOR LIFE CYCLE SCENARIO

3.1 Representation scheme for life cycle scenario

A life cycle scenario represents scenes of a product life cycle in the form of 5W1H; who, where, what, why, when, and how [2]. In this paper, we define the life cycle scenario composed of the following five elements; objective of the life cycle, life cycle concept, life cycle options, life cycle flow, and situations of processes in the life cycle flow.

Objective of the life cycle: Specifying objective of the life cycle is required to clarify a target of the life cycle. We represent the objective by sentences and target values. For example, a target is 'to keep profits on a manufacturing process and to reduce CO2 emission', and target values are 'profit: over 100% on the current product, and CO2 emission: below 75% on the current product life cycle'. Target values can be used as a basis of evaluation for the described life cycle scenario.

Life cycle concept: Life cycle concept indicates a fundamental direction of the life cycle scenario; for example, 'extending product lifetime' and 'reuse based scenario'. Describing the life cycle concept supports to embody the objective of the life cycle as a life cycle scenario.

Life cycle options: Life cycle options represent life cycle processes of product and its components, e.g., maintenance, product reuse, component reuse, and recycling, and determine a basic structure of the life cycle scenario. In order to manage the relationships between life cycle options and a product, first, we construct a product structure model, as shown in Fig. 1. The top node in the product structure model represents the whole product, and the others represent each component of the product. Designers select life cycle options for each node in the product structure model; i.e. 'motor is reused in the first cycle, and recycled in the second'.

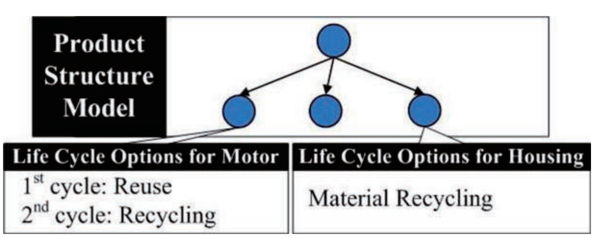

Fig. 1: Product structure model and life cycle option

Life cycle flow: Life cycle flow is a model represented by flows of a product and its components as a network of life cycle processes. Life cycle flow model is composed of nodes and links, which respectively represent processes in the life cycle and flows of objects such as products, money and information between processes. Moreover, each link in the flow model is associated mutually with a node in the structure model. This association between two models enables designers to find out flows of objects; for example, Fig. 2 shows that 'motor' in a product structure model goes into an inspection process after disassembled, while 'housing' is recycled and transported into a manufacturing process.

Situations of the processes in the life cycle flow: Situation represents how a product and its components are managed in each process by whom. We represented the situation with use case diagram in Unified Modeling Language (UML [8]). Lower part in a life cycle flow model of Fig. 2 shows an example of representation of situation in a recycling process. 'To recycle the housing with shredder' is described as a UseCase, which represents operations applied to objects inputted in each process. 'Recycler' is described as an Actor, which represents people who have a deal with the operations. In addition, process parameters and conditions are described in each process, such as collection rate, inspection fee and limitation of exchange time for disassembling. These parameters and conditions can be design requirements for a product and its life cycle.

3.2 Description of design rationale

As mentioned in Section 2, the system should support describing and managing design rationale in order to record designer's decisions. Therefore, we represent design rationale as a network of design information based on the cognitive design process [9]. In the cognitive design process, the basic process of solving design problems is defined as four design phases; problem definition, design solution creation, evaluation, and decision. In addition, design information derived by designer against each problem definition is classified into three types; background information, design solutions, and evaluation results. Based on this classification of the design information, we propose a representation scheme

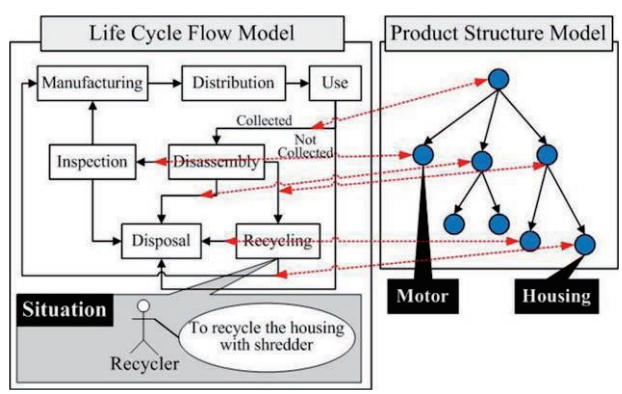

Fig. 2: Relationship between flow and structure model

for the design rationale with nodes and links, as shown in Fig. 3. A node represents information derived by designers, which is classified into four types; 'problem definition', 'design reason', 'solution candidate', and 'selected solution'. Each node is related by a 'positive', 'negative', or 'refinement' link. Design reason is described based on designer's knowledge, external information and evaluation results from external tools for supporting life cycle design. Solution candidate indicates a candidate of design solution against a problem definition, and selected solution is a solution chosen from solution candidates. Additionally, we set a state 'valid' or 'invalid' to each node, which respectively indicates the described information is acceptable or not for designers. The light-colored node in Fig. 3 indicates invalid state.

Several solution candidates against each problem definition are derived based on design reasons, and connected by positive or negative link if the design reason supports or denies the solution candidate. Then, the designers determine one or several selected solutions by examining the derived solution candidates. By repeating this design process, a design solution, which means life cycle scenario in this research, should be developed by describing each solution candidate with a refinement link. That enables designers to confirm how and why they derive and determine the selected solution.

3.3 Management of alternatives

As mentioned in Section 3.2, designers derive several solution candidates against each problem definition in a life cycle planning, and plan a strategy by repeating derivation, evaluation, and selection of solutions based on various rationales. In this repetition, designers often face a problem on selecting a solution because of trade-off problems. Therefore, a management for examining several solutions in parallel should be supported.

We realize the management of design alternatives by using the Truth Maintenance System (TMS) [4] as information network. The TMS network is composed of nodes and justifications, and manages logical consistency between old believed information and current believed information respectively. Each node in the TMS network has a state of either 'IN' or 'OUT', which indicates the validity or invalidity of information, as shown in Fig. 4. A justification keeps consistency among the state of nodes in the whole network. In other words, a justification connected only from 'IN' input nodes makes an output node 'valid'. On the other hand, a justification connected from at least one 'OUT' input nodes changes an output node 'invalid'.

The design rationale network manages alternatives based on the TMS. In other words, when designers describe a solution candidate in the design rationale network, the TMS network creates three types of nodes; 'candidate node', 'selection node', and 'selected node', as shown in Fig. 5. When two solution candidates in the design rationale network have a trade-off relationship against a problem definition, corresponding selected nodes are connected by a justification and a 'contradiction node', which has a state only of 'OUT'.

Here, when designers select a solution from candidates in design rationale network, corresponding selection node changes its state to 'IN'. Moreover, a solution candidate in design rationale network changes its node type into selected solution when corresponding selected node in TMS network changes its state to 'IN'. In other words, when a solution candidates are selected, the corresponding selected node change its state to 'IN', and nodes in the whole network change their state based on consistency management by justification, as shown in Fig. 6.

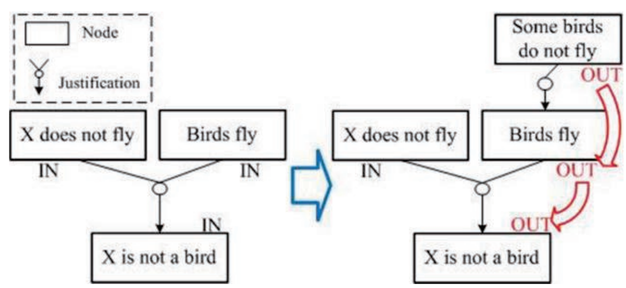

Fig. 4: The Truce Maintenance System network

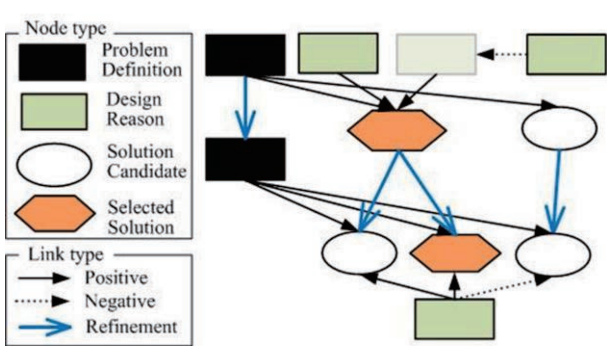

Fig. 3: Representation of design rationale

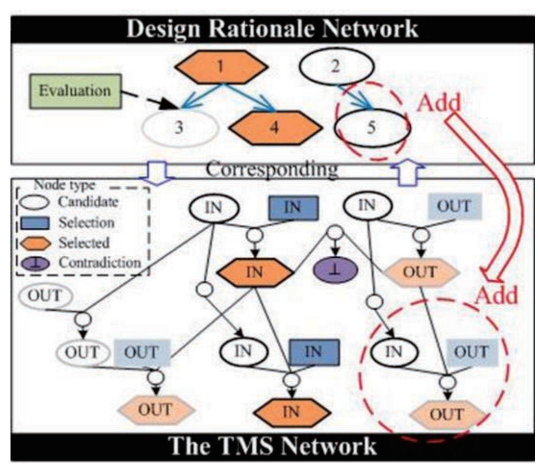

Fig. 5: Design rationale and TMS network

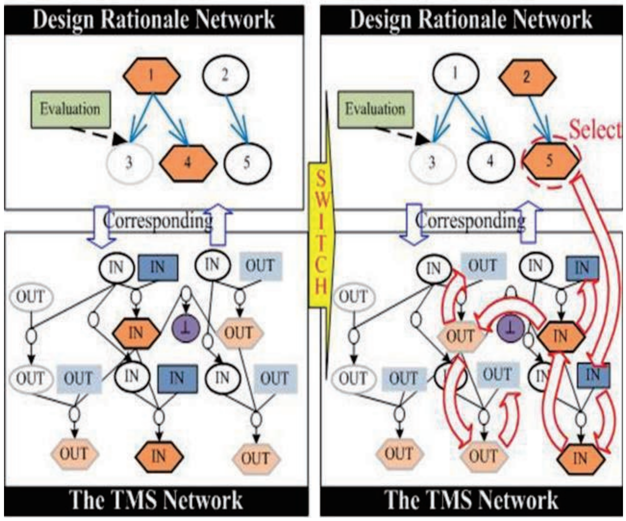

Fig. 6: Management of alternatives

As a consequent, management of alternatives in whole design rationale network, which means the switching of solution candidate and selected solution, can be conducted with designers changing the state of selection node.

4 LIFE CYCLE SCENARIO DESCRIPTION SUPPORT SYSTEM

Based on the approach described in Section 3, we propose a procedure for describing a life cycle scenario in step-wise manner, as shown in Fig. 7, and construct a scenario description support system, as shown in Fig. 8.

First, designers describe the current circumstance of the target product such as market information and business policy in their company, and record information about result from external tools such as Disposal Cause Analysis Matrix [5] on Current Analysis Tool.

Here, the designers design a life cycle scenario with five elements mentioned in Section 3.1 as problem definition on Design Rationale Description Tool.

Second, in order to clarify the objective of the life cycle, designers describe sentences of the target product and its life cycle, and set target values with Objective Description Tool. Third, designers describe several candidates for the life cycle concept with Life Cycle Concept Description Tool. Fourth, designers select life cycle options for each component in a product structure model with Life Cycle Option Select Tool. Here, the selected life cycle options can refer to information as design reasons such as results from Life Cycle Planner described with Current Analysis Tool. Fifth, designers construct a life cycle flow model with Life Cycle Flow Modeling Tool, and sixth, describe a detailed situation of each process with Situation Modeling Tool.

Life Cycle Scenario Manager manages all information described with Design Rationale Description Tool, and Alternative Manager manages alternatives described as the information.

Finally, with constructed life cycle flow model, designers should evaluate the life cycle scenario with evaluation tools such as Life Cycle Simulator (LCS) [7]. LCS is a tool for evaluation by simulating dynamic flow of products, information and money, with discrete event simulation technologies. The simulation model of the LCS can evaluate the life cycle scenario with constructed life cycle flow model. Designers evaluate the life cycle scenario with the LCS, and modify the scenario until the objective of the life cycle is satisfied.

5 CASE STUDY

We conducted a case study on a mobile phone with the system described in Section 4. This mobile phone consists of PCB, CCD camera, vibrator, speaker, battery, housing, and liquid crystal display (LCD).

First, we described product attributes of the target product and market information. Here, we analyzed the life cycle of the target product, and constructed a life cycle flow model. Then, we clarified which process of the product

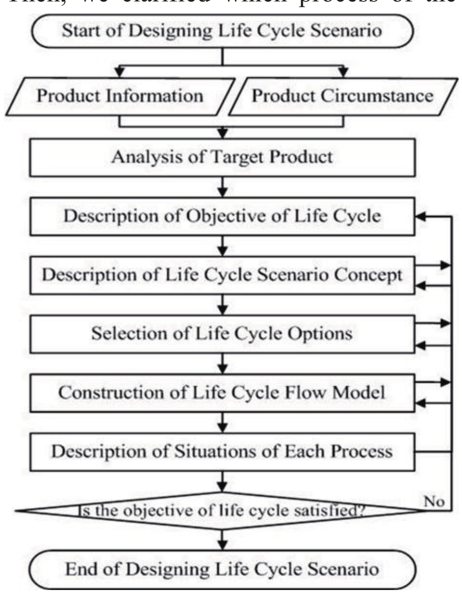

Fig. 7: Process of describing life cycle scenario

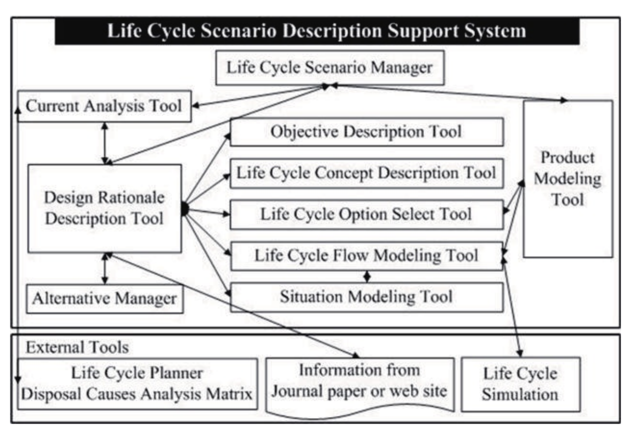

Fig. 8: Life cycle scenario description support system

life cycle should be solved to reduce the environmental loads and cost by calculating with LCS. The result from the evaluation showed that LCD and PCB have large environmental and economic loads. We also analyzed the main disposal causes of the mobile phone by using Disposal Cause Analysis Matrix [5]. In addition to these analyses, we described several assumptions as design reasons; for example, 'customers do not release their mobile phones to keep their personal data' and 'LCD is difficult to be reused for different mobile phones because mobile phone has various size, shape or function'.

Second, based on these analyses, we set the objective of the life cycle scenario to be 'to reduce the amount of CO2 emission without decreasing the profit'. Then, in order to examine several possibilities of objectives, we set a target value on profits of manufacturing to be 'over 100% of the current profit', and two levels of CO2 reduction rate as 20% and 10%. Here, we selected 20% reduction rate at first.

Third, we determined the life cycle concept. As candidate solutions, we examined three concepts; reduce based scenario, reuse based scenario, and recycling based scenario. As for the reduce based scenario, which aim to reduce the amount of resources invested in the manufacturing process, we set this concept 'invalid' based on a negative design reason that the current mobile phone is already designed to attain lighter product. We also set the recycling based scenario 'invalid' because recycling has lesser potential for reducing CO2 emission. Therefore, the reuse based scenario was selected as the life cycle concept.

Fourth, we selected life cycle options for the reuse based scenario, as shown in Fig. 9. For the LCD, for example, we examined reuse and cascade material recycling options as solution candidates. Among them, we selected the reuse option for LCD at first to realize the longer physical life of

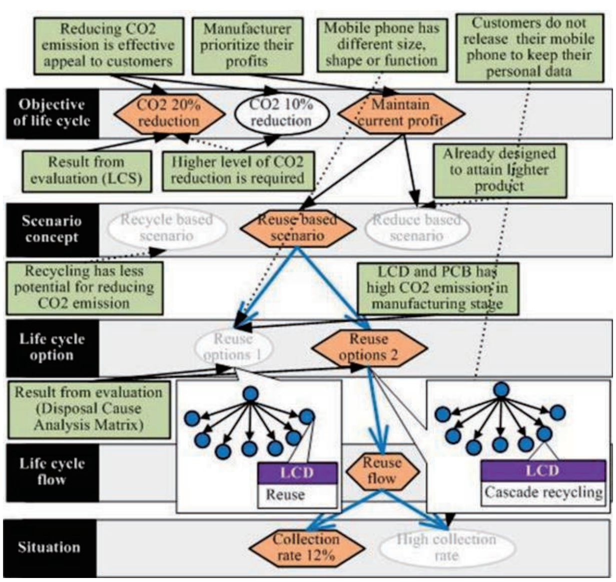

Fig. 9: Design rationale network of reuse based scenario

the product. This solution was supported by the reference to the result from Disposal Cause Analysis. According to the assumption that LCD is difficult to be reused, however, reuse option for LCD is denied. Here, we selected material cascade recycling option for LCD. As for the other components, the result from Disposal Cause Analysis supports reuse option for vibrator, speaker, and CCD camera, while the reuse option for PCB, battery and housing are not supported because of their short lifetime. Then, we selected material cascade recycling option for them.

Fifth, we constructed the life cycle flow based on the selected life cycle options, and described situations on each process in the life cycle flow model. For the collection process, for example, we described retail store workers as Actor and 'to collect mobile phones' as UseCase, and set the collection rate as 12% based on the current analysis.

Sixth, we evaluated the reuse based scenario by the Life Cycle Simulator. The result of the evaluation showed that the profits was more than 100%, but CO2 emission rate

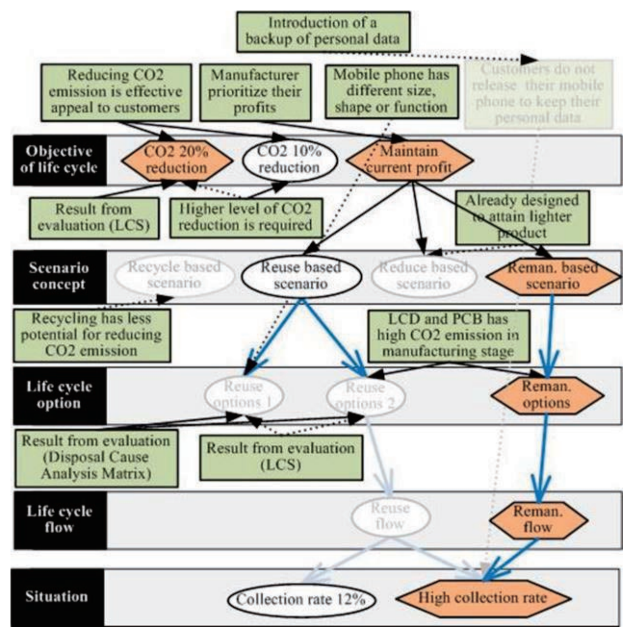

Fig. 10: Modified design rationale network

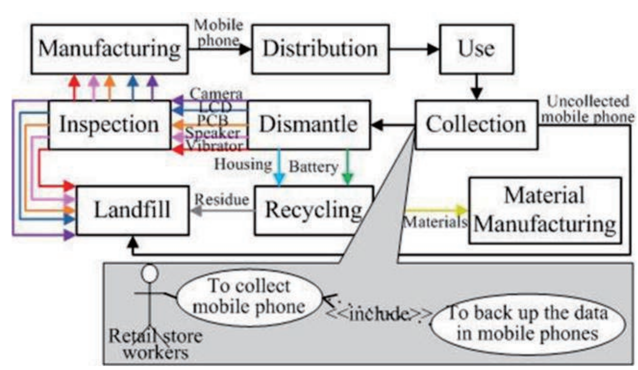

Fig. 11: Life cycle flow of remanufacturing based scenario

Table 1: Scenario Evaluation

Scenario	Profit	CO2 emission
Current scenario (recycling based)	100%	100%
Reuse based scenario	101%	99%
Remanufacturing based scenario	102%	79%

Table 2: A part of design requirements

Life Cycle Phase	Design Requirement
Manufacturing	Manufacturing cost: less than 16,850 yen/product
Sale	Price of a remanufacturing phone: 60%
Collection	Collection rate: more than 80%. Data backup service is required.

was less than both objectives of life cycle scenario set in the second step. This is because LCD and PCB were assumed to be recycled in the same way as the current product flow even if they have large environmental and economic loads.

Therefore, we modified the reuse based scenario as new scenario concept named 'remanufacturing based scenario', as shown in Fig. 10. In the remanufacturing based scenario, a refurbished product is produced and sold by reusing all components except for short lifetime components and by assembling these components with battery and housing manufactured as brand new. We set the sales prices of the remanufactured product to 40% discounted from ordinal. Besides, in order to increase the collection rate to 80%, we introduced a data backup service, and extended the UseCase 'to collect mobile phones' on the collection process with a UseCase 'to back up the data in mobile phones'. Fig. 11 shows the life cycle flow model of the modified scenario. Here, we determined the remanufacturing based scenario as selected solution by comparing with the evaluation results of each scenario, as shown in Table 1. Finally, we clarify design requirements from remanufacturing based scenario summarized in Table 2.

6 DISCUSSIONS

The case study clarified the proposed system supports designing various life cycle scenarios. First, various solution candidates against each problem definition were examined by formalizing life cycle scenario in step-wise manner. Second, the proposed representation scheme of design rationale clarified how and why each solution was created. Third, the design rationale network supported the management of various alternatives by maintaining validity or invalidity of each node based on the TMS. However, the same level of importance is set on each link in design rationale network. Therefore, even if a solution candidate is supported by a design reason node with high level of importance, it can be invalid by denying from a low level of important node. Fourth, we constructed a workspace to describe design requirements for product and process design. The design requirements, however, are not supported to be extracted automatically from the described scenario. Fifth, import of results from external tools supported designer's rationale on selecting solutions.

7 CONCLUSION

We proposed a life cycle scenario description support system for planning various life cycle strategies. The system supports describing process of design rationale, and manages design alternatives with the TMS. Moreover, we verified the proposed system by describing life cycle scenarios for a mobile phone as a case study.

Future works include integration with external tools efficiently to support designers for deriving solution candidates and for determining a solution from the candidates.

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Computer-aided Design for Product Upgradability under Geometric Constraints

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Abstract

Long-life design for products is seen as a promising approach for improving the resource efficiency of their lifecycle. Implementing design to support upgradability allows products to be used for longer than conventional items, which may be abandoned because of functional obsolescence before the end of their physical life. One of the difficulties of upgrade design involves the prediction of future trends such as technological development and market movements, and upgradable products must be robust against such future uncertainties. In order to deal with the unpredictability of future technological trends, the authors previously proposed a method for the formulation of product upgrade plans that specify a lineup of candidate components for upgrades with each generation. However, the design for a geometric model of an upgradable product that can be adapted to the upgrade plan remains an unresolved issue in the proposed method. In order to support this design stage, the present paper outlines a proposal for a computer-aided design method that helps designers to reconstruct geometric product models for adaptation to the upgrade plan by satisfying geometric constraints. The paper also demonstrates the suitability of the method with a sample design of a cellular phone.

Keywords: Long-life design, design for upgradability, CAD

1 INTRODUCTION

Increasing the efficiency of resource utilization is a major consideration within the framework of sustainability in manufacturing, and long-life design is a promising approach for improving the resource efficiency of products in multi-generation usage. Conventional products are sometimes abandoned because of functional obsolescence before the end of their physical life. That is, products have both a physical life and a value life, the latter of which may be terminated due to obsolescence [1]. Here we focus on the extension of this value life through upgrading to deal with obsolescent functionality. Design for upgradability enables products to be used for longer than their conventional counterparts [2]. However, one of the difficulties of upgrade design involves the prediction of future trends such as technological development and market movements, and upgradable products must be robust against such future uncertainties. In order to deal with the unpredictability of future technological trends, we previously proposed a method for the formulation of product upgrade plans that specify a lineup of candidate components for upgrade with each generation [3]. Such plans include information on upgradable design, the timing of product upgrades and which components should be updated. Then, the plan is implemented with design for product structure and geometry. However, the design for a geometric model of an upgradable product that can be adapted to the upgrade plan remains an unresolved issue. In order to support this design stage, the present paper proposes a computer-aided design method for geometric models of upgradable products. In parametric feature-based solid modeling [4], product models have geometric constraints among components regarding their shape, location and connectivity. Our upgrade design assumes that such constraints are included in the original product model. Based on this information, the method helps designers to reconstruct product models for adaptation to the upgrade plan by satisfying these constraints. This paper also demonstrates the suitability of the method with an upgrade design of a cellular phone.

2 DESIGN SUPPORT METHOD FOR PRODUCT UPGRADABILITY

2.1 Upgrade planning

The proposed upgrade design method is based on the assumed advance provision of an upgrade plan that indicates the timing of product upgrades, related functions and the extent of upgrade changes. To devise such a plan, designers need to predict technological trends and user demand. In our previous research [3], we proposed a methodology for upgrade planning based on the prediction of user demand, and on the assumption that technological trends influence such demand.

The upgrade plan also includes a lineup of candidate components to replace those of the original product with each upgrade generation. This lineup includes geometric models of the components, and Figure 1 depicts the lineup of the candidates with each generation. In this way, the uncertainty of a product's geometry in future generations is included within the candidates' geometric variations after upgrade planning. As shown in Figure 1, with each

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upgrade process, one or more components are selected from the candidates to replace the corresponding components of the product for functional upgrade. At the design phase, however, there is no way for designers to know which components will be selected.

2.2 Geometric constraints among components

As the proposed method is primarily applicable to the redesign process of a product's structure and geometry for adaptation to a given upgrade plan, the input is a geometric model of the original product with the geometric constraints among its components. These constraints are assumed to have been embedded previously by the schemes of parametric feature-based solid modeling [4]. Examples of such constraints include axis correspondence, where the axes of two rotary components must be on the same line, and avoidance of interference, where components must not interfere with each other.

In this study, upgrade design is defined as a set of design changes to a geometric model enabling it to receive any component from among the candidates designated in a given upgrade plan. In such design, the structure and geometry of the original product model are changed in line with the given geometric constraints.

2.3 Upgrade design process

Design changes are applied to the product model with each generational upgrade. That is, the method involves initially changing the product model for adaptation to the first upgrade, and then again for subsequent upgrades. In this way, redesign processes are performed in a stepwise manner up to the last generation described in the upgrade plan.

As shown in Figure 2, all product components are classified as platform, target or adaptive types. The platform category consists of static components for upgrade with all generations. Target components are replaced with candidate components with each upgrade for updating their functionality. Adaptive components act as buffers against variation through the process of

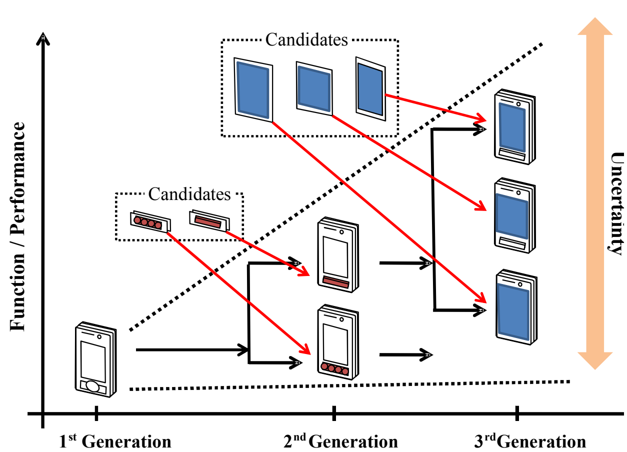

Fig. 1: Upgrade process in each generation

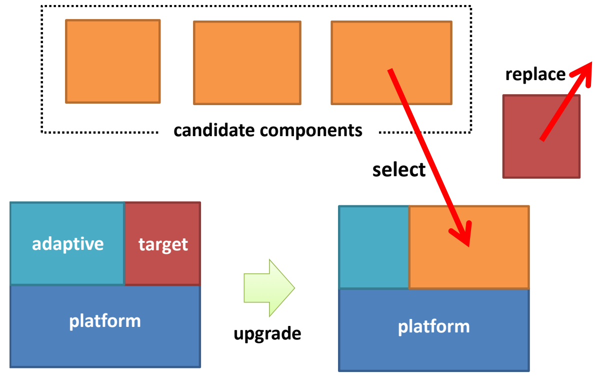

Fig. 2: Platform, target, adaptive and candidate components.

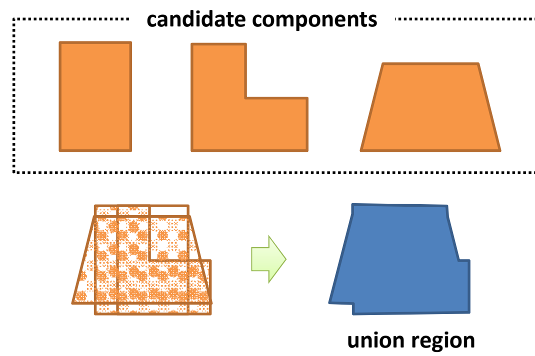

Fig. 3: Union region of candidate components

replacement when upgrade processes are implemented.

The redesign procedure involves the following processes:

1. Identification of a union region of candidate components for the upgrade
2. Component layout change to make room for the union region
3. Interface/component geometry change for adaptation to upgrades

Here, the union region is a provisional component consisting of a set of the internal regions of all candidate components as shown in Figure 3. Thus, geometrical uncertainty for each upgrade generation is included in the region boundary.

In the second process, designers make space in the product model for the union region by changing the layout of the platform components. This space allows the product model to receive all the candidate components. The layout changes are propagated from the space to its surrounding components on the platform to avoid violating the geometric constraints such as interferences between components.

In the third process, designers change the interfaces and shapes of components for adaptation to the individual geometric conditions of all candidate components. For example, some adaptive components are replaced with new ones of different shapes to enable the fitting of components selected and replaced from among the candidates in the upgrade process. To facilitate this process, designers should specify adaptive components in the product model and change their interfaces to support the replacement.

This design procedure is repeated cumulatively until the end of the upgrade generation.

3 PROTOTYPE SYSTEM OF UPGRADE CAD

Based on the proposed method, we developed a prototype system that includes a parametric feature-based 3D CAD modeler and an upgrade planning tool, a design process management tool and a geometric constraint management tool as subsystems. The system provides a workspace for design changes to a product model under geometric constraints as managed by the constraint management tool. The design process management tool structures the operational procedures of design changes as shown in Figure 4. The root of the tree structure involves the operation of replacing a target component with a union region of candidate components, and the nodes represent operations propagated from the root. For example, when a union region is replaced with a target component and a geometric constraint is violated, such as when a union region and neighboring components collide, the neighboring parts must be moved or changed in successive operations to avoid such collisions. The subsystem records and manages these relationships among design changes.

4 CASE STUDY

We conducted upgrade design on a cellular phone as a case study. The input of the study included an upgrade plan and a 3D solid model with predetermined geometric constraints. Table 1 summarizes the upgrade generations, the requirements for each upgrade, and the target and candidate components for the upgrades.

In the second generation, for example, the objective of the upgrade is to increase the size of the product's display. For this purpose, the display module is replaced as a target component with a larger-size candidate display module. The lineup consists of three differently sized candidate components. We made a union region of these components and changed the layout of the platform components to receive it. Then, we changed the interface of the adaptive components, one of which is the front frame. To allow adjustment for variation of the display size, we changed the interface of the frame to allow replacement along with the display module in the second-generation upgrade process. Of course, we can select another design, such as a different shape for the frame component to be transformed, to allow fitting for any of the candidate components. The CAD system also manages such design alternatives with the tree structure of the design operation management tool described in Section 3.

In this way, the design of the product model was changed in a stepwise manner with each generation. Figure 5 shows the platform (blue), target (red) and adaptive (green) components of the model as classified in this case study. Figure 6 shows the cell phone model upgraded with each of the three generations, where one component from among the candidates was selected to replace another one in each generation. In this way, it was also confirmed that the product model can be adapted to all candidate component combinations within the geometric constraints. As a result, it can be concluded that upgrade design processes are successfully supported by our design scheme and CAD system.

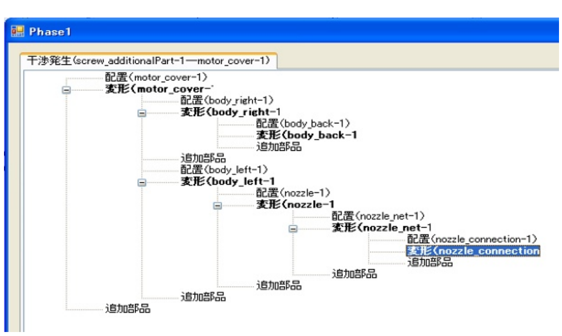

Fig. 4: Operation tree for adaptation to upgrade variants.

Fig. 5: Platform (blue), target components (red), adaptive components (green)

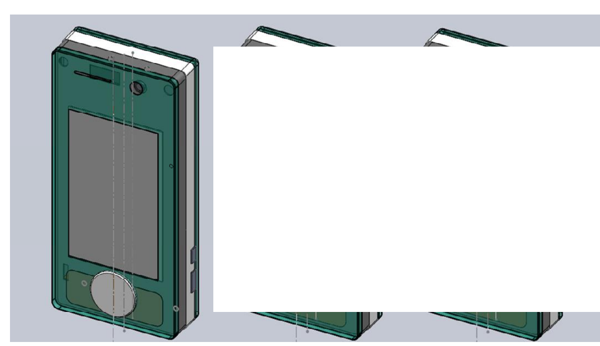
1st generation 2nd generation 3rd generation

Fig. 6: Upgradable product models for each generation

5 CONCLUSION

We proposed a computer-aided design method that helps designers to redesign geometric models of products for adaptation to a predetermined upgrade plan. In compliance with the geometric constraints inherent in the product model, designers change the layout, geometry and interfaces of components for adaptation to geometrical uncertainty in future generations. To support this method, we developed a CAD system for product upgradability that provides a workspace for upgrade design and enables management of design operations by allowing them to be structured. This paper also demonstrated the effectiveness of the method with a sample design of a cellular phone.

In future work, we plan to develop an evaluation index for upgrade design to support the selection of appropriate design changes in consideration of resource efficiency, environmental friendliness and economic benefit.

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Table 1: Requirements and candidate components for upgrading

Generation	Upgrade requirements	Target component	Candidate components for upgrade
2	Increase of display size	Display_module: H70, W42, D2 (mm)	Display_module 1: H73, W45, D1.8 (mm) Display_module 2: H75, W47, D1.8 (mm) Display_module 3: H80, W50, D1.5 (mm)
3	Replacement of display with a touch-sensitive type	Display_module: (Module 1, 2 or 3)	Touch_sensitive_display 1: H90, W50, D2 (mm) Touch_sensitive_display 2: H93, W52, D2 (mm)
	Miniaturization of camera	Main_camera_module: H14, W22, D7 (mm)	Main_camera_module 1: H12, W20, D7 (mm) Main_camera_module 2: H10, W18, D7 (mm)
	Removal of center button	Center_button: φ20, D1.5 (mm)	

Development of a Consistency Management System between Product and Life Cycle Flow in Life Cycle CAD

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Abstract
In order to increase value and reduce the environmental loads of a product life cycle, integrated design for the product and its life cycle is important. This paper proposes a consistency management system between product and its life cycle in order to support such design. For this purpose, we define two levels of consistency: the model consistency level and the requirement fulfillment level. A case study indicated that the relationship between a product and its life cycle is successfully represented and that a designer can design them in an integrated manner.

Keywords:
Life Cycle Design, Product Design, Life Cycle Simulation, CAD

1 INTRODUCTION

In order to solve global environmental issues such as resource depletion, it is important to design a product considering the reduction of environmental loads and resource consumption over the entire product life cycle. For such design, life cycle design [1] is a hopeful approach. In the life cycle design, it is necessary to design a product life cycle based on the product concept and the characteristics of its market at the early stage and to design the product so as to realize this life cycle effectively. Here, the concept of designing a product life cycle includes determination of life cycle options (LCOPs, including maintenance, recycling, and so on) of each component of a product and describe the circulation of products, components, and materials around the life cycle as a network of life cycle process. We refer to this as life cycle flow.

Appropriate life cycle design depends on the product's characteristics, and appropriate product design depends on its life cycle. For example, when a designer aims to make a long life product by applying maintenance, the suitable product structure for the case in which worn-out parts are replaced by its user at home should differ from the suitable structure for the case in which worn-out parts are replaced by an engineer at the plant. Accordingly, it is important to compare the design information of a product (i.e., results of product design such as structure), with that of life cycle flow (i.e., the results of life cycle flow design such as process situation).

In order to support the integration of product design and life cycle flow design, we are currently developing a Life Cycle CAD (LC-CAD) system. This paper outlines an important aspect of this work in the form of a system for the management of consistency between a product and its life cycle flow. For this purpose, we propose a product model and a life cycle flow model to represent a product and its life cycle flow. We also define the relationships between these two models and propose a scheme to manage the consistency between them.

2 FUNDAMENTAL CONCEPTS OF THE LC-CAD SYSTEM

2.1 Overview of Life Cycle Design

Life cycle design has been proposed as a novel approach in which a product is designed in consideration of its entire life cycle from the stage of product conception to final reuse/recycling or disposal [1]. In the life cycle design, the life cycle flow of the product should be considered as well as the nature of the product itself. We assume that there are three phases in the life cycle design; the life cycle planning phase, the detailed design phase, and the life cycle implementation phase (see Fig. 1). In the

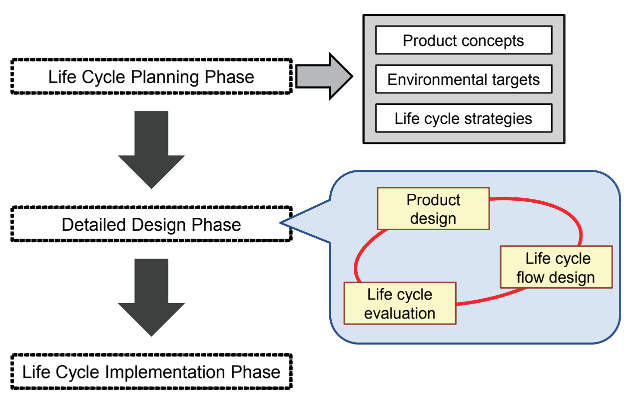

Fig. 1: Life Cycle Design Procedure

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life cycle planning phase, a design team analyzes the present situation of society, markets, and so on, and determines the product's concepts, environmental targets, and life cycle strategies based on the analysis result. The life cycle strategies indicate the basic concepts of the product and its life cycle flow, which include the combination of life cycle options (LCOPs). In the detailed design phase, the team designs the product and its life cycle flow, including the various life cycle processes (e.g., manufacturing, sales, and recycling) so that the life cycle strategy can be realized. In this phase, the designer should evaluate the product life cycle to check whether the strategy is feasible. Accordingly, the development cycles, including those of product design, life cycle flow design, and life cycle evaluation should progress in an integrated manner as shown in Fig. 1. In the life cycle implementation phase, the team realizes the life cycle flow by organizing the supply chain, constructing factories, developing recycling plants, and so on. The team then operates and manages the product life cycle.

Many studies have focused on support for the life cycle design. Kobayashi [2] proposed an approach that supports the choice of life cycle options of parts through the linkage of QFD and LCA data. We proposed the life cycle scenario description method [3] as a previous study. This method provides two support schemes: representation of design rationale, and management of alternatives. Kwak [4] proposed a framework for evaluation of the relationship between product design and resource circulation flow with Transition Matrix. And a number of studies have also addressed environmentally conscious design technologies including design for recycling, and such technologies have been practically adapted to product design [5]. Fasoli [6] proposed the management method for some data of product and its life cycle on the framework of Product Life cycle Management (PLM).

However, the relationship between a product and its life cycle has not been clarified, and the support environment for integrated design between a product design and a life cycle flow design remains insufficient. Therefore, our support system focuses on the integrated design for the detailed design phase.

2.2 Fundamental Concepts of the LC-CAD System

In life cycle design, it is important to declare the objectives of product life cycle (i.e., the criteria for evaluating the designed life cycle flow) in the early stage of the life cycle design and to design a life cycle flow so as to realize the objectives. Designers should design a product (including, structure, geometry, layout, and so on) so as to enhance the feasibility of this flow. Here, "feasibility of a life cycle flow" means that the life cycle flow fulfills that (i) feasible process in physical and technical term is chosen, (ii) economically desirable process is chosen, and (iii) correspondence between a product and its life cycle flow is kept. For example, the life cycle flow in which a part including non-recyclable materials is recycled is not feasible. In order to facilitate the identification of this feasibility, we assume that each process has the requirements, which are the necessary conditions of the components passing through the process. The design team identifies these requirements due to economic or technical reason. Accordingly, following two points should be considered in the life cycle design: (i) whether the designed life cycle flow satisfies the objectives of the product life cycle, and (ii) whether the designed life cycle flow is feasible. For the point (i), it is necessary to evaluate environmental loads and costs of product life cycle at each stage of life cycle design. For the point (ii), it is important to identify which component of a product passes through which process of a life cycle flow in order to judge whether the requirement of each process (e.g., lifetime of reuse parts) is fulfilled. The assembly state and quality (e.g., existence of trouble or dirt, and so on) of a product is changed throughout a product life cycle. For example, a product is disassembled to some modules and parts, repaired, shredded for recycling, and so on. Accordingly it is important to make visible the whole product life cycle by corresponding the design information of a product and that of its life cycle flow.

In this paper, therefore, we assume the procedure of the integrated design for the detailed design phase is based on the development cycles including product design, life cycle flow design, and life cycle evaluation. We mention following three approaches for the management of consistency:

(1) Propose the representational scheme of a product and its life cycle flow in order to design and evaluate them on a computer

(2) Define the relationship between a product and its life cycle flow and propose the management scheme of the consistency of this relationship

(3) Enable the life cycle evaluation by using both the design information of a product and that of a life cycle flow

In this paper, we propose a product model and a life cycle flow model as the representational scheme of a product and a life cycle flow respectively on section 3.1 and 3.2. And then we define the relationship between these two models and propose the management scheme of this relationship on section 3.3.

3 CONSISTENCY MANAGEMENT SYSTEM

3.1 Product Model

Since the assembly state and quality of a product is changed throughout a product life cycle, product model should represent the hierarchical relationship among product, module, sub-module, and part. Therefore, we employ the hierarchical structure as the representational scheme of a product structure. Through unifying the components which go through the same path in a life cycle

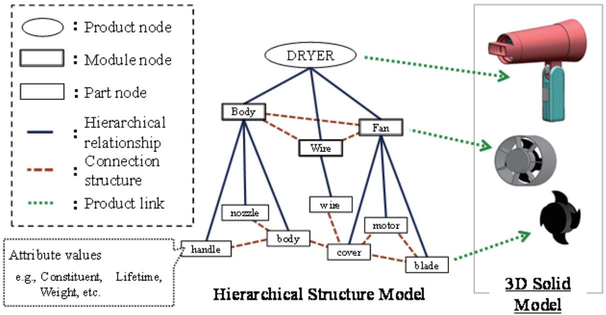


Fig. 2: Product Model

flow by using this hierarchical structure, the reduction of costs due to improvement of disassembrability and the enhancement of the feasibility of the life cycle flow due to the improvement of recyclability are expected. In order to enable to check the feasibility of designed life cycle flow visually, we also employ the 3D solid model as the representational scheme of geometry and layout of the components.

The architecture of the proposed product model is shown in Fig. 2. The product model consists of hierarchical structure model and 3D solid model. In the hierarchical structure model, we define three kinds of constituent nodes: product node, module node, and part node. A product node represents the whole product at the top of the hierarchical structure, a part node at the bottom, and a module node represents an assembly of parts or sub-modules in the middle of the hierarchy. Here, the module node is related to the state of assembling or disassembling of components in the product life cycle. Each node has its attribute values such as constituents, lifetime, weight, etc. The connection structure, which represents the physical or electric connection between modules or parts in the same level of hierarchy, is represented in the form of topology between them. The 3D solid model represents geometric form and layout of the components. Each part has links with correspondent nodes of the structure model. The link enables to correlate between structural and geometrical information.

3.2 Life Cycle Flow Model

In order to represent the assembly state and quality of a product on a certain process of a life cycle flow for verification of the feasibility, life cycle flow model should represent (i) a series of process which certain component passes through, (ii) the situation and the requirements of the process. Therefore, this paper proposes the life cycle flow model as shown in Fig. 3. The life cycle flow model consists of the process, which represents the change of the state of a product and exchange of money, and the flow link, which represents the flow of products, modules, and parts by connecting some processes. Each process has input and/or output substances according to the circulation of products, components, and materials on each process. Each process also has a situation formulated using the 3W1H (When, Where, Who, and How) approach and the requirements.

3.3 Consistency Management between the Product Model and the Life Cycle Flow Model

In order to manage the consistency between product and life cycle flow, this paper defines the relationship between the product model and the life cycle flow model. For mutual information reference, each flow link in the life cycle flow model links to the hierarchical structure model's node corresponding to the I/O substance of each process. The hierarchy structure of a product is changed throughout a product life cycle. For example, modular structure may change due to the difference between the composition of assembly on the manufacturing and that of disassembly on the inverse manufacturing. In this case, a designer should draw two or more hierarchical structure models and make linkages to the life cycle flow model (see Fig. 4). Through this linkage, we can represent (i) which node of the hierarchical structure model passes through which process of the life cycle flow model, and (ii) the assembly state and quality of a product on a certain process of a life cycle flow.

In order to evaluate product life cycle by using design information of product and life cycle flow, we employ Life Cycle Simulator (LCS) [7]. The LCS can evaluate environmental loads and costs throughout the entire

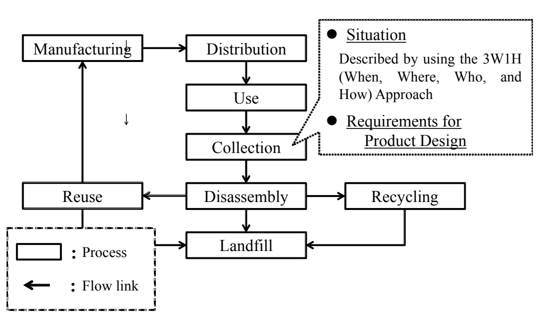


Fig. 3: Life Cycle Flow Model

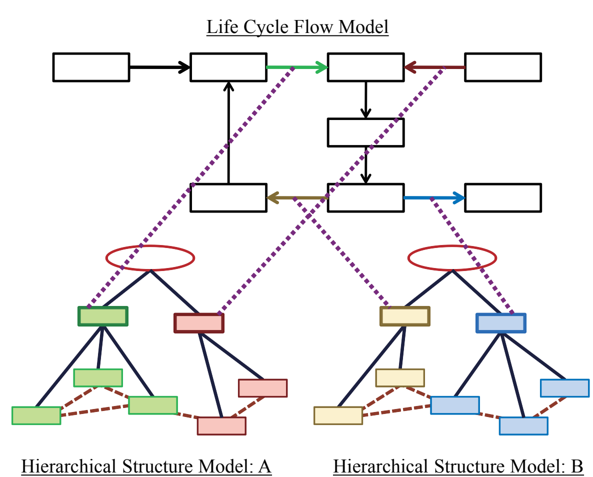
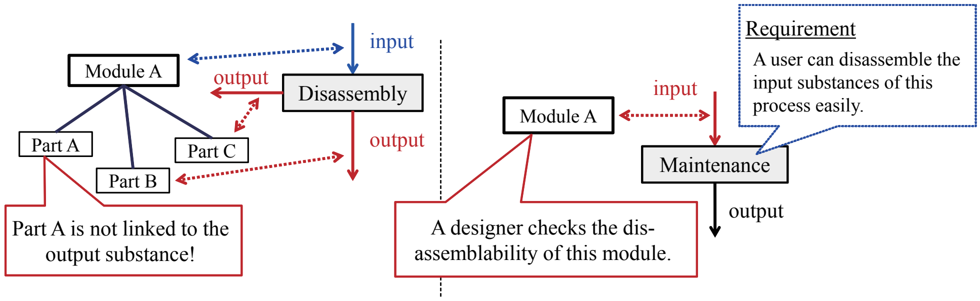


Fig. 4: Variation of Hierarchical Structure Model



(a) physical consistency (b) requirements for product design

Fig. 5: Examples for the consistency management

product life cycle using a discrete event simulation technique and LCA data such as intensities for LCA. Since the simulation model for LCS accords with the life cycle flow model, we can evaluate product life cycle with the life cycle flow model by describing indispensable parameter and calculating formula on each process.

This paper proposes the management scheme for feasibility of life cycle flow (outlined in Section 2.2) by using proposed linkage. This is achieved as two type of consistencies: (i) the coherence of the linkage between product model and life cycle flow model (model consistency level), and (ii) the fulfillment of requirements for technically and economically desirable process which assumed by design team (requirement fulfillment level).

In the model consistency level, our system checks whether the linkage between product model and life cycle flow model is made correctly. For example, when certain module is linked to the input substance of the disassembly process, it is incoherence the case in which some parts isn't linked to the output substances of the disassembly process (see Fig. 5 (a)). In order to manage this consistency type by computer, we define five process types of the life cycle flow model as shown in Table 1. We also define the rule for model linkage: the concourse of output substances equal to that of input substance (conservation law). This rule is applied to the process type (3), (4), and (5). When the linkage between product model and life cycle flow model obeys this rule, we assume that this linkage is preserved correctly.

In the requirement fulfillment level, the fulfillment of the requirements (outlined in Section 2.2) should be identified. Since this type of consistency is hard to judge by computer, the design team should judge by using the result of LCS or other assessment tools. Through the proposed linkage, our system support the judgment by the design team on following two points: (i) show the requirements described in each process, and (ii) show the attribute values and quality of the parts which passes through certain process of life cycle flow model.

4 CASE STUDY: LCD TV

We make design changes of Liquid Cristal Display (LCD) TV with the prototype system as a case study in order to verify the effectiveness of proposed system. We assume that both the product model and the life cycle flow model of current situation are given (as shown in Fig. 6 and Fig. 7). The linkage between the product model and the life cycle flow model is also given, and each flow link in the life cycle flow model is color-coded according to the linkage with the constituent nodes of the hierarchical structure model. In the current status, LCD TV is disassembled into its basic components and the fluorescent tubes containing mercury which is a toxic substance are removed, and then the other parts including a LCD panel are recycled [8]. The average physical lifetime of LCD TV is approximately seven years, and the lifetime of a back light module containing fluorescent tubes is dominant. Therefore, we aim to make LCD TV to be long-lived by exchanging this back light module which is shown by red nodes in Fig. 6.

The procedure of this case study was as follows:

Table 1: Process Type

Process type	Definition
(1) Start	$f(L_{in})=0$, $f(L_{out})\geq 1$ This process has only output objects.
(2) End	$f(L_{in})\geq 1$, $f(L_{out})=0$ This process has only input object.
(3) Pass	$f(L_{in})=f(L_{out})\neq 0$ This process has identical objects on both input and output.
(4) Compose	$f(L_{in})>f(L_{out})\geq 1$ This process has many input objects than output objects.
(5) Separate	$f(L_{out})>f(L_{in})\geq 1$ This process has many output objects than input objects.

L_{in}, L_{out}: One node of a hierarchical structure model

$f(L_{in/out})$: The number of L_{in} or L_{out}

(1) We added a maintenance process to the current life cycle flow model and described a situation and requirements on this process. Since we assumed that an engineer exchanges the back light module by visiting to user's home, we gave two requirements: (i) to secure the disassemblability for exchanging the back light module, and (ii)not to expose fluorescent tubes from the aspect of fragility at the exchange.

(2) We changed the hierarchical structure model and the linkage between two models according to the design change of the life cycle flow. We linked the product node "LCD TV" of the hierarchical structure model to the input substance of the "Maintenance" process. We also linked the module node "Back Light Module", which is expected to be exchanged at the maintenance process, to the input substance of the "Mercury Removal" process.

(3) We checked the requirements of the maintenance process. Since the "Stand Module", the "Board Plate", and the "LC Frame" are fixed through the "Back Light Module" in the current structure (see Fig. 6), the engineer should disassemble the LCD TV finely in order to exchange the back light module. Moreover, as shown in Fig. 8, the "Back Light Module" is exchanged with the fluorescent tubes (described as "Back Light" in Fig. 6) exposed. Therefore, we judged that some design improvements are required in order to fulfill the requirements of the "Maintenance" process.

(4) We made new module "LC Module" with "LC Panel", "LC Frame", "LC Board", "LC Board Cover", Back Light", and "Back Light Board". In addition, we change the connection structure as shown in Fig. 9. This design change improved the disassemblability of LCD TV. LCD TV enables to be disassembled into three modules: "Back Case Module" (including "Stand Module", "Stand Cover", "Board Module", and "Rear Case"), "Front Case Module", and "LC Module". Moreover, we can exchange the back light module without the exposure of fluorescent tubes by allowing to exchange as the "LC Module". Since some inconsistencies on model

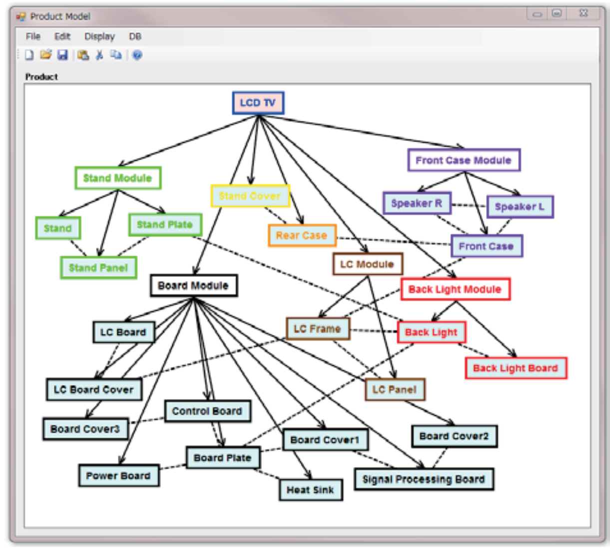


Fig. 6: Hierarchical Structure Model (current situation)

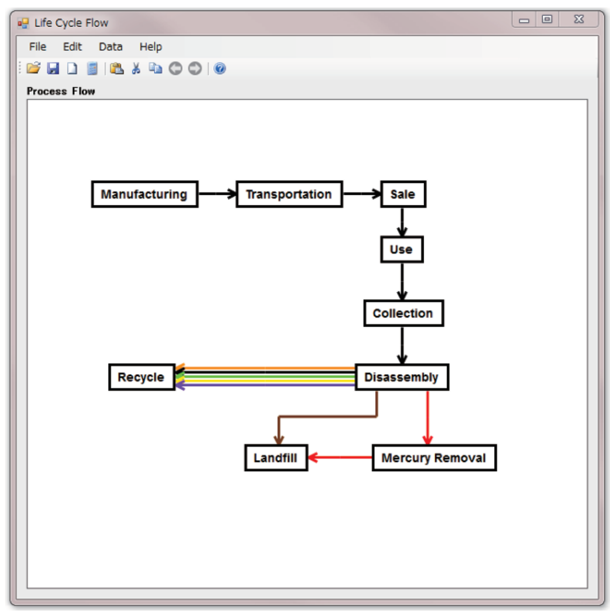


Fig. 7: Life Cycle Flow Model (current situation)

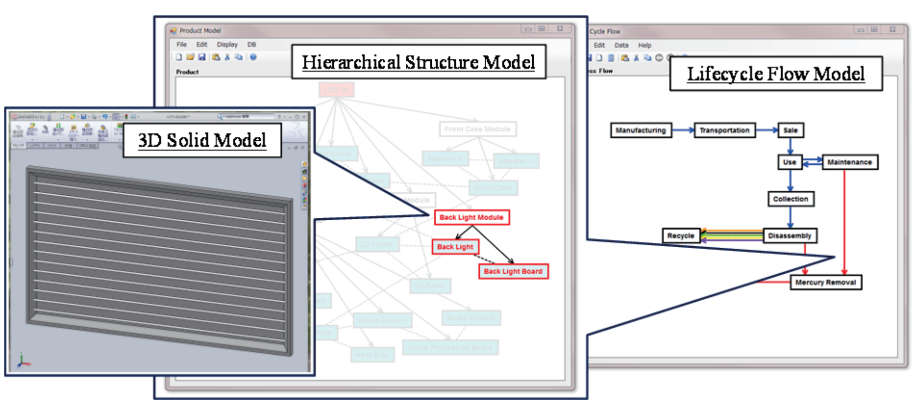


Fig. 8: Correspondence between Product Model and Lifecycle Flow Model (revised for maintenance)

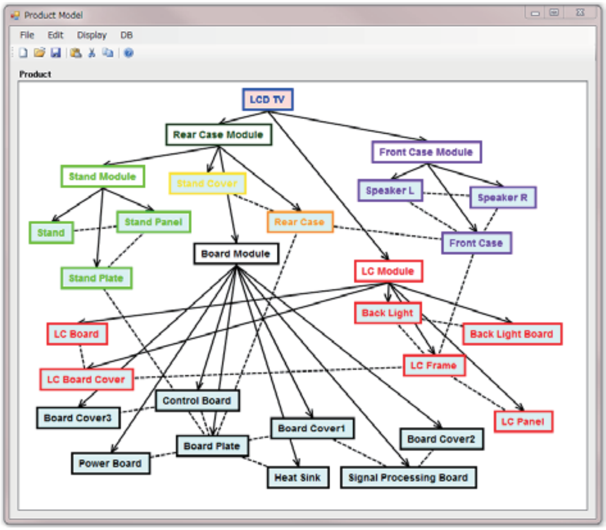


Fig. 9: Hierarchical Structure Model (Re-designed)

consistency level were arisen from the design change of the hierarchical structure model, we revise the linkage between the hierarchical structure model and the life cycle flow model.

Here, we focused on the design changes of the product model and the life cycle flow model. In practical design, we should consider the connection, geometry, attribute values, and so on. We also should evaluate product life cycle in order to verify the satisfaction of objectives of the product life cycle.

5 DISCUSSION

In this study, we implemented the design changes to extend the lifetime of a LCD TV by replacing the back light module in a case study. The results indicated that the relationship between a product and its life cycle flow (especially, the assembly state of a product on a certain process of life cycle flow model) can be successfully represented with the proposed system. In fact, the system was helpful in identifying the problem of fluorescent tube exposure when the back light module is replaced.

However, the system cannot represent shredder dusts, recycled materials, and other considerations (e.g., existence of trouble or dirt) because it addresses only the assembly state. Also, this system cannot handle two or more kinds of products simultaneously such as variety design because it addresses only the variety of hierarchical structures. Although this paper proposed the management schemes of the feasibility of life cycle flow with the two level of consistency, we need to verify whether these schemes are necessary and sufficient for the management.

6 CONCLUSION

Toward developing the LC-CAD system for life cycle design, this paper proposed a consistency management approach involving a product model, a life cycle flow model (as a representational scheme of a product and its life cycle flow), and linkage between the two models. It also outlines a scheme to manage the feasibility of life cycle flow with two levels of consistency (the model consistency level and the requirement fulfillment level). We performed a case study on a LCD TV with the prototype system to verify its practical effectiveness. In future work, we plan to construct a design support system for the phase from the life cycle planning to detailed design (see Section 2.1) by integrating the life cycle scenario description method, which can be used to manage design rationale and alternatives in a trial and error manner, into the proposed system.

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Construction of a Simulation Model for Future Scenario Analysis of Energy Consumption and CO_2 Emissions in Japanese Prefectures

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Abstract

The objective of this study is to create a simulation model for Japanese energy consumption and CO_2 emission levels that will effectively contribute to and guide the 2000–2050 policy-making process of each Japanese prefecture. Data for the study has been gathered from the Japanese domestic, transportation, and industrial energy sectors. The model can test the effects of the introduction of energy-saving technologies, changes in social requirements, economic trends, and urban spatial structure processes. By using the proposed simulation model, the examination of future energy consumption and CO_2 emission levels will facilitate the formulation of new policies and the effective implementation of policy-related decisions.

Keywords:

simulation model, future scenario analysis, energy consumption, CO_2 emissions, prefecture

1 INTRODUCTION

Owing to the industrial accident at the Fukushima Nuclear Power Plant caused by the 2011 earthquake and subsequent tsunami off the Pacific coast of Tohoku, Japanese energy and low-carbon policies need to be reexamined. In addition, because of the resulting tragedies, renewable energies, such as solar, wind, and geothermal energies, need to be addressed. With 40% of Japan's energy consumption being electric, such energy use dominates all other types of energy consumption in the country. The reexamination of the aforementioned policies as well as people's requirements and their expectations of the provision of new energy strategies should impact Japan's future energy consumption and CO_2 emission levels.

The objective of this study is to contribute to the policy-making process and positively guide the process by constructing a simulation model that can estimate the energy consumption and CO_2 emission levels for each Japanese prefecture from the year 2000 until 2050. It will also test the effects of the introduction of energy-saving technologies, changes in social requirements, trends of the economy, urban spatial structure, etc. The simulation model covers such energy-using sectors as the domestic, transportation, and industrial sectors. The domestic sector includes household and service activities. The transportation sector is composed of inter- and intra-prefecture passenger and freight transport. Finally, the industry sector includes the primary sector, which involves material; the secondary sector, which involves the processing/assembly-manufacturing industries; and the tertiary sector, which includes non-manufacturing industries. The energy consumption and CO_2 emission levels in each sector were estimated by using the values of the amount of activity, the energy units (energy consumption per activity), and CO_2 emissions factor. The simulation model also deals with the kinds of energy consumption, such as sectors producing electricity, gas, kerosene, and renewable energy. By using the constructed model, we tested the technological effects from photovoltaic power generation (PV), cogeneration systems (CGS), heat pumps (HP), hybrid electric vehicles (HEV), and electric vehicles (EV). The effects of urban planning (compact city or sprawling city), that of working women, and economic trends for different scenarios were also estimated. With the aid of the proposed simulation model, a macroscopic viewpoint was used to estimate future energy consumption and CO_2 emission levels. We also incorporated an operation touch panel into the model that allows policy makers to easily examine and select the parameters for different scenarios; it also enables them to view the simulation results in the form of graphs and tables in real time. The goal of the study is to build new policies and quickly devise effective policy-related decisions by examining future energy consumption and CO_2 emission levels; this goal can be met by using the proposed simulation model.

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2 DEVELOPMENT OF SIMULATION MODEL

2.1 Outline of simulation model

This study estimates the energy consumption and CO_2 emission levels for every prefecture in Japan from 2000 to 2050. The simulation time step is five years and based on the population cohort model. The driving forces of the model are population and populace economic levels. The model can estimate the activity volumes of each sector and calculate each sector's CO_2 emission levels by multiplying energy units and CO_2 emission factors.

To describe the future activities, we estimated energy consumption and CO_2 emissions under three different categories: "BAU (business as usual)," "urbanized society," and "localized society."

2.2 Estimation of population and household

The population was separated into sex and five-year-age-group categories on the basis of the 2000 National Census (2000) [1] in order to project the population. The projected population was estimated by using the cohort component population projection method. The cohort method of demography is a method of grasping the population's dynamics by tracing a shift of a group born in the same time period, or inter-annually. The group born in the same time period is called a "cohort." Values expressed in the cohort shift are birth rate, death rate, net-migration rate, and sex ratio at birth. The birth rate of each scenario was set at different values. The "localized society" values were the highest (1.54 based on a 1990 value), "BAU" was in the middle (1.36 based on a 2000 value), and "urbanized society" was the lowest (1.26 based on a 2005 value).

The number of households was then estimated by calculating the ratio of households to the estimated population. Specifically, information obtained from the 2000 National Census [1] showed that the number of households was calculated by multiplying the population by the ratio of households, according to sex and five-year-age groups. The number of households was calculated according to the total number of people reflected in the census. The working-women category was reflected in the "urbanized society" scenario. It is projected that there will be as many women working in 2050 as there are men working in 2000.

2.3 Estimation of economic level

Economic levels in this study were represented as a value of the gross prefectural domestic product (GDP) that was obtained from the 2000 Prefectural Economic Accounts (2000) [2]. The annual growth rate of GDP of each scenario was set at different values. The annual growth rate for "BAU" was set at 0.928%, referring to the average rate from 1990–2010. The annual growth rate of the "urbanized society" was set at 2.222%, referring to the average rate from 1980–2010, including the asset-inflated economy. The annual growth rate of the "localized society" category was set at 0.171%, which is the lowest value from 1980–2010 (minus the annual growth rates that were omitted). All annual growth rate scenarios were taken from the International Monetary Fund statistical records. The industrial structure of the primary, secondary, and tertiary industries was calculated on the basis of estimated formulas, which were determined by per-person GDP.

2.4 Estimation of domestic sector

The domestic sector comprises household and service activities. In order to estimate energy consumption and CO_2 emission from the household sector, it is important to understand the numbers and sizes (building area, floor area, etc.) of houses by housing type, such as detached or multiple-dwelling houses and by construction type, such as wooden or non-wooden. The construction type is not directly related to energy consumption or CO_2 emissions, but floor area size is. The dwelling houses were separated into four types. The ratio of households of detached dwelling houses was estimated by the correlation of the tertiary industry and population density (population divided by building house area [3]). The ratio of households of multiple-dwelling houses was estimated one minus estimated above the ratio of household of detached dwelling house. The number of each housing type of household was calculated by the total household multiply above each ratio of the household.

In order to estimate the total floor area, it is important to understand the floor area of each household according to the four types of dwelling houses. We acquired the data of the floor area of each household from the 2003 Housing and Land Survey [4]. The ratio of detached and multiple dwelling houses was determined by the scenario. The population density was twice as high as that of 2000 and for the "BAU" under the "urbanized scenario," the ratio of multiple dwelling houses also increases by the above-estimated correlation. On the other hand, the population density reduces two fold compared with that of 2000, and with regard to the "BAU" under the "localized scenario," the ratio of detached dwelling houses increases.

The amount of energy consumption per total floor area (MJ/m^2) was used as the unit value for the household sector. The energy units were subdivided by housing types, size of floor area, regions, and fuel used. The energy consumption for the household sector was estimated by the above-floor area multiplied by the energy units.

The commercial buildings were generally categorized according to the usages, such as office buildings, department stores, supermarkets, wholesale product buildings, restaurants, hospitals, schools, hotels and inns, public facilities, and other services. The demand for these usages was determined by the services provided and customers' needs. It is important to examine these factors in order to estimate the types, numbers, and floor areas of buildings. However, in this study, the types of buildings were determined by the existing circumstances, and the numbers and the floor area of the buildings were estimated by the estimated population and industrial structures for every step of the simulation process. The data used in this study for commercial buildings was the 2003 Corporations Survey on Buildings [5]. For the estimation, the data was categorized into the primary, secondary, and tertiary industry sectors. The amount of energy consumption per total floor area (MJ/m^2) was used as the unit value for the commercial sector. The energy units were subdivided into building type, region, and fuel used. The energy consumption for the commercial sector was estimated by the above-floor area multiplied by energy units.

In order to estimate CO_2 emission for the domestic sector, a basic unit, called the CO_2 emission factor (kg-CO_2/MJ), was used.

This study also considered technological effects from PV, CGS, and HP. From the data, it is projected that 50% of the CGS and HP technologies, respectively, will be introduced by 2050. By 2050, 10% of the PV technology is also slated to be utilized, with the PV technology projected to be an effective household sector energy source.

2.5 Estimation of transportation sector

In order to estimate CO_2 emissions for the transportation sector, inter- and intra-prefecture passenger and freight transport were subdivided.

Passenger transport was divided into the business and school transportation segments. Trips were mainly taken by individuals ranging from 15 to 64 years, who had jobs or went to school. In this study, if the working-woman segment becomes more popular in the future, the number of female trips will occur more often, and the rate will be reflected as the same value in 2050 as the number of working males in 2000. Trips taken by working women is reflected in the "urbanized society" category. CO_2 emissions are different when driving cars or taking public transport, such as trains, subways, and buses. Therefore, these modal shares were explained by using GDP per capita and population density. The usage of cars is usually explained by population density. If the density is high, people tend to use more public transportation than cars. The effects of the modal shares were expressed under "urbanized society" and "localized society." In addition, population density was two times higher for the "BAU" and "urbanized society" scenarios in 2000, while population density within the "localized society" segment was two times lower. Further, two round trips per day per person were calculated, and the lengths of the trips of each modal type were taken from data contained in the 2000 Statistical Survey on Motor Vehicle Transport [6].

Trip generation and attraction of inter-prefecture passenger transport were calculated on the basis of the estimated population divided by the amount of inter-transportation trips. The data was obtained from the 2000 Investigation and Analysis Report on the Regional Flow of Cargo and Passengers [7]. Inter-prefectural passenger transportation was calculated by the present-pattern method and used data from the origin-destination table. The kinds of modal shares were cars, trains, buses, ships, and airplanes, and they were assumed to be the same shares in 2000. The trip lengths among inter-prefectures were calculated utilizing the centroid method and by analyzing GIS (Geographic Information System) data.

The estimation of CO_2 emissions for intra-prefecture freight transport was subdivided into the primary and secondary industries. The upward or downward market trends of these industries influence the amount of freight transport generated. Trip generation and attraction of the intra-prefecture freight transport was estimated on the basis of the value of each industrial production divided by the amount of each intra-transportation [7]. The kinds of modal shares used were cars, trains, and ships. However, since the amount of CO_2 emitted from the private-use and the business-use cars is markedly different, the segment was subdivided. The private use and business use sectors were classified in the "urbanized society" and "localized society" categories. The length-of-trip data for each mode of transportation was taken from the 2000 Statistical Survey on Motor Vehicle Transport [6].

The CO_2 emissions estimation for the inter-prefecture freight transport was subdivided into the primary and secondary industries. The trip generation and attraction of the inter-prefecture freight transport was estimated on the basis of the value of each of the industrial productions divided by the amount of each inter-prefecture transport [7]. The inter-prefectural freight transportation was calculated by using the present-pattern method and attaining data from the origin-destination table. The kinds of modal shares utilized were cars, trains, and ships and were taken from the 2000 data. The length of trips among inter-prefectures was the same as the inter-prefecture passenger transport.

In order to estimate CO_2 emissions, a CO_2 emission factor (kg-CO_2/MJ) was used from Trends of Greenhouse Gas Emissions from the Transportation Sector [8]. This study also considered the technological effects that are produced from HEV and EV automobiles. The HEV and EV cars are projected to enter the marketplace at 60% and 40%, respectively, of the number of all cars to enter the market in 2050. The CO_2 emission data was taken from Kobayashi [9].

2.6 Estimation of industrial sector

Energy consumption and CO_2 emissions from the industrial sector are mainly determined by economics, industrial activities, and the individual technologies. The majority of energy consumption and CO_2 emissions are caused by the material manufacturing industries, such as steel, pulp and paper, and chemicals. The steel and cement industries are abundant in Japan; therefore, the production levels of these industries highly influence energy consumption and the amount of CO_2 emissions being emitted from the factories.

The industrial sector includes the primary and secondary industries. The second industry was subdivided into material, processing/assembly-manufacturing, and non-manufacturing. The value of each industry was calculated from the industrial structures. The amount of energy consumption per each industrial value was obtained from the 2000 Energy Balance Table [10]. The carbon emission factor (kg-C/MJ) was also taken from the same resource, and the CO_2 emissions were calculated from the carbon emissions discharged from the various sectors' usages.

Regarding the industrial sector, the material industries completely converted to the less-CO_2-emission industries under the "urbanized society" and "localized society" sectors.

3 SCENARIOS

We set three different scenarios to describe different future visions. The three scenarios used to describe future visions were "BAU," "urbanized society," and "localized society."

The introduction of technologies for the "BAU" scenario was not considered, while the birth rate, GDP growth rates, and population density were different from the other scenarios. Overall, the social and economic situations as well as the technology level for the "BAU" scenario will continue to be constant from that of 2000. The differences between the "urbanized society" and "localized society" were the birth rate, GDP growth rates, working women, and population density. The types of introduction technologies and their rates remain the same; the social and economic situations were only different between these scenarios.

4 RESULTS

4.1 Results of population and household

The Japanese population level indicating the three scenarios is shown in Fig. 1. The results indicate that the population in 2000 was 126.70 million, which increased until 2010; after 2010, the population continues to decrease until 2050. By 2050, the "BAU" population will be approximately 97.67 million, the "urbanized society" will be 93.55 million, and the "localized society will be 103.97 million. The difference in the results is largely influenced by birth rates. The birth rate for the "localized society" was the highest, with population decreases in the other categories. The population levels of Tokyo and Okinawa prefectures increase until 2050, while the populations of most of the other prefectures consistently decrease. From 2000 to 2050, the population of Akita prefecture decreases to about 50% under any of the scenarios. The populations of Wakayama, Aomori, Iwate, Shimane, Yamaguchi, and Nagasaki prefectures also significantly decreases. On the other hand, populations in Kanagawa, Aichi, and Shiga are almost constant.

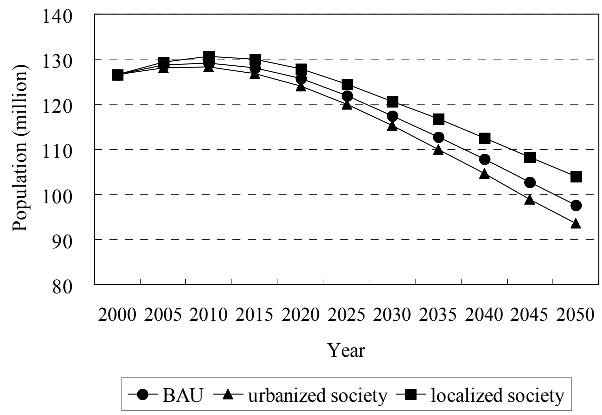

Fig. 1: Japanese Population by Scenarios

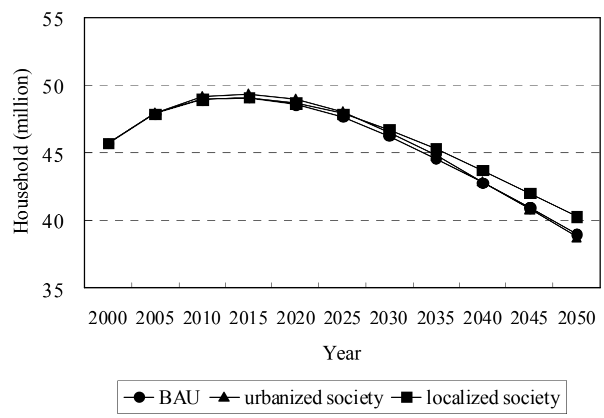

Fig. 2: Japanese Households by Scenarios

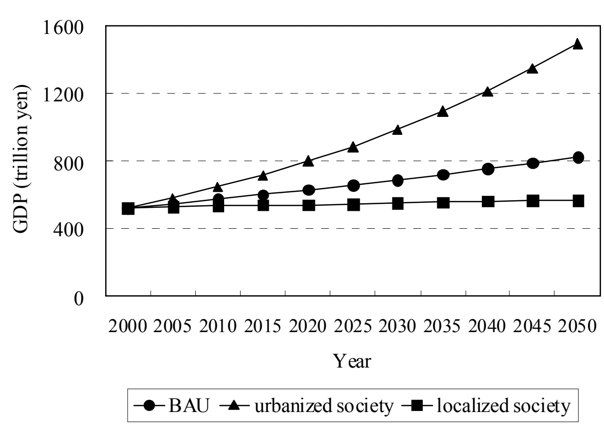

Fig. 3: Japanese GDP by Scenarios

The number of households in Japan divided according to the three future-vision scenarios is shown in Fig. 2. The results indicate that in 2000, the number of households was 45.69 million, and this increases until 2015 with a continual population decrease until 2050. The "BAU" population was approximately 38.92 million, the "urbanized society" was approximately 38.74 million, and the "localized society" was about 40.30 million. The household decrease rate under the "urbanized society"

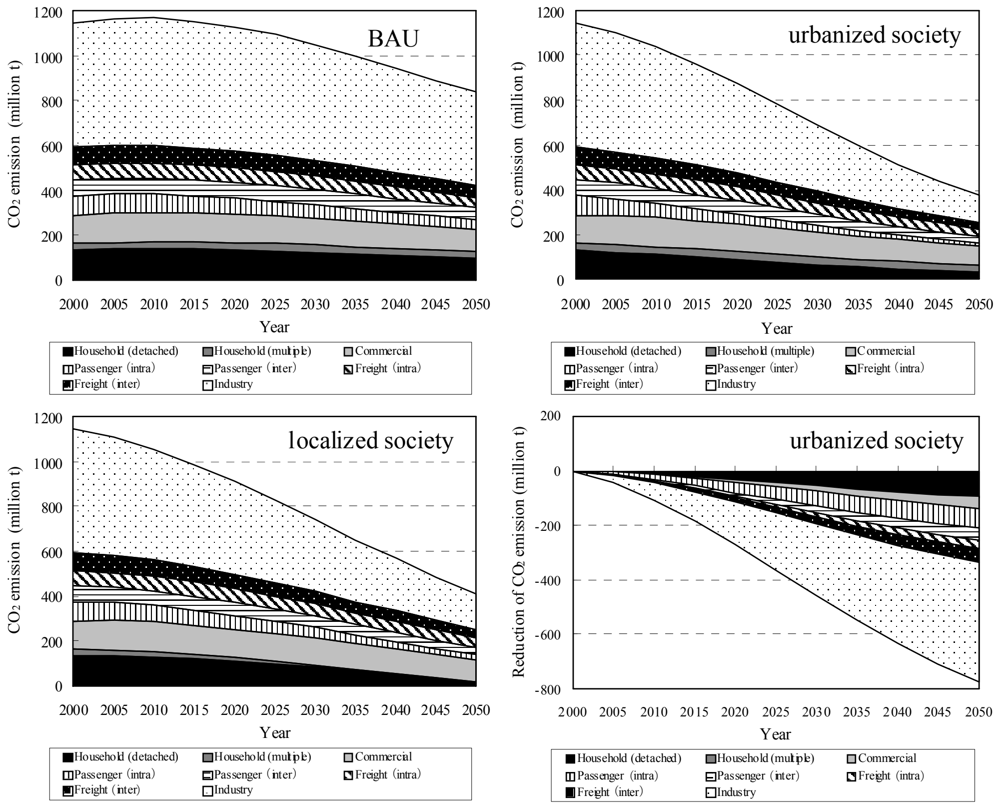

Fig. 4: Japanese CO_2 emission by Sectors and Scenarios

The figure on the bottom right reflects the reduction in CO_2 emissions from 2000 to 2050 under the "urbanized society" scenario.

category was not significant, compared to the population, since the increase in working women results in a slower decrease in the number of households. Significantly, the number of households in Tokyo under the "urbanized society" was higher than that of the "BAU" category. In addition, the number of households in the Okinawa, Tokyo, Aichi, Kanagawa, and Shiga prefectures increases, while the number of households in other prefectures decreases.

4.2 Results of economic level

The results of the escalation of Japan's GDP for each scenario during the period of 2000–2050 are indicated in Fig. 3. The results show that GDP in 2000 was 521.32 trillion yen, which increases to 820.40 trillion yen under the "BAU" scenario; 1495.29 trillion yen under the "urbanized society" scenario; and 567.65 trillion yen under the "localized society" scenario in 2050. By following the abovementioned economic growth, the industrial structures shifted from the primary to the secondary and tertiary industry sectors. The tertiary sector economic growth share under the "urbanized society" category increased to 92.82% by 2050, while the "BAU" category increased to 84.3%, and the "localized society" to 75.14%.

4.3 Results of CO_2 emission

CO_2 emissions are only shown in this chart; the results of energy consumption were omitted, owing to a limitation in the size of the report. Fig.4 shows Japanese CO_2 emissions by sectors and scenarios, and the reduction of CO_2 emissions from 2000 to 2050 under the "urbanized society." The 2000 CO_2 emissions were 1145.78 million tons: 834.76 million tons under the "BAU" category, 374.99 million tons under the "urbanized society," and 408.83 million tons under the "localized society." The reduction in CO_2 emissions from 2000 to 2050 was the highest under the "urbanized society" at 770.79 million tons. The CO_2 emission reduction was 311.02 million tons under the "BAU" category and 736.95 million tons under the "localized society."

Fig.5 shows the CO_2 emissions of various Japanese prefectures by sectors in 2000 and by scenarios in 2050. The results indicate that CO_2 emissions in the Tokyo, Kanagawa, Osaka, Aichi, and Hokkaido prefectures were sizable in 2000. The amounts in Tokyo and Kanagawa prefectures exceeded 70 million tons in 2000. The CO_2 emissions in 2000 in Saitama, Chiba, Fukuoka, and Hyogo prefectures also contained large amounts of CO_2. The CO_2 emission trends in the Tokyo and Okinawa prefectures under the "BAU" category tended to increase, while the other prefectures' emissions continually decreased. In particular, the CO_2 emissions in the Okinawa prefecture under the "BAU" category increased about 20% from 2000 to 2050. The CO_2 emissions of both prefectures under the "urbanized society" and "localized society" segments decreased; however, the trends were not as

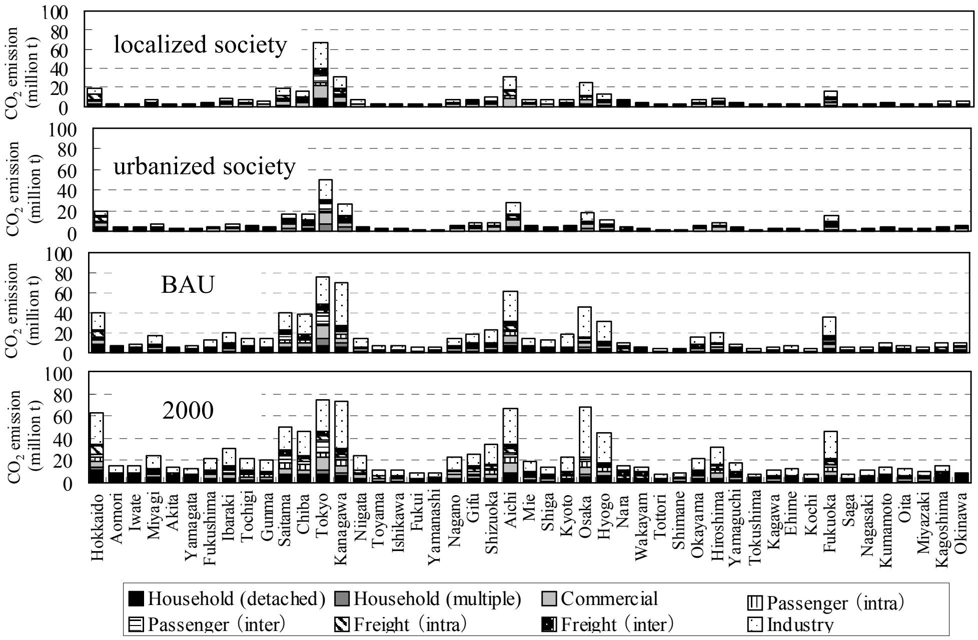

Fig. 5: CO_2 emission of Prefectures by Sectors and Scenarios

The figures of BAU, urbanized society, and localized society are as per the results of 2050.

significant as that of the other prefectures. Moreover, the reduction amounts of CO_2 emissions from 2000 in the Kanagawa, Aichi, and Shiga prefectures under the “BAU” category were not significant. On the other hand, the reduction trends were significant in the Akita, Yamaguchi, and Niigata prefectures, especially under the “urbanized society” segment.

5 SUMMARY

This study’s goal was to construct a simulation model of Japan’s energy consumption and CO_2 emissions. Information gleaned from the model will assist in the policy-making process and support leaders’ long-range decision-making steps and procedures. The model is able to simulate the energy consumption and CO_2 emissions from each Japanese prefecture from 2000 to 2050. The model can also estimate the effects of the introduction of energy-saving technologies, changes in social requirements, trends of the economy, and the effects of urban spatial structure.

The simulation model produced a one-of-a-kind touch-panel product that allows policy makers to easily examine the parameters and simulation results in real time. The results exhibit functional relationships between sets of statistical numbers and might be observed in the form of graphs and tables. The proposed simulation model will be beneficial to decision makers as they weigh options and devise new policy-related decisions for the betterment of their country.

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Reduction Potential for CO_2 Emissions by Urban Structure Changes and Introduction of Photovoltaic Power Generation in Buildings and Unused Area in Nagoya City

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Abstract

In order to mitigate global warming, there is a trend to promote a “low-carbon society” in cities. In recent years, the Japanese government has set up a program called the “Eco-Model Cities” program. The dissemination of generated photovoltaic (PV) power is seen as one of the measures for obtaining a low-carbon society. This study estimated the reduction potential for CO_2 emissions in Nagoya city under several scenarios. These scenarios involved urban structure changes, changes in the three-dimensional structures of buildings, the placement of buildings, the amount of unused area resulting from the placement of the buildings, and the installation of PV systems on building roofs and in unused areas. The results of this study could assist in realizing a low-carbon society, by examining the future urban structure, effective use of unused areas, and possibility of installing PV systems.

Keywords:

reduction potential for CO_2 emissions, urban structure, PV, buildings, unused area

1 INTRODUCTION

Currently, there is a trend to promote a “low-carbon society” in cities. The Japanese government has started a program called the “Eco-Model Cities” program. The diffusion of generated photovoltaic (PV) power is an important measure for obtaining a low-carbon society.

On the other hand, we are currently witnessing a decrease in the population and an aging society, while at the same time, we find that the buildings constructed after the Second World War are also aging and will soon require rebuilding. Therefore, it is high time for an examination of a more functional and efficient urban structure. Such a reorganization of the urban structure aims at further improving inefficient energy consumption and current utility levels by functionally reconstructing a city. One of the objectives of the Nagoya city government is to realize “working on transforming Nagoya into a comfortable, low-carbon city” as part of “the 2050 Nagoya Strategy for Low-carbon City” [1]. To accomplish this objective, the Nagoya city government has set up a policy for urban structure reorganization; according to this policy, houses and convenient facilities should be concentrated around public transportation stations. In addition, the unused space in facilities and large-scale unused areas could be utilized for renewable energy in the future. Thus, this policy also suggests that large-scale PV power systems should be installed in cooperation with the industrial sector.

When planning for a low-carbon city, reorganization of the concerned city into a compact city may affect the amount of unused area. Therefore, its use for energy production could potentially aid in the transition into a low-carbon city. Therefore, it seems appropriate to generate PV power. PV panels are commonly installed on the roofs of buildings. However, by installing them in unused areas as well, more energy could be produced than ever before.

PV systems are one of the renewable energy sources that do not emit CO_2 during power generation. Therefore, the dissemination of these types of systems would play a major role in global warming mitigation. At the same time, there is a certain distribution and amount of unused area in the land composition of urban areas, and in future, this amount may further increase because of changes in the urban structure. If it is possible to show that the emission of CO_2 will decrease when such unused areas are utilized for the generation of PV power, this measure might have significance in the development of low-carbon cities.

Therefore, in this study, the reduction potential for CO_2 emissions in Nagoya city is estimated under several scenarios. These scenarios include changes in the urban structure, changes in the three-dimensional structures of buildings, the placement of buildings, the amount of

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unused area resulting from the placement of the buildings, and the installation of PV systems on building roofs and in unused areas.

The obtained results could help to realize a low-carbon society, by examining the future urban structure, effective use of unused areas, and possibility of installing PV systems.

2 METHODOLOGY

2.1 Outline of estimation model

This study estimates the effect of reducing CO_2 emissions by installing PV systems on building roofs and in unused areas under different scenarios for urban structures in Nagoya city using the following 6 steps.

(1) The population and household dynamics in the city are estimated. (2) The lifecycles of housing and commercial buildings are calculated. (3) The reorganization of urban structures is presented using various scenarios. (4) The energy consumption and CO_2 emissions are estimated. (5) The electricity output of PV systems installed on building roofs and in unused areas is calculated. (6) The obtained reduction potential for energy consumption and CO_2 emissions are examined in comparison to (4).

First, in (1), the populations of different age groups are estimated using a population cohort with a grid structure based on data from the 2000 national census [2]. Furthermore, by considering the ratios of householders to population and family type (relatives, non-relatives, and one-person), the numbers of households by grid and family type are obtained. Next, according to (2), using data from the Nagoya City Urban Planning Basic Research 2001 [3], which has information on individual building attributes, the data are organized by the housing construction method and structure using the grid, and the housing waste of these attributes are expressed by the building cohort. The number of newly built houses and their total floor area are determined by taking balance amount of populations and households and houses with considering increase and decrease of the populations and the households and housing life. For an estimation of the commercial sector, using the data of the Nagoya City Urban Planning Basic Research 2001 [3], the number of commercial buildings by usage and their total floor area are organized using the grid, and the number of buildings is determined in proportion to the population of the city. Next, according to (3), the estimated population and households, and the number of houses and commercial buildings, are allocated in certain areas based on the concentration scenario, that is, at the new construction stage for houses and in accordance with a change in the population distribution for commercial buildings. Next, according to (4), an estimation is made of the energy consumption and CO_2 emissions generated by the domestic sector, which consists of the residential sector and the commercial sector, according to the urban structure scenario of (3). Moreover, according to (5), the electricity output is estimated for PV panels installed on building roofs and in unused areas according to the scenario of (3). Finally, according to (6), the reduction amount is calculated by subtracting the amount of electricity obtained by the PV system from the energy consumption of (4) estimated previously. In addition, by converting the amount into the CO_2 emissions, the reduction potential for PV power is estimated.

All of the input data are compiled using a half grid square (of about 500 m per side), which is obtained by dividing a standard grid square (third-order grid unit) into two equal parts in the latitude and longitude directions as the analysis space unit.

2.2 Area of building roofs and unused areas

Building roofs and unused areas are chosen as locations to install PV panels. First, the area of a building's roof is estimated based on the building's footprint. The roof is regarded to be equal to the building area, only moved in the vertical direction. However, in a case where a vacant house occurs in the future, its building area is not counted because there is no power demand. Next, the size of the unused area is expressed as a site area calculated by multiplying the surplus building area by the building coverage. Surplus building area occurs if houses and commercial buildings decrease in relation to future populations and households. On the other hand, if houses and commercial buildings increase, the unused area decreases because the surplus building area also decreases. In addition, if concentrating, an unused area occurs in the previous location because the houses and commercial buildings are moved from the area where they were originally built to a concentration district. Therefore, the unused area is determined according to the fluctuation in the site area of houses and commercial buildings.

2.3 Energy consumption and CO_2 emissions

The amount of energy per total floor area (MJ/m^2) is used as the unit value for the residential and commercial sectors. In the residential sector, energy consumption is classified by housing type, while in the commercial sector, it is classified by the use for the commercial building. Energy consumption is subdivided by the fuel used. The unit values are taken from the Commercial and Residential Sector Energy Data Survey 1996–1998 [4]-[6] edited by the Institute of Energy Economics, Japan.

The energy consumption each year is expressed by the following equations.

$$E_i = Er_i + Ec_i \tag{1}$$

$$Er_i = \sum_{j=1}^{j}\sum_{k=1}^{k} H_j \times Fr_{j,k} \tag{2}$$

$$Ec_i = \sum_{l=1}^{l}\sum_{k=1}^{k} S_l \times Fc_{l,k} \tag{3}$$

E: total energy consumption (MJ), Er: residential sector energy consumption (MJ), Ec: commercial sector energy consumption (MJ), Fr: residential sector basic unit for energy, Fc: commercial sector basic unit for energy, H: housing total floor area, S: commercial building total floor area, i: grid, j: housing type (detached house, multiple dwelling house), k: kind of energy (electricity, city gas, LPG, kerosene, heavy fuel oil A), and l: use of building (office building, wholesale or retail store, restaurant, hotel or inn, school or test laboratory, or hospital or other service)

In order to estimate the CO_2 emissions, a basic unit called the emission factor (kg-CO_2/MJ) is used for each kind of energy [7]. In this study, in view of the target cities, the electricity part of the emission factor [8] from Chubu Electric Power Company for the year 2000 is used. CO_2 emissions are expressed for each year using the following equations.

$$C_i = Cr_i + Cc_i \tag{4}$$

$$Cr_i = \sum_{j=1}^{j}\sum_{k=1}^{k} Er_{j,k} \times G_k \tag{5}$$

$$Cc_i = \sum_{l=1}^{l}\sum_{k=1}^{k} Ec_{l,k} \times G_k \tag{6}$$

C: total CO_2 emissions, Cr: residential sector CO_2 emissions, Cc: commercial sector CO_2 emissions, and G: CO_2 emission factor

2.4 Electricity output of PV power system

The electricity output of the PV system for each year is expressed by the following equation.

$$EO_i = R_i \times A_i \times Ef$$

EO: electricity output (MJ), R: solar radiation (MJ/m^2), A: panel footprint (m^2), Ef: conversion efficiency

Solar radiation is estimated using the solar radiation model in Arc-GIS. The total radiation is usually calculated as the sum of direct radiation, diffuse radiation, and reflected radiation. In this study, however, reflected radiation is not included in the calculation of total radiation. This is because reflected radiation is negligible, generally constituting only a small portion of the total radiation, except for locations surrounded by highly reflective surfaces such as snow cover. In addition, in the model of this study, radiation is estimated on land surfaces. However, if a building exists in a certain spot, the radiation is calculated on the building's roof. In addition, the inclination and gradient angle of the surface are not considered. Furthermore, the influence of shadows is also not considered.

The conversion efficiencies of the panels are set to 10% for both building roofs and unused areas. The conversion efficiency is defined as the electricity output per m^2 divided by the total radiation per m^2 on the panels.

The footprint of a panel is set to 37% of its area if it is installed on a building roof [9].

The obtained electricity output from the PV system on the building roof is used for the energy consumption such as the lighting and motive power for each grid. This consumed energy is subtracted from the obtained output. In this way, an energy saving effect is expressed, and then the reduction in CO_2 emissions can be estimated. On the other hand, in the case of an unused area, this is done by calculating the total electricity output for the entire Nagoya city area with the ratio of the lighting and motive power of the energy consumption in each grid. The energy saving effect is expressed by subtracting the output from the lighting and motive power of the energy consumption by grid.

3 SCENARIOS

3.1 Scenarios of urban spatial structures

There are two urban structure reorganization scenarios: the "Poly-Centric" case and BAU (business as usual). The Poly-Centric case is a scenario where houses and buildings are concentrated around stations. This scenario targets all of the stations that exist in the city. The sphere of the stations is set to within a 500-meter radius of a station, and the grids within the sphere are targeted.

BAU appropriately reflects the current state of the urban structure, where households continue living in the grid even if move-ins or housing losses occur. On the other hand, in the Poly-Centric case, it is assumed that the locations of households change because of the concentration. Thus, concentration households are relocated to live in sample houses having an average total floor area per household in the concentration district, that is, non-wooden multiple dwelling houses. In this setup, all of the households rebuild houses or move into the concentration district. Thus, the potential energy consumption and CO_2 emissions after a change in the urban structure and the potential for installing PV systems as an extreme case are estimated.

3.2 Integration scenarios with installation of PV power system

To analyze the reduction potential for CO_2 emissions by installing PV systems, the scenarios listed in Table 1 are used. In scenarios (1) and (2), the reduction potential by only changing the urban structure is analyzed. In (3) and (4), an analysis is made of the potential in a case of installing PV systems on building roofs in addition to changing the urban structure. In (5) and (6), the potential

Table 1: Scenarios of urban structure change and installation of PV systems.

Scenarios	Urban structure	PV system	
		Building roof	Unused area
Scenario (1)	BAU	No	No
Scenario (2)	Poly-Centric	No	No
Scenario (3)	BAU	Yes	No
Scenario (4)	Poly-Centric	Yes	No
Scenario (5)	BAU	No	Yes
Scenario (6)	Poly-Centric	No	Yes
Scenario (7)	BAU	Yes	Yes
Scenario (8)	Poly-Centric	Yes	Yes

"Yes" means installing the PV system at a certain place.
"No" means not installing it.
The PV system installation rate in unused areas is set at 50%.

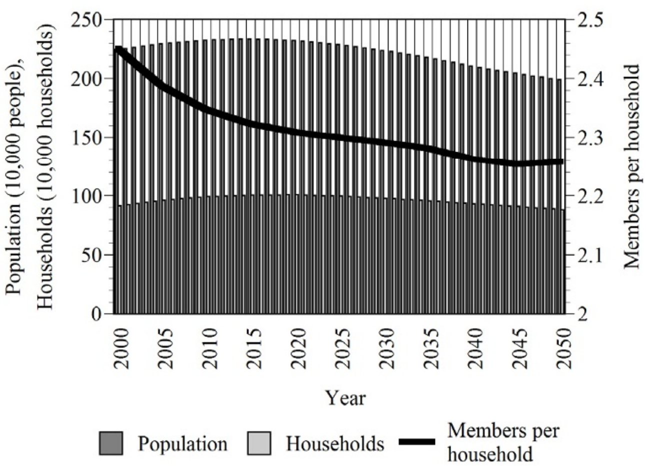

Fig. 1: Population, number of households, and persons per household.

Table 2: Scenario results for urban structure and PV system in 2050.

	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)
CO_2 emissions (1000 t)	6180.926	5823.648	5239.414	5260.672
Reduction rate	8%	13%	22%	22%
	Scenario (5)	Scenario (6)	Scenario (7)	Scenario (8)
CO_2 emissions (1000 t)	5742.219	3825.94	4800.707	3262.964
Reduction rate	15%	43%	29%	51%

in a case of installing the PV systems in unused areas in addition to the change is examined, and in (7) and (8) the effect in the case of installing the PV systems in both locations in addition to the change is investigated.

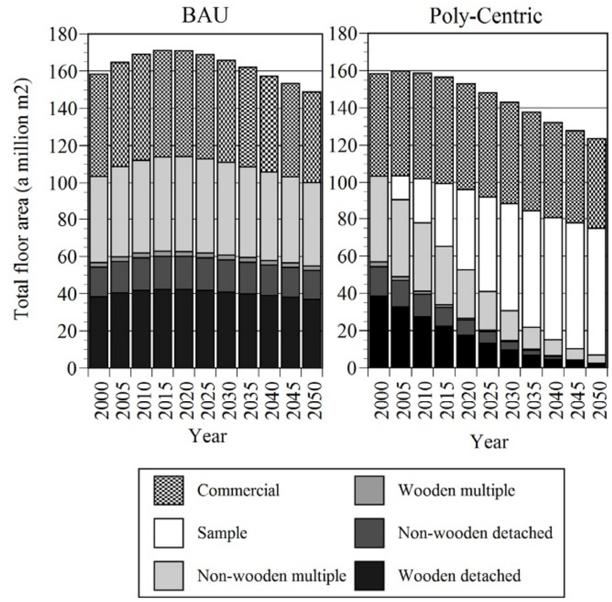

Fig. 2: Total floor area of buildings by urban structure scenario.

4 RESULTS AND DISCUSSION

4.1 Population and households

In Fig. 1, the results for the population, number of households, and persons per household in Nagoya city are shown. The total population of Nagoya city was 2.24 million as of 2000 and will reach 2.33 million in 2015. After that, it will decrease to 1.99 million in 2050. The total number of households in Nagoya city was 0.92 million as of 2000 and will reach 1.01 million households in 2015. After that, it will decrease to 0.88 million in 2050. From the results for the population and households, there were 2.45 persons per household in 2000, which will change to 2.26 people per household in 2050. This indicates a continuing trend toward the nuclear family.

4.2 Houses and commercial buildings

In Fig. 2, the results for the total floor area of the buildings by the urban structure scenarios in Nagoya city are shown. According to these results, in BAU, the number of households increases until around 2020, resulting in an increase in the total floor area. After that, the number of households decreases across Nagoya city, resulting in a decrease in the total floor area. However, the figures for the types of houses do not change compared to the Poly-Centric scenario.

The houses and buildings under the Poly-Centric scenario case are concentrated from the surrounding districts into a comparatively centric district. In this case, the total floor area per household is controlled by moving to the sample non-wooden and multiple houses. Therefore, the total floor area decreases greatly.

4.3 Unused area

In Fig. 3, the results for the ratio of unused areas by the urban structure scenarios in Nagoya city are shown. As

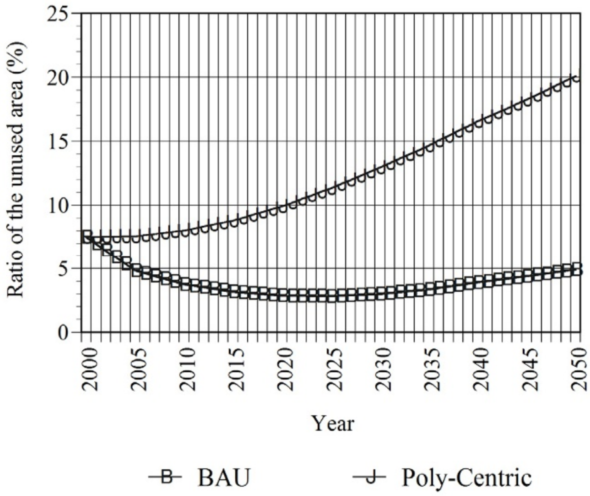

Fig. 3: Ratio of unused area by urban structure scenario.

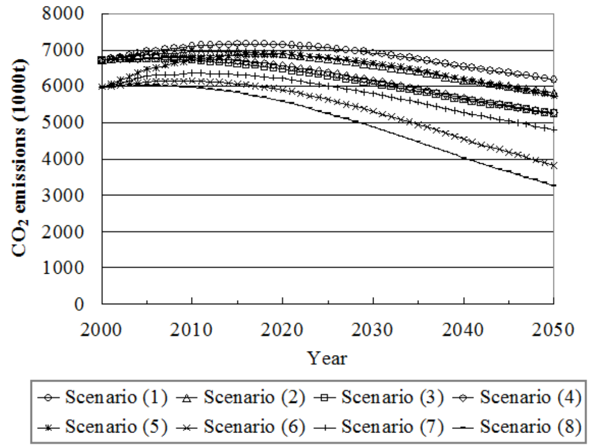

Fig. 4: Changes in CO_2 emissions by scenario.

can be seen, the unused area ratio decreases from 7% in 2000 to about 4% in 2020 for BAU. Afterward, it stays at about 5% until 2050, although it experiences a somewhat increasing tendency. This result originates from the changes in the population and households. However, in Nagoya city, the development of detached houses is advanced and a comparatively large number of young people live on the east side. Therefore, the unused area ratio in 2050 is lower than in 2000 from an increase in the householders in this region and the further development of detached houses. As a result, when the urban structure is reorganized into a similar BAU type from the current state, the unused area in 2050 is almost the same as the current state or is even lower. On the other hand, the unused area ratio increases from 7% in 2000 to 20% in 2050 for the Poly-Centric case. Therefore, the unused area is greatly affected in the Poly-Centric case.

4.4 Reduction in CO_2 emissions

In Table 2, the results of all the scenarios in 2050 and the rate of the reduction in CO_2 emissions by scenario compared to 2000 are shown. In addition, the changes in the CO_2 emissions for all of the scenarios from 2000 to 2050 are shown in Fig. 4.

First, scenario (1) and scenario (2) show the results of a scenario where no PV systems are installed but a change in the urban structure is considered. As a result, under either scenario, the CO_2 emissions increase with increases in the population and households until 2015. After that, they tend to decrease. CO_2 emissions in 2050 are approximately 8% lower for BAU in comparison with those of 2000. This decrease is a result of the declines in population and households. On the other hand, when concentrated, the CO_2 emissions decrease by approximately 13%. Therefore, the reduction potential by aggregating is approximately 5% (scenario (2) - scenario (1)). Secondary, scenario (3) and scenario (4) show the results of installing PV systems on building roofs in addition to changing the urban structure. As a result, a reduction in CO_2 emissions of approximately 22% in both the BAU and Poly-Centric cases are obtained by 2050. This is the result of a decrease in the building roof area with the potential for installing PV systems because the relocations of households often occur from detached-dwelling houses to comparatively large-scale multiple housing facilities by concentration. In addition, the reduction rate for CO_2 emissions from installing PV systems is approximately 14% (scenario (3) - scenario (1)) using BAU. When concentrated, the potential is approximately 8% (scenario (4) - scenario (2)). Third, scenario (5) and scenario (6) show the results of a scenario that includes both installing PV systems on unused areas and the change. A reduction in CO_2 emissions of

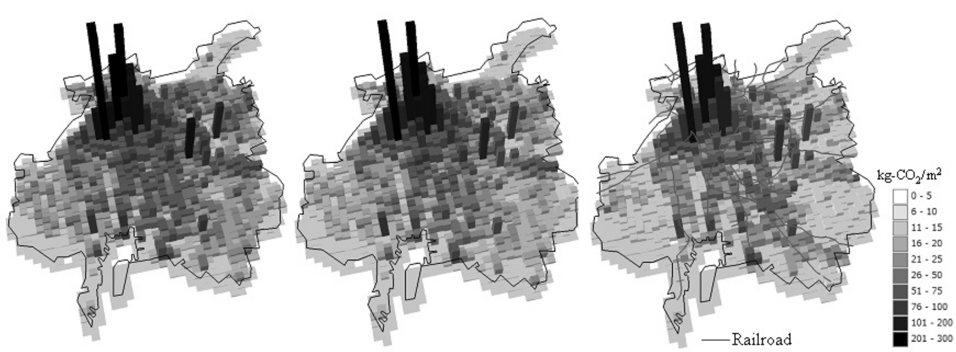

Fig. 5: Spatial distributions of CO_2 emissions in scenario (1), scenario (7), and scenario (8) in 2050.

approximately 15% is obtained when using BAU and of approximately 43% when concentrating in 2050. For this reason, the potential is high in the Poly-Centric case where unused areas are more likely to occur. Moreover, the reduction potential for CO_2 emissions is approximately 7% (scenario (5) - scenario (1)) for BAU, and when concentrating, the potential is approximately 30% (scenario (6) - scenario (2)). Finally, scenario (7) and scenario (8) show the results for the scenario that includes installing PV systems on both building roofs and in unused areas, in addition to the change. A reduction in CO_2 emissions of approximately 29% is obtained when using BAU and of approximately 51% when concentrating in 2050. In addition, the reduction potential for CO_2 emissions in the case of installing PV systems is approximately 21% (scenario (7) - scenario (1): a potential of approximately 14% in scenario (3) + a potential of approximately 7% in scenario (5)) for BAU, and when concentrating, the potential is approximately 38% (scenario (8) - scenario (2): a potential of approximately 8% in scenario (4) + a potential of approximately 30% in scenario (6)). The spatial distributions of the CO_2 emissions in scenario (1), scenario (7), and scenario (8) are shown in Fig. 5. As can be seen, the CO_2 emissions are greater in Naka district of Nagoya city, which is the most central area in Nagoya city. This mostly derives from the emissions from commercial buildings. In addition, a comparison of scenario (1) with scenario (7) shows that the emissions are reduced by installing PV systems on building roofs and in unused areas even if the spatial structure of the city does not change. On the other hand, in scenario (8), the spatial emission origin is shifted to around railroad stations by changing to a concentrated urban structure, and the amount is reduced by installing PV systems. Generally, for BAU, installing PV systems on building roofs is more effective at reducing CO_2 emissions than installing them in unused areas. On the other hand, when concentrating, the installation of PV systems in unused areas is more effective. When comparing the results for installing PV systems on building roofs with BAU and changing the urban structure, the reduction potential for CO_2 emissions is higher in the former. Therefore, to reduce CO_2 emissions, promoting the installation of PV systems is more effective than selecting a reduction method because of the comparative difficulty involved such as the reconstruction of the urban space structure.

5 SUMMARY

In this study, the reduction potential for CO_2 emissions using PV power generation was estimated in order to realize a low-carbon society in Nagoya city. Specifically, several scenarios were used, taking into account changes in the urban structure, changes in the three-dimensional structures of buildings and their locations, the occurrence of unused areas by location, and the installation of PV systems on building roofs and in unused areas. The reduction potential for CO_2 emissions was estimated under these scenarios. This study examined the future urban structure, the effective use of unused areas, and the installation potential for PV systems to realize a low-carbon society.

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Development of Land Use Area Intensity Database Using Asia International Input-output Table for Life Cycle Assessment

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Abstract

As corporate activities are needed for biodiversity conservation, a number of companies have started to understand the relationship between their supply chain and biodiversity. Life cycle assessment (LCA) has been required to apply to assess impacts on biodiversity and ecosystem throughout life cycle of a product. However, most of LCA case studies focus on global warming such as carbon footprinting, a number of studies assessed an impact on biodiversity is still limited. Land use is considered as key inventory item to promote biodiversity assessment in LCA. This study therefore aimed at the development of land use inventory database using input-output analysis. This study estimated occupied land area caused by a certain amount of production activities, and to verify the adequacy of this study, an estimation of total land use area induced by final consumption was carried out.

Keywords:

Life cycle assessment (LCA), Biodiversity, Land use

1 INTRODUCTION

As corporate activities are needed for biodiversity conservation, a number of companies have started to understand the relationship between their supply chain and biodiversity. Life Cycle Assessment (LCA) has become to assess environmental interventions throughout a life cycle of products or supply chain. However, most of LCA case studies focus on global warming such as carbon footprinting, a number of studies assessed an impact on biodiversity is still limited. Land use is considered as key inventory item to promote biodiversity assessment in LCA.

There are a number of studies which estimate the area of land use. Most of these studies followed the concept of Ecological Footprint. However the definition of land area is different between Ecological Footprint and LCA. Although several LCA case studies considering land use were carried out in Europe and U.S.A., few studies focused on land used in Japan. The development of inventory database which reflect Japanese conditions are required.

This study aimed at the development of land use inventory database using input-output analysis. This study estimated occupied land area caused by a certain amount of production activities. This presentation especially focused on calculating 'practical' land area used by producing imported commodities considering international trades. To verify the adequacy of this study, an estimation of land use area induced by final consumption was carried out.

2 METHOD

2.1 Definition of 'Land Use'

This study defined 'Land use' as the follows [1].

Land use is an environmental intervention identified as an entry in an LCI (life cycle inventory). It has the dimension of area ×duration of use if the occupation of a certain area for a certain purpose is to be expressed. If the entry in the inventory refers to change or transformation of the properties of the land area in view of an intended use (or non-use), we propose the dimension area. We reserve the term land use for these 2types of intervention:

1) Land occupation

2) Land transformation

This paper focuses on the inventory of 'land occupation', and defined the term 'land use intensity' as occupied land area per a certain amount of production. Thus the intensity is described by hectare year per a million yen of production. This means a certain number of hectares of area are occupied per a year and per a million yen of production.

2.2 Outline of the Intensity

Existing indicators for land use such as Ecological Footprint and LCIA methods use several classifications for types of land. This study made the following classification; 'rice paddy', 'cropland', 'grazing land', 'forest' and 'Built-up land'.

This study estimated land area in the following countries; Indonesia, Malaysia, Philippines, Thailand, Singapore,

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China, Korea, Japan and the United States. The intensity represents the area induced by a certain amount of demand in these countries.

The items of the intensity database contain 76 items each countries. The classification of these items based on Asian International Input-output Table [2].

2.3 Method of Calculation

This study employed input-output analysis. The land use area L was calculated as the follow.

$$L=l(I-A)^{-1}$$

where l represents direct land use area and $(I-A)^{-1}$ is Leontief inverse matrix. The inverse matrix represents economic production induced by a certain amounts of demand. Thus the land use area including indirect land use area induced by a certain amount of demand can be calculated.

Land use area was estimated as the follows. As a first step, FAOSTAT was employed, and we listed land use area inventory in each countries.

2.4 Difference with Ecological Footprint

Difference between this study and ecological footprint is recognized as the follows. In ecological footprint, environmental intervention is described as land use area, and in some cases the area is multiplied some coefficients in order to float property such as primary production potential all over the world. This study also describe land use area for a certain production, on the other hand, any coefficients is not multiplied the area. In stead this study involved term of land occupation to the indicator.
Therefore the land area indicator in this study is described as an area per year and a certain amount of production.

3 RESULTS

Figure 1 shows the result of estimation the intensity. Agriculture and forestry indicates high values comparatively. Paper production and food production indicates also high values. The reason of these results is that there are relationships between these sectors.

4 CASE STUDY

As a case study of this intensity, an estimation of total land use area induced by final consumption was carried out. Figure 2 shows the result. The result shows a trend of land use. Although almost of the countries use mainly their domestic land, Singapore, Korea and Japan use comparatively large land area in other countries. The reason of this result shows dependence on imports from other countries. It can understand 'imported land' virtually.

5 SUMMARY

This paper summarized development of land use area intensity database. This study implemented an attempt

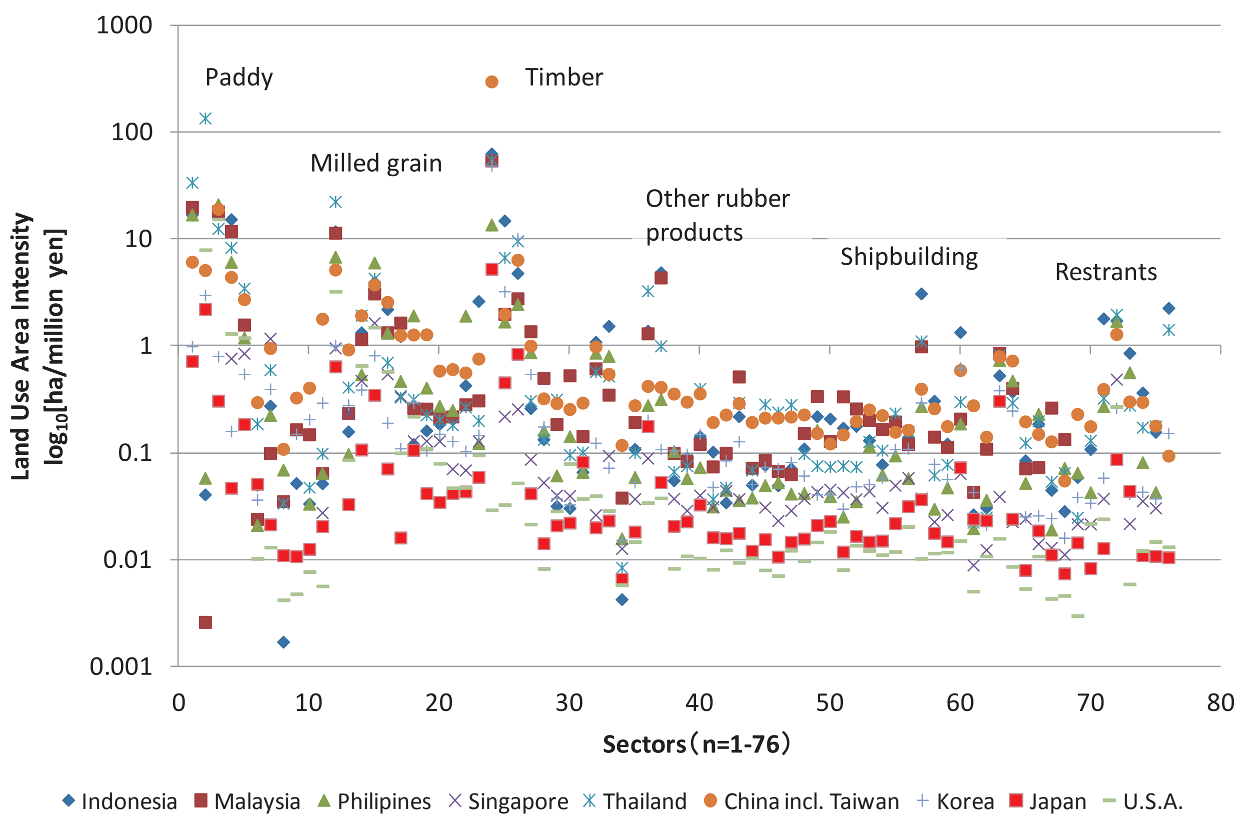

Fig. 1 Results of estimation the intensity

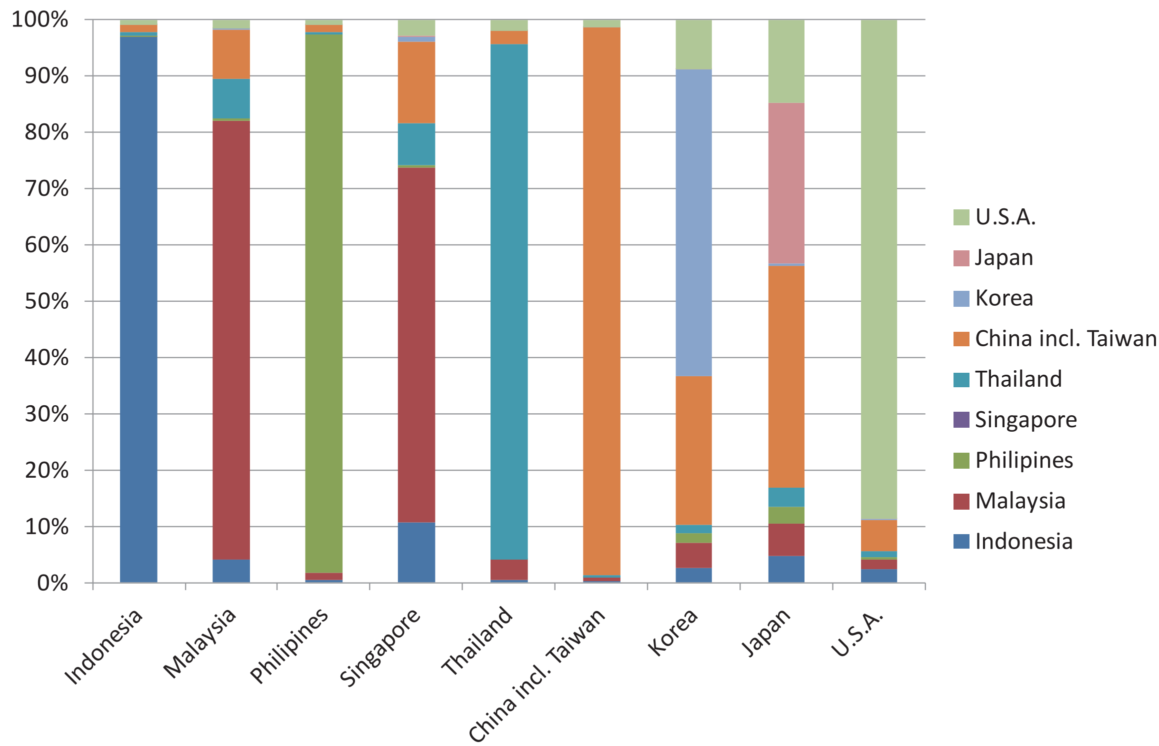

Fig. 2 Results of estimation land use area induced by final consumption

land use area induced by a certain amount of economic demand of 9 countries using input-output analysis. This study employed Asian International Input-output Table and estimated land use area induced by final consumption each countries. The result of case study shows that Japan and some countries imported land virtually.

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Analysis of China's Current Waste Paper Collection Rate

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Abstract
Waste paper collection rate is one of indexes to calculate how many percentage of waste paper collected in the total amount of paper and paper board consumption and measures the effectiveness of one country's waste paper collection process. Nowadays, waste paper collecting has become a serious issue in China for its low collection rate. This article tries to use of linear regression and grey correlation to analyze both endogenous factors and possible exogenous factors affect on collection rate. The results shows that the amount of waste paper collection influences largely on collection rate comparing with other factors, and level of aging and gross domestic product per capita are positive related with waste paper collection rate.

Keywords:
China, waste paper, collection rate, grey correlation

1 INTRODUCTION

Waste paper refers to the paper and paper board are used or produced in the paper-making process, which can be used to produce paper and paper board or the raw material of other industries, according to ISO 4046-2:2002 [1]. Waste paper collection rate is a kind of index to calculate the waste paper collection situation within a country. It directly shows how many percentage of waste paper collected in the total amount of paper and paper board consumption. Since it has became the major papermaking raw material, it is used to measure the effectiveness of one country's waste paper collection process.Confederation of European Paper define the collection rate is "percentage of apparent collection compared to the total paper consumption". While paper&paperboard consumption (country data) = domestic deliveries + imports from other CEPI countries + imports from countries outside CEPI [2]. This calculation is also defined by Paper Recycling Promotion Center of Japan [3] and China Technical Association of Paper Industry [4] [5] [6] . Collection rate is also defined as recovery rate by Food and Agricultural Organization (United Nations) Advisory Committee on pulp and paper with the same calculation formula.

With the increase of the demand of papermaking raw material in China and the development toward circular economy, Chinese waste paper collection increase from 1988's 2.7million ton to 42million in 2010, accompanying with the collection rate from 20.11% to 45.74%. Meanwhile it experienced 3 dramatic changes during this period: From 1988 to 1989, Chinese waste paper collection rate had a rapid growth which is from 20.11% to a peak of 26.33. In the next two year, the rate kept in 25.63, 26.04 respectively. After 1991, it starts to decline at 23.71%. The second peak is shown in 1995 at 27.17%, and then it falls back to 25.76% in 1996. The third fluctuation occur in 1998, the curve hasty move back to another peak that is 36.15% in 1998. The fourth stage which is also called recovery phase with continuous and steady growth after 2001 and finally reaches to 45.74% in 2010.

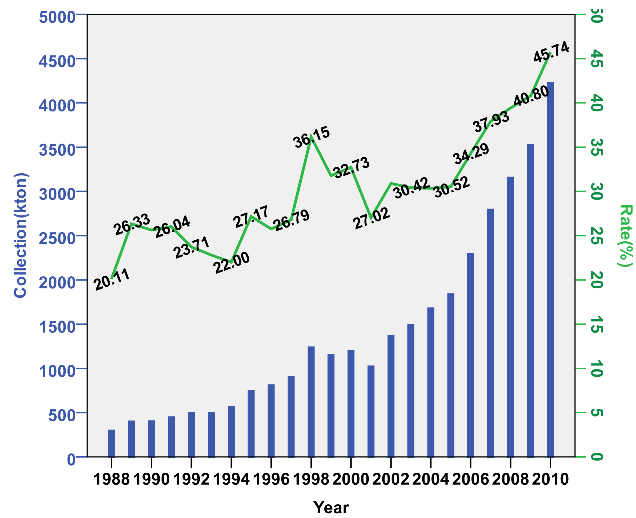

Fig. 1 Chinese waste paper collection amount and collection rate from 1988-2010

(Data from: China Paper Association, China Technical Association of Paper Industry. [4] [5] [6] [7] [8] [9] [10] [11])

However, when comparing with the world situation, Chinese waste paper collection rate is very low. Fig.2 shows the waste paper collection rate in countries with large paper&paperboard consumption amount in the world in 2009. Among these, South Korean is the top one (93%), followed by Germany (85%), Japan (80%), United Kingdom (79%). Although China consumes the largest amount of paper&paperboard in the world, its collection rate is only 40% (the second lowest of all). In China, 51318 kton of waste paper is not collected in 2009 by calculation.

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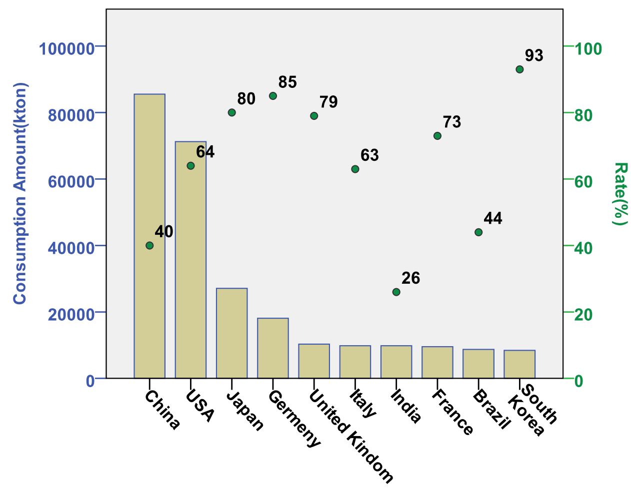

(Data from: CEPI, RISI; China Paper Association; Statistics of Korean Paper Production Association; Paper Recycle Promoting Center of Japan [12])

Fig. 2 Waste paper collection amount and collection rate in countries with large paper&paperboard consumption in the year of 2009

2 ENDOGENOUS VARIABLES ANALYSIS

After abbreviating the formula in Table 1, it is as follows:

$$R = \frac{WC}{PC} = \frac{WP + WE - WI}{PS - PE + PI}$$

[3] (R-- Collection Rate; WC-- Waste Paper collection amount; PC-- Total paper & paperboard consumption; WP-- Total Fresh Supply of Waste paper; WI-- Import of waste paper; WE-- Export of waste paper; PS-- Total sales of Paper& paperboard; PI-- Import of Paper& paperboard; PE-- Export of Paper& paperboard)

In order to observe each of variables impacting on collection rate, we choose data such as collection amount of waste paper, amount of waste paper import which are listing the formula above from year of 2005 to 2010 in China [7] [8] [9] [10] [11] to calculate the elasticity of collection regarding the annual change of variables each. Given that the others variables are constant, annual fluctuation rates are shown as follows,

Table1 Average fluctuation of collection rate regarding change of each variable from 2005 to 2010

ΔR_{WC}	ΔR_{PC}	ΔR_{WP}	ΔR_{WI}	ΔR_{WE}	ΔR_{PS}	ΔR_{PI}	ΔR_{PE}
6.05%	-3.01%	8.92%	-2.31%	0	-3.35%	0.20%	0.25%

From the table 1, it shows the total amount of fresh supply of waste paper influence the most on collection rate. Enhancing domestic collection amount will increase the collection rate 6.05% in annual average. Current increasing large amount of waste paper import contribute 2.31% decrease of collection rate in the 6 years' average. By contrast, increase of annual consumption amount of paper&paperboard leads a decline (3.01%) in collection rate of waste paper, and for total sales of paper&paperboard, is a decline of 3.35% . Import and export of paper&paperboard, and export of waste paper have smaller effect on collection rate, which are 0.20%,0.25%,0(because amount of waste paper import is little) respectively.

3 EXOGENOUS VARIABLES ANALYSIS

Exogenous fators which outside of previous model may influent collection rate of waste papers, including territory, economy, demography, education, sustainability. Shown as Table 2.

Table2 List of variables

Dependent Variable	Collection Rate (%)
Independent Variable	Area (km^2)
	Population (people)
	Population Intensity (people per km^2)
	Gross Domestic Product per Capita ($)
	Level of Aging (%)
	Average Education Years (year)
	School Life Expectant (year)
	Literacy (%)
	Urbanization Population (%)
	Urbanization Rate (%)
	Forest per Capita (km^2 per thousand people)
	Energy Depletion (%of Gross National Income)
	Carbon efficiency (CO2 emissions/$ GDP)

We collected these data from 56 countries in the world [12], using SPSS Software and the stepwise method to launch linear regression, the results shows as follows,

Table 3 Coefficients of Entering Variables

Coefficients[a]					
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std.Error	Beta		
Constant	24.953	4.499		5.546	0
Level of aging(%)	1.44	0.54	0.446	2.669	0.012
GDP per Capita($)	0.001	0	0.427	2.558	0.016
a.Dependent Variable Rate(%)					

In the collinearity statistics, Tolerance >0.1, VIF<10 stand for there is no obvious multicollinearity. The goodness of fit is proper for R square is equal to 0.68.

Finally, only Level of Aging and GDP per Capita have entered into the model. Other variables is excluded in the model implies no linear significance. The function is shown as R=1.44LA+0.001*GDP+24.953.

Increase one percentage of level of aging will lead to an increase of collection rate of waste paper by 1.44 percentage. Increase of one dollar of GDP per capita raise 0.001 growth of waste paper collection rate.

In order to test the variables of level of aging and GDP per capita influencing on collection rate of waste paper, by further analysis, we select the panel data of China's waste paper import price(AIP), GDP per capita(GDP), level of aging(LA) and education expenditure(EI) from 2005 to 2010 as the independent variables and the dependent variable is collection rate, to make grey correlation analysis.

Table 3 List of panel data of predictors

Year	R	AIP	GDP	LA	EI
2005	30.51	144.24	14185	7.7	429
2006	34.29	140.07	16500	7.9	516.91
2007	37.93	179.19	20169	8.1	712.23
2008	39.42	229.6	23708	8.3	901.02
2009	40.8	137.99	25575	8.5	1043.75
2010	45.75	219.8	29748	8.9	1255

Using Grey theory to calculate the correlation degree of the predictors,

a. Calculate absolute correlation degree

let $X^0_i = (x_i(1) - x_i(1), x_i(2) - x_i(1), x_i(3)-x_i(1), x_i(4) - x_i(1), x_i(5)-x_i(1), x_i(6)-x_i(1) = (x^0_i(1), x^0_i(2), x^0_i(3), x^0_i(4), x^0_i(5), x^0_i(6))$; i = 0,1, 2, 3, 4;

Thus, $x^0_0 = (x^0_0(1), x^0_0(2), x^0_0(3), x^0_0(4), x^0_i(5), x^0_i(6)) = (0, 3.78, 7.42, 8.91, 10.29, 15.24)$;

$x^0_1 = (x^0_1(1), x^0_1(2), x^0_1(3), x^0_1(4), x^0_1(5), x^0_1(6)) = (0, -4.17, -34.95, 85.36, -6.25, 75.56)$;

$x^0_2 = (x^0_2(1), x^0_2(2), x^0_2(3), x^0_2(4), x^0_2(5), x^0_2(6)) = (0, 2315, 5984, 9523, 11390, 15563)$;

$x^0_3 = (x^0_3(1), x^0_3(2), x^0_3(3), x^0_3(4), x^0_3(5), x^0_3(6)) = (0, 0.2, 0.4, 0.6, 0.8, 1.2)$;

$x^0_4 = (x^0_4(1), x^0_4(2), x^0_4(3), x^0_4(4), x^0_4(5), x^0_4(6)) = (0, 87.91, 283.23, 472.02, 614.75, 826)$

$$\because \ |s_i| = \left|\sum_{k=2}^{5} x_i^0(k) + \frac{1}{2}x_i^0(6)\right|, \text{ i= 1, 2, 3, 4}$$

$$\therefore, \ |s_0| = \left|3.78 + 7.42 + 8.19 + 10.29 + \frac{1}{2}\times 15.24\right| = 38.02;$$

$|s_1| = 147.67$; $|s_2| = 36993.5$; $|s_3| = 35.42$; $|s_4| = 1832.89$;

$$\because \ \varepsilon_{0i} = \frac{1+|s_0|+|s_i|}{1+|s_0|+|s_i|+|s_i-s_0|}, \text{ i = 1, 2, 3, 4, 5, 6, 7, 8}$$

$\therefore$ $\varepsilon_{01} = 0.63$; $\varepsilon_{02} = 0.50$; $\varepsilon_{03} = 0.54$; $\varepsilon_{04} = 0.51$; $\varepsilon_{05} = 0.51$;

b. calculate relative correlation degree,

given $X_i' = x_i'(1) + x_i'(2) + x_i'(3) + x_i'(4) + x_i'(5) + x_i'(6)$

$$= \left(\frac{x_i(1)}{x_i(1)}, \frac{x_i(2)}{x_i(1)}, \frac{x_i(3)}{x_i(1)}, \frac{x_i(4)}{x_i(1)}\right) \text{ i = 1, 2, 3, 4,}$$

thus, $X_0' = (1, 1.1239, 1.2432, 1.2920, 1.3373, 1.4995)$;

$X_1' = (1, 0.9711, 1.2423, 1.5918, 0.9567, 1.5238)$;

$X_2' = (1, 1.1632, 1.4219, 1.6713, 1.8030, 2.0971)$;

$X_3' = (1, 1.0260, 1.0519, 1.0780, 1.1039, 1.1558)$;

$X_4' = (1, 1.2049, 1.6602, 2.1003, 2.4330, 2.9254)$

$\because X'^0_i = (x'_i(1) - x'_i(1), x'_i(2) - x_i'(1), x_i'(3)-x_i'(1), x_i'(4) - x_i'(1), x_i'(5)-x_i'(1), x_i'(6)-x_i'(1) = (x'^0_i(1), x'^0_i(2), x'^0_i(3), x'^0_i(4), x'^0_i(5), x'^0_i(6))$; i = 0,1, 2, 3, 4;

$$|s'_i| = \left|\sum_{k=2}^{5} x'^0_i(k) + \frac{1}{2}x'^0_i(6)\right|, \text{ i= 1, 2, 3, 4}$$

$$r_{0i} = \frac{1+|s'_0|+|s'_i|}{1+|s'_0|+|s'_i|+|s'_i-s'_0|}$$

Thus, $r_{01} = 0.9559$; $r_{02} = 0.7614$; $r_{03} = 0.8059$; $r_{04} = 0.6315$;

c. Calculate Comprehensive Correlation Degree:

Given $\theta = 0.5$, $\rho_{0i} = \theta\varepsilon_{0i} + (1-\theta)r_{0i}$, i = 1, 2, 3, 4;

So $\rho_{01} = 0.7929$; $\rho_{02} = 0.6310$; $\rho_{03} = 0.6731$; $\rho_{04} = 0.5709$

In the same way, by regarding WC,PC as X^0_i, we calculate the comprehensive correlation degree of each which is shown as the table below.

Table 4 List of grey correlation degree with different independent variables

Variables	AIP	GDP	LA	EI
R	0.7929	0.6310	0.6731	0.5709
WC	0.6047	0.8637	0.5349	0.6615
PC	0.7097	0.7517	0.6408	0.5766

For R, $\rho_{AIP} > \rho_{LA} > \rho_{GDP} > \rho_{EI}$, it implys average import price of waste paper affects the most on collection rate, follows by level of aging, GDP per capita and education expenditure. While GDP per capita have much correlation with collection amount of waste paper and also with amount of paper&paperboard consumption. Average import price of waste paper is the second largest predictor influence on amount of paper&paperboard consumption. Education expenditure has larger correlation with collection amount of waste paper than with collection rate and paper&paperboard consumption. Level of aging has much more obvious correlation on collection rate and consumption amount of paper&paperboard.

4 SUMMARY & CONCLUSION

The waste paper collection rate in China has been increasing since 1987, but it still very low comparing with the developed countries which also has a large waste paper consumption. Large quantity of domestic waste paper is not effectively collected and not recycled. To increase collection rate of waste paper, China should reduce its dependence on waste paper import meanwhile improve domestic collection. Also, lessen consumption of paper&paperboard will create collection rate increase.

Though it is found that GDP and level of aging are positive linear related with collection rate in the part of linear regression of 56 countries' data, the analysis didn't take time flactuaion into consideration.

Further, by using grey comprehensive correlation degree to process the panel data of China from Year 2005 to 2010, we found among the predictors, the average import price of waste paper found most obvious correlation with the collection rate. It may implies that on one hand as import price of waste paper have been experiencing a rapid process of appreciation in the recent year, the high cost of import drives paper&paperboard manufacturers shift on to find possibility to utilize domestic waste papers as raw material and subsequently stimulate the domestic collection of waste papers. On the other hand, the gradually increasing demand of paper&paperboard pushes the import price of waste paper to a high level.

Also, as it is coherent with the first part, level of aging and GDP per capita both have high correlation with collection rate. However, the difference is GDP per capita affect much more on waste paper collection than on collection rate, may explain that when Chinese people are richer it turned out that more waste paper will be are collected. In addition, the higher the level of aging grows, the more collection rate of waste paper increases. And it is more likely that level of aging leads to a decrease of paper and paperboard consumption than facilitates more waste paper collection. But as the reasons might be complicated and the process will be difficult, we need to have further analysis on these in the future. Moreover, limitations of data and expanding the selecting range of variables need to be solved in the next research.

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Development of Low Carbon Districts Simulator

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Abstract
We developed an HVAC energy consumption simulation system for analyzing annual hourly transitions in the solar radiation environment. Since the solar environment is influenced by the configuration of buildings in a city block, the reflections between buildings, and the influence of roadside shade trees, it is important to understand the environment of the city block when planning building projects. We developed an annual solar radiation simulation method that uses a radiation balance analysis output database and standard climate data. The method reduces to 1/30th or less the number of analyses necessary to predict the annual hourly solar environment distribution as compared to the number required by the general method.

Keywords:
Simulation, Energy savings, Radiosity method, Solar radiation analysis, Annual thermal load

1 INTRODUCTION

Recently, there has been a growing interest in need for constructing smart cities as a next generation low-carbon energy/social system. In order to achieve them, tasks such as a drastic reduction in building-wise CO_2 emissions and a promotion of actively utilizing renewable energy resources in buildings and street blocks should be properly handled, in addition to design of a smart grid network and heat interchange. It is necessary to not only establish a comprehensive environmental plan including buildings, street blocks and an entire city, but also develop associated operational and control technologies. Of particular importance is the proper monitoring for energy consumed by air-conditioning, since it occupies a large fraction of the entire energy consumption of a building in operation. It also exhibits significant fluctuations in time in response to changing outdoor weather conditions. Such knowledge should be at hand even in architectural planning stages.

The present authors have developed a system called "low-carbon street block simulator" enabling assessment of environmental comfort, energy conservations, and CO_2 emissions throughout the year in buildings and street blocks in which sunshine, wind, vegetation and other sustainable energy resources are actively used. Simulation would be useful in promoting architectural and urban planning to realize a comfortable and low-carbon society.

The present simulation system has been materialized by coupling a computer program for outdoor environment of street blocks to energy balance software. By analyzing temporal variation in solar radiation and reflection, it is possible to estimate the effects of changes in sensible temperatures due to shifting tree shades and solar reflections to the building walls on air-conditioning load of the building and power generation by solar cells. Additionally, through fluid flow analysis of indoor and outdoor wind, we can obtain the number of hours per year, during which fresh outdoor air may be taken directly from open windows without air-conditioning.

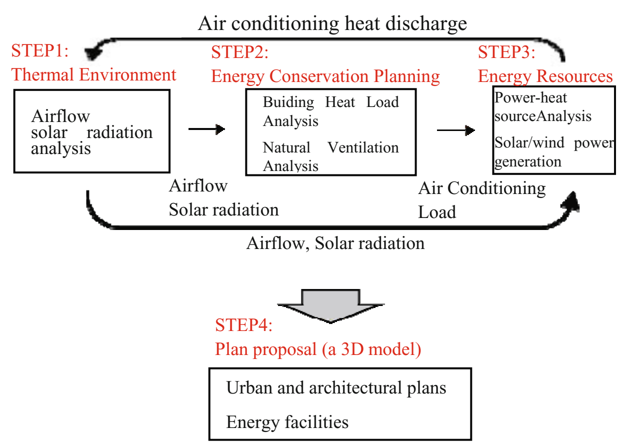

Fig. 1: System Overview

2 SYSTEM OVERVIEW

2.1 General set-up

In an attempt to propose a low-carbon street blocks with low CO_2 emissions to which measures for the surrounding environment and energy resources are incorporated in

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addition to energy conservations of buildings, an analysis system capable of handling complex interactions between patterns of wind and solar radiation in a street block and air-conditioning load of the buildings has been constructed. Furthermore, the system can present a comprehensive outlook of future images, which may be useful for searching an optimum solution and consensus formation.

As the main functions, it enables environmental analysis of fluid flow, thermal and solar radiation around the building, calculations of yearly building air-conditioning load and energy balance, and their coupling effects. Smart grid analysis and visualization of results are also possible. An overview of the system is schematically shown in Fig.1.

Coupling analysis

For yearly building air-conditioning load analysis (thereafter, abbreviated as YBAcL analysis), it has been customary to use standard weather data, such as Expanded AMeDAS available from the Architectural Institute of Japan based on the observation data of the Japan Meteorological Agency, for solar radiation, wind, and the like. However, in urban street blocks, localized weather may be formed arising from the effects of, for example, wind avenues, solar reflections on the building walls, and shades of street trees. In the present research work, care is exercised to properly account for such features in urban (street block) planning; namely, environmental analysis of fluid flow-solar radiation in street blocks is coupled to YBAcL analysis. This makes it possible to reflect variations in outdoor environment caused by such factors as arrangements and shapes of buildings on YBAcL analysis. Furthermore, by coupling YBAcL to energy analysis, we can obtain CO_2 emissions from buildings using results of analysis based on urban and building-wise energy conservation planning. Similar to air-conditioning load, solar and wind power generation can be much influenced by local weather conditions mentioned earlier. When environmental analysis for fluid flow and solar radiation around buildings are coupled to energy analysis, year round results may satisfactorily incorporate the effects of surrounding buildings and street blocks.

Visualization

Previously, results of assessment for wind, solar radiation, energy and so forth have often been provided separately as two-dimensional information. They have been of little help in the clarification of formation mechanisms for environment in which interactions of individual factors could have taken place. Furthermore, urban planning and consensus formation have little been benefited from such discrete knowledge. In the present numerical simulator, in contrast, all the related information is grouped as three-dimensional digitalized information, thereby serving as a basis for proposals of final architectural and urban planning by providing justifications and explanations for them. Comprehensive future images may be displayed, along with dynamic representations of wind, solar, and energy flows. Some of them may be modified in real time through a dialogue interface and recomputed results may even be viewed instantly.

2.2 Fluid flow analysis

Similar to wind assessment systems for buildings currently in much practical use, a set of 16 wind directions are assigned: for each direction, *k*-ε turbulence model computation is performed by non-dimensionalizing the wind distribution in street blocks with upper wind which is taken to be the reference speed. By combining obtained results with yearly data for the wind speed and directions extracted from the standard weather database, the year round wind speed distribution may be calculated. Computational conditions of a ventilation network for natural ventilation analysis of the building are set by picking up the outer-wall wind pressure coefficients at the locations of natural ventilation openings from the distribution of directional wind pressure coefficients on building walls (provided as outcome of fluid flow analysis).

2.3 Air flow-Solar radiation analysis

The present solar radiation analysis extends the standard methods used to calculate a single hour in such a manner that yearly results may be obtained. Taking advantage of its ability to accounting for the effects of mutual reflections even among complex-shaped buildings in short-wave radiation, we have adopted a radiosity-based methodology[1]. In outdoor building environment research, the present technique was first used by Urano et al. (1993)[2], followed by Nishioka et al. (1999) [3], Urano et al. (2001)[4], Oguro and Moriwaka (1995)[5], among others. For the present simulation system, we have developed a method for year round solar radiation analysis by extending the single hour radiosity method for outdoor thermal environment of Oguro and Morikawa (1995)[5].

In the conventional hour-wise solar radiation analysis, initial outward radiation flux are taken to be temporal data gained by direct and global solar radiation; however, in the present work, non-dimensionalized values with respect to hourly global radiation are employed. Note that such non-dimensional radiation flux are independent of individual time and depend only on the position of the sun. A virtual hemisphere having a sufficiently large radius so that spatial scales of buildings may be safely neglected is considered as the sky globe, which is equally divided into 151 segments. At every sun position during the entire time period under investigation, calculation of non-dimensional radiation flux is made. Hourly flux are known from the output by multiplying E_a given by the corresponding standard weather data.

Using the above-mentioned method, a database of radiation flux computations becomes available up to 151 cases. Combination with the standard weather data serves as a basis for investigating year round short-wave radiation balance. Prediction of the hourly solar radiation distribution usually requires some 12 calculations per day, exceeding 4000 a year (365 days). In the present analysis, the number has been drastically cut to less than 1/30.

2.4 Thermal load analysis

A ventilation circuit network analysis module TRNFlow[7] has been incorporated into a heat circuit-based software package TRNSYS. Our system is further coupled to appropriate data input functions.

In light of the progress in BIM (Building Information Modeling) technologies, three-dimensional design data have come to be available. The present authors are in the process of completing an analysis environment in which the entire numerical models will be ready from the existing 3D data. In the present analysis, a 3D data set was reproduced up to the interior zoning of air-conditioning ventilation of the building. The fluid flow computation is based on the outer wall lines of the database, as well as setup data files for heat-ventilation circuit network analysis. Specifically, zonal (nodal) information in the 3D database serves to form the inter-zone network. Both the location and the dimension of windows and openings, together with heat resistance data, are drawn from information on outer and inner walls, windows and natural ventilation ports. Furthermore, by unifying building data, we can pass results of fluid flow and solar radiation to the corresponding windows and openings in a heat-ventilation circuit network, since it is possible to manage the position and the size of each component under the identical coordinate system in different analyses. Such a building database may also be employed in solar radiation analysis.

2.5 Energy balance analysis

The present simulator allows assessment for optimization of an energy system or an initial phase of system development through the following four analyses: power and thermal load, energy consumption, environmental impact, and economic evaluation.

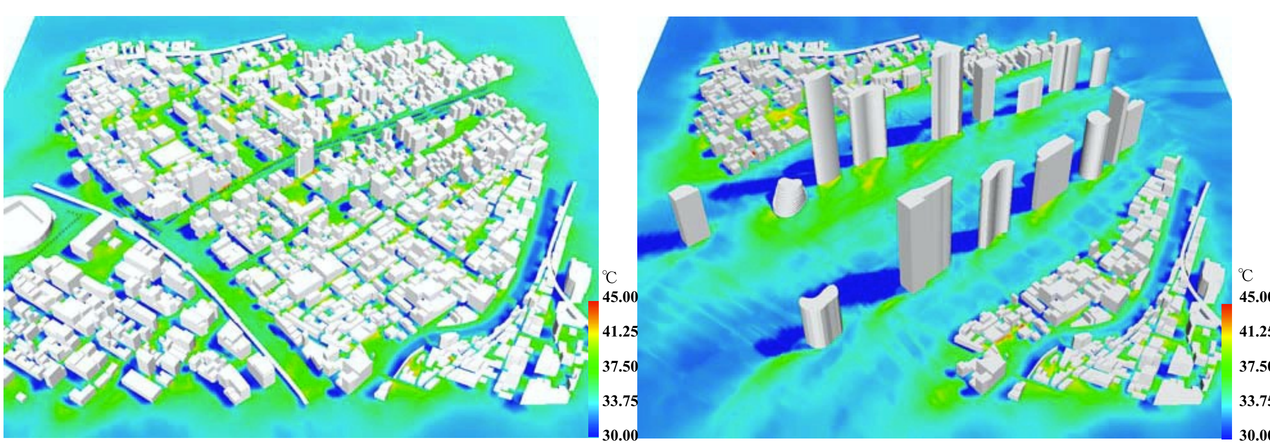
1) Power and thermal load calculations – For the buildings and the street blocks using an energy system, load for electricity (not including air-conditioning) and heat (cooling, heating and hot water supply) is itemized in terms of the total floor area or the site location. Results are available on an hourly basis for a year and measurement data may also be used.
2) Evaluation of energy consumed – A desirable energy system may be set up, for which the amount of commercial electricity and individual fuels (consumption on a caloric basis) are computed for a year.
3) Environmental assessment – For given fuel types and power companies, the primary energy consumption and CO_2 emissions are evaluated on a yearly basis.
4) Economic assessment – Assuming initial and maintenance costs, we can estimate cash flow, life cycle cost and the payback period for investments in years.

3 EXEMPLARY RESULTS OF ANALYSIS

Coping with characteristics and various needs of every project for buildings and urban blocks, the present system shown in Fig. 1 may be applied as a whole or component-wise. In what follows, results of individual analysis functions as well as coupled solar radiation-thermal load-energy analysis will be presented.

3.1 Fluid flow-solar radiation analysis

In Yokohama City, comparison was made of the current thermal environment in summer with that of a future eco city in year 2050. In the simulation, South-West wind was considered as the prevailing wind direction of the city in summer. In contrast to the present city (case 1), a future urban model (case 2) aimed better ventilation among street blocks by grouping centrally-located high-rise buildings along the main wind direction. Vacant spaces arising from the urban planning were covered with plants or paved with water-retaining material, so that they would function as green avenues for wind.



(a) case 1 the current city (b) case 2 a future city

Fig. 2: Distribution of sensible temperatures (SET*)

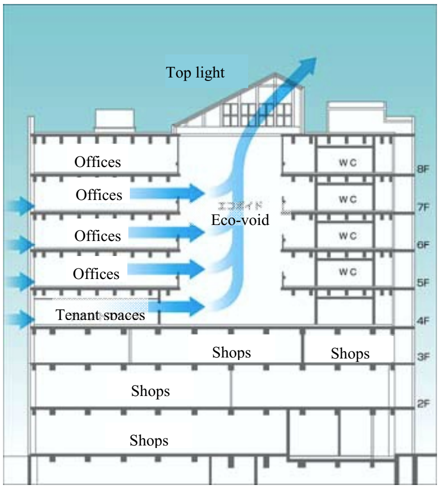


Fig. 3: Section view of the building analyzed

The distribution of SET* representing sensible temperatures of the human body is depicted in Fig. 2 at 1.1m above the ground. While SET* in main streets and the central area of parks in the current city is at around 35°C and colored in green, it exceeds 40°C locally on streets and in the vicinity of buildings where they are standing packed. In a future city, in contrast, lower SET* prevails, associated with cooler surface temperatures and improved radiation properties owing to vegetation and water-retaining pavements. Better ventilation is also thought to arise. In the current city, ascending air was present (not shown) attributable to heated upward flow caused by hot surface temperatures. Such vertical motions were not detected in the future model due to low surface temperatures. There, results indicates cool breeze passing through the entire urban area. Even though humidity appears to rise significantly by plantation, SET* (used as an index of the comprehensive thermal sensation) drops as a result of improved radiation and ventilation characteristics. They work to more than offset a degeneration in the thermal sensation arising from high humidity.

3.2 Thermal load analysis

The effects of natural ventilation planning were predicted in an eco-friendly building for business offices in cool-climate Sapporo City, Hokkaido. Reduction in yearly cooling load by air-conditioning was studied. Figure 3 shows a section view of the eight-story building with the total floor area of 6, 970 m^2. Business areas occupying from the fourth to seventh floors are connected to an atrium called an "eco void" which acts as a ventilation passage from the floors to the top light. Natural ventilation was assumed to be actively adopted by the occupants by opening windows in mild weather. Hourly temperature, ventilation rate, and air-conditioning load were computed on a zone-by-zone basis. As to the directional specification of wind pressure coefficients, data for the

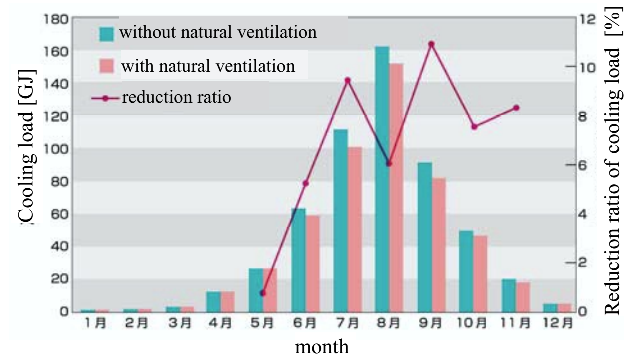


Fig. 4: Monthly cooling load with reduction ratio

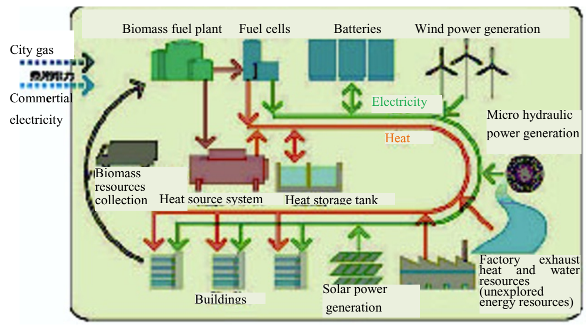


Fig. 5: Image of a next generation energy park

fourth through sixth floors and the seventh floor up to the top light were grouped together vertically.

Figure 4 demonstrates the monthly reduction ratio of cooling load, obtained from the load difference between with and without natural ventilation separately calculated. It peaks at 10.8% in September and leads to 7.4% annually.

In terms of CO_2 reductions, this amounts to 1,720 kg-CO_2 on a yearly basis. Here it is assumed that COP of heat sources for cooling is equal to 3 and the discharge coefficient of CO_2 is 0.000479t-CO_2/kWh provided by Hokkaido Electric Power Co., Ltd. (Discharge coefficients for the electric power industry assigned by the Ministry of the Environment in FY 2006)

From the standpoint of energy conservations to cut cooling load, it is preferable to extend periods relying on natural ventilation to daytime business hours, during which air-conditioning was turned on previously.

3.3 Energy balance analysis

A next generation energy park in a local city was envisioned as represented schematically in Fig. 5, which fulfilled requirements posed by the local government. There, in addition to cutting CO_2 from the region, one may learn about environmental issues as well as gain more sight-seeing opportunities. Tasks to be resolved included active utilization of an existing wind power generation facility and exhaust heat from power regulators located where low heat demand existed, and business feasibility. As to the last item, an optimum capacity for wind power generation had to be investigated; a larger generation capacity would result in more excess electricity which could be sold by itself and/or as carbon discharge credits, whereas it would increase the initial cost.

Therefore, we have proposed a set of a 600 kW-wind turbine, a 30 kW-solar power generator, an battery-equipped all electric system without a power regulator, and an electricity-heated hot spring for foot bath, among others. Our estimation indicated an approximately 83% reduction in both the primary energy consumption and CO_2 discharge, leading to a positive annual cash flow if the proposal would be accepted.

3.4 Coupled simulation

As an example of coupled solar radiation-thermal load-energy analysis using the present system, an eleven-story office building depicted in Fig. 6 is presented here. By changing conditions around the building (32.2 m wide, 27 m deep, and 45.1 m high), the effects of solar radiation on energy consumption by air-conditioning was studied in detail.

Comparison was made of a self standing building (case A) and a situation in which it was surrounded by city blocks (case B). For the latter, three identical buildings each separated by a 2 m-wide street was considered as a set and they were placed as seen in Fig. 7 in series. Each three-building unit was spaced 30 m by a street. The centrally located building colored in red was selected for analysis of air-conditioning energy.

Weather conditions in Tokyo area were given to compute year round energy consumption.

Absorption of solar radiation on the surface of building walls are presented in Fig. 8 for cases A and B at noon in March, July and December. Since case B accounts for the effects of surrounding buildings, receiving heat is seen to be higher than in case A.

Figure 9 depicts the difference in cooling load for the two cases examined. In summer, case A is often higher by 600 kWh than case B. On September 28, the sum of cooling load reaches 5111 kWh in case A, while that for case B stays at 4113 kWh, resulting in roughly a 20% difference. On a yearly basis, it further widens by as much as 25% with 328 MWh (case A) vs. 244 MWh (case B).

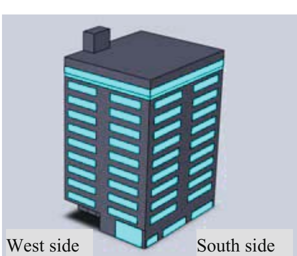


Fig. 6: Building overview

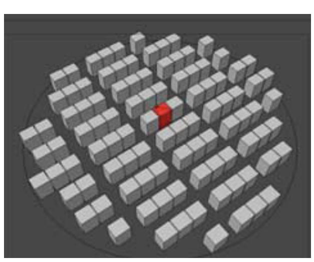
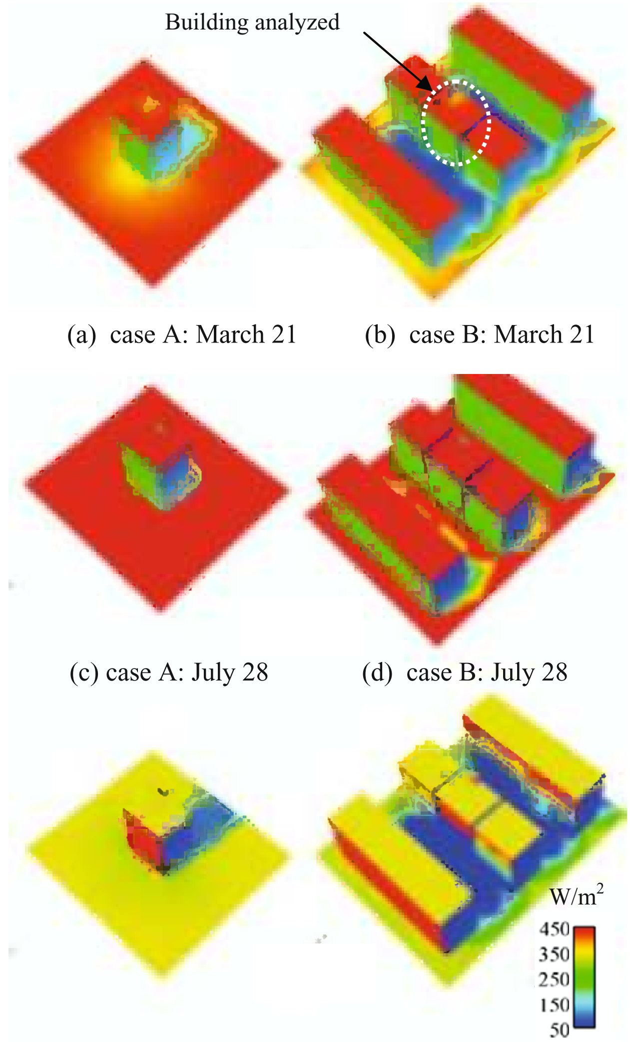


Fig. 7: Street block model



(a) case A: March 21 (b) case B: March 21

(c) case A: July 28 (d) case B: July 28

(e) case A: December 22 (f) case B: December 22

Fig. 8: Absorption of solar radiation on the building surace at noon.

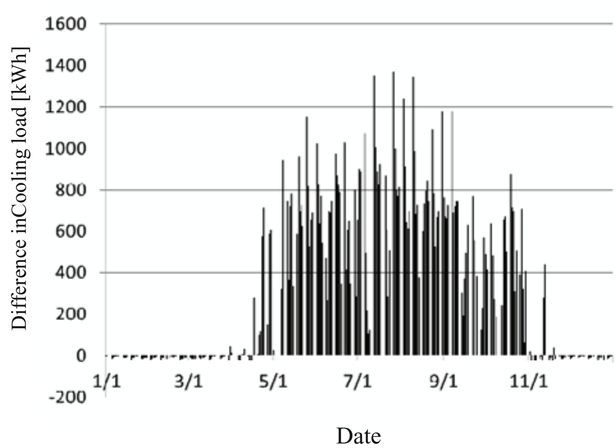


Fig. 9: Diffrence in cooling load in cases A and B ([case-a]-[case-b])

4 SUMMARY

The present developed system enables us to promote comfortable and low-carbon architectural/urban block planning by properly combining measures for indoor comfortability and CO_2 emissions to the surrounding of the building.

The yearly analysis function capable of predicting the effects of changes in solar reflection and air flow on annual energy consumption by air-conditioning permits us to readily gain knowledge of peak hours and locations of power consumption, thereby taking appropriate measures beforehand. Visual representation of in-block flow motion, sensible as well as indoor temperatures, energy consumption, and discharged CO_2 in an interlocked manner provides an easily comprehensible proposal focusing on air flow and solar radiation. Load analysis using the yearly solar radiation method discloses the difference in cooling load due to the variation in city block patterns. Compared to the case of a self standing building, year round cooling load is found to fall by some 25% when shades and solar reflections formed by the surrounding blocks are taken into consideration.

As specific measures possibly implemented into objects of analysis, we can raise the proper arrangement of buildings and the creation of plant areas and shores, among others. They may not only generate comfortable environment by actively employing existing wind and light but also reduce CO_2 of air-conditioning and lighting origin. The present system also allows quantification of these effects. With further applications of solar and biomass power generation near the building, CO_2 may be cut by sharing such clean energy for full utilization. This may be considered as an alternative.

As remaining future tasks for active use of the present system, we plan to propose power saving in architecture by fulfilling environmental friendliness, energy conservation, and thermal comfort. They will also be extended to construction of a smart community and heat island mitigation measures by building arrangement as part of urban renaissance projects.

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Development of a Sustainable System Emulator for Sustainable Environment Design

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Abstract

Several interdisciplinary research projects of renewable energy-driven residential environment have been actively conducted at College of Engineering, Nihon University. However, most of renewable energy such as solar energy is strongly affected by atmospheric conditions so that predicting its generated power is relatively difficult in practical. This means that renewable energy should be used under adequate energy management especially to realize sustainable systems.

In this paper, a modeling platform which emulates dynamics of natural and residential environment in real-time has been presented. First, the architecture of proposed emulator has been explained. Then, an experimental prototype employing a reduced-size model house with adequate energy supply, power storage and appliance consumption has been developed. Finally, experimental result shows that the developed system can precisely emulate environmental states such as energy data and atmospheric sensing data in real-time. The experiment also implies that some accelerated tests can be performed by the emulator under certain environment conditions.

Keywords:
emulator, living environment, energy management, solar energy, renewable energy, real-time OS

1 INTRODUCTION

The serious accident of Fukushima Daiichi nuclear power plant due to 3.11 mega earth quake as well as the corresponding tsunami has not yet been returned to normal condition. Cosequentrly, there happend significant confusions in energy supply system in Japan, such as suddenly announced "planned power outage" in Tokyo metropolitan area. Therefore, for example, several energy district plans for post-disaster rehabilitation have been launched so that acceleration of renewable energy installation is widely expected in Japan.

One of the major problems in renewable energy harness is its low energy density compared to conventional energy sources. Moreover, their power generation characteristics significantly depend on natural environment. Hence, exquisite combination of different renewable energy sources should be considered based on regional peculiarities. This kind of dispersion type power sources with output fluctuation may affect the system power supply. To solve the problem, a number of research and development have been done about smart-grid/micro-grid systems [1]. Corresponding to the above trend, many studies related to so called eco-house and smart-house have been performed especially in Japan.

Fig.1 shows a schematic view of eco-house called "House of LOHAS 3" being built in the college of engineering, Nihon-University [2]. Takehi et al indicated that environmental-oriented system integration as well as capacity of renewable energy storage is important factors on this project [3].

The experimental data from those eco-house projects are useful for practical design studies, however, it is still difficult to apply those data to another systems built in different nature/residential environments and conditions.

Fig.1. Concept Model View of LOHAS #3 House

This means that eco-house systems should be positively treated as sustainable systems because system dynamics becomes another key factor for designing energy-efficient systems. Visualization of system dynamics is quite common and inportant issue in the field of factory automation (FA). The visualization techonogy has been efective espacially for carbo reduction, power

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leveling as well as cost reduction of production[4]. This is one of the reasons why a large investments have to applied to manufacturing industries. On the other hand, personal living environment is more strongly and variously connected to natural environment. Thus, in some sense, it has more open and complicated situation compared to FA related environments. Furthermore, the personal dwelling is generally small-sezed so that no siginificant attentions have been paid to its energy problems. However, the problems concerning about both energy and living environment are now the hottest issues especially in the post-disaster Japan.

Static modelling has been considered to be sufficient for the energy management of personal living environment. But, its dynamic characteristcs definitely depends on time-variant factors such as solar energy fluctuation. In addition, the significance of its dynamics must increase by the demand of precise energy saving as well as effective renewable energy utilizations in future lifestyle.

The authors have been working on the development of a sensor based real-time monitoring system of living environmets [5]. Renewable energy-driven living environment should be considered to be a dynamical system in our context. For the purpose of dynamic analysis and its application to sustainable system design, an emulation system as measurement and analysis platform is being developed. The system emulates the living environment consists of residential as well as nature envisonment such as atmospheric condition

In this paper, the development of the sustainable system emulator (SSE) for living environmental systems driven by renewable energy has been presented. The system architecture, prototype using small sized house model and experimantal results have been explained.

2 CONCEPT OF SUSTAINABLE SYSTEM EMULATOR

The main concept of presented sustainable system emulator (SSE) is to emulate distinguished factors of sustainable environments by simple but engineering manners. Renewable energy-driven living environment with self-sufficiency is a key issue for SSE concept. Therefore, the SSE design concept simply consists of outer-system emulator (OSE) and inner-system emulator (ISE). OSE controls not only artificial sunlight but also air blowers emulating the atmospheric condition such as daylight hours in Fukushima area. Here, the long-term data provided by Japan Weather Association can be referred to OSE operation.

On the other hand, ISE emulates inner residential environment driven by renewable energy and its power storage. Here, ISE consists of a reduced-scale residence model with solar cells/wind power turbine as renewable energy generators. It also includes DC appliances and electro-chemical battery as power storage.

3 SYSTEM ARCHITECTURE OF EMULATOR

Fig.2 shows a schematic of SSE system architecture [5]. The necessary energy to SSE can be provided by the artificial sunlight and blower imitating sunshine duration and wind power in natural environment. The generated renewable energy is provided to living appliances, model EV of ISE. Surplus energy through the energy management sub-system can be stored in the power storage.

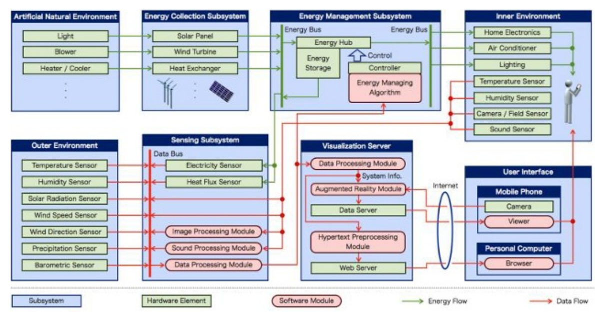

Fig. 2: Overview of SSE Architecture

Energy power leveling and input/output balance in SSE may be achieved by the controller in which energy management algorithm is implemented. A number of studies have been reported about EMS [6]. A QNX based controller is being implemented for power supply to the appliances in real-time. Synchronizing sensory data is processed in the real-time measurement sub-system [5]. The visualization server handles the sensor data post-processing and the data transfer to the client terminals. Real-time visualization of SSE can be realized the above procedures.

4 EMULATION OF NATURE AND RESIDENTIAL ENVIRONMENTS

Two types of SSE residential model have been introduced. One is a small-sized model house and the other one is a small living room in real size. Moreover, adequate sensors and its network are distributed over SSE so that optimum control algorithms can be implemented. Monitoring outer-system condition as well as generated energy, the atmospheric influence to available energy of the residence environment can be emulated. Furthermore, the relation of the power consumption of the living appliances and the storage energy can be emulated.

4.1 Experiment System Overview

Fig.3 shows a schematic of the SSE experimental apparatus employing a reduced-size model house. The model house is a 1/24 scaled miniature model of "House of LOHAS 3" which is under construction [2].

Photovoltaic cells on roof, double layer capacitors as SSE house battery, LEDs as living appliances and a model vehicle EV have been equipped in the model house. Necessary sensors in the SSE environment, such as temperature sensors with irradiance sensor are located between the artificial sunlight and the model house.

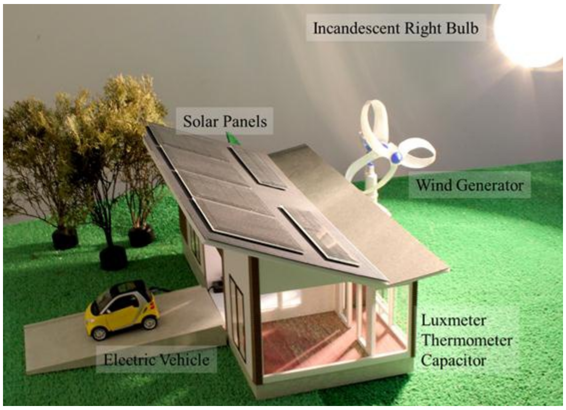

Fig.3: Schematic of SSE Experimental Apparatus (1/24 scale)

Fig.4 shows a schematic of the electric circuit of emulated living environment.

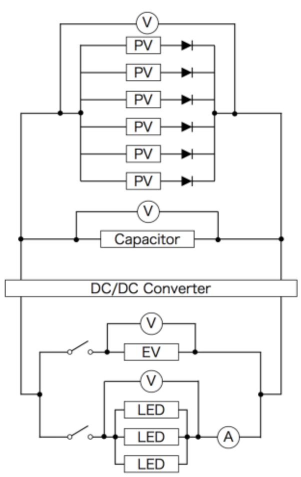

Fig.4: Electric Circuit of Emulated Living Environment

Table1: Energy Devices of SSE Living Environment

Device	Company	Part Number	Characteristics	
Solar Panel #1	Denryo	ST-2G	Cell	Single Crystalline Silicon
			Nominal Power [W]	2
			Dimensions [mm]	129.5*129.5*4
Solar Panel #2	Denryo	ST-1G	Cell	Single Crystalline Silicon
			Nominal Power [W]	1.3
			Dimensions [mm]	210.5*49.5*4
Capacitor	Vina Technology	VEC 2R5 606 MG	Type	Electric Double Layer Capacitor
			Nominal Capacitance [F]	60
			Rated Volage [V]	2.5
DC/DC Converter	Texas Instruments	TPS61200	Input Voltage [V]	0.3 to 5.5
			Output Voltage [V]	5
Electric Vehicle (EV)	Tamiya	-	Type	Electric Double Layer Capacitor
			Nominal Capacitance [F]	3.3
			Rated Volage [V]	2.3
LED	Opto Supply	-	Rated Volage [V]	3.3
			Rated Current [mA]	30

Table 2: Sensing Devices for SSE Environment

Sensing Device	Company	Part Number	Unit	Range
Luxmeter	Akitzukidenshi	K-00029	Lux [lx]	0 to 2000
Thermometer	National Semiconductor	LM61CIZ	Temperature [deg]	-30 to 100
A/D Board	Inerface	PCI-3135	Voltage [V]	0 to 10
Current Sensor	Asakusagiken	AS-AM	Current [A]	0 to 17

Table 1 shows the energy devices specification of the emulated living environment, while Table 2 shows specification of SSE mounted sensing devices.

4.2 Experimental properties

SSE experiment has been conducted considering atmospheric condition examples. Theoretically, the orientation $\theta(t)$ and altitude $\varphi(t)$ of the sun is given as follows. In Koriyama-city, for example, the orientation $\theta(t)$ and altitude $\varphi(t)$ of the sun is given as follows (see Fig.5).

$$\theta(t) = \tan^{-1} (a_1 \sin(a_2 t - a_3) / (a_4 (a_5+a_6 \cos (a_7 t - a_8))-a_9)) \ (rad.) \cdots(1)$$

$$\varphi(t)=\sin^{-1} (b_1+b_2 \cos (b_3 t-b_4)) \ (rad.) \cdots(2)$$

Where, a_i, b_i are constants determined by the location and other observation properties.t is the time represented by hours from am 00:00.

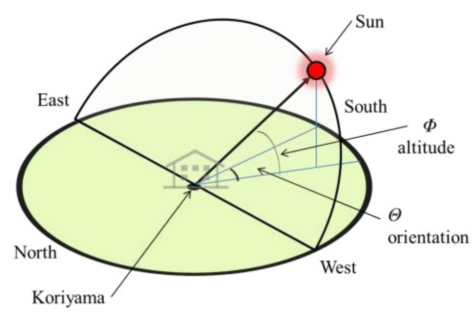

Fig.5: Schematic Altitude and Orientation of the Sun

In the experiment, nature environment is represented by the artificial sunlight using 2 incandescent 90 watt light bulbs, respectively. The sunlight power is controlled by a transformer to emulate the light and shadow contrast due to actual daily irradiance characteristics. The height and orientation of the lights can be controlled by a robotic manipulator.

Fig.6 shows a schematic of typical solar radiation examples observed in Koriyama-city, Fukushima prefecture in Japan. The plotted radiation data are based on the mean value of vertical quantity of total solar radiation observed from 1990 to 2003 [7]. Each graphic chart corresponds one day of February, May, August and November, respectively. In the experiment, the artificial sunlight was controlled every 100 seconds considering those radiation characteristics.

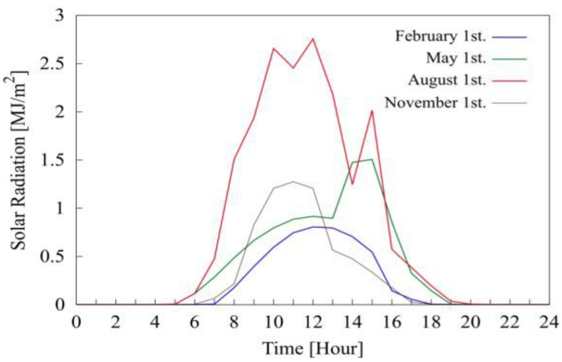

Fig.6: Solar Radiation Example in Koriyama-City

The living appliances are driven by ISE controlled mechanical switching and all the sensing data are captured by the QNX-based measurement sub-system. Finally, the whole SSE experimental apparatus was set-up in a shading test room with 3.5 m×2.5 m×2.7 m volume. The initial experimental period was set to 60 minutes which is supposed to be one day for SSE (1/24 of real one day). The system sampling frequency was set to 2Hz.

5 EXPERIMENTAL RESULTS

Fig.7 (a) shows the experimental result of the transformer voltage for sunlight control, and Fig7 (b) ~ (f) similarly show the results of monitored sensing data, respectively. The artificial sunlight photographs at every 300 second are also shown in the headline of Fig.7.

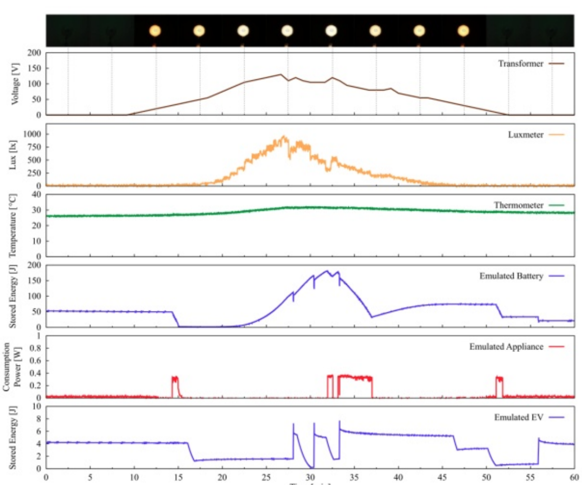

Fig.7: Examples of SSE environmental information

Here, Fig.7 (b) ~ (f) indicate irradiance, temperature, battery stored energy, the power consumption by appliances and EV, respectively. The energy of house battery has been estimated by using eq. (1).

$$W=0.5\,C\,E^2 \quad \cdots \quad (1)$$

Where, *W*: stored energy (J), *C*: electrostatic capacity (F), *E*: circuit terminal voltage (V).

The power consumption of the living appliances is computed by multiplying the terminal voltage via an A/D board and the measured circuit current. At first, the irradiance increases and then decreases corresponding to the transformer voltage driving the artificial sunlight as shown in Fig.6 (b) and (a). Similarly, although accompanying slight time delay, the temperature increases and then decreases corresponding to the irradiance change. In addition, as shown in Fig.7 (d), (e) and (f), the battery power changes when the system loads such as living appliances and EV are driven for their operations. Here, surge voltage effect can be observed in the EV stored energy. As shown above, the dynamic characteristics of SSE can be precisely and repeatedly investigated in real-time. This may be a major advantage of SSE when pre-design of real residential environments is required

On the other hand, discharge of the SSE battery is equal to the power consumption of other appliances and devises. As shown in Fig.7, it should be noted that the time-delay constants of appliances and EV are much smaller than that of the atmospheric temperature. Not only atmospheric temperature but also room temperature has relatively large time-delay constant in general [8]. In case of living environment emulations, this implies that energy-related acceleration test for the appliance which significantly affects residential atmosphere such as room temperature is difficult. However, on the other hand, accelerated testing may be effective for most appliances so that the design efficiency of energy utilities may be much improved. Moreover, based on the SSE state information, a variety of control algorithms for effective energy management can be rapidly and efficiently tested and developed. This is another advantage of SSE in case of designing renewable-energy driven systems.

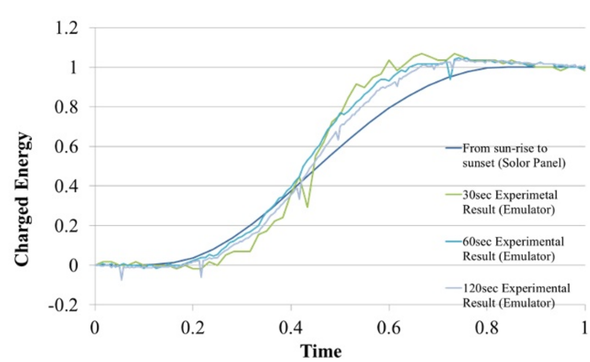

Fig8: Time Normalized Charged Power of SSE Battery

Fig.8 shows charged power examples in the SSE battery compared to a full charged energy example of typical photovoltaic cell system mounted on the roof of an actual house. The charging time for the SSE battery was set to 30, 60 and 90 seconds while the photovoltaic cell data is the case of 24 hours. Here, the energy values and the charging time in the figure are normalized for the comparison. Both charging characteristics have similar tendencies so that SSE may be also used to acceleration test for energy utilities of renewable-energy driven systems.

In the next step, the developed SSE will be extended to another experimental facility using the real small living room.as shown in Fig, 9 in the near future.

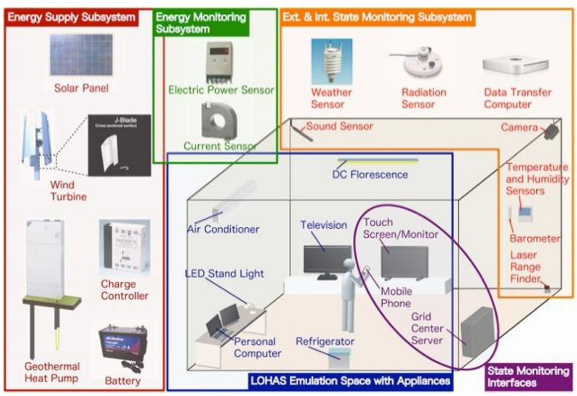

Fig.9 Schematic of SES implemented living room

6 SUMMARY

The development of a sustainable system emulator (SSE) for sustainable environmental systems driven by renewable energy has been presented. The SSE concept, the system architecture, and the experimental apparatus as a prototype of SSE which mainly consists of outer-system emulator (OSE) and inner-system emulator (ISE) have been addressed. By the experimental investigation emulating the nature environment as well as living environment, it has been clarified that the relationship among the SSE state information can be precisely and repeatedly investigated. Furthermore, the experiments shows that accelerated testing may be effective for most appliances so that the design efficiency for renewable-energy driven systems will be improved.

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Study on the Operation Analysis of a Compound Energy System using Orthogonal Array-GA Hybrid Analyzing Method

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Abstract
Generally, the output characteristics of the energy apparatus are nonlinear. Furthermore, because multiple power sources are used in microgrids, many variables must be considered to optimize the system. Although the operation of energy systems has been optimized before, nonlinear problems with many variables have been approximated by linear formulas with mixed-integer-programming. Moreover, the conjugate gradient method and genetic algorithm (GA) were also used. In this study, a method of searching for the optimal solution with GA is reported. Any method for obtaining the optimal solution will require a longer time if the number of variables is increased or a higher accuracy is required in the analysis. Otherwise, only quasi-optimal solutions and unsatisfactory solutions of the energy balance equations are obtained. Therefore, orthogonal array used to experimental design are employed in this presentation to reduce the complexity of the problem to plan the optimal operation method of a compound energy system. The initial values of design parameters of the system near the optimum operation method are determined using result of orthogonal array experiment and the factorial effect figure. Next, the optimal solution is obtained by introducing this result as initial values of GA. An example is given in this presentation to explain the orthogonal array (L18)-GA hybrid analyzing method. The proposed analysis method can be utilized to improve the design parameters and the accuracy of the performance analysis. The trial number of times of GA largely decreases. By analysis results, the orthogonal array-GA hybrid analyzing method needs some technique for the setting of each design parameters. This method is available for improvement of the analysis precision by the increase of the number of gene models and the increase of the design parameters. Therefore, proposed analyzing method was overcame weak points of the optimal calculation of conventional simple GA.

Keywords:
Orthogonal array, Genetic algorithm, Microgrid, Compound energy system, Operating optimization

1 INTRODUCTION

It is thought that the distribution of an energy system reduces the power transmission loss, allows for the effective use of exhaust heat, and promotes the utilization of green energy. However, to realize a stable supply of energy in a renewable energy system, it is necessary to combine power sources . Recently, a network of the energy distributed by a microgrid has been widely studied [1-3]. Furthermore, it is expected that a microgrid evolves into a smartgrid with various added values [4-6]. Therefore, a technology for optimizing the combination of energy systems with various output characteristics is required. In many cases, renewable energy systems store both electrical and thermal energy. For this reason, a plan for dynamically optimizing the operation of such systems is required. Moreover, because the input and output characteristics of the energy equipment are nonlinear, the operation plan of a compound energy system must solve a nonlinear problem with many variables. Recently, an analysis method that utilizes mixed-integer-programming and a genetic algorithm (GA) to optimize the operation of an energy system has been developed [7-10]. In this method, the nonlinear characteristics of the energy sources are divided into many linear characteristics, and approximate solutions are obtained by mixed integer programming. Additionally, a GA is easily introduced to assist in solving nonlinear problems with many variables [10]. However, when many variables are introduced and a precise analysis is required, the GA requires a long computation time. Furthermore, in cases where the GA attains a local maximum, quasi-optimal solutions are obtained. The values of the valuation function (adaptive value) of the quasi-optimal solutions close together. Therefore, the solution is considered to be the optimal solution if it is obtained by repeating the analysis of the same conditions many times with the conventional analysis method using a GA.

The purpose of this syudy is to develop a computer algorithm for planning the operation of a compound energy system with many design parameters with a high

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accuracy by introducing a GA. In this algorithm, the GA does not reach the optimal solution by repeating the analysis of the same conditions many times. Rather, an orthogonal array [11-13], which was first known as a technique for experimental design, is introduced to reduce the operation range that is considered to include the optimal operation of the compound energy system. Then, the GA searches for the optimal solution in the operation range that is considered to include the optimal operation. Accordingly, the use of the orthogonal array greatly reduces the number of trials that the GA must conduct to arrive at the optimal solution. Thus, the hybrid method, which combines orthogonal arrays and a GA, is a significant improvement over optimization methods that employ a traditional GA.

2 OPERATIONAL OPTIMIZATION OF ENERGY SYSTEMS

2.1 Analysis System

Figure 1 shows a compound energy system that supplies the power and heat 30 houses used as an analysis example for operational optimization. This compound energy system consists of a power grid, a heat grid (hot water), a solid-oxide fuel cell (SOFC), two photovoltaic power conditioners (1) and (2), a heat pump, a battery and a heat storage tank. This system is an example of an independent microgrid with green energy.

When a natural gas (CH4) is supplied to the SOFC, alternating current power (200 V and 50 Hz are assumed) will be output to a power grid from power conditioner (1). Moreover, the power of the SOFC can be altered by adjusting the supply of natural gas. However, the power generation efficiency of the SOFC depends on the load factor. Accordingly, the output characteristics of the SOFC are introduced [14] in this study. The characteristics can determine the output power ratio of power and heat (exhaust heat) from the load factor of the SOFC without being influenced by the capacity of the SOFC. On the other hand, the power from the photovoltaic equipment is supplied to the power grid from power conditioner (2).

The power from the SOFC and the photovoltaic equipment can be stored in a battery. However, the charging and discharging of the battery and power conditioner is not without loss.

The heat sources in the Heat supply system are the exhaust heat of the SOFC and the air heat source heat pump. Moreover, the exhaust heat of the SOFC can be stored in the heat tank to be used at adesired time. However, heat is lost due to radiation when it is stored in the tank.

2.2 Energy Balance

Equations (1) and (2) are the balance formulas of power and heat for the microgrid shown in Fig. 1.

The left- and right-hand sides of each formula express the power input and output terms, respectively. $E_{needs,t}$ and $H_{needs,t}$ of the right-hand side of each formula are the electricity and heat demand, respectively, and load patterns applied on a standard house in Sapporo are used for the analysis example[15-16]. An electric light and a household appliance comprise the power load. The heat load includes the space heater and hot water supply,.

$$E_{fc,t} + E_{pv,t} \cdot \varphi_{cd,t} + E_{btd,t} \cdot \varphi_{btd} = E_{needs,t} + E_{hp,t} + E_{btc,t} \cdot \varphi_{btc} \quad (1)$$

$$H_{fc,t} + H_{hp,t} + H_{st,out,t} \cdot \varphi_{st,out} = H_{needs,t} + H_{st,in,t} \cdot \varphi_{st,in} + H_{rad,t} \quad (2)$$

The loss of power conditioner (1) is included in the power of the fuel cell $E_{fc,t}$. Here, t denotes the sampling time. The power generation efficiency $\varphi_{fc,\lambda fc,t}$ of a fuel cell can be acquired by first calculating the load factor $\lambda_{fc,t}$ of the fuel cell with Eq. (3) and then calculating Eq. (4)using $\lambda_{fc,t}$. Here, C_{fc} is the capacity of a fuel cell. Each factor in Eq. (4) was obtained from the output characteristics of the SOFC (Fig. 2). When $\varphi_{fc,\lambda fc,t}$ is inserted into Eq. (5), the fuel consumption $F_{fc,t}$ of a fuel cell is obtained.

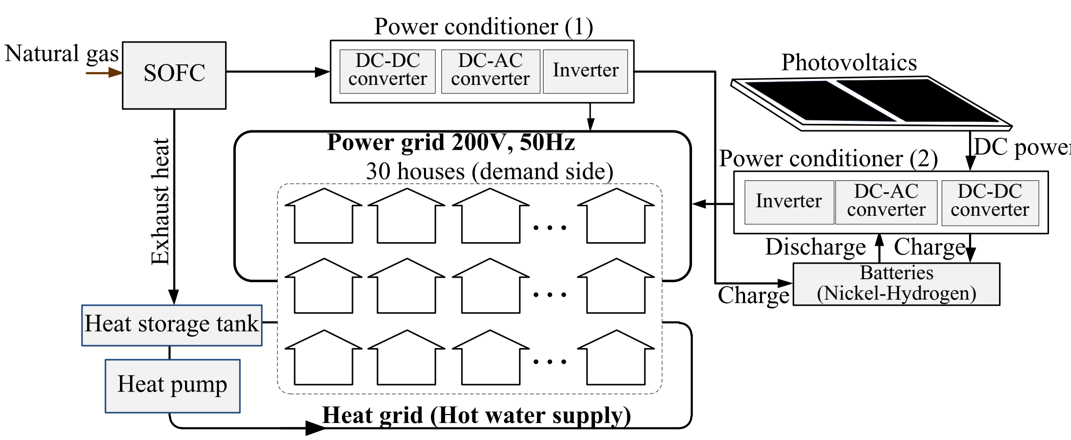

Fig. 1: System scheme

$$\lambda_{fc,t} = E_{fc,t} / C_{fc} \quad (3)$$

$$\varphi_{fc,t} = 6.11 \cdot 10^{-5} \cdot \lambda_{fc,t}^2 + 9.46 \cdot 10^{-3} \cdot \lambda_{fc,t} + 0.167 \quad (4)$$

$$F_{fc,t} = E_{fc,t} / \varphi_{fc,\lambda fc,t} \quad (5)$$

On the other hand, the heat power $H_{fc,t}$ generated by the fuel cell is calculated with the following Eq. (6).

$$H_{fc,t} = -2.45 \cdot 10^{-5} \cdot \lambda_{fc,t}^2 + 3.78 \cdot 10^{-3} \cdot \lambda_{fc,t} + 0.0667 \quad (6)$$

The load factor $\lambda_{hp,t}$ of a heat pump is calculated from Eq. (7) using the heat power $H_{hp,t}$ and the capacity C_{hp} of the heat pump. Furthermore, the coefficient of performance $COP_{hp,t}$ is obtained by introducing $\lambda_{hp,t}$ into Eq. (8). Eq. (8) is obtained from the reference of the load factor, and $COP_{hp,t}$ is obtained from the heat pump. The power consumption $E_{hp,t}$ of the heat pump is obtained by introducing $H_{hp,t}$ and $COP_{hp,t}$ into Eq. (9).

$$\lambda_{hp,t} = H_{hp,t} / C_{hp} \quad (7)$$

$$COP_{hp,t} = 2.70 \cdot 10^{-6} \cdot \lambda_{hp,t}^3 - 8.11 \cdot 10^{-4} \cdot \lambda_{hp,t}^2 + 0.0813 \cdot \lambda_{hp,t} + 0.879 \quad (8)$$

$$E_{hp,t} = H_{hp,t} / COP_{hp,t} \quad (9)$$

In the optimization calculation used in this study, the seven design parameters shown in Table 1 are used: the capacity of a solar cell C_{pv}, the capacity of a battery C_{bt}, the amount of battery discharge E_{btd}, the amount of battery charge E_{btc}, the capacity of the fuel cell C_{fc}, the heating storage capacity of the heat storage tank C_{st}, and the capacity of the heat pump C_{hp} . Moreover, the amount of power and heat that are demanded ($E_{needs,t}$ and $H_{needs,t}$) are input into the computer program. Optimization of the system is necessary to search for the optimal values of each design parameter. Therefore,the optimal values of design parameters is searched by introducing a combined orthogonal array and a GA.

Table 1: Level of each design parameter

Design parameters		Level 1	Level 2	Level 3
(A) Capacity of photovoltaic	C_{pv}	0	100	
(B) Capacity of battery	C_{bt}	5	15	25
(C) Amount of battery discharge	E_{btd}	0	4	8
(D) Amount of battery charge	E_{btc}	0	4	8
(E) Capacity of fuel cell	C_{fc}	350	400	450
(F) Capacity of heat storage tank	C_{st}	0	100	200
(G) Capacity of heat pump	C_{hp}	500	600	700

3 PROBLEM OF ANALYSIS METHOD USING GA

Eq. (10) is an objective function of this system. The objective function of this study is chosen to minimize the fuel consumption for the represented day. Fuel consumption of this system is the same as the fuel consumption of the SOFC $F_{fc,t}$.

$$\sum_{t=0}^{24} F_{fc,t} \rightarrow \text{minimize} \quad (10)$$

A GA can be used to solve a nonlinear problem with many variables. However, introducing many design parameters and increasing the number of genes to improve the accuracy of the analysis accuracy greatly reduces the probability that the optimal solution will be obtained. Accordingly, wide spreads in the calculation results in each analysis and the appearance of many wrong solutions occur frequently. When searching for the optimal solution, a satisfactory solution of Eq. (1) and Eq. (2) will not be obtained in most cases. Therefore, the optimal solution of the design parameters of Table 1 is difficult to obtain with a GA alone. To obtain the optimal solution using a GA, it is necessary to narrow the search range by introducing many restricted conditions.

For this purpose, an orthogonal array is limit the analysis range of each design parameter, and the optimal values of design parameters is tried to GA introducing a combined orthogonal array.

4 ORTHOGONAL ARRAY–GA HYBRID ANALYSIS

Generally, compound energy systems have many design parameters. Therefore, changing all of them to optimize the operation of a system is difficult. In this study, to limit the analysis range of each design parameter, an L18 orthogonal array is used. Various types of orthogonal arrays are used in experimental design. The L18 orthogonal array is known as a mixed system orthogonal array, and it is thought to have little influence on the alternate effects between parameters. The response ofthe output characteristics when changing the design variables (control factor) of the object system is considered in the experimental design. Table 2 shows the L_{18} orthogonal array used in this paper. The orthogonal array has 18 rows, and e1 to e18 are numerical simulation numbers. Moreover, although the orthogonal array has eight columns that can be used as design parameters that are denoted as (A) to (H), only columns (A) to (G) will be used here. Only one design parameter (A) has two levels, and the rest have three levels in the L_{18} orthogonal array. Fig. 3 shows Analysis flow of the orthogonal array-GA hybrid analysis.

Table 2: Orthogonal array of L_{18}

Experimental number	Row number (Design parameter)							
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
e1	1	1	1	1	1	1	1	1
e2	1	1	2	2	2	2	2	2
e3	1	1	3	3	3	3	3	3
e4	1	2	1	1	2	2	3	3
e5	1	2	2	2	3	3	1	1
e6	1	2	3	3	1	1	2	2
e7	1	3	1	2	1	3	2	3
e8	1	3	2	3	2	1	3	1
e9	1	3	3	1	3	2	1	2
e10	2	1	1	3	3	2	2	1
e11	2	1	2	1	1	3	3	2
e12	2	1	3	2	2	1	1	3
e13	2	2	1	2	3	1	3	2
e14	2	2	2	3	1	2	1	3
e15	2	2	3	1	2	3	2	1
e16	2	3	1	3	2	3	1	2
e17	2	3	2	1	3	1	2	3
e18	2	3	3	2	1	2	3	1

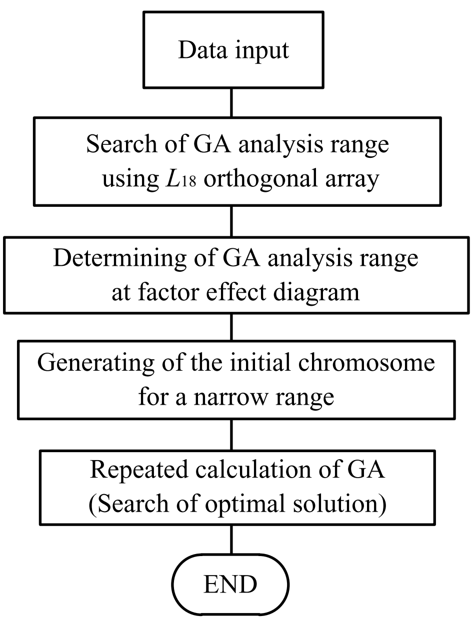

Fig. 3: Analysis flow of the orthogonal array-GA hybrid analysis

5 ANALYSIS EXAMPLE

A microgrid system as shown in Fig. 1 is introduced in Sapporo. The conditions of a representative day in February (mid-winter) are assumed for analysis of optimization. Figures 4 and 5 define the energy demand pattern and the forecasted amount of solar radiation, respectively. Each value shown in Table 1 is chosen to be a design parameter. However, the ranges of the optimal values of each design parameter and whether certain pieces of equipment should even be introduced are unknown. Thus,as shown in Table 1, the levels of the design parameters are chosen over a wide range. Although there is no restriction on the upper and lower limits of each level, the difference between each level is chosen to be the same value. The loss of the heat storage tank is set to 20% of the amount of thermal storage, and the efficiency of the power conditioner for charging and discharging the battery is chosen to be 90%.

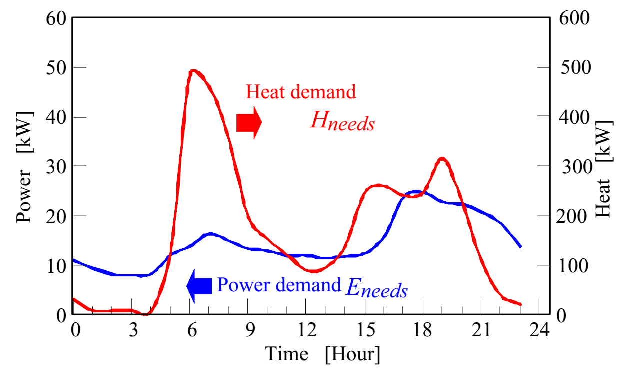

Fig. 4: Energy demand of 30-houses microgrid in February in Sapporo

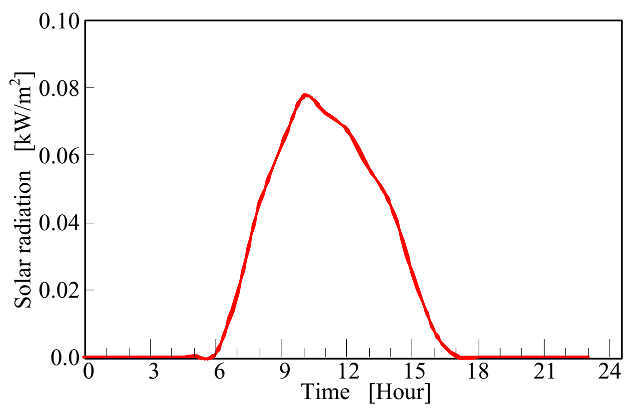

Fig. 5: Solar radiation in February in Sapporo

In this analysis, the temperature dependence of the battery properties, the power transmission loss, and the radiation of heat of the hot water supply are not considered. Results of the fuel consumption at sampling times t 0 to t 23 using L_{18} orthogonal array of Table 2, substituting the level values of each design parameter of Table 1, are calculated. Next, the average values of fuel consumption are calculated according to the level of each design parameter (A) to (G). The factor effect figure shown in Fig.6 can be obtained from the average values of fuel consumption according to the level of each design parameter. By examining the factor effect figure shown in Fig.6, the search range of level value of each design parameter can be determined. Therefore, the value of the initial chromosome model group of the GA is set to be a range of a values or a particular value shown in Table 3.

These figures were determined by referring to the level that contributes most to reducing the fuel cost of the system for each design parameter, as shown in Fig. 6. By using the results of Table 6 to define the search range of the GA, the frequency of trial analyses decreased greatly.

Table 3: Analysis range of each design parameter

Design parameters		Level 1	Level 2	Level 3
(A) Capacity of photovoltaic	C_{pv}	0		
(B) Capacity of battery	C_{bt}		7.5-15.5	
(C) Amount of battery discharge	E_{btd}		2.0- 6.0	
(D) Amount of battery charge	E_{btc}	0		
(E) Capacity of fuel cell	C_{fc}	<350		
(F) Capacity of heat storage tank	C_{st}	50-100		
(G) Capacity of heat pump	C_{hp}	<500		

6 OPTIMAL SOLUTION OF THE DESIGN PARAMETERS

The minimum fuel consumption of the system was determined to be 3077kWh as a result of the calculation in the orthogonal array-GA hybrid analysis. This analysis result has also been verified with conditions other than the analysis parameters of the GA. On the other hand, the minimum of the fuel consumption of the system in one day of the numerical simulations e1 to e18 was 4192kWh for the case of e1 .

Table 4 shows the calculated optimal value of each design parameter. The photovoltaic cell and battery are not considered in this example.For this reason, when the photovoltaic cell is introduced, the load factor of the SOFC will decrease and the power generation efficiency will fall, and as a result of the charge-and-discharge efficiency of the battery, installation of a battery cannot increase the efficiency of the system.

However, the introduction of a battery may become effective when an operation plan is extended until the next day because the stored electricity from the previous day can be used for the period of a power load peak. On the other hand, the heat storage tank is not considered either because it is assumed that the heat supply from the heat pump is more efficient due to the heat loss of the tank.

Table 4: Optimum design parameters of proposal system

Design parameters		
(A) Capacity of photovoltaic	C_{pv}	0kW
(B) Capacity of battery	C_{bt}	0kWh
(C) Amount of battery discharge	E_{btd}	0kW
(D) Amount of battery charge	E_{btc}	0kW
(E) Capacity of fuel cell	C_{fc}	135kW
(F) Capacity of heat storage tank	C_{st}	0kW
(G) Capacity of heat pump	C_{hp}	470kW

7 ANALYSIS RESULTS OF OPTIMAL OPERATION PLAN

Figure 7 shows the results of the operation plan on the SOFC. The load factor, the electric power, and the heat power of the SOFC are shown in this figure. The operation of the SOFC corresponds to the sum total value of the power load and the electricity consumption of the heat pump. The heat load is larger than the power load shown in Fig. 4. Therefore, the heat load pattern significantly influences the load factor of the SOFC.

Figure 8 shows the results of the operation plan of the load factor and COP of the heat pump. Moreover, Fig. 9 shows operation planning of the heat pump. The sum total of the heat of the heat pump and exhaust heat of the SOFC corresponds to the heat load pattern shown in Fig. 4.

Although the analysis parameters of the GA require some trial and error for the proposed orthogonal array-GA hybrid analysis method described in this study, they converge to the same value. Moreover, the proposed method is expected to easily account for additional design parameters and an improved analysis accuracy (i.e., an increase in the number of genes in each chromosome model). An orthogonal array-GA Hybrid analysis method can be eliminated the drawbacks of only a GA analysis.

CONCLUSIONS

Genetic algorithms (GAs) are known to be able to optimize the operation of compound energy systems, such as microgrids. However, when increase in variables and extensive improvements of analysis accuracy are tried,

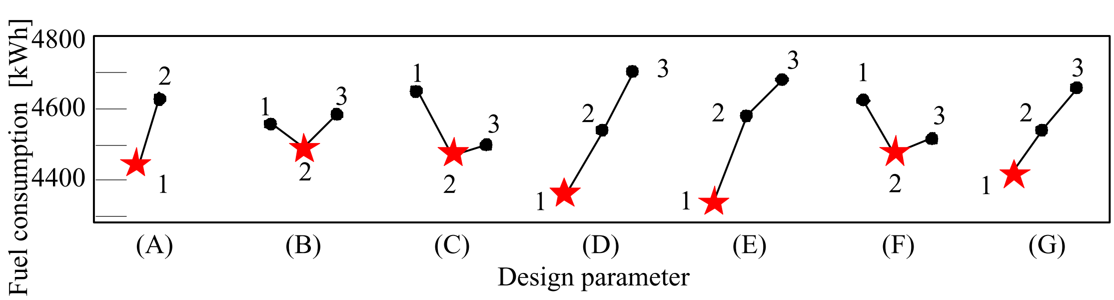

Fig. 9: Factor effect Figure

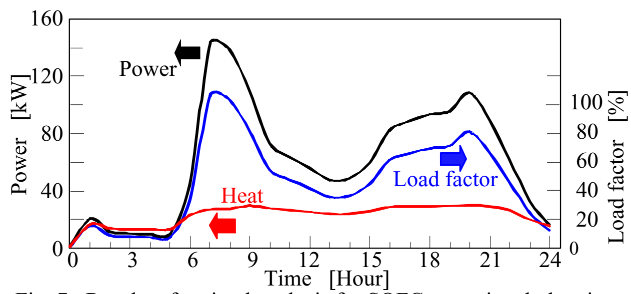

Fig. 7: Results of optimal analysis for SOFC operational planning

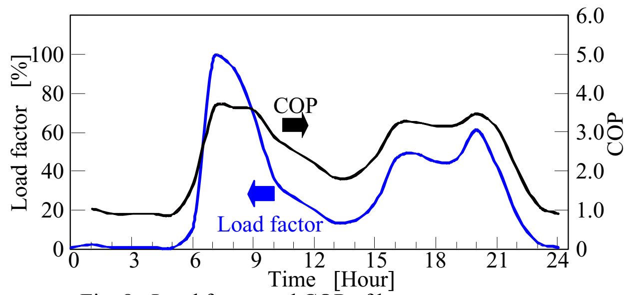

Fig. 8: Load factor and COP of heat-pump system

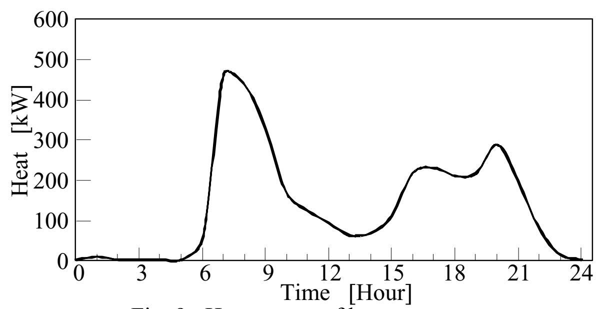

Fig. 9: Heat output of heat-pump system

very long computation time will be taken to obtain the optimal solution. In addition, quasi-optimal solutions and otherwise unsatisfactory solutions of the energy balance equation could be reached. To reduce the required computation time, the orthogonal array-GA hybrid analysis method was proposed in this study. This new algorithm limits the operation range of a system with an orthogonal array and factor-effect-figure, which are widely used techniques in experimental designs. Next, a GA was introduced for system operation within a limited range to search for the optimal solution. It is predicted that the orthogonal array-GA hybrid analysis method will improve the analysis accuracy of microgrids with many design parameters.

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Estimation of Greenhouse Gas Emissions in Micro-fabrication of MEMS Devices

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Abstract

We study on estimation of greenhouse gas emissions in micro-fabrication of MEMS devices. The estimation is made on a test element groups of silicone-based sensors fabricated on an 8-inch SOI wafer at the green 8-inch MEMS prototype station. The estimation includes electric power, materials, and consumables used in fabrication equipments as well as contribution from usage of cleanroom's facilities such as supply and waste disposal. The estimation is also made separately in each process steps. The result shows that electric power and purified nitrogen are major sources of greenhouse gas emissions. Our process-by-process approach for the estimation enables us to identify major sources in each process to reduce emissions.

Keywords:

greenhouse gas emissions, micro-fabrication, MEMS, sensor network

1 INTRODUCTION

Reduction of greenhouse gas (GHG) emission is one of the greatest challenges for sustainable civilization of human being. The major GHGs are carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulfur hexafluoride, HFCs, and PFCs), which are the subject of the Kyoto Protocol. A carbon footprint of product is the total set of GHG emissions caused by a product. Labeling the carbon footprint on the product is expected to promote the reduction by mechanism of product market.

Microelectromechanical systems (MEMS) are electronic devices indivisibly with movable parts of micron scale. Nowadays, MEMS are used in smart phones, controllers of video games, airbags of automobiles, etc. for sensing motions or mechanical quantities. MEMS are fabricated in cleanroom with a controlled level of contamination, by utilizing semiconductor manufacturing technologies as well as those specialized ones for forming the movable parts.

GHG emissions of MEMS products in fabrication processes have not been analyzed unlike in the case of semiconductor electronic devices for possible reasons of small market size, various fabrication processes, and lack of facilities for estimate. Shipping quantities of MEMS products now become large enough to reach 1.86 billion a year (2008, actual) and will increase to 5.21 billion a year (2019, estimate), and so GHG emissions will increase together.

MEMS products should be considered as intermediate goods just like other electronic components. Therefore product lifecycle of MEMS is similar to that of electronic components. MEMS-specific and complicated parts in the product lifecycle for calculation of carbon footprint are manufacturing stage. On account of the production methods, GHG emissions in the manufacturing stage may be comparable to those of electronic devices. Thus a methodology to calculate and analyze GHG emissions in MEMS fabrication needs to be established.

We, therefore, carried out a study on the above methodology and then estimated GHG emissions in micro-fabrication of MEMS devices (Fig.1).

2 ESTIMATION

The green 8-inch MEMS prototype station (TKB-812) was newly constructed in Nov. 2010 at the east division of the National Institute of Advanced Industrial Science and Technology, Tsukuba (AIST Tsukuba East). After the construction some test element groups (TEGs) were made for verification of the line. Our study for GHG emissions was made on one sort of the TEGs cooperatively with the verification.

2.1 Objectives

GHG emissions in micro-fabrication may depend on fabricated devices, used facilities and processes. Objectives of the estimation are described in the following.

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Fabricated MEMS devices

30 shots out of 60 on an 8-inch SOI wafer were patterned by photolithography and 1,920 devices were fabricated on the wafer as a TEG of silicone-based sensors. The devices include capacitive accelerometers and gyros with comb-drive actuators, and silicone oscillators.

Facilities for fabrication

TEG described above was fabricated by using equipments in TKB-812. For GHG emission we count equipments for fabrication as well as facilities of cleanrooms for supply and waste disposal. The fabrication includes photolithography, etching, deposition, annealing, and cleaning.

Processes for fabrication

For estimation of GHG emission, we cover processes of making alignment marks, forming electrodes, and fabricating movable structures on SOI wafers. There are 24 steps on the processes with 9 manufacturing equipments, where each step means continuous use of single fabrication equipment.

2.2 Inventory

Items of possible sources for GHG emissions were collected from the analysis of process used in the fabrication. The 41 items in total are categorized as input and output to/from the fabrication processes. The input includes electrical power, materials, consumable supplies. The materials are process gases and metals, while the consumable supplies are de-ionized water, chemical solutions, utility gasses, vacuum source, and cooling water.

The output is direct emission of GHGs and waste treatment/disposal. The waste disposal includes PFC/halogen exhaust treatment, heat/acid/alkali exhaust treatment, acid/alkali/organic liquid treatment, and rinse water treatment.

2.3 Measurements

In order to measure amounts of used resources for each equipment, TKB-812 has sensor network system to monitor electrical power supply, process/utility gasses, water, and exhausts. We utilized this system to obtain amounts of the input and output and calculated GHG emission factors for several items in the inventry. We also measured electrical power supplies separately, for the sake of data aquisition in adequate granurarity.

2.4 GHG emission factors

There must be GHG emission factors for all items in the inventry to estimate the emissions. We preferentially used public databases, where GHG emissions are expressed in terms of the amount of carbon dioxide with equivalent greenhouse effect. For the items specific to TKB-812 such as supply and waste disposal, we calculate their GHG emission factors by using measurement data. For the chemical species or thier solutions missing GHG emission factors, we estimate them by use of several ways. They include estimation by modeling synthsis processes, analogical inference by chemicals with similar molecular

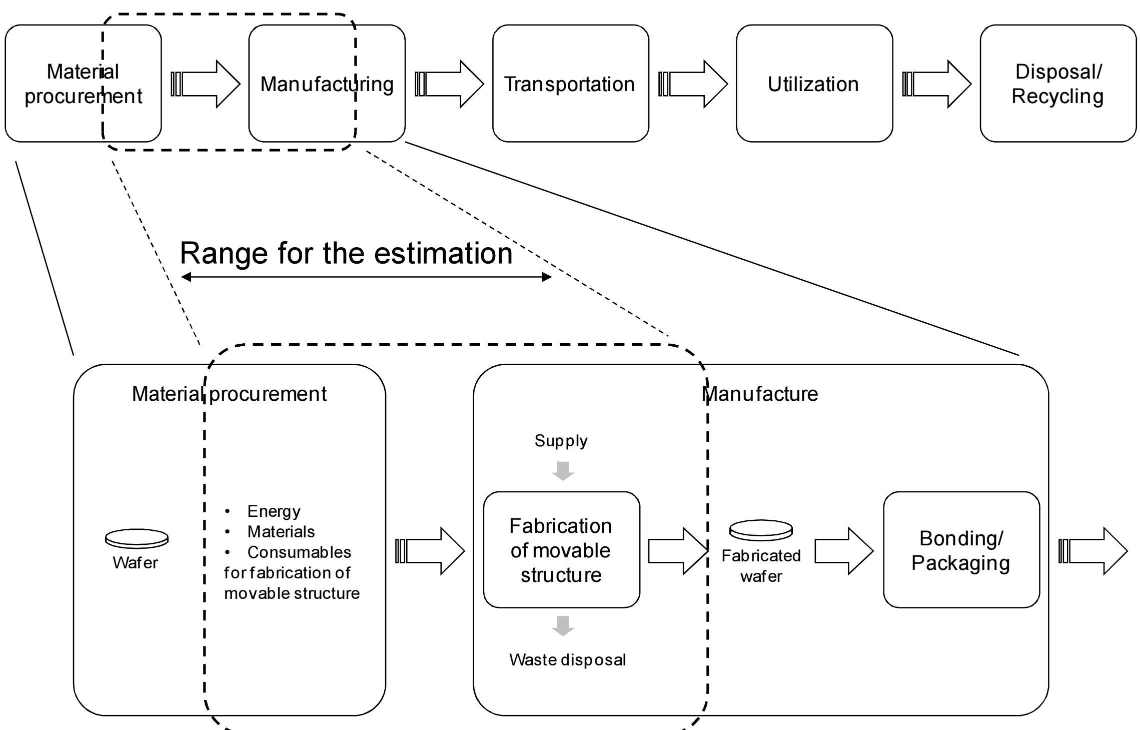

Fig. 1: Product life cycle of MEMS and range for estimation of GHG emissions

scaffolds, and comparing prices in the cases with much less information about their composites.

3 RESULT

Result of process-by-process estimation of GHG emissions is shown in Fig. 2. GHG emissions per wafer are summed up to become 41.6kg-CO2e in total. Main sources for GHG emissions totally in overall processes are electric power and purified N_2. Among fabrication processes major causes of GHG emissions are Al etching, the second Si etching, and cleaning. Among items in each process large parts of GHG emissions arise from purified N_2 in development (occurring 3 times), electric power in Al sputtering, electric power in Si etching (occurring twice), electric power and compressed dry air in Al etching. In order to reduce GHG emissions we can pay attention to these major source.

In view of characteristics of process steps and items in the inventry, the estimation result imply potential major source of GHG emissions for general MEMS fabrication; processes with high electric power, for a long time, used repeatedly, of wet (using de-ionized water and liquid waste disposal), of silicone deep reactive-ion etching (through wafer), with much use of cleanroom facility (purified nitrogen and compressed dry air), with use of particular chemical solution, or with use of particular waste disposal.

4 CONCLUSION

Our method of process-by-process estimation for each item enables us to identify major sources (processes and items) for GHG emissions, to obtain targets to GHG reduction for the fabrication of MEMS devices. Also, the estimation result provides general implication for potential major source of GHG emissions.

Our approach to calculate and analyze GHG emission for each process of MEMS fabrication can be used when designing the fabrication processes, so that a design guideline for GHG reduction would be realized.

Estimation methodology has not covered all micro-fabrication process used in various MEMS production. In the current case, we still need to estimate emissions in bonding and packaging processes at least. Nonetheless we would do with TKB-812 powered by the sensor network system for monitoring resource usage of equipments.

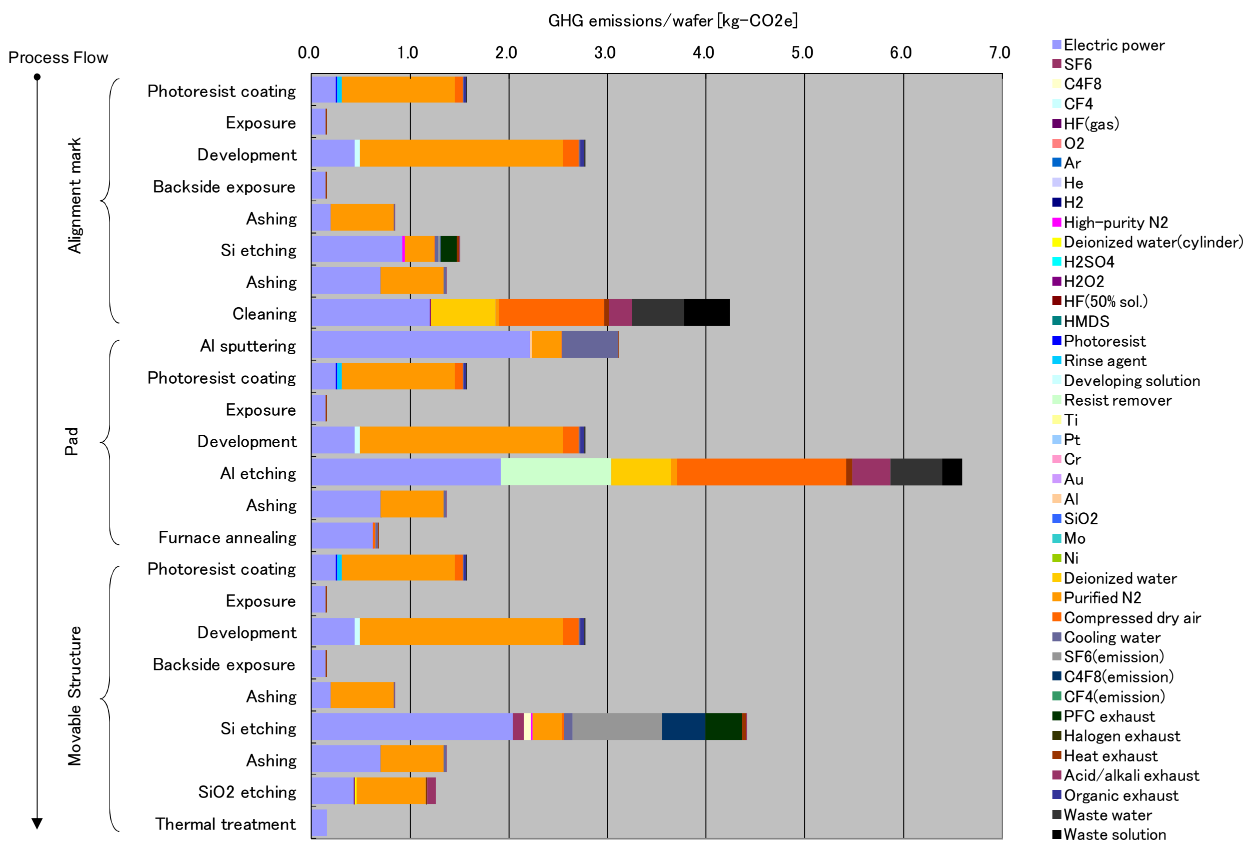

Fig. 2: Estimation of GHG emissions of a TEG of silicone-based sensors

Comparison between Wooden and Conventional Prototyping: An Eco-Manufacturing Perspective

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Abstract

Two physical models (prototypes), one made of wood and the other made of resin, have been produced directly from the same 3D CAD model. To produce the wooden prototype, the CNC machine tool for woodworking developed by the Hokkaido Forest Products Research Institute has been used. To produce the resin prototype, conventional rapid prototyping machine (Stereolithography based) available at Kitami Institute of Technology has been used. The CO2 emission, time, and materials consumed for both prototyping processes have been determined. It is found that from the CO2 emission and time consumed viewpoints, wooden prototyping technology is better than resin prototyping technology. On the other hand, wooden prototyping process consumes more materials compared to the other one. Further study is needed to see other issues, e.g., saw-dust disposal energy, energy for curing process, environmental impact of resin and wood productions, and alike.

Keywords:

Rapid Prototyping, CAD/CAM, Sustainable Manufacturing, CO2 Emission

1 INTRODUCTION

Manufacturing ("Monozukuri" in Japanese) has gradually been entering into an era called *sustainable manufacturing*. One of the key enablers of sustainable manufacturing is eco-manufacturing. In eco-manufacturing, efforts are being made so that the materials, processes, and systems used in product realization inflict little harm on the environment [1]. There are studies that show the environmental impact of machine tools [2], cutting tools [3-4], and manufacturing systems/processes [5-7] of conventional manufacturing (manufacturing that uses subtractive process to create a shape from a blank).

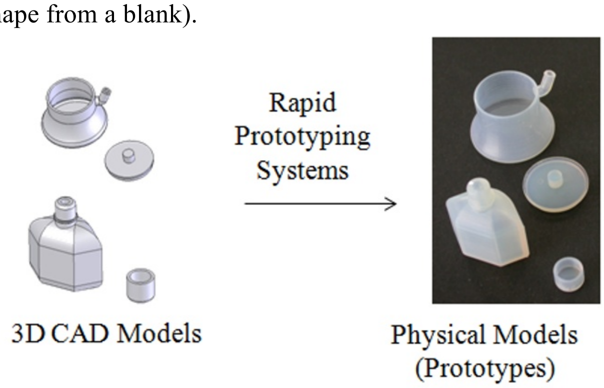

Fig. 1: Input-Output of rapid prototyping

However, there are few studies that provide insights into the environmental impact of rapid prototyping [8-10]. In fact, rapid prototyping (see Fig. 1) has extensively been used to producing physical models (prototypes) directly from 3D CAD models mainly using additive processes (e.g., Stereolithography) [11-12]. This helps stakeholders improve a design. Instead of using additive manufacturing process (e.g., Stereolithography, 3D Printing, Selective Laser Sintering, Laminated Object Manufacturing) [11-12], subtractive processes (e.g., milling, drilling, turning, etc.) can also be used to produce a prototype directly from a 3D CAD model. In this case, machining of wooden blank using a numerically controlled circular saw could be a better option because wood can easily be recycled and requires less energy to machine. This study explores this option and provides some insights into the environmental impacts of this option compared to that of Stereolithography (hereinafter referred to as conventional rapid prototyping).

The remainder of this article is organized as follows: Section 2 provides the case study of conventional prototyping. Section 3 provides a case study of wooden prototyping. Section 4 provides an environmental analysis of two prototyping processes described in Sections 2 and 3. Section 5 discusses some further research issues and provides a summary of this study. Section 6 concludes this study.

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2 CONVENTIONAL PROTOTYPING

Figure 2 describes a process of conventional rapid prototyping based on Stereolithography. First, a 3D CAD model is produced by using a commercial package, as shown in Fig. 2. Afterward, the CAD model is transformed into a model of facets (triangulation of the outer surface of the 3D model) wherein a facet is defined by three vertices of the triangle and the unit normal vector showing the orientation of it (facet) [11-12]. This provides a data format called STL (Stereolithography) data of the 3D CAD model. The STL data is then sliced into thin layers. Closed contours are generated for each layer. The data of the contours are used to generate the commands for controlling a rapid prototype machine. Accordingly, the machine solidifies photosensitive resin (in case of Stereolithography) with the help of a laser beam so that the solidified resin takes the shape of given 3D CAD model.

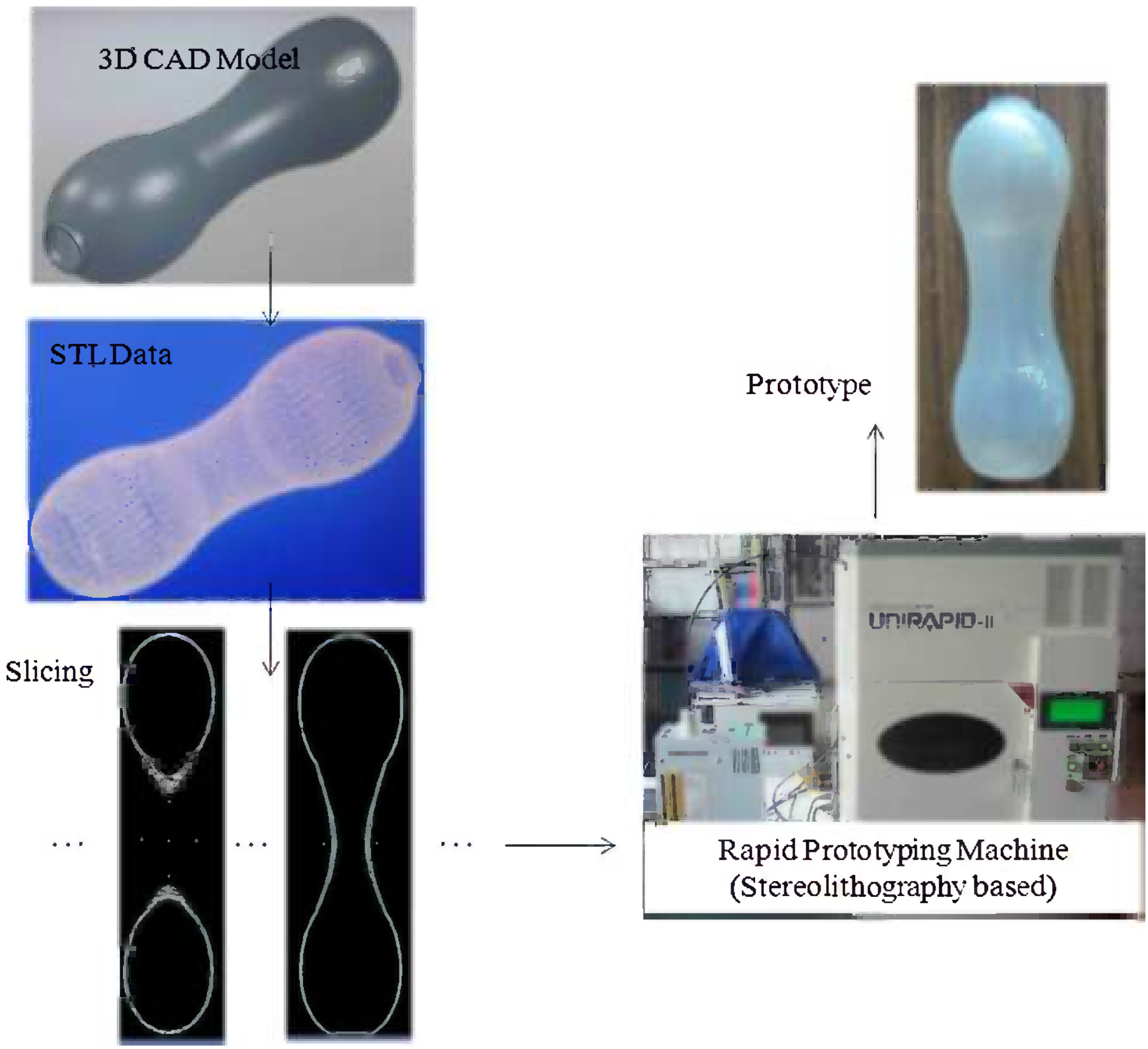

Fig. 2: Conventional rapid prototyping

3 WOODEN PROTOTYPING

On the other hand, instead of adding materials layer by layer, while producing a prototype, one can subtract materials from a blank to produce a shape, as it is done in conventional material removal processes (turning, milling, drilling, grinding, etc.). As such, wood can be machined to produce a prototype. To make the process similar to that of a conventional rapid prototyping, CNC controller should be used so that the 3D CAD model can be directly used to make the prototype. In particular the machine tool should remove materials from the surroundings of the contours produced during slicing (Fig. 2) and blank at each layer of slicing. The Hokkaido Forest Products Research Institute has developed such a machine tool [13-14]. The working principle of the machine is demonstrated by video-clips downloadable from the website in the reference [13].

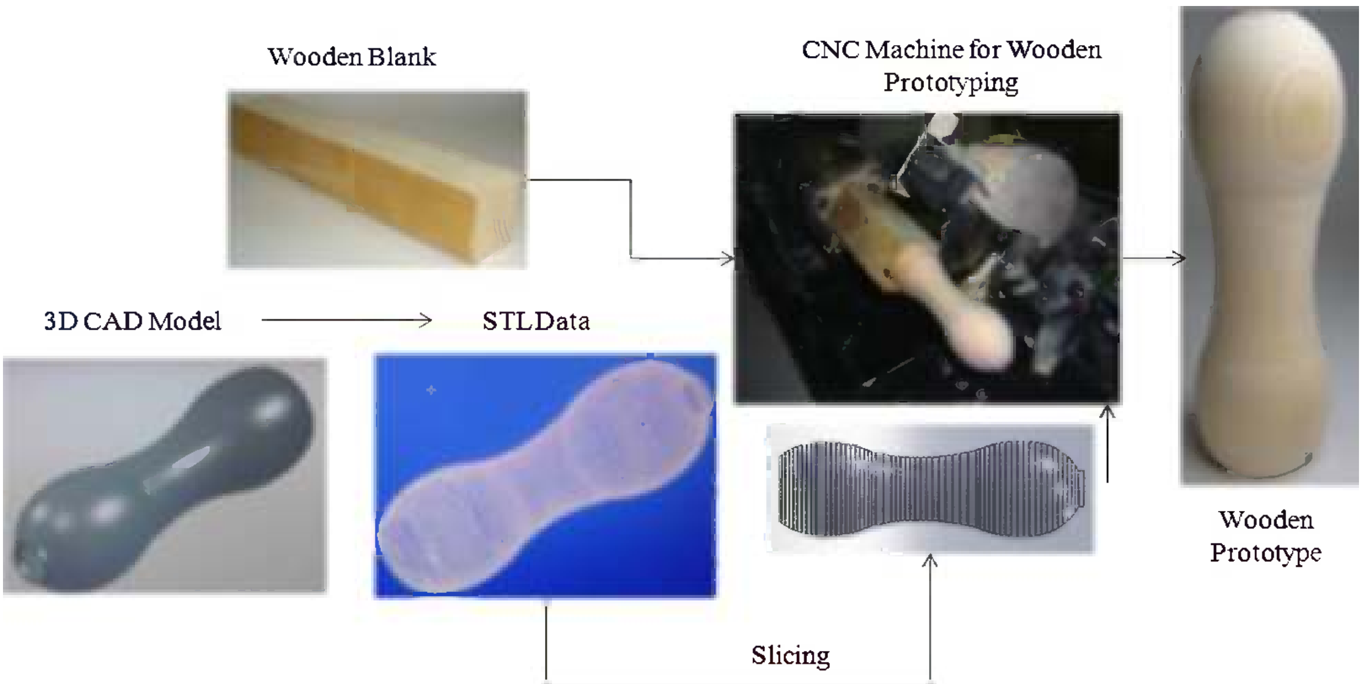

Fig. 4: Wooden prototyping

As seen from Fig. 3, a 3D CAD model is transformed into STL data and, then, slicing is performed as it is done in conventional rapid prototyping (e.g., Fig. 2). For each layer, a close contour is generated. The material between the blank and contour is removed by a circular saw. The movement of the saw (linear and rotational movements) and blank (rotational movement) is controlled by a CNC system. It is needless to say that the CNC system produces NC program using the data of contour for each slice.

4 ENVIRONMENTAL IMPACT ANALYSIS

This section shows the environmental impact assessment of two prototyping processes described in Sections 2 and 3 in terms of CO2 emission, time, and materials consumed. To perform the analysis, two prototypes, one made of resin and other made of wood, of the same 3D CAD model were produced, as illustrated in Figs. 2 and 3, respectively. First, consider the case of prototype made of resin. The prototype was made at Kitami Institute of Technology using the Stereolithography machine shown in Fig. 2. Table 1 lists the details of the process. As seen from Table 1, to produce the prototype, a relatively long time was needed (21 hours and 38 minutes) because the solidification of resin needs time. The prototype wall thickness was 1 mm and the volume of the material (amount of resin) used was 17.605 cm^3. The electrical energy (E) needed to complete the process was measured to be 11.83 kWh (resolution of measurement was 0.01 kWh). In Hokkaido prefecture (the region where Kitami Institute of Technology is located) the electrical energy has a CO2 footprint factor (F) of 0.433 kg-CO2/kWh, according to the Ministry of Environment, Japan [15]. Thus, the estimated CO2 emission of the process is as follows: $E \cdot F = 11.83 \times 0.433$ kg-CO2 = 5.12239 kg-CO2.

Consider the other case: prototype made of wood, as shown in Fig. 3. The study was carried out at Hokkaido

Forest Products Research Institute. The same 3D CAD model (the model used in the previous case study) was used.

Table 1: Results of prototype made of resin

Items	*Details*
Time needed	21 hours 38 minutes
Energy Consumption (E)	11.83 kWh
Thickness of (prototype) wall	1 mm
Internal Structure	Hollow
Material Consumed	17.605 cm^3
CO2 Footprint Factor (F)	0.433 kg-CO2/kWh
Estimated CO2 emission (E·F)	5.12239 kg-CO2

Table 2: Results of prototype made of wood

Items	*Details*
Time needed	Around 5 minutes
Energy Consumption (E)	0.04 kWh
Blank Size and Material	50 mm × 50 mm 300 mm (dry pine)
Internal Structure	Solid
Material Consumed	750 cm^3
CO2 Footprint Factor (F)	0.433 kg-CO2/kWh
Estimated CO2 emission (E·F)	0.01732 kg-CO2

Table 2 lists the details of the process. To produce the prototype shown in Fig. 3, a relatively short time was needed (around 5 minutes) because the circular saw could remove materials at a very high rate. The size of the blank was 50 mm × 50 mm × 300 mm made of wood (pine or *Todomatsu* in Japanese). For this case, the volume of the material consumed is the volume of the blank used (750 cm^3). The electrical energy (E) needed to complete the process was 0.04 kWh (resolution of measurement was 0.01 kWh). Thus, the estimated CO2 emission is as follows: E·F = 0.04×0.433 kg-CO2 = 0.01732 kg-CO2.

5 Summary and Discussion

Using the results in Tables 1 and 2 and also the observations of the authors, the performance of two types of prototyping technologies can be summarized, as listed in Table 3.

In synopsis, wooden prototyping process is faster and requires less energy and thereby produces less CO2 burden. In this sense, it is a better alternative for producing prototypes directly from 3D CAD models. On the other hand, resin prototyping process consumes less amount of material. In this sense, it is a better alternative for making prototypes directly from 3D CAD models. Wooden prototyping process requires hand polishing to make the prototype surface smooth enough. At the same time, it requires disposal of sawdust produced during material removal operation. These operations might produce an extra amount of CO2 burden. This issue remains open for further investigations.

Table 3: Summary of comparison

Items	*Resin Prototype*	*Wooden Prototype*
Manufacturing Process	Additive Process	Subtractive Process
Materials Consumption	Low	High
CO2 Burden	High	Low
Processing Time	High	Low
Hollow Prototype	Easy to make	Not easy to make

Resin prototypes also needs drying operation (curing) using ultraviolet rays. This operation might produce an extra amount of CO2 burden. This issue also remains open for further investigation.

One important issue is CO2 burden of respective materials [10]. In this particular case, the materials are resin and wood. Like any other raw materials, production of resin and wood put a substantial amount of burden on the environment in terms of CO2 emission, water usage, NOX, SOX, etc. This issue needs careful investigations.

6 Conclusions

Like additive processes of rapid prototyping, subtractive process woodworking by CNC machines can also be used as prototyping technology. Conducting real-life case studies identifies some eco-manufacturing issues of these two technologies. Scopes for further researches are also highlighted.

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Laminated Plastic Electronics: Energy Saving and Low Stress on Environment

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Abstract
We propose the hotpress method as a novel fabrication process of flexible sheet electronic devices. This process has the same advantages with the printing processes. And also, "solvent free" and "crystallization of organic semiconductor" are the additional advantages of this process. Sufficient crystallization of organic semiconductor contributes to the device performance, and no solvent emission provides a low environmental load process. Legal control on solvent emission will be overcome by this process. The low energy and no solvent emission process will also lead to not only the factory manufacturing but also the personal production of flexible sheet electronic devices in the future.
Keywords: Plastic sheet electronic device, Flexible electronics, Organic electronics, Solvent free process

1. INTRODUCTION

Recently the plastic electronics aiming for an ubiquitous society have been extensively developed [1, 2]. Now the plastic electronics is mainly developed by printing process of organic semiconductors, including inkjet printing, gravure printing, and so on because organic materials are soluble in various industrial solvents to make an ink for the printing processes. The plastic films of organic materials formed by printing processes also limit electronic properties and stability. Therefore, we propose a novel complemental method of printing technologies. This process will provide low energy cost, no solvent emission, and highly crystalline organic device. We call the novel method as "Melting process", which utilize a thermally melting organic semiconductors as a paint or a flexible plastic film itself [3]. By using a principle of a thermal press, a card laminator or a heat transfer printing, one can fabricate organic semiconductor devices on the plastic sheet with low input energy and without any solvent emission. Moreover, additional or succeeding thermal treatment will achieve a crystallization of the organic semiconductor. In fact, sufficiently large grain of anthracene of which grain size was over several millimeter had been achieved in our demonstrated experiments. Although the achieved grain size depends on organic materials and it's dimensionality, obtained grain diameters sufficiently exceed the typical device size.

Figure 1 is a conceptual illustration of a manufacturing system for a solvent free, low heat energy, and flexible plastic electronics. Pattering roller determines a designed pattern of semiconductor layers in a electronic circuit. To feed a raw material onto a patterning roller, heat transfer printing or electrostatic toning which is used in copy

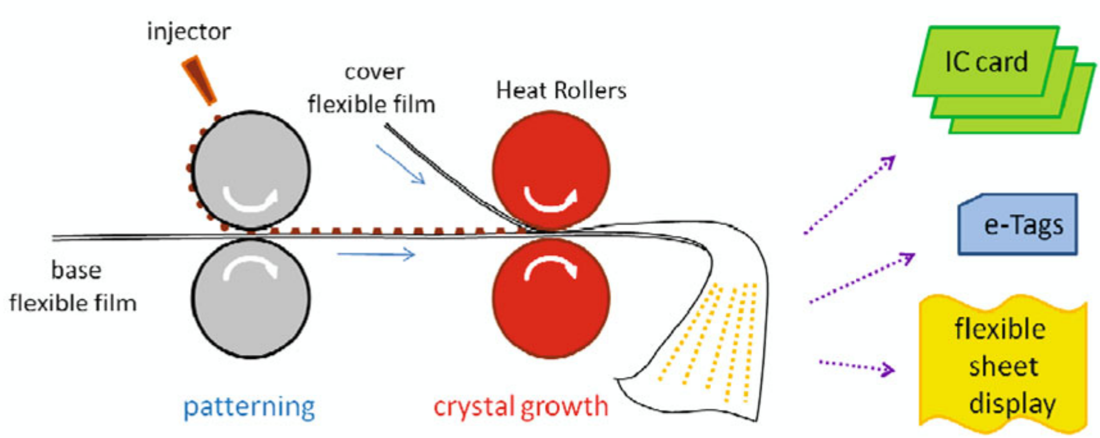

Fig.1 Conceptual illustration of hotpress patterning and printing process

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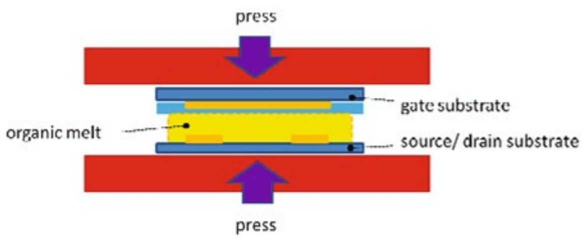

Fig.2 Schematic illustration of the experimental setup of the hotpress equipment and device structure.

machine are useful. The patterned organic semiconductors are transferred onto a sheet film substrate with the rotation of the patterning roller. These patterned organic semiconductors are conveyed to heat rollers to be molten, compressed and crystallized to become a crystalline organic device. The flexible sheet substrate is rewound to become a large roll. The densely rewound plastic sheet device also have a merit to low transportation and storage cost. The crystalline flexible devices are cut, completed and delivered as electronic tags, plastic IC crads, and sheet displays.

2. EXPERIMENTAL DETAILS

Figure 2 is a schematic illustration of our experimental setup. In this research phase, a small-scale clamp equipped with a load sensor and two individual heater blocks are used to find out an optimal melting temperature, applied initial/secondary pressure, and annealing temperature and so on. The melting temperature depends on target organic materials. The target material presented in this work is tetrakis(octadecylthio)tetrathiafulvalene (TTC_{18}-TTF) of which nominal melting point is 88^{o}C. Since this melting point is lower than the melting point of many industrial plastic sheet substrates, this material is the possible candidate for the flexible film device fabrication. Although we do not intend that the electrical properties of TTC_{18}-TTF is sufficient for industrial products, this material is suitable for a starting material for a demonstration of the proposing novel process. A search or synthesis of better organic materials are priority subject for future manufacturing. In addition, applied pressure control thickness of the molten material which define the device property and flexibility, or contribute to a decreasing a melting point of organic material.

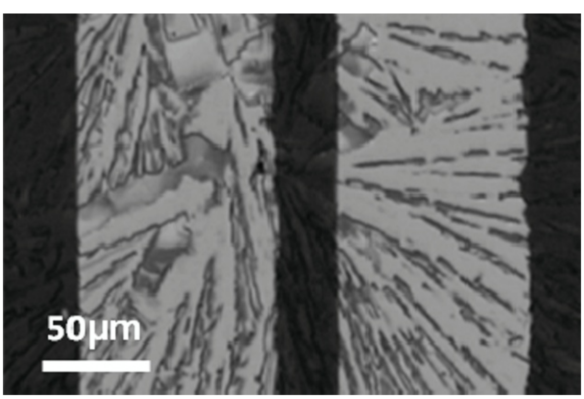

Fig.3 Optical micrograph of the grown crystals of TTC_{18}-TTF.

3. RESULTS AND DISCUSSION

An optical micrograph of the grown crystals of TTC_{18}-TTF was shown in Fig.3. Two vertical belts seen in the center of the image are Au/Cr source and drain electrodes of the transistor. The grain boundary of TTC_{18}-TTF crystals are seen. The shape of these crystals are rectangular, which reflects the one dimensional nature of molecular packing. The estimated typical grain size is 10 – 20 µm in width, over 50 µm in length. This size is larger than that of the TTC_{18}-TTF crystals grown by a solution cast method (1.5 - 5.5 µm in width and 20 - 30 µm in length).

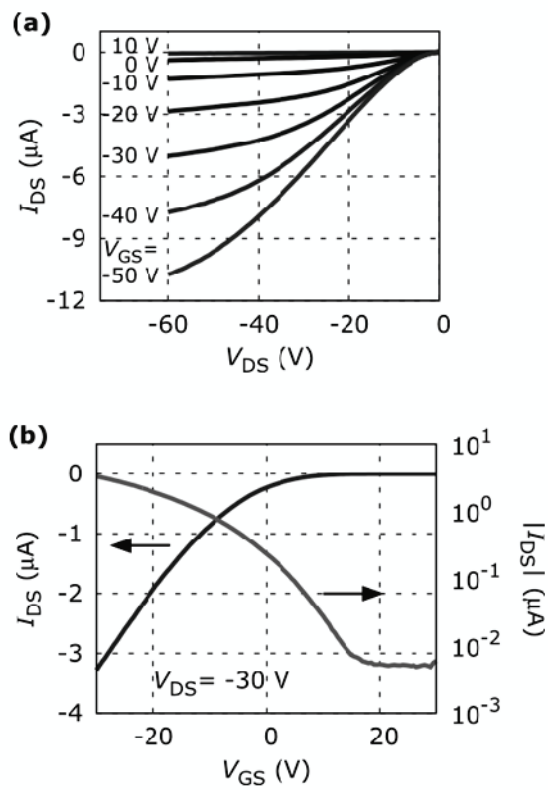

Fig.4 Output characteristics (a) and transfer characteristics (b) of TTC_{18}-TTF thin-crystal field-effect transistor.

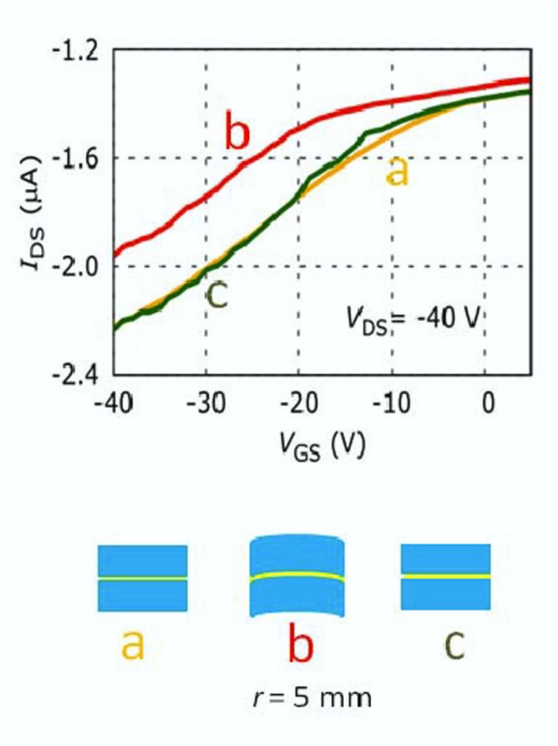

Fig.5 Transfer characteristics of a TTC_{18}-TTF flexible FET ; before the bending (a), during the bending (b), and after the release (c).

Figure 4 is output characteristics (a) and transfer characteristics (b) of the TTC_{18}-TTF field-effect transistor (FET) fabricated by the hotpress method by using two glass substrates. Typical p-type FET characteristics are obtained. The p-type characteristics are due to the donor nature of the tetrathiafulvalene ring in the TTC_{18}-TTF molecule. Estimated field-effect hole mobilities are in the range of 10^{-3} cm^2/Vs. The obtained hole mobility is over 7 times larger than that of the TTC_{18}-TTF FET grown by a solution cast method. Although the obtained carrier mobilities have not reached to practical use level yet, this issue will be resolved by a development of novel organic materials. In addition, FET characteristics of flexible TTC_{18}-TTF FETs fabricated by using two polyimide films as substrate also show the same level of hole mobilities.

Next, we carried out the bending test on our flexible film FETs. The bending test was examined by twisting the flexible film FET onto an Al round bar of which radius was 5 mm. Figure 5 is the transfer characteristics of a TTC_{18}-TTF flexible FET ; before the bending (a), during the bending (b), and after the release (c). Although the threshold voltage of the flexible FET shifts to higher side, field-effect mobility does not change even during the bending. Moreover, the transfer characteristics completely return to the initial curve after the release ; the mobility and threshold voltage are stable and reversible to the bending for the radius of curvature of 5 mm. This result indicates that the carrier channel do not have a irreversible mechanical damage by the bending operation. On the other hand on the threshold voltage shift, it is supposed that the number of hole trap site at around the observed grain boundaries increase by affecting the tensile stress on the boundaries.

4. SUMMARY

We have proposed the hotpress process for a high throughput manufacturing of flexible thin film electronic devices. We examined the fabrication of the flexible FET and the bending test by using TTC_{18}-TTF as a test material. The size of the grown crystals of TTC_{18}-TTF is several times larger than that of the crystals grown by a solution cast method. As a result, the grain size was sufficient for directly bridge the source and drain electrode. The obtained field-effect hole mobilities were also several times larger than those of the crystals grown by the solution cast method. Moreover, the bending test of which radius of curvature was 5 mm got sufficiently good results. The field-effect hole mobilities were not affected by the bending operation. By the development of the novel materials, practical application on the Roll to Roll process will be expected.

In addition, this type of melting process are effective for not only small molecule materials but also polymers. The polymer materials are soft, thermoplastic and have a mechanical strength compared to small molecule crystals. The existing technologies such as injection molding on the plastics are applicable for polymer materials. This degree of freedom on the device fabrication will also contribute to the invention of non planar, three dimensional new type devices.

ACKNOWLEDGEMENT

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Environmental Assessment of the Mobile Phone Considering the Consumption of Rare Metals

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Abstract

Nowadays mobile phones are essential for our daily life. The number of users of mobile phone in the end of November 2010 in Japan is nearly the population of Japan. The percentage of using precious metals in mobile phones is higher than that in other electric appliances to fulfill varies requirements. However, the assessment of mobile phone mainly focused on CO_2 emission, and few case studies were analyzed the environmental impact of resource depletion. Therefore, in this case study for mobile phone, the impact on resource depletion was evaluated as well as global warming. The mobile phones were actually disassembled, and the number of parts and their weights were measured. CO_2 emissions of all of the devices in mobile phones were calculated by using existing inventory database. The mobile phone manufactured in 2004 and 2010 were analyzed to detect the type and the amount of metals using the ICP (inductively coupled plasma) method. As a result, the resource depletion is evaluated by using TMR (total materials requirement), the LIME (life cycle impact assessment method based on endpoint modeling) damage factor and the LIME characterization factor. Several impact assessment methods were applied, and compared their results to raise common points and differences.

Keywords:
Rare metal, resource depletion, LCA, mobile phone

1 INTRODUCTION

Nowadays mobile phones are essential for our daily life. The number of users of mobile phone in the end of November 2010 in Japan [1] is nearly the population of Japan. Furthermore a variety of functions such as television, telephone and camera, are involved in a mobile phone, while the size of body is small. The percentage of using precious metals in mobile phones is higher than that in other electric appliances to fulfill varies requirements. The speed of technical innovation of mobile phones is fast. The amount of resource consumption is also changing through the improvement of technology. However, most of the assessment of mobile phone mainly focused on CO_2 emission, and few case studies were analyzed the environmental impact of resource depletion. Therefore, in this case study for mobile phone, the impact on resource depletion was evaluated as well as global warming. To evaluate the transition of environmental performance of mobile phones, the environmental assessment for several mobile phones were carried out.

2 METHOD

The mobile phones are actually disassembled, and the number of parts and their weights are measured to obtain the reliable data. Using this result, we assessed CO_2 emission. This study employed the database compiled by Japan association of communications and network, database published by JLCA (LCA society of Japan) and literature. JEMAI-LCA was used for calculation.

The mobile phone was analyzed to detect the type and the amount of metals using the ICP (inductively coupled plasma) method. As a result, the resource depletion was evaluated by using TMR (total materials requirement), the LIME2 (life cycle impact assessment method based on endpoint modeling) damage factor and the LIME characterization factor.

3 LIFE CYCLE ASSESSMENT OF MOBILE PHONE

3.1 Goal and scopes

This study's goal is to assess CO_2 emissions and the resource depletion. The studied product system is mobile phones manufactured in 2004, 2008, and 2010. System boundary of this study is showed in lined box; material procurement, parts manufacturing assembly transportation and use. However disposal and repair is not included. Substance evaluation is CO_2 emission and resources were analyzed as inventory items.

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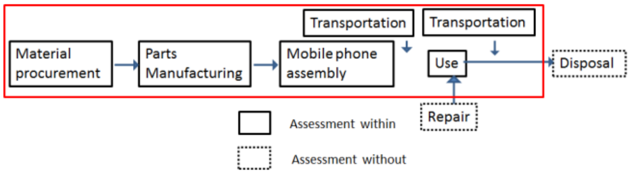

Fig. 1: Scope of study

3.2 Functional unit

Functional unit is one mobile phone except a charger. Life time is three years.

4 RESULT OF ASSESSMENT

4.1 Weight of parts of mobile phone

Figure2 shows the weight of three types of mobile phones. Total amount of mobile phones are similar. However, the amount of each part is different. It was confirmed that weight of metal in mobile phones increases from 2004 to 2010.

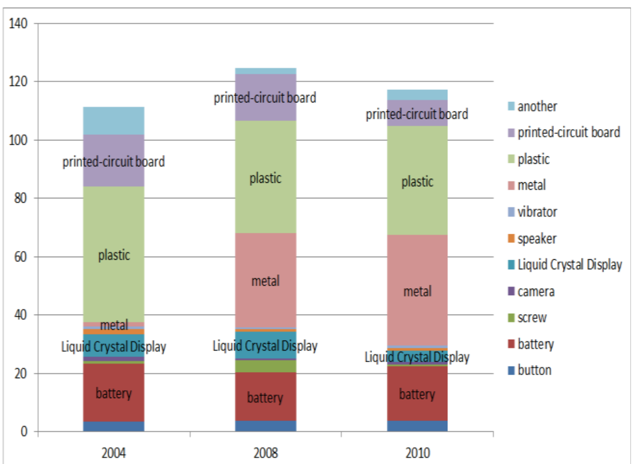

Fig. 2: weight of mobile phones

4.2 Life Cycle Inventory of mobile phone

Figure3 is the result of CO_2 emission. Accoding to the figure3, CO_2 emissions are decreasing. All of assessed products showed CO_2 emission is manugactureing stage occupied more than 90% of total..

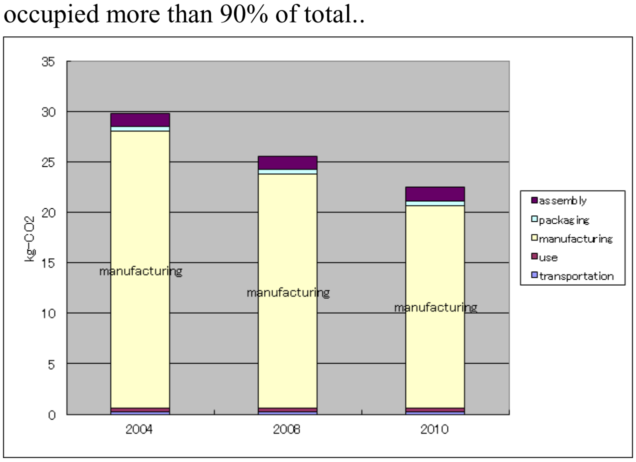

Fig. 3: result of CO_2 emission

4.3 Impact Assessment

The studied product system is mobile phones manufactured in 2004 and 2010. Figure4 shows the weight of metal contained in the mobile phone. Total amount of metal for both products are almost same or the weight of new product is slightly. Bromine was widely applied to flame retardant in the past. Present mobile phone does not contain bromine, because this substance is considered to generate toxic chemicals when it burns. With regard to rare metals and rare earth, 20 percent of all metals. Using this result, we evaluated environmental impact on resource depletion using four types of LCIA methods; TMR, LIME2 characterization factor, LIME2 damage factor. Figure4 showed the result of impact assessment using TMR approach. TMR is indicates the total amount of natural resources including over burden and gravel at mining. Total amount of new product showed higher than that of old type of product. This is because of the amount of gold containing in new product was decreased to minimize this. Gold is used to avoid corrosion. The result has the same tendency. Figure5 is the assessed results for on rare metal and rare earth. The calculated results using several methodologies also showed same tendency. Figure6 showed the result of assessment of TMR.

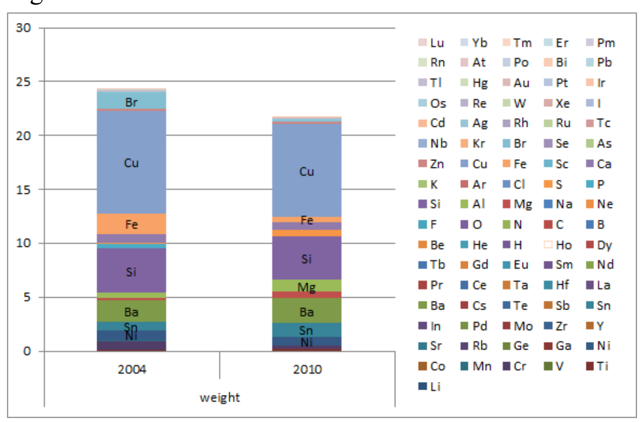

Fig. 4: the weight of metal contained in the mobile phone

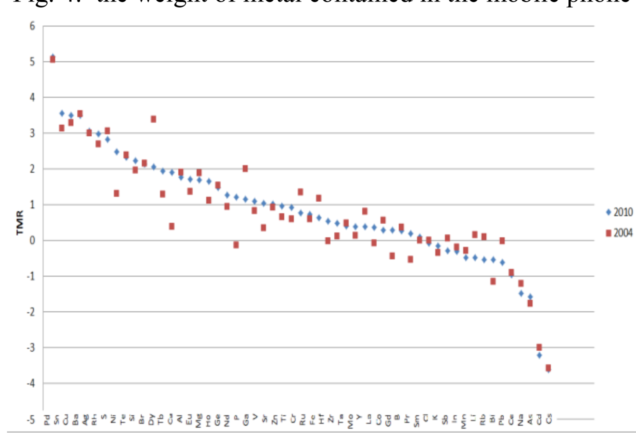

Fig. 5: result of assessment of resource depletion

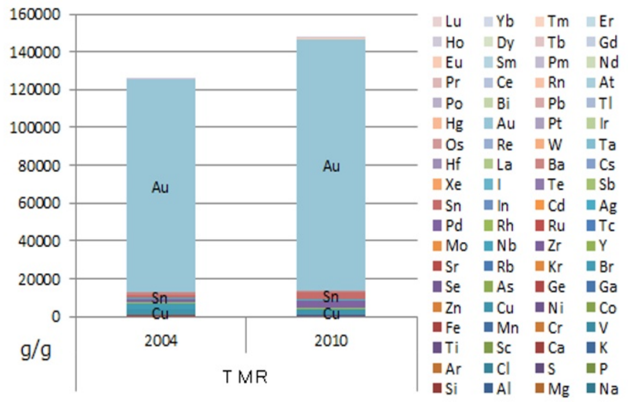

Fig. 6: result of assessment of TMR

5 LIMITATION

We used common database for all of assessed products although environmental burdens in the stage of metal production will vary as technology change. So, we couldn't see deferent of each other.

6 CONCLUSION

CO_2 emissions were decreasing, because emission form manufacturing stage was decreasing. However, it is necessary to reduce CO_2 emissions at manufacturing stage as subscribers increase. This study revealed that gold and silver have a larger impact. But precious metals such as gold and silver would be recycled after mobile phone throw away. On the other hand, the rest of metals including rare metals will not be recycled in general. If we include recycling stage in our study, the main result of impact assessment would be changed.

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Material Flow Analysis and Human Risk Assessment of Mercury

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Abstract
In this study, the material flows of mercury are identified using Material Flow Analysis (MFA) methodology and the effects of mercury on human are also examined using Human Risk Assessment (HRA). The MFA study shows that the total consumption of mercury in 2009 is reduced by 42% compared to 2000. It is used mainly in lighting appliances such as High-Intensity Discharge (HID) lamp, florescent lamp, and Cold Cathode Fluorescent Lamp (CCFL). Mercury-containing products are used in construction and electronic & electricity industries. Mercury is discharged into environment throughout its life cycle, especially in the stage of waste management. From the HRA study for different regions of Korea it is found out that the region with the largest amount of mercury emission into environmental media is different from the region with the highest risks. While Seoul is the second largest mercury emission region, Seoul is the most harmful place from the perspective of human risks by mercury.

Keywords:
Material flow analysis, Human risk assessment, Mercury-containing product

1 INTRODUCTION

Concerned about the harmful effects of mercury on human, the flows of mercury needs to be analyzed to trace where it is used and decide how to manage it. In this study, main flows of mercury throughout its life cycle are identified from MFA study and then human risks of mercury in different regions of Korea are assessed based on HRA study.

2 METHODOLOGY

2.1 MFA(Material Flow Analysis)

MFA is a systematic assessment of the flows and stocks of materials within a temporal and spatial system[1]. There are two types of MFA model - static and dynamic models. In the static model analysis, quantified results for material inputs and outputs are identified using data for production, import, export, and use pattern of the material in a particular year. The dynamic model is a method to predict material flow, stock and discharge using the Population Balance Model (PBM)[1][2]. The lifetime distribution of each product is applied to add the time lag concept to the static model. There is no international standard for the procedures of dynamic MFA, yet. In this study, dynamic MFA of mercury is conducted on the following procedures ; definition of system boundary, determination of the flow and stock, and analysis of the material flow and stock.

[1] Population Balance Model(PBM) is a way of ascertaining the total number of a product in use[4].

2.2 HRA(Human Risk Assessment)

HRA is defined as the process to qualitatively or quantitatively estimate the nature and probability of adverse health effects in human who may be exposed to chemicals in contaminated environmental media. In this study, the HRA of mercury is carried out through a series of interconnected steps including hazard identification, dose-response assessment, exposure assessment, and risk characterization[3].

3 DATA COLLECTION & CALCULATION

3.1 MFA

3.1.1 Definition of system boundary
The material flows of mercury are analyzed throughout its whole life cycle. The spatial and temporal boundaries of the MFA study are defined as the year 2009 and Korea, respectively.

3.1.2 Determination of the flow and stock
In this study, life cycle of mercury is divided into four stages; ‘material’, ‘manufacturing’, ‘use’, and ‘waste management’. Quantitive material flows are quantified from statistical data, documents, and expert interviews. With material input and lifetime distribution for each industry, dynamic model is conducted using PBM. Material flow diagram is drawn for better understanding the results of MFA on mercury with identified flows, processes, and stocks.

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3.2 HRA

3.2.1 Hazard identification

Hazard identification is used to determine if a material is likely to be hazard of human health[5]. Mercury is included in the priority list of 17 chemicals in Korean Chemical Ranking and Scoring System (CRS-Korea)[2][6].

3.2.2 Dose-response assessment

Dose-response assessment is used to estimate the amount of a material that is expected to produce a hazardous effect on human[3].

Since U.S. Environmental Protection Agency (U.S. EPA), mercury is classified as a non-carcinogen, the hazardous effect of mercury is estimated based on the method of risk assessment of non-carcinogen which is modeled by European Union System for the Evaluation of Substances (EUSES)[5].

3.2.3 Exposure assessment

Exposure assessment is used to determine the extent to which a population is exposed to a material[3].

In this study, the hazard of mercury through air and water emissions is considered except soil emissions. Since the soil emissions of mercury are specially managed as hazardous waste in Korea, it is assumed that there is no harmful effect by soil emissions.

3.2.4 Risk characterization

This is the quantitation of the risk following consideration of the exposure and the dose-response relationship[3].

In this study, hazardous quotient for human health is deducted using reference concentration of human toxicity through inhalation and ingestion of mercury.

4 RESULTS

4.1 MFA

In Korea mercury consumption is completely dependent on import in the 'material' stage.

Imported mercury is then processed for various mercury-containing products, and some of them are exported in 'manufacturing' stage. The amount of mercury consumed in the mercury-containing products are calculated including the amount of mercury in the imported mercury-containing products. HID lamp [3] accounts for 33%, fluorscent lamp for 26%, battery for 25%, CCFL[4] for 11%, and others for 4% of the total mecury consumed in the mercury-containing products in 2009. The mercury-containing products are used in construction and electronic & electricity industries. Since most of mercury containing products have short lifetime, it is discharged into environment within relatively short period of time.

The total domestic consumption of mercury decreased from 29,683ton in 2000 to 20,720ton in 2009. Fig. 1 shows the amounts of mercury annual consumption in mercury-containing products from 2000 to 2009. While 60% of mercury was used for fluorescent lamp, 22% for amalgam and 11% for HID in 2000, 50% is being used for HID lamp, 26% for fluorescent lamp and 20% for CCFL 2009. Because of recent increase in the damand of mercury in HID and CCFL, the consumption of mercury increased significantly in both HID and CCFL over the last ten years. On the other hand, there is no significant change in the demand for fluorescent lamp compared to that in the past.

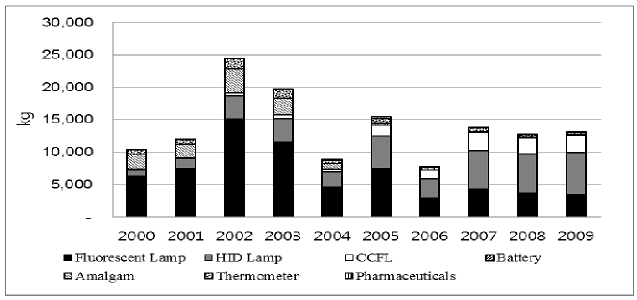

Fig. 1 : Mercury consumption in mercury-containing product

The dynamic MFA using PBM shows that as a result of recent decrease in the use of mercury, net stock of mercury became minus and, thus, the total stock also decreased since 2000. Mercury is being discharged into environment throughout the entire life cycle processes. The total mercury emission also decreased during 2000-2009. In 2000, mercury emission was 50,817 ton, compared with 21,452 ton in 2009. Soil wastes account for 78% of the total mercury emission. In Korea most of mercury soil wastes are from the stage of 'waste management', while no mercury is emitted in the stage of 'material', since mercury is not produced in Korea. At present, the recycling rate of mercury from the waste mercury-containing products is very low, it is essential to improve the recovery rate and develop recycling technology together with appropriate life cycle management of mercury-containing products.

4.2 HRA

As show in Fig. 2, the results of emissions and human risk of mercury for 16 cities/probvinces in Korea are represented.

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2 The CRS-Korea system takes a basic concept of risk assessment in that risk score is determined by the product of toxicity score and exposure score.

3 HID lamp is a type of electrical lamp which produces light by means of an electric arc.

4 CCFL are used for backlighting of LCD displays, for example computer monitors and television screens.

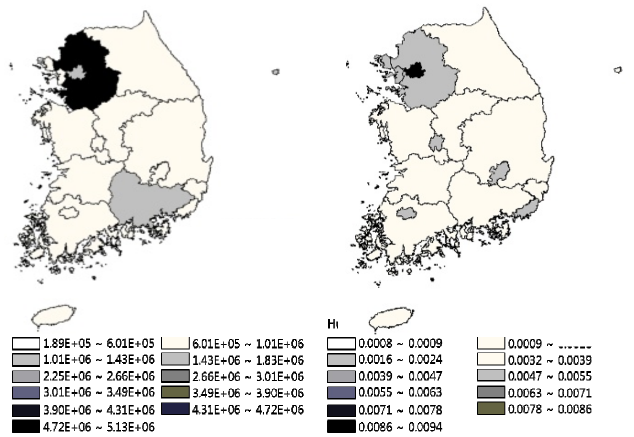

Fig. 2 : Results of emissions and human risk of mercury in Korea

Table 1 provides the results of emissions and human risks of mercury in major 5 regions in Korea.

While the region GG has the largest mercury emission in Korea, SU is the most harmful place from the perspective of human risks by mercury. The reason for this discordance is that human risks of mercury is calculated based on the amount of mercury exposed by air inhalation and water ingestion which reflect not only the amount of mercury emission but also the volume of air and water for each region.

The contribuions of each environmental media for human risks is 93.60% in air and 6.40% in water, respectively. In addition, the contributions of human risks throughout its life cycle are 0.85% from 'manufacturing', 0.06% from 'use' and 99.09% from 'waste management', respectively.

Table 1 : Results of emissions and hazardous quotient of mercury

Emissions of Mercury		
Region	Emissions(mg-day)	Contribution(%)
GG	4.33.E+06	33.11
SU	1.58.E+06	12.10
GSN	7.96.E+05	6.09
CCN	7.92.E+05	6.06
GSB	7.44.E+05	5.69
Human risk of Mercury		
Region	Hazardous quotient	Contribution(%)
SU	8.95E-03	37.80
BS	2.89E-03	12.23
IC	2.61E-03	11.03
GJ	1.93E-03	8.14
DJ	1.57E-03	7.22

* SU : Seoul, BS : Busan, DG : Daegu, IC : Incheon, GJ : Gwangju, DJ : Daejeon, US : Ulsan, GG : Gyeonggi, GSN : Gyeongsangnam, GSB : Gyeongsangbuk, CCN : Chungcheongnam, CCB : Chungcheongbuk

5 CONCLUSIONS

In this study the material flows of mercury in Korea are identified by using the MFA methodology. The total domestic consumption of mercury decreased from 29,683ton in 2000 to 20,720ton in 2009.

Mercury is used mainly in lighting appliances such as HID lamp, florescent lamp, and CCFL. As a result of recent decrease in the use of mercury, net stock of mercury became minus and, thus, the total stock also decreased. Mercury discharged into environment becomes crucial. Most of mercury soil wastes are from the 'waste management' stage, while no mercury is emitted in the stage of 'material', since mercury is not produced in Korea. It is essential to improve the recovery rate and develop recycling technology together with appropriate life cycle management of mercury-containing products.

The emission of mercury into environmental media in the HRA study are calculated based on the material flows identified from the MFA. The main sources of human risks for environmental media and life cycle are identified as air and 'manufacturing' stage, respectively. In addition, human risks of mercury are anayzed for different regions of Korea. The region with the largest amount of mercury emission into environmental media is different from the region with the highest risks, since human risks of mercury for regions is determined not only emissions but also pollution quality.

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Analysis of China's Forest–Paper Integration Project

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Abstract
China's pulp and paper industry grows rapidly in recent decades. During the raw material transformation from non-wood to wood, the demand pressure of wood increased dramatically. The forest–paper integration project was launched to support the sustainable development of China's pulp and paper industry. The necessity of the implementation of forest–paper integration project, it's enforcement mode, the achievement, existing problems and suggestions are analysed in this paper.

Keywords:
forest–paper integration project, existing problems, suggestions

1 THE BACKGROUND OF FOREST–PAPER INTEGRATION PROJECT

China's pulp and paper making industry develops very fast, it's domestic consumption of paper and paper board increased to 85.69 million tonnes in 2009, while the domestic production of paper and paperboard reached to 86.4 million tonnes. With these two high records of 2009, China has surpassed the United States to be the largest producer and consumer globally. However, as ZHU Xing-yue [1], LIN Yun-hua [2] studied, the international competitive power of China's pulp and paper making industry was comparatively incompetent, it does not improve simultaneously with the rapid growth of production and consumption scale. The reasons of this industry's unbalanced development should be vary, the predominant one lie in it's uncommon raw material structure [3]. Fig. 1 showed the raw material structure variation of China's pulp and paper making industry from 2000-2009 [4]. It is easy to find that the wood pulp consumption percentage is barely above 20%, quite lower than that of Finland, Sweden and America of 95% [5]. The shortage of wood resource restricts the manufacture of more kinds of high grade paper products that significantly undermining the international competiveness of China's pulp and paper making industry. Meanwhile it brings huge pollution because of mass use non-wood pulp that makes the industry to be one of the most direct criticism of the objects whenever mentioning high energy consumption and high pollution industry in China. For the industry's further sustainable development, the raw material transformation from non-wood to wood is imperative. Because of limited subsistent forest resource, to some extent, the supply of wood pulp are depend on abroad. In 2009, the imported wood pulp and recover paper pulp took 44% of the gross pulp. More specific

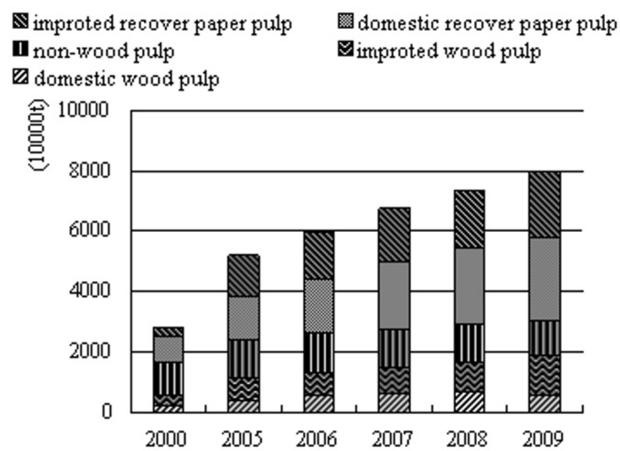

Fig. 1 The raw material structure variation of China's pulp and paper making industry from 2000-2009

evaluating, those imported pulp possess over 50% of the wood-based pulp indicating that China's wood resource imported dependency is excessively high. The large importation promotes the capital out-flowing, as statistic, in 2001, the cost of importing wood pulp, paper and paperboard was 117 billion dollars equalling to the investment of Three Gorges Project [6]. With the high importing dependence, our country lost the word's power of international pulp and paper price; it has become a big potential problem of our pulp and paper industrial economy. Under this unfortunate circumstances, the Forest–Paper Integration Project which concerns further development of pulp and paper industry that combines fast-growing and high-yield plantation , pulping and paper together, emphasising on domestic wood resource supply was proposed and carefully implemented.

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2 THE STATE OF ART OF FOREST-PAPER INTEGRATION PROJECT

2.1 The distribution of fast-growing and high yield plantation for forest-paper integration project

On July 4, 2002, the State Planning Commission formally approved the implementation of "construction project planning of key areas fast growing timber forest base" [7]. In this construction project, there are four key areas, the southeast coastal, the middle and lower reaches of Changjiang River, the middle and lower reaches of the Yellow River and the northeast and Inner Mongolia designed to plant fast growing timber with the purpose of supplying raw material for the forest product industry of pulp, paper, made board and construction, furniture manufacturing and architectural decoration. The main fast-growing and high-yield tree species and designed planted area especially for pulp and paper making industry are listed in table 1[8]. It could be find that the eucalyptus, poplar and pine are the most favourate fast growing species. According to different climate conditions, most of eucalyptus are planted in the south while poplar are planted in the north.

On February 16, 2004, approved by the State Council, led by the National Development and Reform Commission, " project construction and the 2010 Special Plan" completed by the State Forestry Administration and light industry sector, and began to implement [9]. In this new project, the southwest area including Sichuan, Yunnan, Guizhou and Chongqing was added as the fifth key fast growing timber forest base. The eucalyptus, masson pine, pinus khasys and especially bamboo were recommended as main fast-growing and high-yield tree species [10]. Until 2008, there were over 20 forest-paper integration plantation bases been built owned by Tiger forest & paper, Fujian Nanping Paper Co. Ltd, Fujian Qingshan Paper Industry Co. Ltd, Guangzhou Paper Co. Ltd and etc. respectively [11].

2.2 The enforcement mode of forest-paper integration project

As the economical and natural conditions in various areas are different, the enforcement modes of forest-paper integration projects carried out are not the same, generally, there are four ways .

(1) The pulp and paper making companies build their own raw material forest bases by themselves, turning the forest bases into the front line workshop [12] .

(2) The pulp and paper making companies sign sales contract and pay a certain amount of subscription to Foresters. Correspondingly, the foresters supply the specified qualified wood to the companies under the contract.

(3) The pulp and paper making companies sign sales contract to foresters to get enough wood as (2). The different point is, the companies also provide the foresters the nursery stock , chemical fertilizer, management fee and some technical support instead of paying subscription [13].

(4) The pulp and paper making companies invest the state-own forest farms, collective tree farms or foresters become the shareholders. The companies have the right to run and manage the forest bases [14] .

Table 1. The distribution of fast-growing and high yield plantation for forest-paper integration project

Area	The southeast coastal	The middle and lower reaches of Changjiang River	The middle and lower reaches of the Yellow River	The northeast and Inner Mongolia
Provinces	Guangdong, Guangxi, Hainan, Fujian	Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Yunnan	Hebei, Shangdong, Henan	Heilongjiang, Jilin, Inner Mongolia
Main fast-growing and high-yield tree species	Eucalyptus, Acacia, Pinus caribaea, Masson pine	Populus euramevicana cv.'I-214', Taxodium ascendens Brongn, Eucalyptus, Phyllostachys Pubescens, Masson pine, Pinus taeda, Pinus elliottii Engelm, Pinus yunnanensis, Pinus Khasya	Triploid Populus tomentosa, Populus euramevicana cv.'I-214', Populus X canadensis cv. 'Sacrou 79'	populus ussuriensis, Populus suaveolens, Pobulus davidiana, Larix gmeliniiKuzenneva, Larix olgensis, Japanese larch
Designed planted area (10^4 hectare)	141.8	124.7	78.2	241.3

3 EXISTING PROBLEMS AND SUGGESTIONS

Insurance is very important for the steady development of high-risk forestry because of forest fires, natural disasters such as droughts, floods, typhoon and mudslides, pest and disease damage. China started forestry insurance in 1982. 12 years later, there were over 20 provinces opening forestry insurance for fir plantation, timber forest, mixed forest and protection forest. However, because of the reform of forestry insurance being classified as commercial insurance, the high rate of payment, difficult claims and lack of experienced professionals, the development of forestry insurance went into the bottom, until 2003, the south tried policy-based forestry insurance [15]. At the initial stage of development , this new type of insurance is just against forest fire. The fig. 2 shows the national damage areas of forest pets, forest rat disaters, forest diseases and forest fire of 2003-2009 [16] [17]. From the figure, it could be seen it is the forest pests that damage the largest areas rather than forest fire, and the damage areas of forest rat disasters and forest diseases are also larger than that of forest fire. In another word, the forest fire is not the only danger that threatens the harvest of forest, the forest pests, forest rat disasters and forest diseases should also be listed in the forestry insurance catalogue. Especially, as to the fast growing timber, the harm of forest pets and forest diseases could be very severe. Take eucalyptus for instance, according to the statistics, there were 285 eucalyptus pets species in 2001, growing 5 times more than that of 1980 and over 30 eucalyptus diseases with the occurence rate of 5%-7% reducing 3×105-7×105m3 of annual accumulation volume growth [18].

Another fact is the foresters' negative attitude of forestry insurance. In LENG Jing's questionnaire survey [19], there are only 39.73% of investigated foresters willing to buy forestry insurance while 12.33% are unwilling to join the insurance, 2.74% oppose the insurance and the rest choose to stand aside. For the foresters who are unwilling or

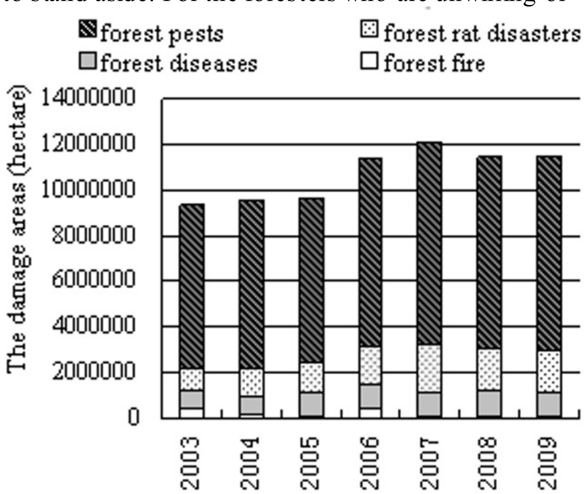

Fig. 2 The national damage areas of forest pets, forest rat disaters, forest diseases and forest fire

oppose buying insurance, the reasons are halfly because of high premium, 30% of inconvenient procedure and 10% of difficult claim. To expend the forestry insurance, it is better for the government to raise the policy-base subsidy lever lowering foresters insurance cost. Specially for the fast growing timber bases, the pulp and paper making companies as the co-operater or shareholders of the forest, are recommended to share the premium with the foresters further reducing their burden. With regards to the improvement of insurance procedure, Japan's national forest insurance could be a good example. The fig. 3 shows the organization and management system of Japan's national forest insurance [20]. The joint of national forest insurance is very convenient for the forest owners. When they want to sign the insurance contract with the national special account for forest, they can send insurance application and premium payment to the related agency such as Municipal, Forestry cooperative and JForest which are business appointed by the special account for forest. When the damage occur, the forest owners do not have to contact with special account for forest directly, they can communicate with nearby appointed agency instead. Then, the agency will ask the representative of legally entrusted to investigate the damage and deliver the report to the special account for forest. Finally, the special account for forest payout the insurance to the forest owners according to the report. All through the process, the only thing forest owners need to do is to send damage notification to related agency then the compensation will be sent to them on time. To contrast, when the damage happen, the forester in China have to inform the insurance company far away they signed contract with directly because the company

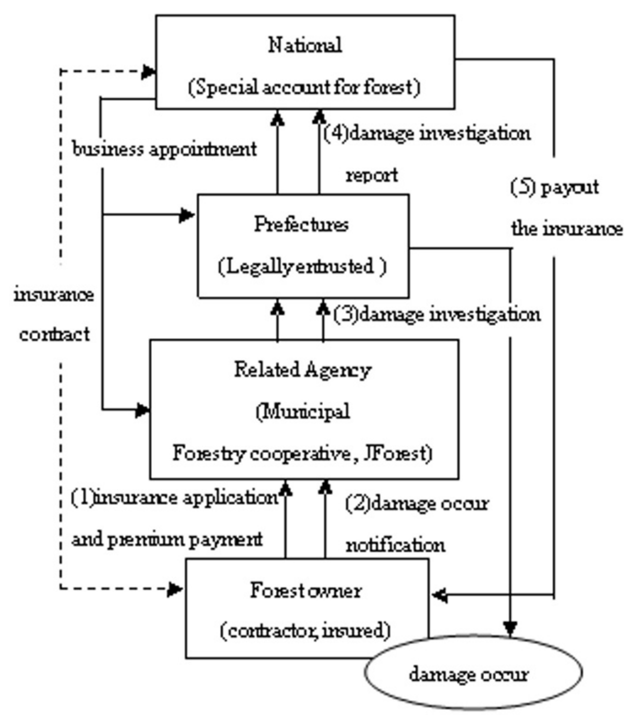

Fig. 3 The organization and management system of Japan's national forest insurance

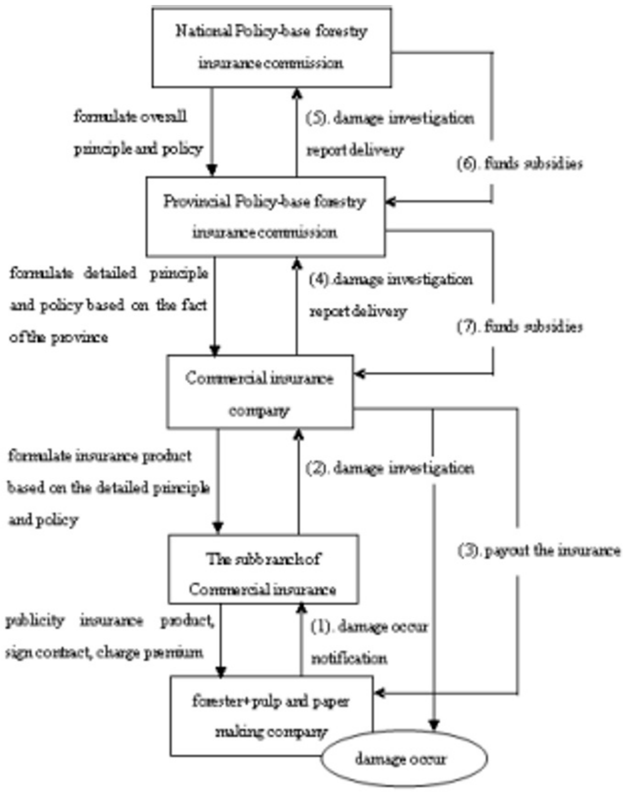

Fig. 4 The modified organization and management system of China's police-base forestry insurance

seldom open affiliated agency in the village. Moreover, the damage survey period could be very long due to the lack of experience professional. As a result, the foresters probably could not get the compensation on time. This may be the reason why many forester show no enthusiasm to the forestry insurance. It is better for the Chinese insurance companies to learn from abroad opening more branches near the foresters where they could turn to in the first place, and train more employees who are familiar with forestry information that could be really helpful for the foresters.

The modified organization and management system of China's police-base forestry insurance was shown in fig. 4. The system is mainly composed of 4 parts, the national police-base forestry commission, the provincial national police-base forestry commission , the commercial insurance company and the forester and pulp and paper making companies. The national police-base forestry commission is on charge of formulating overall principles and policies and pass them to the provincial police-base forestry commissions. Then the provincial commissions make and publish detailed principles and policies based on the truth of province. The local commercial insurance companies develop forestry insurance product according to the detail principle and policies. Finally, the subbranches of the commercial insurance companies publicise the forestry products to the foresters and pulp and paper making companies. The paper making companies who had contract with the foresters may help the forester to pay part of the premium, the percentage is decided by the contracted sales volume or the negotiation between the foresters and paper making companies. When the damage occur, the foresters together with paper making companies may send damage notification to the nearest subbranch of insurance company. Then the subbranch deliver the message to the head office. After the damage investigation, the insurance company could payout the insurance to the forester and paper making companies according to the detailed principles and policies and the insurance contract to advance , after the clearing financial subsidies. By this routine, the wait time that foresters cost for the compensate is dramatically shorten.

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Effect of Alkali Metal Oxide on Pb Recovery from the Waste CRT Glass by Reduction Melting Method

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Abstract
Treatment of waste CRT glass has been a social subject. Pb was separated from waste CRT glass contains Pb by reduction melting method. PbO is the easiest to reduce oxide in CRT glass component. But most of Pb exists not as PbO but as Pb^{2+} ion in CRT glass. And as Pb removes from glass, viscosity of glass becomes higher. So reduction of PbO and separation of Pb from glass is barred. By addition of alkali oxide, activity of PbO increases with an increase in the basicity and glass viscosity decreases. Relationship between addition of alkali metal oxides and Pb separation from glass was investigated.

Keywords:
Cathode Ray tubes (CRT), Reduction Melting, Pb, Recycling, alkali metal oxide

1 INTRODUCTION

Waste CRT (Fig.1) from TV and PC monitor are collected in many countries in the last decade, but it is becoming difficult to use the collected CRT glass as the raw materials of new CRT. That is because the display system of television changed from CRT to LCD quickly. CRT production in Japan has finished in 2005, and CRT production in the world is limited now.

Glass composition of CRT is very different from other popular glass, such as bottle, sheet glass, light tubes, etc. CRT glass cullet can't be utilized for other glass raw materials. Funnel that is backside part of CRT contains about 20 mass% of hazard PbO (oxide conversion value). It is not easy to landfill for risk of leaching Pb from glass. On the other hand, Pb is important base metal for industry, for example, raw material of lead storage battery. Pb recovering from funnel will be one of important option for waste CRT treatment.

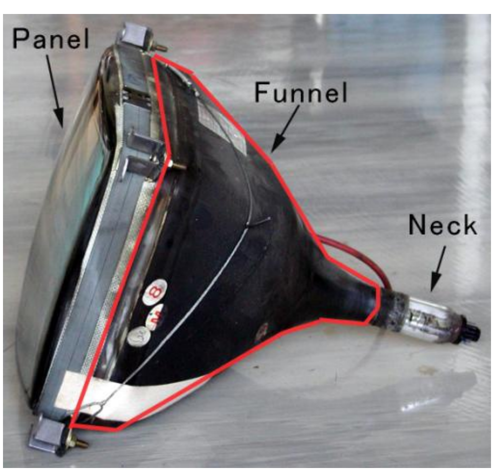

Fig. 1: Dismantled CRT from TV .

Pb recovery was investigated by method of reduction melting [1-4], electrolysis [4], chloride volatilization [5], pyrovacuum [6], chelate extraction [7], etc. In reduction melting method, Pb is separated from glass through a chemical process and physical processes. The chemical process is reduction of PbO in glass. And the physical processes are Pb particle growth and precipitation in glass. For both processes, it is necessary to decrease viscosity of glass. Viscosity depends on temperature and composition of glass. Ordinary, glass is composed of network former (NWF) like SiO_2 and network modifier (NWM) like alkali and alkaline earth metal oxides. Viscosity becomes lower by addition of NWM source. Simultaneous PbO activity increases with an increase in the basicity by addition of alkali metal oxide, too.

In the previous paper [1], Pb recovery from CRT funnel glass by reduction melting with only Na_2CO_3 as viscosity improver was reported. In this study, existence of Na addition to reduction melting was compared. Next, added Na was replaced by other alkali metal elements, Li and K. Effect of adding alkali metal oxides on Pb separation from glass was investigated.

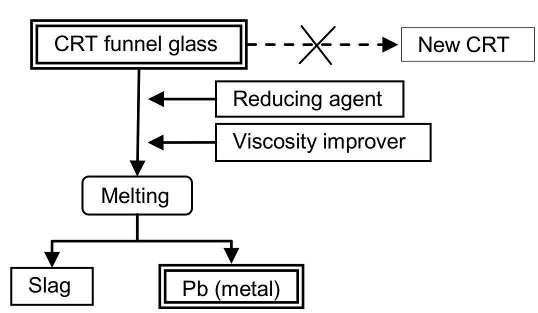

Fig. 2 : Scheme of the CRT treatment system.

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2 EXPERIMAENTAL

2.1 Materials

The glass used in this study was waste CRT funnel glass powder (in Short, FG powder) generated by crushing and grinding of funnel glass at demonstration plant of Association for Electric Home Appliances in Japan. Particle size is under 1mm. FG powder includes about 20mass% of PbO. FG powder is estimated by X-ray Fluorescent analysis (XRF), X-ray diffraction (XRD), Thermogravimetric analysis (TG) and optical microscope.

Flour is used as reducing agent like dry process for determination of gold and silver in ores. Alkali carbonate is added as viscosity improver source. Mainly Na_2CO_3 was used .To compare viscosity decrease effect, Li_2CO_3 and K_2CO_3 were used.

2.2 Reduction Melting

The samples prepared from 20g of FG powder mixed with 0-10g of flour and 0-10g of alkali carbonate were put into heated alumina crucible in electric furnace at 1523K in several times. After whole quantity was put, electric furnace was kept 1523K for 1 hour and turned off.

2.3 Characterization

After natural cool down to room temperature, glass in crucible was cut by diamond wheel saw. Cross section was observed. The microstructure was observed by transmission optical microscope. Glass part without precipitated Pb was ground by alumina mortar and particle size under 106 micrometer was used for analysis by XRF, XRD and differential scanning calorimetry (DSC). Pb content decrease relatively as adding alkali carbonate, Pb separation is estimated by PbO/SiO_2 mass% ratio and Pb elimination ratio. Pb elimination ratio $E_{pb}(\%)$ was calculated by the following formula.

$$E_{Pb}(\%) = \frac{M_{E-Pb}}{M_{FG-Pb}} \times 100 = \frac{M_{FG-Pb} - M_{M-Pb}}{M_{FG-Pb}} \times 100 \quad (1)$$

$E_{pb}(\%)$: Pb elimination ratio

M_{E-Pb} : Pb elimination mass

M_{FG-Pb} : Mass of Pb contained in FG powder

M_{M-Pb} : Mass of Pb contained in melted glass

3 RESULTS AND DISCUSSION

3.1 Characterization of FG powder

A microscope photograph of FG powder is shown in Fig. 3. XRF analysis result of FG powder is shown in Table 1. FG powder contains 20.6 mass% of PbO.

TG curve of FG powder is shown in Fig. 4. The weight does not change until 1273K. Over that, weight decreases a lot. At 1573K, weight loss is 1.6%.

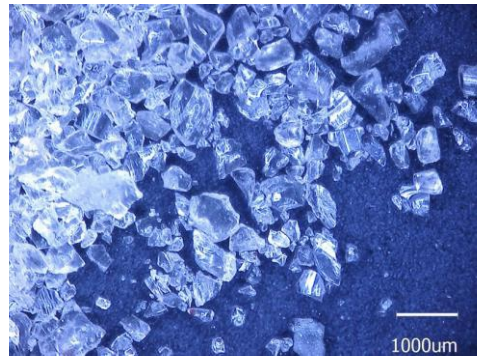

Fig. 3 : Microscopic photo of FG powder.

Table 1 : XRF analysis result of FG powder. (Oxide conversion)

Component	mass%
Na_2O	4.6
MgO	1.7
Al_2O_3	3.8
SiO_2	55.6
K_2O	5.8
CaO	3.9
SrO	1.5
PbO	20.6
The other	2.5

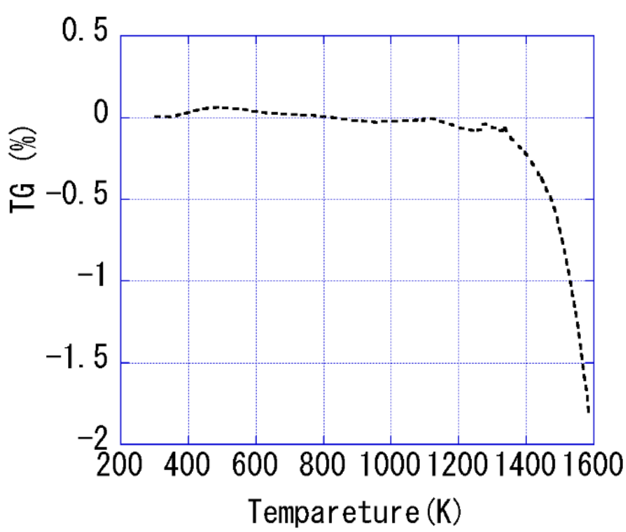

Fig. 4 : TG curve of FG powder.

3.2 Reduction melting of FG powder

When only FG powder was melted at 1523K, transparent pale green glass was obtained. Coloring is influence of small amount impurity iron included in FG powder. XRD pattern is shown in Fig. 5 (a). The broad halo pattern without peak is observed. That indicates typically amorphous. PbO content in glass decreased to 19.0

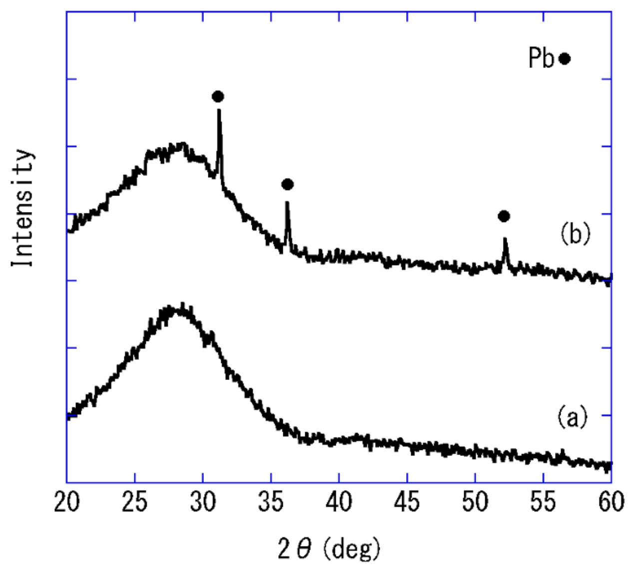

Fig. 5 : XRD pattern of (a) melted only FG powder, (b) melted with flour.

mass%. By TG measurement, the weight loss is found over 1273K, so it seems that Pb in glass decreased by volatilization while melting.

Obtained glass that is melted mixture of 20g of FG powder and 3g of flour looks gray and metal Pb lump was found in glass.

Reduction and Oxidation (Redox) equilibrium of Pb and PbO with CO and CO_2 is written as:

$$PbO + CO = Pb + CO_2 \qquad (2)$$

PbO is oxide which is the easiest component to be reduced in funnel glass. PbO in glass is reduced by CO gas generated by combustion of flour.

PbO content in glass decreased to 11.0 mass%. By microscopic observation, it found that a lot of small particle was distributed in colorless clear glass. Radius of the particles was about 1-10 micrometer. XRD pattern is shown in Fig. 5 (b). Pb peak was detected. By DSC measurement, endothermic peak beginning at 600K that is Pb melting point was observed. It is assumed that the cause by which melted glass became gray is distribution of Pb particle. Amount of flour added to 20g of FG powder was increased 4, 6, 10g. The relationship between added flour and PbO content in glass is shown in Fig. 6. When the amount of added reducing agent was increased from 3 to 10g for 20g of FG powder, PbO/SiO_2 ratio did not change a lot. Sample of melted glass with 10g of flour was not melted enough and unburned carbon was remained in center of glass. Reducing agent was excess. Even if it increases the quantity of the reducing agent to add to FG powder, Pb is inseparable from glass only by it. Maximum Pb elimination ratio is 58%

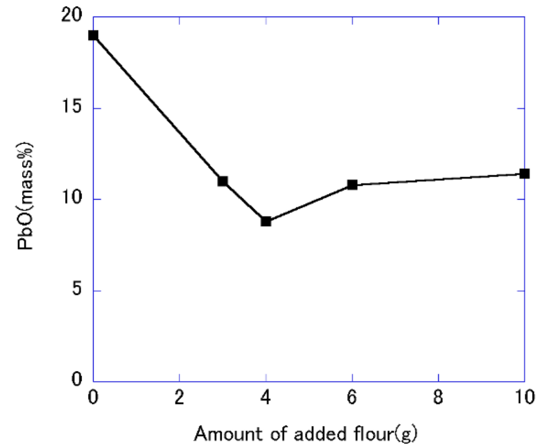

Fig. 6 : Amount of added flour to 20g of FG powder and PbO content of melted glass.

3.3 Reduction melting with Na_2CO_3

To elucidate relationship between glass viscosity and Pb separation from melted glass, FG powder was melted with not only flour as reducing agent but also Na_2CO_3. This is the most popular alkali oxide source for glass production.

Glass melted with only Na_2CO_3 without flour is colorless clear glass. Pb metal was not generated. PbO was not reduced by only increasing of basicity. PbO/SiO_2 mass% ratio is not different from that of FG powder melted. Pb was not removed from melting FG powder with only Na_2CO_3. Glass melted with flour and Na_2CO_3 together was clear and big Pb metal precipitated at the bottom of crucible.

Pb separation was investigated by varied amount of Na and fixed amount of flour. Relationship between Na_2O /SiO_2 and PbO /SiO_2 mass% ratio of sample that mixed with 20g of FG powder, 4g of flour and 0-14g of Na_2CO_3 and melted at 1523K for 1 hour is shown in Fig. 7.

Until Na_2O/SiO_2 mass% ratio became 0.53, PbO /SiO_2 mass% ratio decreased greatly with increasing an amount of adding Na_2CO_3. There is no big change in Pb separation more than that. The maximum elimination ratio of Pb contained in FG powder is 94%.

Next, amount of added Na_2CO_3 was fixed and amount of flour was varied.

The relationship between amount of adding flour and PbO/SiO_2 ratio is shown in Fig. 8. (a) is Glass melted FG powder and flour, (b) is glass melted FG powder with flour and Na_2CO_3. Compared with addition of flour only, PbO/SiO_2 ratio is decreased drastically by addition of flour and Na_2CO_3. PbO/SiO_2 ratio decreases with an increase in the amount of reducing agent when FG powder is melted with Na_2CO_3.

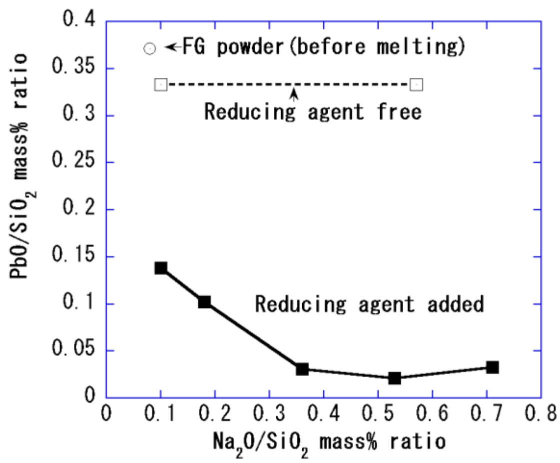

Fig 7 : Relationship between Na_2O/SiO_2 mass% ratio and PbO/SiO_2 mass% ratio.

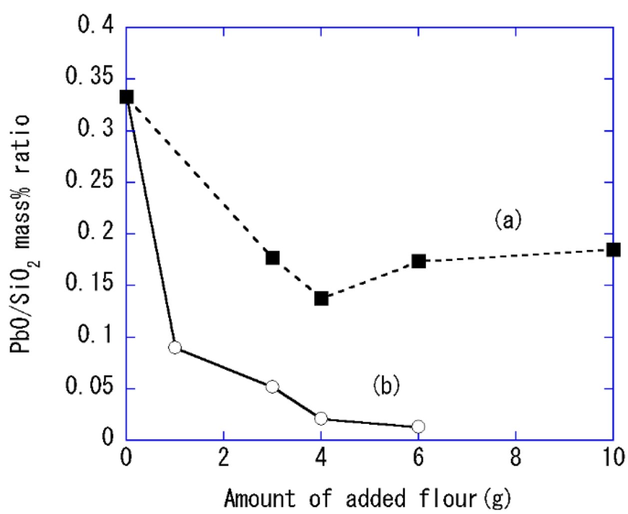

Fig. 8 : Relationship between amount of added flour to 20g of FG powder and PbO/SiO2 mass % ratio. (a) glass melted with flour only, (b) added 10g of Na_2CO_3

3.4 Effect of alkali metal exchange

Kinds of additional alkali metal oxide were exchanged to compare effect of Pb separation. PbO/SiO2 mass% ratio is compared to glass melted of 20g of FG powder, 4g of flour and 2g of Na_2CO_3. Na_2CO_3 was replaced to the same number of moles (0.019) of Li_2CO_3 and K_2CO_3.

The results of added alkali metal element and PbO/SiO_2 mass% ratio are shown in Fig. 9. It is found from the result that the order of Pb separation ability is Li > Na > K. It agrees with effect of decrease viscosity of melting glass. An order which basicity increases is K > Na > Li. In this case, viscosity is more important factor than basicity.

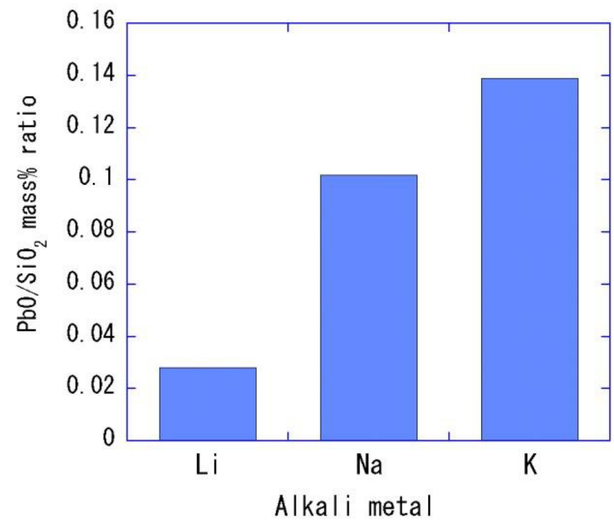

Fig. 9 : PbO/SiO_2 mass% ratio at reduction melting with 0.019 mol of alkali metal carbonate added to 20g of FG powder.

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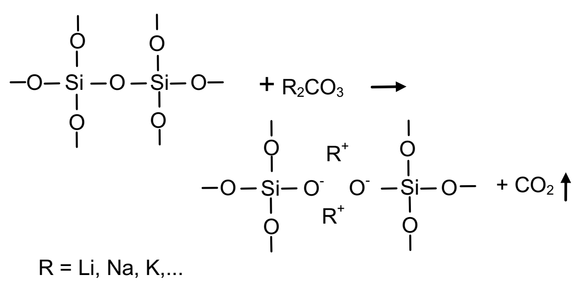
3.5 Relationship between glass viscosity, basicity and Pb separation

SiO_2 in glass forms 3-dimensional viscous network by strong covalent bond. Alkali metal carbonate (R_2CO_3 R = Li, Na, K…) reacts with SiO_2 in glass. Reaction is written as:



(3)

R_2O is strong base that donates O^{2-} to SiO_2 and SiO_2 network is broken. So melting glass viscosity becomes lower. PbO is weaker base than alkali metal oxide [8]. PbO decomposes like alkali metal oxide at PbO low concentration region in glass.

$$PbO = Pb^{2+} + O^{2-} \qquad (4)$$

PbO content in funnel glass is about 7 mol%, so it is assumed that most of Pb in funnel glass exists as not PbO but as Pb^{2+} ion.

PbO activity in glass is lower than PbO concentration. Moreover, basicity of glass increases with increasing in amount of alkali metal oxide. As a result, PbO activity in glass increases, and PbO becomes easy to reduce [8].

Table 2 Change of composition from original FG powder to all Pb removed and after addition of Na_2CO_3

Component	mass%		
	FG powder	If all Pb is removed	10g of Na_2CO_3 added and all Pb removed
Na_2O	4.6	5.8	18.8
MgO	1.7	2.1	1.8
Al_2O_3	3.8	4.8	4.1
SiO_2	55.6	70.0	60.4
K_2O	5.8	7.3	6.3
CaO	3.9	4.9	4.2
SrO	1.5	1.9	1.6
PbO	20.6	-	-
The other	2.5	3.1	2.7

$$Pb^{2+} + Na_2O = PbO + 2Na^{+} \quad (5)$$

By reduction melting, PbO is removed from glass. Viscosity increases with an increase in relative SiO_2 content. Reduction of PbO is barred by high viscosity. Because flour combustion, CO gas generation, reaction of CO and PbO, precipitation of generated Pb metal, etc. are barred. If all Pb is extracted from glass, composition becomes in Table 2. PbO as NWM is removed from glass and SiO_2 as NWF concentration increases to 70.0 mass%, so viscosity becomes higher**.** NWM increases with increasing amount of adding Na_2CO_3, so viscosity decrease. Addition of 10g of Na_2CO_3 to 20g of FG powder decreases content of SiO_2 to 60.4% as in Table 2. Addition of alkali carbonate is very effective in Pb separation from CRT glass by reduction melting.

4 SUMMERY

Effect of added alkali metal oxides on Pb separation from waste CRT glass by reduction melting was investigated.

The conclusions are as follows.

- Pb metal was removed from CRT funnel glass of used TV set by reduction melting method.
- Pb separation from glass was not promoted by amount of added reducing agent increase.
- It is essential to add alkali metal oxide for separating Pb effectively. Because alkali metal oxide increases PbO activity and decreases glass viscosity.
- It is more important to lower viscosity than rising basicity in this case.

It is desirable to add Li from a viscous standpoint. But Li is very expensive compared to Na. The development which reduces cost and energy consumption is required.

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Tribological Behavior of Polymer Brushes Designed Based on Biomimetic Water Lubrication

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Abstract

We investigated the environmentally friendly water lubrication by tethering polyelectrolytes on the substrates with sufficiently high grafting density, so-called 'polymer brushes'. The hydrated brushes in aqueous media formed water lubrication layer to reduce friction coefficient without any organic surfactants and oils, which must be useful not only for artificial joints and bio-devices but also for roller bearing. Macroscopic tribological properties of polyelectrolyte brushes bearing ammonium salt, sulfonic acid, or phosphorylcholine unit were characterized by ball-on-plate type tribotester in the air, water, and salt solution sliding a glass ball on the surface under a loading of 0.49 N. The low friction coefficient below 0.02 was observed in polyelectrolyte brushes in water.

keywords: tribology, water lubrication, polymer brush, polyelectrolyte, polyzwitterion

1 INTRODUCTION

The Biological surfaces show extremely low friction properties supported by water lubrication.[1] For example, Synovial joints, such as hip, knee, shoulder, ankle and finger joints can display friction coefficients in the range 0.001-0.03. However, extremely low friction in natural joint systems cannot be achieved by water alone, because the viscosity of water is too low even at high pressure to form useful boundary films.[2] Nature overcomes the disadvantage by biological lubricant additives such as glycoproteins with bottlebrush structure,[3] which have suitable viscoelastic properties in solution and immobilize large amounts of water molecules to aid lubrication.

We investigated the environmentally friendly water lubrication by tethering hydrophilic polymers [4] or polyelectrolytes [5-7] on the substrates with sufficiently high grafting density, these have been named 'polymer brushes'. The hydrated brushes in aqueous media form water lubrication layer to reduce friction coefficient without any organic surfactants and oils,[8] which must be useful not only for artificial joints and bio-devices but also for roller bearing.

In this study, macroscopic tribological properties of polyelectrolyte brushes prepared by surface-initiated controlled radical polymerization of 2-methacryloyloxyethyl phosphorylcholine (MPC) and 2-(methacryloyloxy)ethyltrimethylammonium chloride (MTAC), and 3-sulfopropyl methacrylate potassium salt (SPMK) from silicon wafer were characterized by ball-on-plate type tribotester in the air, water, and salt solution sliding a glass ball on the surface

2 EXPRIMENTAL

Surface-initiated atom transfer radical polymerizations of MPC, [5] MTAC, [9] and SPMK [10] from the alkylbromide-immobilized silicon wafer and glass ball were carried out at 303 K for 12 h under argon atmosphere to generate polymer brushes, as shown in Figure 1. The resulting polymer-grafted wafers were washed with methanol using a Soxhlet apparatus for 12 h. The frictional coefficient of the polymer brushes was recorded on a Tribostation Type32 (Shinto Scientific Co. Ltd.) by linear reciprocating motion of the brush specimen at a selected velocity for a distance of 20 mm under loading of 0.49 N applied to the stationary glass ball (d= 10 mm) at 298 K. Every friction test was conducted on a fresh area of the brush. The friction coefficients were stored and averaged after the third reciprocating motion, at which the stable value was observed. The theoretical contact area between a glass ball probe and a silicon wafer under these conditions can be calculated to be 3.51×10^{-9} m^2 by Hertz's contact theory, and the average pressure on the contact area was estimated to be 139 MPa.

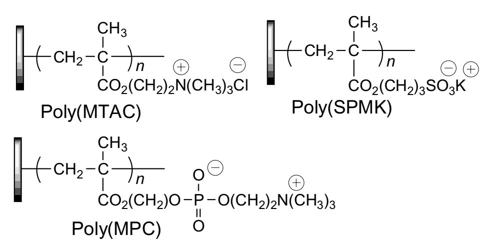

Figure 1. Chemical structures of polyelectrolyte brushes

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3 RESULLTS ANS DISCUSSIONS

3.1 Wettability of polyelectrolyte brush surfaces

The polyelectrolyte brushes exhibited excellent wettabilitiy of the brush against water. Static water contact angles of poly(MTAC), poly(SPMK), and poly(MPC) were 18°, 7°, and 3°, respectively. Figure 2 shows photographs of water droplet on poly(SPMK) brush in air and air bubble attach to the brush surface in water. A water droplet was quickly spread on the poly(SPMK) and poly(MPC) brush surfaces. The surface free energy of the poly(SPMK) and poly(MPC) brush surfaces were estimated to be 72.9 mJ m^{-2}, by the Owens' protocol, [11] which is quite similar to that of water. Interestingly, the air bubbles in contact with the polyelectrolyte brush surfaces formed sphere-like shapes. The contact angles ϕ of the air bubble in water measured by Hamilton's method [12] was 160, indicating that the surfaces of the polyelectrolyte brushes repelled air bubbles in water. The hydrophilic polymer brushes with high graft density were hydrated in water due to the excellent affinity with water, forming an extended conformation as a result of the osmotic pressure, which leads to the formation of water-swollen brush layer repelling the air bubble. Previously, we estimated the thickness of water-swollen poly(MTAC) brush to be 70 nm by neutron reflectivity, while the thickness in air-dried state was 22.5 nm.[13] The water-swollen layer of ionic polymer brush is expected to work as a good lubrication layer under wet condition.

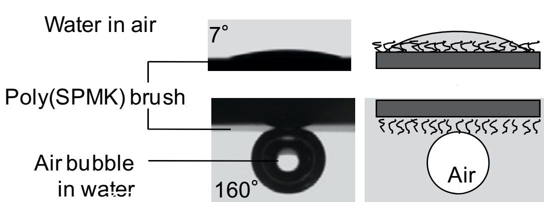

Figure 2. Photographs (side view) of water droplet on poly(SPMK) brush in air, and air bubble in contact with the brush surfaces in water.

3.2 Macroscopic frictional properties of polyelectrolyte brush

Friction coefficient of non-modified glass ball sliding on the silicon wafer was 0.32 under dry N_2 condition, and was slightly reduced to be 0.21 in water due to the fluidic effect. Larger friction coefficient than 0.2 were also observed under the dry N_2 condition by the friction of the glass ball covered with ionic polymer brushes sliding on the identical brush substrates. In contrast, the ionic polymer brushes in water showed much lower friction coefficient than that of non-modified glass ball and silicon water. Although the poly(MTAC) and poly(SPMK) brusesh showed much higher friction coefficient under the dry N_2 than the non-modified silicon wafer, the friction coefficient of poly(SPMK) brush on silicon wafer in water decreased to be 0.05. The opposing swollen brushes in water would form a thicker boundary layer to restrict the direct contact of a glass probe with the silicon substrate.

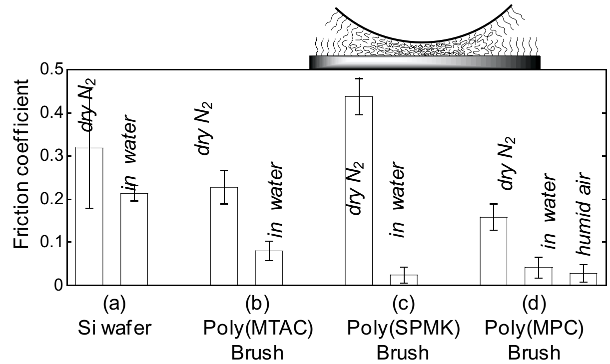

Figure 3. Friction coefficient of (a) silicon wafer, (b) poly(MTAC) brush, (c) poly(SPMK), (d) poly(MPC) and in dry nitrogen atmosphere, water, and humid air (relative humidity >75%) by sliding a glass ball (10 mm diameter) immobilized with the corresponding polymer brushes over a distance of 20 mm at a sliding velocity of 1.5×10^{-3} m s^{-1} under a load of 0.49 N at 298K in water.

Interestingly, the friction coefficient of the poly(MPC) brush under the highly humidified air condition was significantly reduced to 0.02, which is lower than that in water. Because the poly(MPC) is super hydrophilic polymer, it is supposed that water molecules in the humid air adsorbed on the brush surface and worked as a lubricant to reduce the friction force.

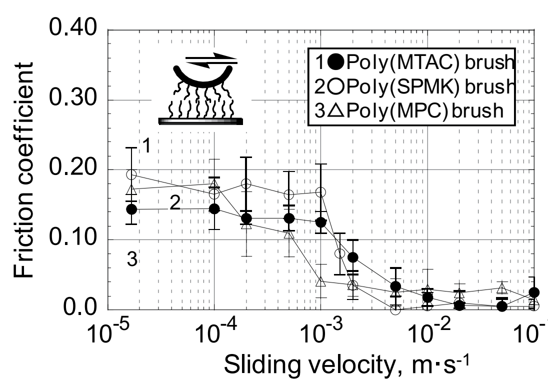

Figure 4. Sliding velocity dependence of the friction coefficient of (a) poly(MTAC), (b) poly(SPMK), and (c) poly(MPC) brushes in water by sliding a glass ball (d = 10 mm) immobilized with the corresponding polyelectrolyte brushes over a distance of 20 mm under a load of 0.49 N at 298 K.

Figure 4 shows the friction coefficients of poly(MTAC), poly(SPMK), and poly(MPC) brushes in water at a sliding velocity of $10^{-5} \sim 10^{-1}$ m s^{-1}. The polymer brushes were immobilized on both surface of silicon wafer and sliding glass ball. The friction coefficients of these brushes were 0.1~0.2 at the slower friction rate of 10^{-5} ~ 10^{-3} m s^{-1}, whereas the friction coefficient was dropped to be 0.01 ~ 0.03 at the higher sliding velocity over 10^{-2} ~ 10^{-3} m s^{-1}. The drastic reduction in the friction coefficients at a certain velocity could be caused by the transition of friction mode. With the low sliding velocity, the interaction between the opposite brushes and the interpenetration of brushes dominated the friction to give a large friction coefficient (boundary or interfacial friction). With an increase in the sliding velocity, a thicker liquid layer would be formed between the sliding surfaces by the hydrodynamic lubrication effect to reduce the actual contact area and the friction force (mixed lubrication region). At higher sliding velocity, we supposed that hydrodynamic lubrication partially took place between opposing swollen polyelectrolyte brushes to reduce the friction.

Since the tethered polymer chain end is strongly bound to the substrate by a covalent bond and multiple hydrogen bonds, the brush layer can hardly be scratched off by a sliding probe. In the case of poly(SPMK) brush, a significantly low friction coefficient around 0.01 was continuously observed even after 450 friction cycles in water at a sliding velocity of 1.5×10^{-3} m s^{-1} under a load of 0.49 N at 298K. We supposed that the abrasion of the brush was prevented owing to a good affinity of the poly(SPMK) brush for water forming a water lubrication layer, and electrostatic repulsive interaction among the brushes bearing sulfonic acid groups.

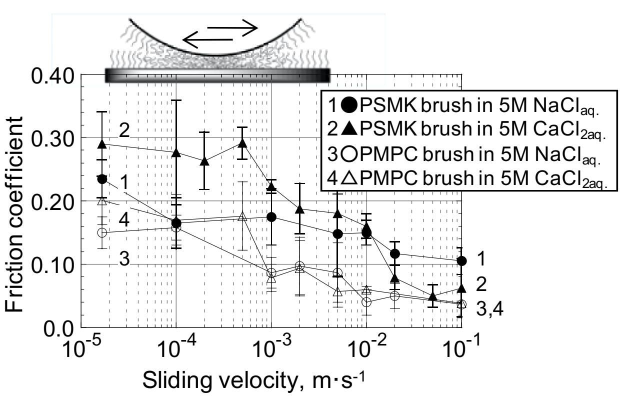

Figure 5. Sliding velocity dependence of the friction coefficient of poly(SPMK) and poly(MPC) brushes in 5 M of aqueous NaCl and $CaCl_2$ solution by sliding a glass ball immobilized with the corresponding brushes over a distance of 20 mm under a load of 0.49 N at 298 K.

The friction coefficients of polyelectrolyte brushes in aqueous solution are affected by a salt concentration. Figure 5 displays the friction coefficients of poly(SPMK) brushes in aqueous NaCl and $CaCl_2$ solution of 5 M at a sliding velocity of 10^{-5} ~ 10^{-1} m s^{-1}. The low friction coefficient below 0.02 was observed in poly(SPMK) brush in pure water and in a lower $NaCl_{aq.}$ concentration than 1 M at the sliding velocity of 10^{-3} ~ 10^{-1} m s^{-1}, however, the friction coefficient increased to be 0.1 in a higher NaCl concentration above 1 M. In general, polyanion or polycation chains in aqueous solution with low ionic strength form a relatively expanded chain structures due to the intermolecular repulsive interaction. In contrast, the polyelectrolyte dissolved in higher ionic strength in solution behaves like an electrically neutral polymer to give smaller dimension because the electric interactions are screened by hydrated salt ions. Therefore, an increase in salt concentration would lead to the reduction of the electrostatic repulsion interaction among the brushes to result in a higher friction coefficient. In particular, larger friction coefficient was observed in a 5 M $CaCl_2$ solution, probably chelating of sulfonate groups to calcium cation enhancing the interaction between the opposing polymer brushes.

Similar trend was observed on the poly(MPC) brushes. The friction coefficient of poly(MPC) brush in 5 M aqueous NaCl and $CaCl_2$ solution at the sliding velocity of 10^{-3} ~ 10^{-1} m s^{-1} were higher than that in pure water. However, influence of salt ions on the friction coefficient was smaller compared with the poly(SPMK) brushes. The origin of this characteristic behavior of poly(MPC) brush in aqueous salt solutions is not clear, but might come from its unique interaction among the phosphorylcholine units and its hydration structure. We previously carried out dynamic light scattering measurement of unbound free poly(MPC) dissolved in an aqueous solution to find out that the dimension of poly(MPC) was independent on the ionic strength of the salt solution.[14] Poly(MPC) can be regard as a quite unique polyzwitterion of which chain structure in a aqueous solution hardly changed by salt effect. This property may contribute usefulness of poly(MPC) as a medical material.[15]

4 SUMMARY

Ion-containing polymer brushes gave super hydrophilic surfaces showing significantly low water contact angles in air and the repelling air bubbles in water because of the hydration of ionic polymer brushes. The hydrated high-denisty polymer brushes in aqueous media formed an extended chain conformation due to the osmotic pressure to give a water lubrication layer reducing the friction coefficient without any organic surfactants and oils. Actually, the low friction coefficient below 0.02 was observed in poly(SPMK) brush in water at the sliding velocity of 10^{-3} - 10^{-1} m·s^{-1}, although the friction coefficient increased to be 0.1 in 5 M aqueous NaCl and $CaCl_2$ solution. In contrast, poly(MPC) brush bearing phosphorylcholine units showed low friction coefficinet below 0.1 even in a aqueous salt solutions. Lubrication in water is expected to promising for bio-lubrication of guide-wire, environmentally friendly lubrication system for rotating parts of wind turbine and tidal turbine.

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Engineering Biomimetics: Integration of Biology and Nanotechnology

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Abstract
The next generation biomimetic materials have been developed by the interdisciplinary collaboration of biology and material nanotechnology. Hierarchic surface structures from nano- to micro-meter scale formed in biological organisms, insects and plants, possess unique functions, e.g. hydrophobic, anti-reflection, adhesion, and controlled tribology. Learning from the biological surfaces has provided novel functional materials whose mechanisms of the functional expression are completely different from those of the manmade products. In order to build new system of biomimetic engineering, it is strongly required to construct the biomimetic database as the platform of the open innovation, which is indispensable for the development of novel materials design and ecological production processes based on biological diversity. Paradigm shift for innovation is potentially inherent in the new trend of biomimetics..

Keywords:
biomimetics, biological diversity, hierarchic structure, insect, plant, nanotechnology, biology, biomimetic engineering, biomimetics database,

1 INTRODUCTION

In a report titled "The Global Biomimicry Efforts: An Economic Game Changer" published in 2010, the San Diego Zoo summarized following comments [1] ;

" Biomimicry could represent a revolutionary change in our economy by transforming many of the ways we think about designing, producing, transporting, and distributing goods and services. Biomimicry, the discipline of applying nature's principles to solve human problems, provides the means to achieve both environmental and economic goals. Many of the mechanisms and systems found in nature are highly efficient, eschew waste, and are sustainable in a virtually closed system. Biomimicry could be a major economic game changer.

While the field today is just emerging, in 15 years biomimicry could represent $300 billion annually of U.S. gross domestic product (GDP) in 2010 dollars. It could provide another $50 billion in terms of mitigating the depletion of various natural resources and reducing CO2 pollution. Biomimicry could account for 1.6 million U.S. jobs by 2025. Globally, biomimicry could represent about $1.0 trillion of GDP in 15 years.

The applications of biomimicry to commercial use could transform large slices of various industries in coming years and ultimately impact all segments of the economy. Industries that could be particularly affected include utilities, transportation equipment, chemical manufacturing, warehousing/storage, and waste management, architecture and engineering. (continue) "

The importance of "Learning from Nature" is a prevailing knowledge in each field of science and technology. From the turn of the century, the research and development on the nature-inspired manufacturing technology, generally referred to as "biomimicry" or "biomimetics" have been coming to the fore in Europe and the United States. The importance of "Learning from Nature" is recaptured from the viewpoint of energy and environmental concerns, too.

2 A BRIEF HISTORY OF BIOMIMETICS

Why has biomimetics research, with its long history, been regaining attention as a new trend since the turn of the century? Figure 1 gives an overview of the history of biomimetics research from the viewpoint of the sizes of research objects and fields of interests.

The term "biomimetics" was coined by neuro-physiologist Otto Schmitt in the latter half of the 1950s. Schmitt is known as the inventor of the "Schmitt trigger", which is an electric circuit used to eliminate superimposed noise from an input signal and transforms it into a series of rectangular pulses. This invention was an example of simulating signal processing taking place in the nervous system. The biomimicry approach in material research dates back further: VELCRO® (known as "magic tape" in Japan) is considered to be an early example of biomimicry realization.

In the 1970s, biomimetics research came along in the fields of chemistry, as "Biomimetic Chemistry," aiming at molecular-level modeling of enzymes and biomembranes. The artificial photosynthesis research that became active in the 1980s laid the foundation for dye-sensitive solar cells, and the actuator research, using gel, brought about such inventions as synthetic muscles. However, the development of molecular biology subsequently turned the

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mainstream of biology toward the elucidation of life phenomena, where the gene plays a central role. The mainstream of biomimetic chemistry research—an area best described as "biomimetics of molecular systems"—began to show tendencies, accompanied by the rise of molecular electronics research in the latter half of the 1980s, to distance itself from biology, and headed toward the chemistry of molecular assemblies and supramolecules.

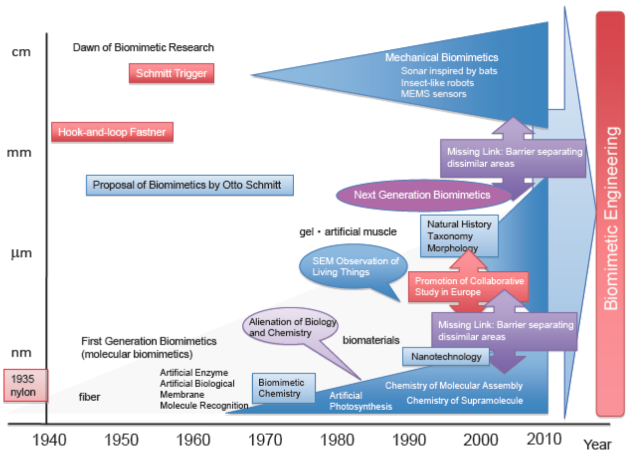

Figure 1. History of Biomimetics

In the 1970s, biomimetics research also blossomed in such fields as mechanical engineering and fluid dynamics; developments in these fields included robots that mimicked movement of insects and fish, and the sonars and radars that mimicked echolocation capabilities of bats and sensory hairs of insects. Mechanical biomimetics research has continued without decline up to now mainly in such areas as military industries, railways and ships, and aeronautics industries. They have also had an impact on such cutting-edge fields as micromachines and MEMS. In present-day Japan, the term "biomimetics" seems to have more of a connotation synonymous with robotics research.

3 SUCCESS OF "NEXT-GENERATION BIO-INSPIRED MATERIALS"

From the beginning of this century, novel biomimetic materials have been developed mainly in Europe. Functional materials having hierarchic nano/micro structures mimicking the surface of insects or plants, such as self-cleaning surface of lotus effect, anti-reflection Moth-eye coating, Gecko-fingers like van der Waals force driven adhesion tapes, etc. etc. have been fabricated (Fig.2). New tide of the next generation biomimetic materials research in Europe and US has generated a new academic discipline based on an intimate interdisciplinary fusion of biology and materials science united by the development of nanotechnology. In the industry, the new trend of biomimetics is expected to bring the paradigm shift and the technical innovation of the processing technology. China has paid strong attention to this emerging field as well as Europe and US.

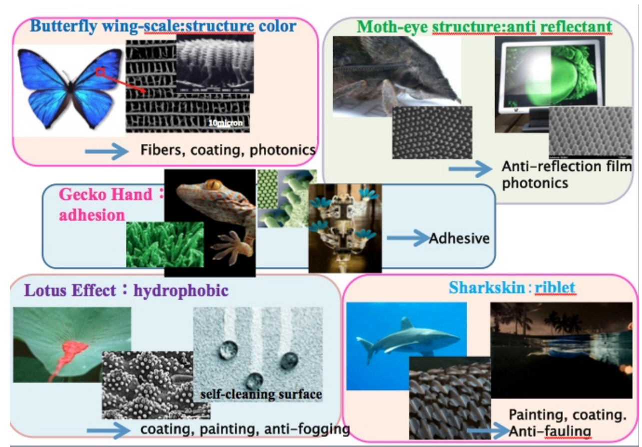

Figure 2. Next Generation of Biomimetic Materials

In many cases, the surfaces of living things are characterized by hierarchical structures in dimensions ranging from nanometers to micrometers. These ranges of dimension are the targets of nano-technology. One of the outstanding characteristics of nano-technology, as compared with conventional technologies, is the fact that its objectives have dimensions that require observation and analysis using electron microscopy, and this very fact embraces possibilities to provide a platform for biology-material science collaborations through the use of common methods for observation and analysis. Electron microscopy has revealed the hierarchical structures of living things that range from nano- to miro-meters range. Inspired by the knowledge of the hierarchical structures in the surfaces of living things, as revealed by the researchers of morphology and taxonomy, the development of nano-technology in the last decade has enabled the material researchers to artificially manufacture similar structures and they are in the process of artificially realizing functions that originate from the structure. Researchers in Europe, especially Germany and the U.K., have been the driving force of these researches. The new generation biomimetics is considered to have been created through collaborations among natural history, biology, and material nano-technology, where electron microscopy and microfabrication technology provided the common platform. The characteristics of nano-technology in Europe are symbolized by the buzz term "Nano meets Bio." That is, the objective is the fusion and linkage between dissimilar fields.

4 IMPORTANT POINTS OF NEW GENERATION BIOMIMETICS RESEARCH

Here summarizes important points in the new generation biomimetics research, paying due consideration to the examples of success in Europe.

Point 1: Evolution and Adaptation of Living Things Provide Good Models for Material Design: Diversity of Living Things Translates into Diversity in Material Designs.

Point 2: Compilation of Biological Resources into a Database is the Key.

Point 3: Win-win Collaboration among Biology, Natural History, and Material Science Is Essential.

Point 4: Design of Energy-saving Materials Should Learn from the Multifunctionality and Environmental Adaptability of Living Things.

Point 5:Collaboration between Material and Mechanical Disciplines Is Highly Desirable.

Point 6:Formation of Self-organized Hierarchical Structure in Living Things Presents Valuable Clues for the Innovation of Manufacturing Technology.

5 ROLE OF NATURAL HISTORY MUSEUM AND BIOMIMETIC DATABASE AS THE PLATFORM OF THE OPEN INNOVATION

The role of museums, with a vast amount of biological specimen, or biological resources information, is essential. It is an urgent task to create a comprehensive biomimetic database through consolidation and organization of the museums' inventories, whereby such approaches as data mining and "knowledge structuring" should be utilized. The database enables researchers to find engineering values in the collected specimen, which is useful for both taxonomy and morphology from an academic point of view as well. In fact, the museums in Europe are actively practicing cooperative activities and academic-industrial collaborations with material/device researchers based on database information (e.g., electron micrographs). The procedure of compiling a database from biological resources inventory from an engineering viewpoint provides a platform for engineers and biologists to know each other. This is exactly the process of transforming a "specimen" into a "treasure," from which the researchers could find an objective of cooperative research. Diversity of living things is reflected in the diversity of new materials, because the latter is designed based on the concept obtained by mimicking the former.

6 CONCLUSION

The research and development of next generation biomimetics is aiming to solve the problems presented by biology in collaboration with other technologies, such as nanotechnology, and is being strongly pushed ahead especially in Europe. It requires human resource cultivation and network formation, taking place everywhere from museums to a variety of industrial sectors.

The biomimetics research in Japan, on the other hand, has been governed by a "vertically compartmentalized" system that tends to hinder active collaborations among dissimilar areas of science and technology. This situation has held back the research efforts in Japan in simple catch-up and follow-up positions, trying to keep pace with the research examples in Europe and the United States. In order for Japan to construct a new system of science and technology that enables new generation biomimetics research, the following are essential: active promotion of collaboration between dissimilar areas (especially between biology and engineering), organization of a comprehensive support system for joint research, and academic-industrial alliance projects. To lower the barrier that hinders collaborative research efforts, establishment of the framework for human resource cultivation and education is also needed urgently.

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Surface texturing for anti-seizure property by using self-organized porous polymer structures as wet etching masks

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Abstract
We demonstrate the preparation of dimpled Fe surface by wet etching using porous polymer masks. The porous polymer masks were prepared by pealing off top layer of the self-organized honeycomb-patterned porous polymer films. After wet etching by HNO_3 ethanol solution, hexagonally arranged micro-dimple textures were formed on the Fe surface. As results of seizure load measurements by using a ring-on-disk testing device, seizure load of the dimpled Fe surfaces was 2400 N, which was four times larger than that of the flat Fe surfaces.

Keywords:
anti-seizure, tribology, self-organization, surface texturing, wet etching

1 INTRODUCTION

Involving improvements of automobile mechanical systems, prevention of burn out, called anti-seizure, become one of the important subjects, because prevention of seizure saves abrading parts. For improving anti-seizure property, texturing of material surfaces attracts much attention. Among the surface texturing methods, wet etching is excellent, because it is easy, low cost and low environmental burden process. And also wet etching achieves surface texturing without surface burred periphery structures. However, the wet etching required etching masks. So preparations of etching masks is a key point of the surface texturing by the wet etching.

We have reported the formation of self-organized honeycomb-patterned porous polymer films by casting polymer solutions containing amphiphilic copolymers under humid conditions by using condensed water droplet arrays as templates [1]. Moreover, peeling off the top layer of the honeycomb-patterned films, polymer "pincushion" films with hexagonally arranged "spike" structures were prepared [2]. In this report, we focus on the peeled layer of honeycomb-patterned films as the etching mask of metal surface. The peeled layer of honeycomb-patterned films is a thin polymer layer having arranged micropores and spike arrays at hexagons. It can be applicable to wet etching masks[3]. We show surface texturing of Fe substrates with the peeled layer of the honeycomb-patterned films as wet etching masks.

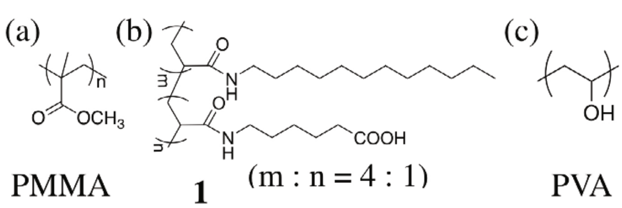

Chart 1. Chemical structures of (a) PMMA, (b) amphiphilic copolymer **1** and PVA.

2 EXPERIMENTAL SECTION

2.1 Preparation of the self-organized polymer masks

Figure 1 shows schematic illustration of the preparation of honeycomb-patterned films. The honeycomb-patterned films were prepared by casting chloroform solutions of poly(methyl methacrylate) (PMMA, Chart 1(a)) and amphiphilic copolymer **1** (Chart 1(b), PMMA : **1** = 10 : 1)

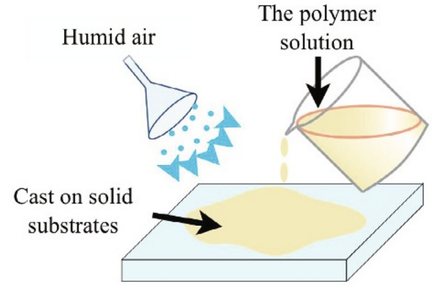

Figure 1. Schematic illustration of the preparation method of self-organized honeycomb-patterned films.

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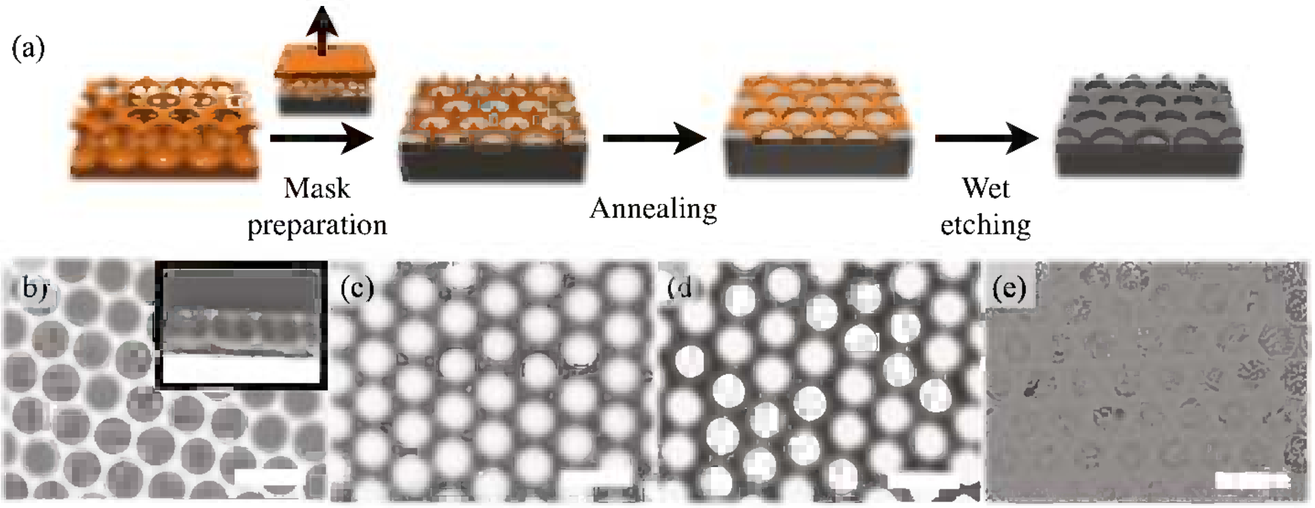


Figure 2. (a) Schematic illustrations of preparation procedure. SEM images of (b) honeycomb-patterned films, porous polymer masks (c) before and (d) after annealing and (e) Fe dimpled surface after wet etching.(Bars are 15 µm)

on 40 x 11 cm glass substrates [4]. For using the top layer of the honeycomb-patterned film as an etching mask, 1 wt% poly(vinyl alcohol) (PVA, Chart 1(c)) aqueous solution was spin-coated (1000 rpm, 120-150 s) on the honeycomb-patterned films, and the honeycomb-patterned films were fixed upside down on Fe substrates (Figure 2 (a)). The Fe substrates with the honeycomb-patterned films were annealed at 90 °C for 10 min for completely drying the PVA aqueous solution. After peeling off the bottom layer of the honeycomb-patterned films with commercial adhesive tape, the excess PVA adhesive on the bare Fe surface was washed out by using deionized water. After annealing the Fe substrates at 350 °C for 10 min, porous polymer masks were formed on the Fe substrates.

2.2 Wet etching of Fe substrates with the self-organized polymer masks

The Fe substrates with the porous polymer masks were immersed in 6.4 % HNO_3 ethanol solution for wet etching. Etching times were controlled from 15 s to 35 s. After washing out etching solution and drying the surface, porous polymer masks were removed by using chloroform and acetone.

2.3 Surface observations and anti-seizure measurements

The surface structures were observed by using a scanning electron microscope (SEM), and dimple depths were measured by using a surface roughness measuring instrument. Seizure loads ware measured by using a ring-on-disk testing device. Rotation rates of rings were 500 rpm, and machine oil (SM0W20, 80 °C) was used as a lubricant. For first 10 min, the load was fixed at 100 N, after that, the load was increased with 100 N/2min until seizure occurred.

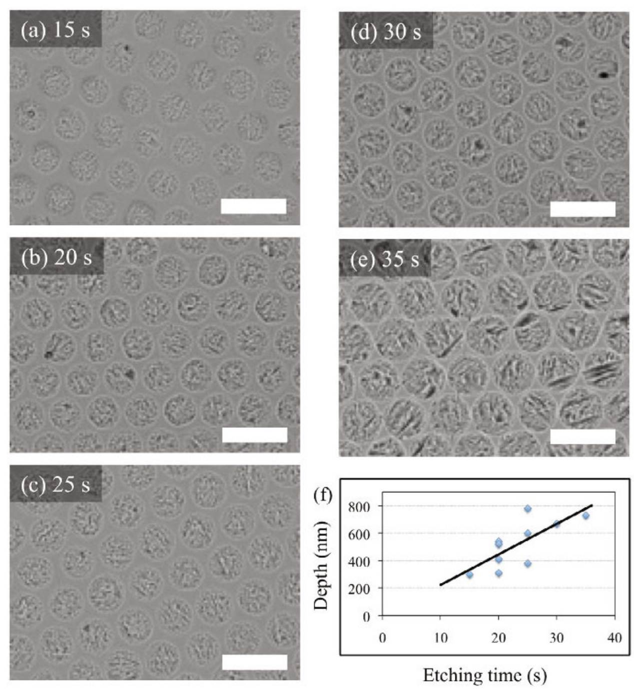


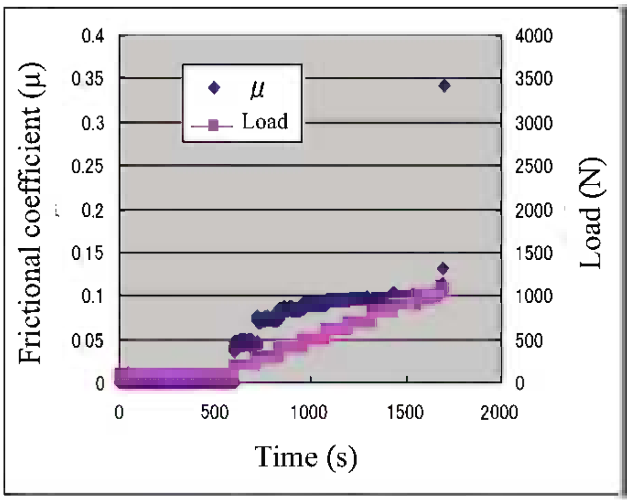
Figure 3. (a-e) SEM images of the dimpled Fe surfaces. (f) A graph of dimple depths versus etching times. (Bars: 15 µm)

3 RESULTS AND DISCUSSIONS

3.1 Surface observation and characterization

Figure 2 (b-e) show SEM images of the honeycomb-patterned films, the porous polymer masks before and after annealing, respectively, and the dimpled Fe substrates. The honeycomb-patterned films has hexagonally arranged 8 µm micro-pores, and cross-sectional SEM images clearly shows that the honeycomb-patterned film consists of two layers, a porous top layer and a dimpled bottom layer, connected with pillars located

(a) Flat surface



(b) Dimpled Fe surface (etching time: 30 s)

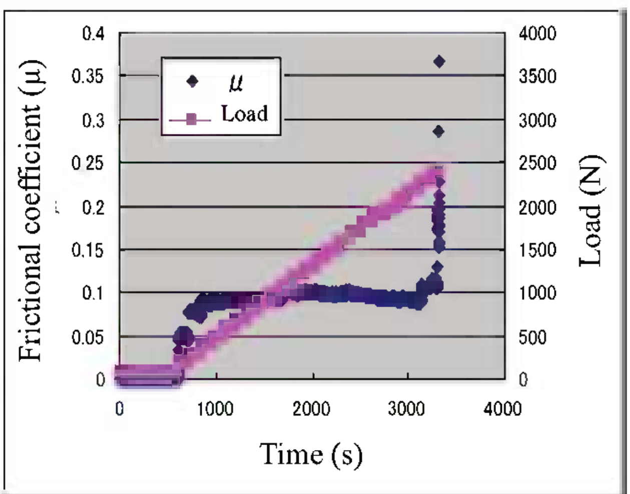


Figure 4. Graphs of seizure loads. (a) A flat Fe surface and (b) a dimpled Fe surface.

on the apexes of honeycomb hexagons (Figure 2 (b) insert image). Thicknesses of these pillars are gradually thinner toward the center part of the pillars, because shapes of these pillars are reflected on the curvature of the template water droplets. Since the center parts of these pillars are mechanically week, the top porous layer can be easily separated from the bottom dimpled layer. Figure 2 (c) shows a SEM image of the porous polymer mask on the Fe substrate before annealing. The porous polymer mask has hexagonally arranged micro-pores and pillar structures were formed. After annealing at 350 °C for 10min, pillars were disappeared because of melting. However, network structures, which have hexagonally arranged uniformed micro-pores, were remained (Figure 2 (d)). After wet etching processes, hexagonally arranged micro-dimples were formed on Fe substrates without burred structures (Figure 2 (e)). Figure 3 (a-e) shows SEM images of Fe dimple arrays prepared under various wet etching times. The SEM images reveal that the diameter of the dimple increased with increasing wet etching times because of isotropic etching. Figure 3 (f) shows a graph of dimple depths. Dimple depths were increased with wet etching time. This result suggests dimple depths can be controlled by changing wet etching times.

3.2 Anti-seizure measurements

Seizure loads of dimpled Fe substrates were measured by using a ring-on-disk testing device. The ring-on-disk tests indicates that average seizure loads of the flat surface and the dimpled Fe surfaces (wet etching time was 30 s) were ca. 600 N and 2400 N, respectively (Figure 4). So, it is suggested that surface texturing of Fe substrates by wet etching with porous polymer masks has great possibilities for anti-seizure property.

4 SUMMARY

In this report, we demonstrate the preparation of the dimpled Fe surface by wet etching with self-organized polymer masks. This method can achieve formation of the dimples without burred periphery structures. Depth and diameter of the dimple can be controlled by changing the wet etching times. The dimpled Fe surfaces show higher anti-seizure properties than the flat Fe substrates. These results suggested that the dimpled Fe surfaces have great potentials for practical use, because dimpled Fe surfaces have not only high anti-seizure property, but also their novel preparation method, such as easy, low cost and low environmental burden process.

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DNA-Templated Self-Assembly of Conductive Nanowires

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Abstract

DNA has been a key component in nanotechnology and material science due to its unique structural and physicochemical properties. Here we show that base-specific binding of cisplatin of artificially synthesized DNA can produce metal nanowires with controllable nanostructures *via* electroless plating. Moreover, the electrostatic interations of DNA with metal nanoparticle and conducting polymer can further result in alternated alignment of conducting building blocks towards conductive nanowires with fine control of structure and composition, which might be difficult to achieve through top-down fabrication techniques.

Keywords:

DNA, condutive nanowires, self assembly, nanoelectronics

1 INTRODUCTION

The rapid development of nanoelectronics has motivated great research efforts on the fabrication of conductive nanowires with potential applications as nanoscale circuits and interconnects. In particular, continuing advances in templated assembly have generated highly controllable conductive nanowires that were difficult to achieve through top-down fabrication techniques.[1-3] Of the many templates available, DNA provides the advantages of well-ordered structure, the availability of many enzymes for DNA manipulation, as well as rich chemical functionality. These properties have made DNA a excellent template for assembling a great variety of materials of interests.[4-6] In addition, the use of DNA template provides benefits in the manufacturing of narrow nanowires owing to its small width. To date, however, fabrication of further miniaturized, ultra-narrow condutive nanowires is still challenging, likely owing to uncontrollable metallization/polymerization reactions, or the large size of nanoparticles used in assembly processes.[7,8] Although a great deal of efforts have been made on the preparation of DNA-templated nanowires, furthermore, hybid nanowires with fine control of structures and compositions remain rarely investigated. In this paper, we described a series of DNA tempating approaches for preparing narrow conductive nanowires. First, electroless plating of DNA was shown to enable the selective silver deposition on DNA *via* cisplatin catalysis, giving rise to highly conductive Ag nanowires.[7] Then, the sequence-specific recognition of cisplatin of artificially synthesized DNA further afforded the fabrication of narrower Pt nanowires with fine controlled nanostructures.[9] Finally, we attempted to fabricate a metal/polymer alternated hybrid nanowire by electrostatic adsorption of gold nanoparticles (AuNPs) and polyaniline on DNA. Our results revealed that the resulting ultra-narrow hybrid nanowire was conductive, and was less than 3 nm in both width and height, suggesting good potential for use in electronic nanodevices.

2 REUSULTS AND DISCUSSIONS

2.1 Fabrication of conductive Ag nanowires

The structural linearity of DNA offers promise for facile preparation of conductive nanowires through metallization of stretched DNA. Nevertheless, the precise and uniform metal deposition on DNA is a challenge owing to the uncontrollable electroless plating. To this end, we introduced purine base N_7-binding cisplatin to λ-DNA template, which can be reduced to Pt metal as efficient catalyst in following metal deposition on DNA.[10]

Bound to the N_7 of purine bases in natural λ-DNA in Tris-HCl (pH 7.8), cisplatin at a concentration of 2.5 μM was then reduced to platinum metal by the addition of dimethylamine borane (DMAB, 10 mL, 25 mM). Next, the λ-DNA template complexing with Pt clusters were stretched and immobilized on a glass substrate using the Langmuir-B lodgett (LB) method.[11] Both the height and width of the linear complex were in the range 1−2 nm, as shown in the atomic force microscopy (AFM) image (Fig. 1a). Silver metal deposition was carried out by dipping the glass substrate into a silver electroless plating solution

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consisting of silver nitrate (0.03 M), ammonia (1.22 M), acetic acid (0.5 M) and hydrazine (0.1 M).[12] After washing the substrate using water and drying it under N_2 gas flow, The silver nanostructures was observed using scanning electron microscopy (SEM). Seen in Fig. 1b are the uniform silver nanowires that were 30 nm in height, 50 nm in average width and 15−17 nm full length.

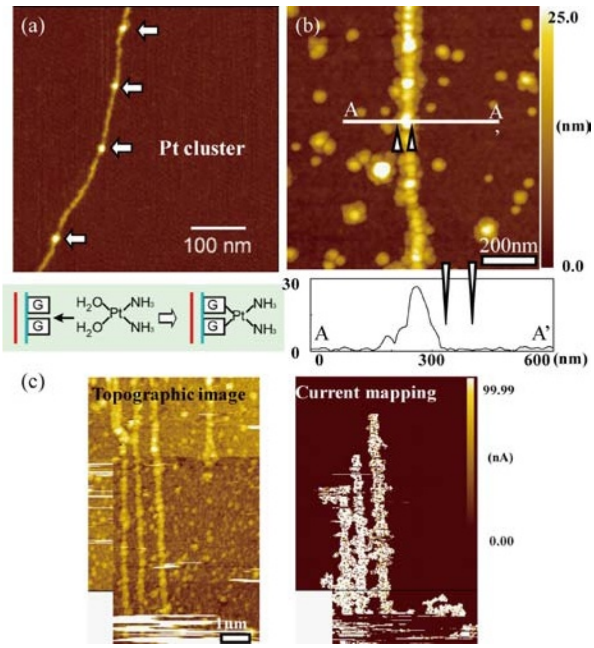

Fig. 1: (a) AFM image of Pt cluster formed by reduction of cisplatin binding to λ-DNA. (b) AFM image showing a single Ag nanowire resulting from the Pt-catalyzed silver depostion on λ-DNA. (c) The AFM image and corresponding current mapping of Ag nanowires.

Under an applied voltage (1 V), current across the Au-coated AFM tip and a small silver paste electrode placed on the surface through the nanowire can be monitored by contact-mode AFM (Fig. 1c). And the current mapping was obtained as a result, indicating a high conductance of the Ag nanowires with potential applications as nanocircuits.

2.2 Fabrication of Pt nanowires with controllable structures

In order to explore sequence-specific metal deposition, we performed the synthesis of artificial DNA sequences by enzymatic manipulation. Here, Klenow fragment (KF$^-$) of *E. coli* DNA polymerase I was chosen to produce DNA molecules with defined length and narrow size distribution.[13] A template-primer composed of three oligonucleotides, dG20, dC20 and dC10(AT)10 was employed for DNA extension in the presence of KF$^-$, and it is expected to be extended at its 3'-end and two single-strand break positions. Gel electrophoresis characterizations revealed that higher molecular weight product that might be composed of poly(dG)·poly(dC) and Poly(AT-part) was obtained after DNA extension reaction, potentially elucidating the polymerase-directed extension. To further identify thus-synthesized DNA block copolymer, purine base N_7 binding-cisplatin was introduced and reduced to Pt metal. The artificial DNA complexing with Pt was stretched using the LB method aforementioned, and characterized by AFM. (Fig. 2a) Two segments (A and B) with distinct height level were observed, and the height of these two segments ranged from 1.1 to 2.3 nm and 0.3 to 0.9 nm, respectively, directly confirming the production of our designated DNA sequence for sequence-specific Pt metallization.

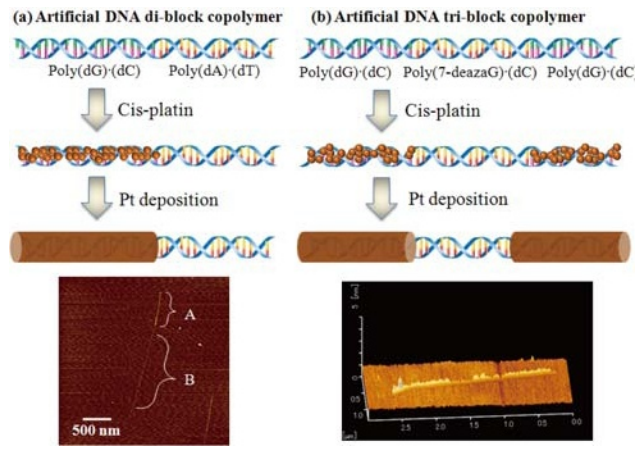

Fig. 2: Schematic illustration of DNA sequence-specific Pt metal deposition using artificially synthesized di-block copolymer (a) and tri-block copolymer (b) as templates. The bottom show the AFM images of the resulting Pt nanowire structures.

We further attempted to produce more complicated nanowires with nanogap structures by synthesizing a DNA tri-block copolymer as the template. In this, an oligonucleotide consisting of dG10 and dC10 was first used as the template-primer. It was extended to poly(dG)·poly(dC) in the presence of KF$^-$, dGTP and dCTP. After purification, an additional part of poly(7-deaza-dG)·poly(dC) was added to the poly(dG)·poly(dC) sequence by polymerization in the presence of KF-, 7-deaza-dGTP, and dCTP. Finally, a poly(dG)·poly(dC) segment was synthesized again to sandwitch the poly(7-deaza-dG)·poly(dC) segment with the initial poly(dG)·poly(dC) segment. As expected, this artificial DNA sequence can be deposited by Pt specifically on the two poly(dG)·poly(dC) segments, forming a nanogap structure. To validate our hypothesis, cisplatin was incubated with thus-obtained DNA tri-block copolymer and then reduced to Pt clusters, followed by AFM characterization. Fig. 2b clearly indicated the construction of a nanogap structure. We further observed the average height of two poly(dG)·poly(dC) segments to be 1.3 nm after Pt deposition, while the poly(7-deaza-dG)·poly(dC) segments were only 0.2 nm high in average because of the absence of N_7 in the 7-deaza-dG. These results demonstrate that our strategy using artificially synthesized

DNA sequence can act as a versatile template tunable to a given application in the fabrication of Pt nanowires. Given the rich chemical functionality of DNA, our approach foretells the emergence of novel conductive nanowires fabricated by the sequence-specific deposition of different metals on DNA.

2.3 Fabrication of metal/polymer alternated hybrid nanowires

In addition to the rich covalent interactions with metals, DNA as a polyeletrolyte possesses highly negative charge that may afford the assembly of various materials of interests. Rather than using electroless plating, next, we attempted to prepare an alternated hybrid conductive nanowire based on DNA-templated linear assembly of conducting building blocks, including AuNPs and polyaniline (Fig. 3a).

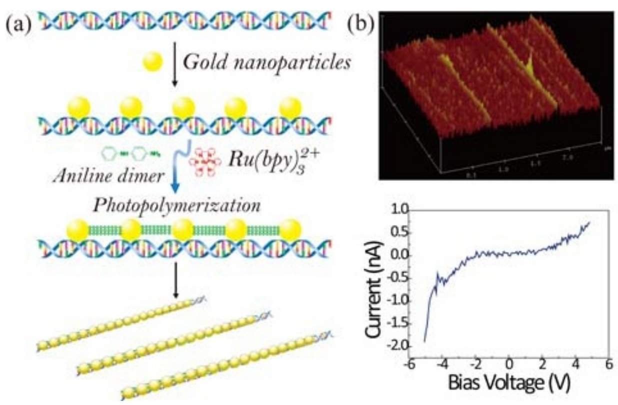

Fig. 3: (a) Schematic illustration of fabrication process of AuNP/polyaniline alternated hybrid nanowires. (b) AFM image of the resulting alternated hybrid nanowire and a corresponding *I-V* curve measured by using PCI-AFM technique.

A self-assembled positively charged monolayer of 3-aminopropyltriethoxysilane (APS) on a Si substrate was prepared to immobilize λ-DNA molecules. After incubation for 3 min, the Si substrate was slowly tilted to ~90˚ to stretch the λ-DNA using air-water interfacial force, as well as to remove water droplet. Then, gold nanoparticles (AuNPs) were synthesized by aniline reduction, and the aniline/oxidized aniline that cap the surfaces of AuNPs rendered a positive charge to the AuNPs. The linear assembly of AuNPs was achieved by incubating the AuNPs with stretched λ-DNA for 8 min based on electrostatic interaction.[8] The photopolymerization of polyaniline was subsequently conducted for 10 min to bridge the gaps between interfacing AuNPs on the DNA template,[14] resulting in ultra-narrow hybrid nanowires of less than 5 nm in both width and height. As shown in Fig. 3b, the alternated hybrid nanowire showed a continuous morphology. *I-V* curve measured by using point-contact current imaging (PCI) AFM further showed that the alternated nanwire was conductive, suggesting good potential for use in electronic nanodevices.

3 SUMMARY

We have shown that DNA can act as a versatile template for fabricating conductive nanowires based on bottom-up self assembly. The Ag metallization was achieved in a catalyst seed-induced selective fashion. The metal nanowires were further narrowed by directly reducing cisplatin on poly(dG)·poly(dc)-rich DNA sequence. More importantly, DNA sequence-specific Pt metallization was demonstrated by using artificially synthesized DNA as templates. The resulting Pt nanowires displayed well controlled structures with nanometer resolution, promising to be novel nanoelectronic devices.

Based on electrostatic interation, the linear assembly of AuNPs and polyaniline towards conductive nanowire was also suggested. The produce revealed alternated hybrid structures with fine control of structure and composition. We hope that our strategy will drive more research effort on DNA-tempated nanowires with new structural and electrical properties.

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Continuous Roll Imprinting of Moth Eye Antireflection Surface Using Anodic Porous Alumina

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Abstract

Moth eye surfaces can prevent reflection by changing a refractive index continuously between air and the matrices, which theoretically was already known. The technology to form such structures at small areas has been developed, but it is too difficult to form moth eye surfaces at large areas. The Anodic porous alumina provided by self-organization can be formed even on the curved surface. We propose a continuous manufacturing process of a moth eye surface on a polymer film with a roll mold and have been researching the process. We produced the moth-eye type AR films with the roll type molds, continuously. A high-productive and low-cost production process of moth-eye surfaces is thought to be realized by developing this research.

Keywords:

Roll imprinting, moth-eye, anodic porous alumina, antireflection, self-organization

1 INTRODUCTION

Generally, as commercial films diminishing reflection, there are an anti-reflection (AR) film and an anti-glare (AG) film. An AR film reduces reflection itself to improve the image dignity, used for plasma displays. AG film makes reflection vaguely with scattering, used for a LCD display. These days, FPD screen becomes larger and then improvement in quality of image has been greatly required. For LCD with an AG film, improvement of clearness of a picture without whitish is required. For PDP with an AR film, diminishing reflection is required. Extremely low reflectance film enables both requirements. Most of currently-marketed AR films are multilayer type. The multilayer type AR film can improve a characteristic by increasing layer numbers. As low cost is basically required for FPD, two-layers type films are usually used by the request of price.

Figure 1 is a photograph of a natural moth-eye structure. Moth-eye has an unevenness surface for anti-reflection. The structure serves as a survival mechanism by making the animal less vulnerable to predators [1]. Recently, researches and developments for the industrial production of the moth-eye structures for anti-reflection have been promoted. These researches and developments are one of the representatives in Bio-mimetics.

Recently, the continuous photo nano-imprinting of moth-eye structures has been developed with the seamless anodic porous alumina mold. This paper explores the technology of the development.

2 ARTIFICIAL MOTH-EYE SURFACE

Figure 2 is the image of our artificial moth-eye surface. The moth-eye surface has a minute unevenness structure

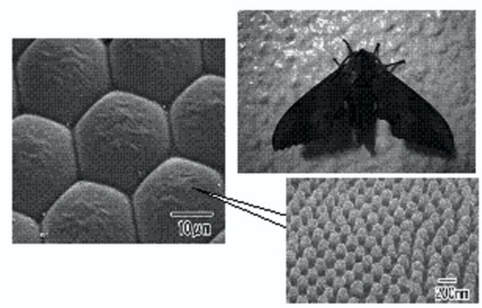
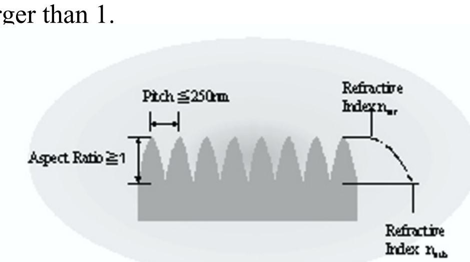


Fig. 1: Natural moth-eye structure.

of nanometer-order. There is a decrease in refractive index from 1.5 at a plastic substrate to 1.0 at the surface which is the value of air. The difference of refractive indices is about 0.5. Individual projection has the cone-like shape. The diameter is lower than 250 nm and the aspect ratio is larger than 1.



Pitch realizing non-reflection

$$\Lambda \leq \frac{\lambda}{n}$$

Λ Pitch (nm)
λ Wavelength (nm)
n Refractive Index

Fig. 2: Image of our artificial moth-eye surface.

When the pitch between adjacent projections is lower than the value of wavelength of incident light divided by refractive index of substrate, reflection becomes

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negligible. If the wavelength is 400 nm and the refractive index is 1.5, the pitch is required to be lower than 267 nm.

3 PRODUCTION PROCESS OF THE MOTH-EYE ANTI-REFLECTION FILMS

Nano-imprinting process, which generates fine patterns of polymers using molds, is a promising candidate for a high-throughput patterning process. When the pattern for imprinting is required to be fine, the manufacture of the mold is one of the most important assignments of the technology. The mold used for nano-imprinting has usually been prepared by electron beam (EB) lithography. However, this technique has a disadvantage of low throughput for preparing molds of large-size. The anodization of Al in acidic solution forms anodic porous alumina by self-organization illustrated in Figure 3. The Porous alumina is a typical naturally occurring ordered material. The porous alumina has cells of a uniform size with hexagonal closest packing. Every cell has same size 50-500 nm controlled by Voltage and has a pore of the size of one-third in the center. Generally, carbon is used as Cathode and several acids such as sulfuric acid, oxalic acid, etc is chosen by applied Voltage [2]. The nano-imprinting processes based on the highly ordered anodic porous alumina had been researched eagerly [3].

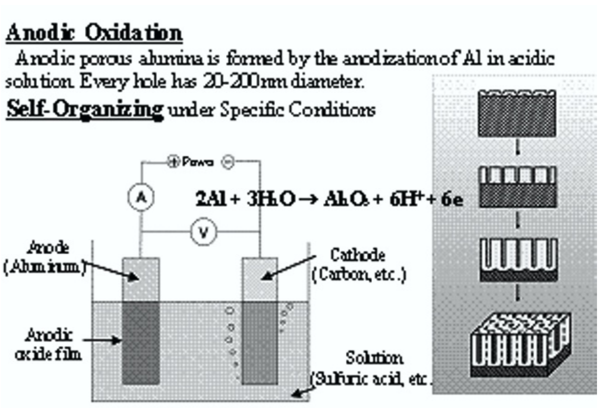

Fig. 3: Formation of porous alumina.

Table 1: Characteristics of moth-eye producing processes.

	Anodic Porous Alumina	Lithography (Electron Beam Drawing Interference exposure)
Structure Formation	Possible	Possible
Wide Area	Possible	Difficult
Roll Type Mold	Possible	Difficult
Production Cost	Low Cost	Expensive

Table 1 shows the characteristics of moth-eye producing processes. Lithography enables to produce moth-eye structures at small area but too expensive. And by Lithography, we can't produce moth-eye structures at large area and on a curved surface. On the other hand, porous alumina can be formed at large area and on curved surfaces. Therefore, porous alumina can realize a big-size roll mold required for Roll to Roll process with high productivity.

Figure 4 illustrates moth-eye alumina mold production process. An oxalic acid water solution is used as an electrolyte. High purity aluminum is anode-oxidized under constant voltage to transform into porous alumina. Next, porous alumina is etched with phosphoric acid water solution to enlarge pore diameters. By repeating theses processes several times, a porous alumina mold with a taper shape is fabricated.

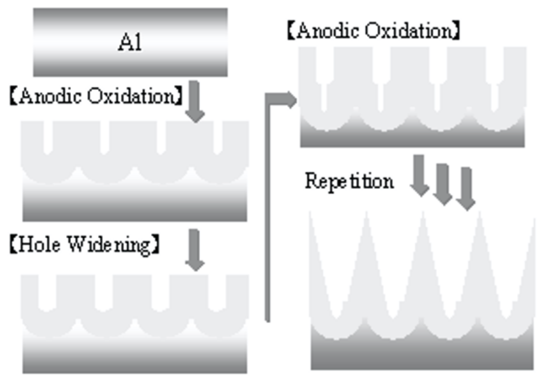

Fig. 4: Moth-eye alumina mold production process.

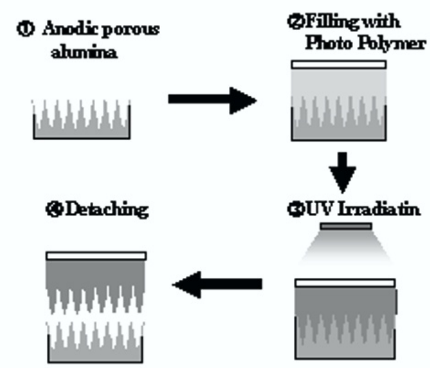

Fig. 5: Photo imprinting process.

Figure 5 shows an image of a photo imprinting process with the moth-eye mold [4]. At first, the photopolymer is filled on the mold and the mold with the photopolymer is covered with the transparent substrate for example, Pet film, PMMA film and glass sheet. Next, it is irradiated with UV light over the covered transparent substrate and last a moth-eye sheet is detached from the mold. Figures 6(a),(b) are TEM images of the typical taper porous alumina mold. Figure 6(a) is the cross section image and Figure 6(b) is the surface image of the mold. Figure 6(c) shows the FE-SEM image of the typical moth eye surface on the PET film. It is confirmed that the shape of the taper porous alumina mold can be properly transferred to the moth-eye surface.

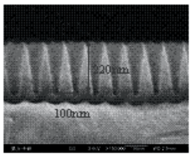

Fig. 6(a): Cross Section TEM image of the tapered alumina mold.

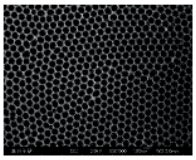

Fig. 6(b): Surface TEM image of the tapered porous alumina mold.

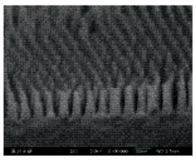

Fig. 6(c): Cross Section SEM image of the moth-eye surface.

4 CONTINUOUS PRODUCTION PROCESS

The continuous production processes of functional films with roll molds have also been developed in these days. Figure 7 illustrates an image of a continuous roll photo imprinting. The photopolymer is spread on the PET film. And then, the film is pressed on the roll mold and next irradiated with UV light. The moth-eye surface is made on the PET film, continuously. Figure 8(a) shows the seamless roll mold for a moth-eye surface. The diameter is 200mm and the width is about 300mm. Figure 8(b) is the photograph of the transferred moth-eye film. The moth-eye film has transparency and the blue color is come from the protection film.

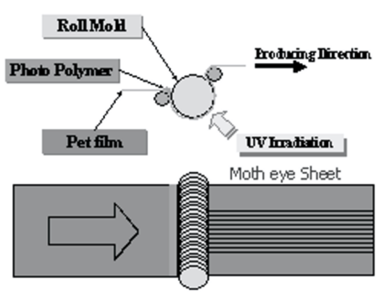

Fig. 7: Image of continuous roll photo imprinting.

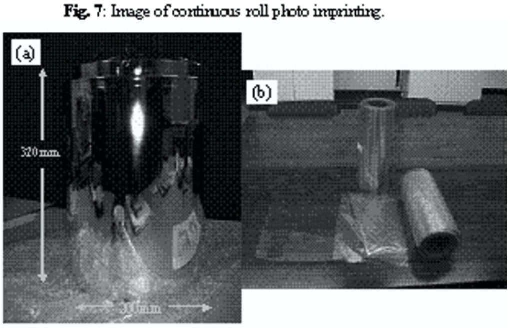

Fig. 8(a): Seamless roll mold for a moth-eye surface.
Fig. 8(b): Transferred moth-eye film.

5 CHARACTERISTICS OF THE MOTH-EYE ANTI-REFLECTION FILM

The moth-eye AR films have lower reflection than multilayer type and have low reflection throughout visible wavelength.

Figure 9 shows the background reflections on the AR films. These images are the reflections of fluorescent lamps. The right is on the multilayer type AR film and the left is on the moth-eye AR film. The right image has the apparent reflection of lamps. The left image has no reflection. It's confirmed that the moth-eye AR film has the best performance.

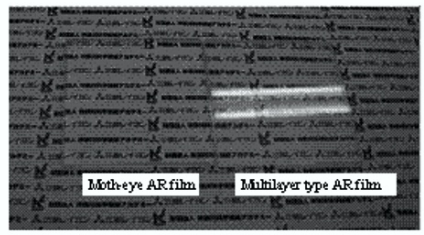

Fig. 9: Background reflections on AR films.

6 SUMMARY

1. The anodization of Al roll in acidic solution forms a big-size roll mold with anodic porous alumina on the surface by self-organization.

2. The moth-eye anti-reflection films are fabricated with the porous alumina molds. The reflectance of the AR films is under 0.4 %.

3. The moth-eye anti-reflection films are also fabricated with the roll mold, continuously. The productive and low-cost production process is thought to be realized by developing this process.

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Sustainability consideration amongst award-winning industrial design graduation projects in Australia

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Abstract
This paper investigates the engagement towards sustainability of graduating industrial design students in Australia. This was achieved by completing a content analysis of the entries in the Australian Design Award - James Dyson Award, focusing on the claims made in the product descriptions, their rationale for representing design excellence and why they believe their work is award winning. The findings were encouraging, as the overwhelming majority of finalists and winners had incorporated an environmentally responsive strategy or addressed an issue of significance to society. The analysis results provide evidence that sustainability issues are increasingly being tackled in Australian industrial design education. That graduating students choose to do final-year projects which reflect their sensitivity to these global issues suggest concern and readiness on their part in exploring real solutions to these problems, and perhaps a desire and optimism for a more promising world for future generations.

Keywords
Sustainable product design, industrial design education, industrial design awards

1 INTRODUCTION

The student category of the Australian Design Award has been running annually since 2002. Originating as the Dyson Student Award and changing name in 2010 into the James Dyson Award (ADA-JDA), the program is a partnership between the Australian International Design Awards, one of the world's longest standing and most respected design endorsement schemes, and Dyson Ltd, an appliance manufacturing company founded by the British industrial designer Sir James Dyson, best known as the inventor of the dual cyclone bagless vacuum cleaner. The ADA-JDA recognizes outstanding projects from tertiary students of design in Australia which are most closely aligned to Dyson's philosophy of "complete design", which suggests that a product should not only look good but use innovation and technology to provide significant advantages over the product it replaces. (The ADA-JDA is affiliated with the international James Dyson Award whose brief is: "put simply: design something that solves a problem".)

The judging criteria for the ADA-JDA accolades are similar with most other design award schemes. It focuses on five main assessment points: *form* (aesthetically pleasing, emotive, resolved details); *function* (performance, meeting user needs); *quality* (designed for manufacture, durable, appropriate finish and materials); *safety* (compliance with applicable standards); and *sustainability* (real need, long lasting, resource efficient, compliance with environmental best practice). The sustainability criterion was introduced in 2007.

During the assessment, entries undergo an internet-based short-listing process, wherein design practitioners from around the world are invited to log onto the website as a judge and vote for entries to proceed to the next stage. Prototypes or models submitted by shortlisted applicants are then assessed by a multidisciplinary panel of design experts. Around 30 of the top voted entries proceed to the final round assessments (see Figure 1), from which the winners of the Gold, Silver, Bronze and Highly Commended awards will be selected.

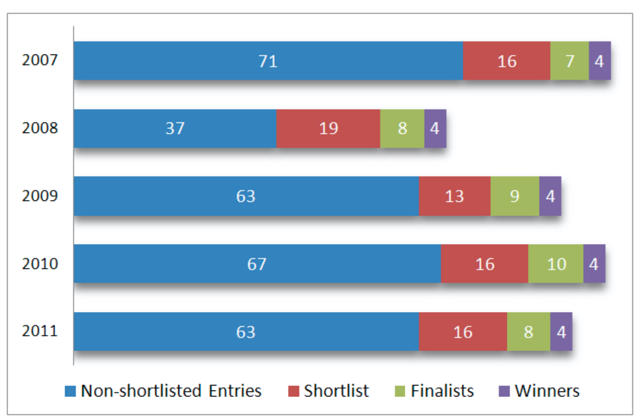

Figure 1. Yearly results of assessments of ADA-JDA entries.

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2 SUSTAINABLE DESIGN

This paper aims to investigate evidences of sustainable design among the finalists and winners of the ADA-JDA. The philosophy of "sustainable design" aligns with the principles of triple bottom-line sustainability: economic, ecological and social. That is, sustainable design offers enduring solutions which enhance the capacity and potential for long-term maintenance, wellbeing, and prosperity of humans and all living things, on the above three dimensions. Too often, "sustainable design" is only thought to focus on environmentally conscious solutions, causing socially equitable and responsible design to be sidetracked.

Consideration of ecological impact and social ethics alongside economic viability are important tasks of the industrial design profession. Article I (Benefit the Client), Article II (Benefit the User) and Article III (Protect the Earth's Ecosystem) of the ICSID Code of Professional Ethics all emphasize the triple bottom-line responsibilities of the industrial designer. The Code asks designers to contribute to the social wellbeing of the general public and to adopt principles of environmental stewardship. Moreover, the industrial designers' ultimate responsibility to their clients is to provide designs which are appropriate, original, efficient and economic, and representing value and benefit to clients and the general public, while meeting ethical business objectives [1].

Most guidelines on Design for Sustainability (DfS) focus on ecologically sustainable design, invariably known as ecodesign or design for environment (DfE). This is understandable because most industrial design works are technical solutions, and the established strategies for achieving ecologically sustainable design [3] are mostly technical schemes. Social sustainability, on the other hand, often calls for socio-technical solutions and very few "socially sustainable design" strategies have been proposed or considered useful by designers. There is also no accepted definition, scope and range of "socially sustainable design". A related definition has been proposed for "socially responsive design", which is one that "takes as its primary driver social issues, its main consideration social impact and its main objective social change" [4].

One emerging strategy for socially sustainable design is "democratic design", which could be understood either as the participative empowerment of the community in a design process, or as affordable and accessible "good design for all". In the 1960s professor Victor Papanek advocated that industrial designers go beyond "appearance design", styling, or "design cosmetics", and use their talents to solve the pressing needs of the disadvantaged minorities in society, including the disabled, the elderly, the developing world, people surviving under marginal conditions, and others ignored by the design profession. He argued that "much recent design has satisfied only evanescent wants and desires, while the genuine needs of man have often been neglected by the designer" [5].

Socially sustainable design is also about exploring solutions that can positively change the lives of people everywhere. It's about responding to "needs" and not merely consumerist "wants": designers ought to ensure that all design benefits the community at large and that they look into social, environmental, economic and political issues [6].

Universal design, inclusive design, design-for-all, barrier-free design, accessible design – which all meant designing products that are inherently usable by as many people as possible, whether able-bodied or physically challenged, without need for adaptation – is also another socially sustainable design philosophy.

Davey et al [7] proposed a model for socially responsible design based on the business management approach of corporate social responsibility. It encourages designers to use their unique skills to address issues of crime, education, government, health, fair trade, ecology, social inclusion and economic policy. Socially responsible design is also about positively transforming the lives of the 2.6 billion people in the developing world who are living on less than $2 a day; in other words, those who are at the "bottom of the pyramid [BoP]" [8]. Designers have been generally blamed for focusing much of their efforts on developing products and services exclusively for the richest 10% of the world's population, thereby neglecting and marginalizing "the other 90%" [9].

There appears to be an emerging stream of "design activism" among people who passionately "use the power of design for the greater good of humankind and nature" [10]. Some design-inspired organizations are now fundamentally challenging how design can catalyze positive impacts to address sustainability. For instance, the global design and innovation consultancy IDEO produced freely downloadable how-to guides and workbooks on designing for social impact and human-centered design [11]. These publications aim to help design firms to get engaged in social responsibility projects. The Industrial Designers Society of America (IDSA) started a "Design for the Majority" professional interest section whose mission is "to bring attention to the large group of humans that most of us do not currently design for" [12].

3 METHODOLOGY

This paper looks at how senior industrial design students, who are at the end of their design education and about to enter design practice, regard aspects of sustainability and sustainable design in their graduation projects. These major projects can be viewed as the accumulated embodiment of their learned design abilities as well as a showcase of the personal design philosophies that they have formed and developed while at university, which they are publicizing for industry and potential employers to see.

Examined in detail were the application entries of the winners and finalists of the Australian Design Award James Dyson Award, as displayed on the website www.student.designawards.com.au. The forms include the entrant's 100-word description of the project and its principal function, and a 500-word response to the question: "Why does this project represent excellence in design and why does it deserve to win an Australian Design Award James Dyson Award?" Content analysis was used to evaluate the sustaining potential of the winning and finalist entries, using a coding protocol based primarily on design strategies suggested in Brezet and Van Hemel [3], and in other published DfS toolkits and checklists [7, 11, 13-16]. While the ADA-JDA dates back to 2002, only entries from 2007 to 2011 are viewable in the publicly accessible online database, and therefore this paper is limited to analyzing these periods only.

For each of the 62 student projects analyzed, the evidence of use of DfS strategies was evaluated; each time a design entry claimed the use of a DfS strategy, the claim was noted in a spreadsheet. Being listed under one strategy doesn't preclude an entry from being listed under another strategy. It is possible for an entry to gain ticks on all the strategies; however no such example was found amongst the entries.

4 ECOLOGICALLY SUSTAINABLE DESIGN

The occurrences of particular ecodesign strategies in the students' design claims were tabulated and the graphs are shown in Figure 2. Among the 62 entries, 29 made mention of an ecodesign strategy in their project descriptions and rationale, while the other 33 had no mention, in spite of sustainability being in the ADA-JDA assessment criteria. This of course does not indicate that the 33 non-mentioning students actually ignored ecological considerations in designing the products; it simply means that sustainable design keywords didn't appear in their 500-word responses.

The most frequently appearing strategies in the claims are "reducing impact during use" and "optimizing initial lifetime". Some of the language and terminologies that the students used to describe the different ecodesign strategies they used are sampled in Table 1. Most of these strategies were about prescribing reusable components rather than disposable; employing renewable energy sources to power the designed products; improving efficiency in water and power consumption; promoting product longevity and durability by specifying tough advanced materials or by building in design details which prevent damage or malfunction.

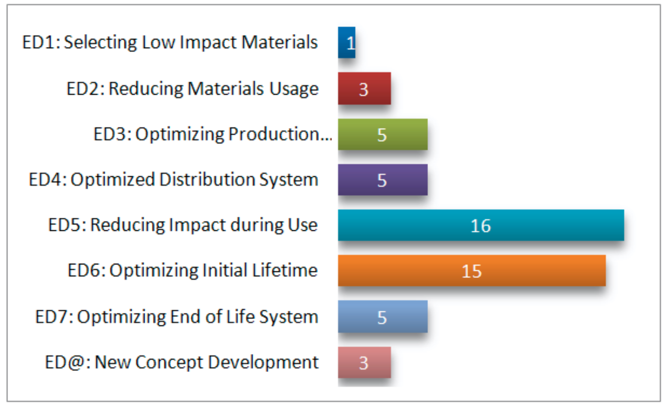

Figure 2: Occurrence of ecodesign strategies in the claims of student designer entries in the ADA-JDA.

Table 1: Samples of the descriptive language used to describe the ecodesign strategies in the ADA-JDA entries.

1	Low impact materials	majority of components use recycled rubber
2	Reduction of materials usage	minimal use of material allows manufacture up to 40% lower cost
3	Optimization of production techniques	snap-fit parts, minimal screws, eliminating any glues or surface finishes to reduce manufacturing and assembly time & cost
4	Optimization of distribution system	reduced weight and size of package allows up to 70% more to be transported per pallet
		flat pack construction and user self-assembly
5	Reduction of impact during use	materials can be sterilized and reused, reducing need for disposable pads
		absorbs solar energy at day, illuminates at night
		efficient impulse technology conserves water
		aeroponic cultivation 500% more efficient than ground farming while using 99% less water
6	Optimization of initial lifetime	replaceable tail guard protects board body from abrasion when dragged through sand
		ABS-PC base to endure years of play; program upgrades allow new activities to be installed
		CPU of high end user pass down to low end user: maximizes life span of components
		each polycarbonate panel extremely tough; batteries handle thousands of on/off cycles
7	Optimized end-of-life system	subscription-based upgrade eliminates improper hardware disposals by consumers
		hidden snap-fits provide strength and reduce components, allowing ease of disassembly

Figure 3: Examples of projects using Strategy @

Brezet and Van Hemel [3] propose strategy "@" or "new concept development" as the most innovative and with the highest sustaining potential. Three of the finalist projects were found with descriptor statements which demonstrate this strategy. The Oriental-looking Made in China PC & infrastructure concept (Figure 3A) is "a $99 low-cost PC with a $1 a day subscription fee". Users can improve their PC's performance by upgrading their $1 subscription; those who are in financially difficult situations or do not require high PC performance can switch to a cheaper subscription. The simpler system infrastructure aims to make PCs inexpensive and accessible to developing countries. Life span of components is maximized by sharing between users: microchips from a high-end subscriber can be passed on to a low-end user, avoiding wastage and improper disposal. This concept demonstrates "dematerialization" and "functional optimization".

Designed for short distance personal mobility and personal effects management, the Everglide (Figure 3B), operates as an infill to public buses and trains, thereby promoting sustainable mobility habits. It can be wheeled like an airport luggage, carried as a backpack, or ridden on as a bicycle; its frictionless dynamo charges mobile phones and iPods. This concept is an example of the "integration of functions" sub-strategy.

Lastly the 'Link' Urban Scooter System (Figure 3C) is a modular CBD transport solution allows users to hire a lightweight electronic scooter from a hub and ride to the desired destination and then return the scooter to another hub, where it is recharged. Aligned with the Sydney 2030 plan to reduce cars in the CBD and make the city more pedestrian oriented, this product-service system is an example of the "shared use of products" sub-strategy.

5 SOCIALLY SUSTAINABLE DESIGN

Similar to the previous section, an analysis of evidences of social sustainability was carried out. However, instead of detecting socially sustainable design "strategies" used, the focus was on determining evidentiary cases of solving problems in society. These social issues and the designers' approaches used to address them are presented in Table 2 and their frequencies graphed in Figure 4.

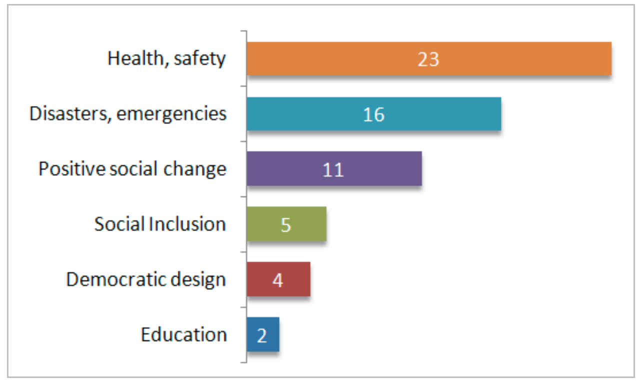

Figure 4: Occurrence of socially sustainable design issues in the claims of student designer entries in the ADA-JDA.

Table 2: Samples of the approaches used to address social sustainability issues in the ADA-JDA entries

Occupational Safety	exhaust fume filtration unit extracts tailpipe emissions in vehicle workshop environments
	plunge system in liquid nitrogen carrier eliminates risk of freeze burns among medical researchers
	vibration sensor along railway tracks alarms maintenance personnel of oncoming trains
Public or Community Health	adrenaline auto injector for anaphylaxis sufferers
	warm perfusion transport system that sustains life of human heart in normal beating state
	pain relief garment for chronic back pain
	urinary incontinence solution to promote patient dignity, comfort, and assistance in self-care
	diagnostic eye care tool for the developing world
	crutch improves comfort from repetitive jarring of body
Early childhood education	interlocking light-up tiles for childcare services to build developmental skills
	toy to assist children in practicing and learning "delay of gratification"
Social inclusion	mobility aid that reduces risk of falls for elderly
	intelligent harness for guide dogs increase independence and mobility amongst blind community
	removing stigma of hearing aids by repositioning from a disability device to an elegant accessory

The most frequently occurring cases of socially sustainable design were those solutions aimed at improving the health standards of the community, and those that minimize injuries and fatalities in hazardous workplaces and occupational conditions. Following closely are projects on disaster crises, emergency situations and extreme conditions. There were also a few proposals which promote a positive impact, social cohesion and a sustainable change in society.

6 DISCUSSION

It was encouraging to see that the great majority of the finalists and winners had either incorporated an environmentally responsive strategy or addressed an issue of significant importance to society. Only 4 of the 62 had no mention of either of these in their project description texts. This minority tended to focus on using design as a tool for improving everyday convenience, enhancing a contemporary urban lifestyle, updating the aesthetic styling of archetypical gadgets, or encapsulating an emerging or advanced technology into another consumer gizmo. This minority seem to be intended for the upper 10% of the world's population who are affluent and can afford to buy more discretionary "stuff".

It is interesting to note that of the 20 winners in this 62-subject study, 11 had no mention of keywords mentioned as ecodesign strategies in the sustainability literature. That they have been proclaimed winners could suggest that the projects were outstanding enough for the judges to not require the explicit satisfaction of the sustainability criteria outlined by the awards, or that the projects obviously do not contradict any ecological design factors, or that the projects scored highly enough in innovation, form, function, quality and safety that missing the environmental criterion can be considered acceptable. It could also be that the projects provided sufficient visual evidence of its apparent need, perceived durability, resource efficiency and compliance with environmental best practice that it was no longer necessary to put down these characteristics of the design into verbal language.

The reduction of impact during use was the most utilized strategy: one quarter of projects had this. In general, energy-using products (EuP) benefit much from this approach since the greatest negative impacts arise from the resource-intensive consumption of such devices. Several students projects successfully applied this strategy, such as by prescribing reusable vs disposable supplies, recharging via solar panels and mechanical dynamos, conserving water, and encouraging reuse and preventing throwaway by facilitating cleaning. An almost equal proportion embodied the optimization of initial lifetime in their designs.

It would be desirable to see more work being done in the area of "new concept development", as these can potentially lead to greater sustainability gains. Questioning whether a product is actually needed should be one of the first reflections when conceptualizing for a solution to a design problem and indeed the ADA-JDA sustainability criteria asks this, but the student responses tend to be design justifications of the value of the entry, rather than reflecting on whether the solution can be less of the material-intensive type, such as a product-service system (PSS). Product sharing as a strategy is not convenient for designers to build into a design, as this requires the presence of a good community spirit for it to work. However, it is possible for the design solution to encourage sharing within a community; book libraries, public transport, car sharing and DVD rentals are exemplars of community-shared solutions which work very well. Still, finding 3 out of 62 projects demonstrating this strategy looks promising and a sign that design students are expanding the boundaries of their problem finding and solving skills.

On the social sustainability side, it was encouraging to notice that the great majority of finalists and winners (49 out of 62 = 79%) looked into using design as a tool for solving significant problems in society. Tackling issues in community health and occupational safety was very popular, particularly in preventing injuries and fatalities.

Addressing disasters and emergencies, and preventing loss of lives and significant physical damage to property and biodiversity was also quite common. Managing risks that could lead to serious crises and lowering people's vulnerability to both natural and manmade hazards is certainly an area where designers can contribute solutions to. Several finalists and winners submitted works which addressed such issues as drowning during maritime disasters, detection and suppression of bushfires, and equipment for emergency response teams.

Fostering environmentally and socially positive behaviors through the design of sustainable products and services is another new challenge for industrial designers. Some of the solutions offered by the students were: a folding commuter bike that riders can carry inside trains and buses, and illuminated accessories for cyclists, both encourage more people to use bikes for daily transport; a contemporary aesthetic for a fan blade to entice people to install ceiling fans rather than air-conditioners; and a childcare toy that develops and strengthens in young children the early ability to delay gratification, since those who grow with a stronger drive to see past their initial urges to spend, waste and destroy are expected to find consideration for the environment and the future of the earth past their immediate existence.

Democratic design was another social sustainability strategy evidenced among the works. The Made in China PC infrastructure mentioned earlier is an example of this philosophy that Papanek [5] and other responsible designers have been advocating in the last four decades. Utilizing simple and affordable hardware, the proposed system hopes to spread computer use, education and knowledge across China.

It must be understood that the sampling done for this study excludes 381 non-shortlisted and shortlisted entries, some of which could possibly demonstrate sustainable design characteristics, perhaps address sustainability issues even better than some of the finalists and winners. Analyzing these is beyond the scope of this article; it was deemed reasonable to limit the analysis to the finalists and winners from 2007 to 2011, as these were the ones adjudged by a national jury as comparatively better-designed, satisfies the assessment criteria better, and more likely to qualify for an Australian Design Award. The finalists and winners are expected to be the "cream of the crop", and by extension represent some of the very best ID graduation projects from Australian universities.

There is a danger that "green design" and "social design" could be perceived by most as being "ugly". Obviously attaining a balance of form and function is important in any designer's work, and the ADA-JDA requires the submission of an aesthetically pleasing form to be eligible to win recognition. If any student entries do not represent "design excellence" they will understandably be culled and not be shortlisted.

7 CONCLUSION

Judging from the finalist results of the ADA-JDA during the last five years, it can be said that the outcomes of Australian industrial design education seem to be showing reasonable progress in supporting issues which are important for the environment and society. That graduating students choose to do final-year projects which reflect their sensitivity to these global issues suggest a concern and a readiness on their part in finding real solutions to global social and environmental problems, and perhaps a desire and optimism for a more promising world for future generations.

Whether or not industrial design education providers had a direct influence on students taking up projects which address ecological or social issues cannot be ascertained by simply looking at the ADA-JDA entries.

It would be optimistic to think that, if this research amongst ADA-JDA finalists and winners is repeated in 5 or 10 years' time, the proportion of projects which showed sensitivity to environment and society would have doubled or tripled. Our current state of the environment is urging all of us to think deeply on how industrial design can contribute to a more sustainable future, one that is threatened by climate change. Unfortunately many design educators still seem to "continue to educate the young as if there were no planetary emergency" [17]. We should take it as our duty to empower students with authentic learning and to ensure that they conscientiously grow with the belief that they could actively be part of the sustainability solution, and not be part of the problem. Obviously all teachers can do is to "ignite the spark", and it is up to the students to take it up in their own practice as their own personal responsibility and commitment to a better world.

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Comparison of Corporate Social Responsibility both in China and Japan

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Abstract

The corporate social responsibilities (CSR) and environment management develop fast in the last several decades. This study selects randomly CSR reports as sample both in China and Japan, and set indexes to check the environment performance and CSR performance, and analyzes and summarizes the current status of environment management and corporate social responsibility. Meanwhile, this study will survey the specific environmental conscious action and social responsibility action in the different countries.

Keywords:

Corporate Social Responsibility, manufacturing, environment responsibility, sample

1 INTRODUCTION

Manufacturing is the use of machines, tools and labor to produce goods for use or sale. It is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Compared to the service industry, agriculture and trade, manufacturing has a close relationship with the employment, environment pollution, and resource degradation. Therefore, the study on the Corporate Social Responsibility (CSR) in manufacturing will play active roles in environmental protection, sustainable use of resource, society harmony and so on. In 2005, the first CSR report came to the world, and then Shenzhen Stock Exchange in 2006 and China Shanghai Stock Exchange in 2008 issued respectively the regulations to require listed companies to disclose the corporate social responsibility information using the standalone CSR report or annual report. Consequently the development speed of CSR reporting in China is faster although the Chinese CSR reporting started later. In 2010, 533 Chinese companies have issued the CSR reports or sustainable development report. Meanwhile, the Economics Division of China Academy of Social Sciences issued the Guideline of Chinese Corporate Social Responsibility Report (CASS-CSR1.0 ） in December, 2009 and issued the CASS-CSR2.0 in March, 2011, it promotes quickly the quality of Chinese CSR report. Therefore, the name of Chinese corporate social responsibility report is unified, named mostly as the Corporate Social Responsibility Report. In fact, many different types and names of reports exists under the umbrella of CSR reporting, such as ‘environmental reports’, ‘social reports’, ‘climate change reports’, ‘carbon reports’, ‘environment reports’ and ‘sustainability reports’ and others. For example, In Japan, many companies issued the relative reports named as sustainability report, environmental & Social report, CSR report and so on. After World War Ⅱ, the idea of corporate social responsibility was introduced to Japanese business society from United States. The Japan Society for Business Ethics Study was established in 1993 [1]. In 2003, Keizai Doyukai which is composed of top managers and corporate executives published The 15th Corporate White Paper on “Market Evolution' and CSR Management: Toward Building Integrity and Creating Stakeholder Value” after investigating European CSR situation [2]. More Japanese companies have set up division of CSR and published CSR report since 2003. By 2010, 798 Japanese companies issued the environmental report or CSR report for fiscal 2009.

2 .METHODS

Because, the standalone CSR report can disclose CSR information as much as possible and as good as possible, more and more companies choose to issue the standalone CSR report, We chose at random 20 standalone CSR reports in China and 20 standalone CSR reports in Japan as samples to research the corporate social responsibility in both countries. These companies refer to printing, electronics, metal casting, mental working, machine building industry, food and drink, textile, paper making, Chemical industry, pharmacy, Plastics, petroleum product industry and other manufacturing. This study classified reports according to the year in which the CSR activities were performed, mainly chose CSR reports in 2009. Corporate social responsibilities include responsibility management, market responsibility, environmental responsibility and community & society responsibility[3]. An Excel spreadsheet was created with the following column headings : name of industry, company, report guideline, third part check, responsibility management, market responsibility, environmental responsibility and

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community & society responsibility. On the other hand, because corporate social responsibility is also viewed as the responsibilities companies should take for the costumer, government, supplier, partner, employees, environment, investor, community and so on. To embrace the CSR contents as much and clear as possible, we classified the market responsibility, community & social responsibility and environment responsibility according to the different shareholders. For example, in the market responsibility, it included the responsibility for the customer, supplier, partner and so on. Therefor this research set up an index system with 46 primary indexes and 85 secondary indexes. If report disclosed information about this index it will be given a 1 for yes, if not, will be given a 0 for no. the sum for every index indicates the amount of company disclosing information about this index. The sum for every company explains whether the content of CSR report is comprehensive or not.

This study classified the score of every index into 4 categories, the indexes scoring 0-4 suggests that these indexes are completely discounted, the indexes scoring 5-9 suggests that they are discounted, the indexes scoring 10-14 suggest that these indexes are paid attention by company, the indexes scoring 15-20 suggest these indexes get much attention by company.

3 RESULTS AND ANALYSIS

3.1The referenced guideline

Through this survey, we can find 14 companies in Japan and 12 companies in China disclosed the referenced guidelines among 40 samples, and the Sustainability Reporting Guidelines published by the Global Reporting Initiative (GRI) become to be most popular international guideline, 18 companies refer to CSR guidelines issued by the GRI. On the other hand, Environmental Reporting Guidelines published by Japan's Ministry of the Environment is also commonly referenced in Japan, while the CASS-CSR is commonly referenced by the Chinese companies. The index system is established based on these guidelines.

3.2 Overall situation of CSR reporting in Japan and in China

We can find the overall situation of CSR reporting in Japan is better than that in China, Japanese companies disclose 40.29% indexes in average, Chinese companies disclose about 34.12% indexes in average, and it is surprising that the company is existing in China whose CSR report disclosed a little of social responsibility information even though they named the report as the CSR report. However, to our joy, 7 companies in Japan and 5 Chinese companies seek external assurance or suggestion to show the accuracy and objectivity of data and information in the CSR report and to improve the quality of CSR report.

Meanwhile, we can find the companies such as KYODO Printing Group, TOSHIBA, ASAHI Breweries and LENOVO Group with best CSR performance disclosed more than 60% indexes, it is an outstanding performance.

Through this survey, we can find Japanese companies emphasized very much on the undertaking of environmental responsibilities, more than 15 companies in Japan disclosed information as following： waste management, environmental education , GHG emission plan and data, nature conservation, environment management system, waste reduction , recycling, promoting efficient energy use at sites and energy saving. The Chinese companies practiced more in career development, maintaining and enhancing corporate value, employee welfare, establishing CSR version or strategy. Because the CASS-CSR guideline points out that the CSR report should include developing CSR version or strategy and maintaining and enhancing corporate value, more Chinese companies disclosed information in both above aspects. Moreover, both Chinese company and Japanese company emphasized on the practice of supporting education. What we need to pay attention is that a few of Japanese companies report the compliance with law and basic corporate ethics. For example, only 1-3 companies listed the lawful employee, compliance with the environment law, fair competition and trade in the report. Many Chinese companies disclosed enough information in the law compliance and some basic business ethics.

3.3 Responsibility management

Perfect CSR management is very important for corporation to sustainably develop. This study set three primary indexes for responsibility management; they are CSR management, CSR promotion and CSR communication. Company should develop CSR version or strategy and carry out risk management. And then, promote the CSR practice, for example, drawing up CSR policy or plan, establishing CSR organization or Committee, developing the CSR education, auditing and monitor CSR activities and so on. CSR communication means enquiry and feedback for shareholder and information disclosure. Therefore, this study set 7 secondary indexes for theses primary indexes. According to the statistics data, 20 companies disclosed 44.29% indexes in average in Japan and 32.14% in China, we can conclude that Japanese companies emphasize very much on the responsibility management and have a better performance in this aspect. And we can find the Japanese companies emphasized very much on risk management, however, only 4 Chinese companies described their rick management in CSR report. Chinese companies should strengthen rick management. On the other hand, 5 Japanese companies drew up the CSR plans and carried out the CSR education, and 3 Chinese companies drew up the CSR plans and carried out the CSR education, both countries have discounted the CSR education and CSR plans.

3.4 Market responsibility

We set three primary indexes for market responsibility; they are market responsibility for customer, market responsibility for stockholder, market responsibility for supplier and partner, and set 12 secondary indexes. The ratios of indexes disclosure are 42.93% in Japan and 40.83% in China. Both country have emphasized and disclosed their market responsibility. Through the statistics data, we can find more Chinese companies paid emphasis on after service management than Japanese companies and we also feel the after service in China is better than in Japan in the daily life. Many Japanese companies made great effort to provide safe products and service and improve customer satisfaction. So the Japanese products is famous for their perfect quality & safety and humanized design in the world. However, Chinese company did not pay enough attention to these aspects. Therefore Chinese companies can learn much from Japanese company in these aspects. On the other hand, about half of Japanese companies took action to protect the custom information, while only 2 Chinese companies disclosed their practice of protecting the customer information. Chinese companies should enhance the protection of customer information. Moreover, CSR supply chain management and technology innovation have captured attention of many Chinese companies; a little more companies in China than in Japan carried out the CSR supply chain and made effort in research and development. Much more Chinese companies disclosed information than Japanese companies in Maintaining and enhancing corporate value and fair competition and trade. 55%-60% companies emphasized on the communication with the shareholder

3.5 Environment responsibility

We set 11 primary indexes to reflect the situation of fulfilling the environment responsibility; these indexes are environmental management, global warming prevention, waste reduction, management and reduction of chemical substances, pollution prevention, green products, biodiversity, environmental technology, environment awards, green purchase, compliance with environmental law and regulation. And set 30 secondary indexes for them. By calculation, we concluded that Japanese companies disclosed 47.83% indexes in average, Chinese companies disclosed 28.33% indexes in average. That is to say, the performance of Japanese company is much better than Chinese company in environment responsibility.

About the environment management, 16 Japanese companies have established the perfect environment management system and most of companies have obtained ISO14000 certification. In China, about half of companies have established the environment management system and have obtained ISO14000 certification. About the application of advanced environment management tool, we can find input-output analysis was widely used in Japan. And almost all of companies carried out the environment education in production. To comparison, only one company applied the input-output analysis in China. On the other hand, 6-7 Japanese companies carried out the environment accounting and environment risk management, while 2 Chinese companies carried out the environment accounting and environment risk management. Japan has issued the environmental accounting guideline in 2005, therefore the Japanese companies got the technical and theory support of environment accounting. Up to now, China has not issued any authoritative guideline; consequently, Chinese government should issue the environment accounting guideline as soon as possible. About the using the life-cycle analysis to assess environment impact of product, the Chinese company is more than the Japanese company, but in both countries less than 5 companies adopted this analysis method. At last, this study also checked the utilization situation of Material Flow Cost Accounting, we find only one company in Japan and no one in China adopted this environment management tool.

In global warming prevention, almost all of Japanese company recorded the amount of CO_2 emission and made a reduction plan, but in China, only 4 companies calculated and recorded the CO_2 emission. To realize the GHG reduction plan, Chinese corporation should firstly know about the calculation method of GHG emission and record GHG emission; it is the foundation of realization of GHG emission reduction plan. On the other hand, we can find about half of Japanese company used green energy in site and tried to reduce the logistical CO_2 emission. 2-3 Chinese company take these both methods into account to undertake the environment responsibility. On the other hand, both Chinese and Japanese companies did not pay enough attention to the energy conservation in office.

In waste reduction, Japanese companies emphasize very much on the waste reduction, recycling and waste management. More than 15 companies disclosed the information in these aspects. Although both countries have issued the law or regulation about industrial waste disposal, only 3 Chinese companied disclosed their waste disposal information. That is to say the Chinese industry waste need be managed further. On the other hand, this study checked environmentally conscious packaging, and finds only a few companies made effort in environmentally conscious packaging in Japan and China. But more than half of companies recorded and tried to reduction the water consumption in China and Japan.

In the environment pollution prevention, Less than 4 companies tried to prevent soil pollution and sound pollution in both countries. More Chinese companies take action to prevent water and air pollution; however, Japanese companies did not disclose the enough information in water and air pollution prevention.

In Management and Reduction of Chemical Substances, the same number of Japanese companies and Chinese companies used environmentally sound substance and reduced environmentally harmful substances. But more than half of Japanese emphasized on chemical substance management. Many Chinese companies ignored chemical substance management.

In the other environmental aspects, Japanese companies emphasized on the biodiversity, while Chinese companies almost completely discounted the biodiversity, only one company took steps to protect biodiversity. However, Chinese companies did not lag behind in researching environmental technology and providing environment friendly product or service. On the other hand, more Chinese companies than Japanese companies disclosed information in the pollution prevention of water and air, environmental awards, compliance with environment law. China governance and organization are making great effort to promote the environment protection through the issuance of environment law and environment protection performance assessment. Therefore, Chinese CSR report would like to disclose compliance to environment law and many Chinese companies win environmental awards. Moreover, from the CSR report of Chinese companies, we can find the many company are implementing the cleaner production, Chinese government issued cleaner production regulation and standard and required some industries to carry out the cleaner production audit and encouraged some industries to carry out voluntarily cleaner production audit. It promoted greatly the implementation of cleaner production. The Japanese government has not adopted any explicit cleaner production policy [4].

3.6 Social responsibility

This study classified the social responsibility indexes into social responsibility for employee, community & society and government. It assessed the social responsibility for employee from the following aspects : lawful employment, respecting human right, prohibition of discrimination, diversity, career development, work hours and paid holiday, evaluation and compensation, employee care, safe production, occupational safety & health and so on. By the survey, we can find the 43.52% indexes in average were disclosed by Chinese companies, is more than the percentage of Japanese companies. Both Chinese company and Japanese company emphasized very much on the safe production and career development of employee. And both countries emphasized on occupational safety and health to the same degree. However in both countries, only 9 companies carried out the employee health and safety management, and 4 companies acquired the OHSAS 18001certification, and 2 companies record the Morbidity of occupational diseases in detail. Therefore, both countries have a long way to go in the Occupational Safety and Health. On the other hand, we can find the difference between Japanese companies and Chinese companies in health check, more Japanese companies paid attention to mental health, and many Chinese companies ignored this point. About half of Japanese companies hired the retired and the disabled, a few of Chinese companies hired the retired and the disabled. Moreover, we can find the Chinese companies had better performance in the employee welfare. They emphasized on the communication between manager and employee, and deal with the specific difficulties faced by individual, cared for the retried, held the literature & art program and sports meeting for employee, provided the accommodation and so on. Japanese companies did not emphasize very much on these activities. The employee welfare is affected by the specific national condition and regional culture to same degree, but Japanese companies can also learn very much from the welfare activities of Chinese companies. On the other hand, Japanese companies focused on how to enhance the work environment, support diverse working styles and achieve work-life balance. Chinese companies should take more action in these aspects.

About the social responsibility for the community, no matter how company fulfills the responsibility for community, all methods can be summarized in donation and voluntary activities. Therefore, this study classified and summarized the social responsibilities fulfilled by company according to the action aims. We can find supporting education got enough attention in both countries, but it is notable that the most Japanese companies conducted environmental education activities and provided opportunity of visiting study except of setting up the scholarships, donating for school and so on. Chinese companies did not often take the social responsibility in these ways. On the other hand, the action most Japanese companies took is planting trees and cleaning-up to protect nature like, while most Chinese companies took more action to support the poor. Only 3-4 companies support the science development and neighboring communities in case of a disaster and accidents in both countries. Moreover, both countries preferred the different aspects during the fulfilling the social responsibility, Japanese companies preferred to supporting artistic and cultural activities, respecting different customs and cultures, protection of intellectual property, while Chinese companies took more action in blood donation, public construction and disaster relief.

At last, for government, company should undertake law compliance, creating employee, tax payment and responding to the national calls for. 25%-35% Chinese companies disclosed the information about these aspects. In Japan, few companies disclosed information in these aspects.

4 CONCLUSIONS

To conclude, what Japanese company emphasizes most on is environment responsibility, and then in order from high to law is responsibility, market responsibility and social responsibility. What Chinese companies emphasize most on is social responsibility, and then in order from high to law is market responsibility, responsibility management and environment responsibility. Japanese companies make great effort in the environment protect and product safety and Chinese companies make great effort in the after service management and responsibility for employee. Japanese companies can learn from the Chinese companies how to provide employee welfare and how to improve the after service. And Chinese companies should provide more visiting learning opportunity, hire the disabled, care for the biodiversity, pay attention to the mental health like the Japanese companies and so on. Chinese companies should emphases on the environment responsibility. Japanese companies discount the disclosure of the information about law compliance and basic business ethics. Chinese companies should enhance further the quality of CSR report.

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Comprehensive Evaluation of Optimal Environmental Policies about Nitrogen cycle for Sustainable Development in China: Case Study of SongYuan City.

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Abstract:

Nitrogen is precursor of environmental problem, which contributes to smog, acid rain and global warming. Anthropogenic input can result in nitrogen saturation, which broken material circulation and can damage the development of sustainable society. In this study, we analyze the conditions of nitrogen material circulation, simulate the interrelation between the excessive emission of nitrogen and socio-economic structure by the mathematical model in the study area, and observe if the nitrogen utilization can satisfy the requirements of environment and economy, in order to reach a decision regarding the optimal solution to the comprehensive problem.

We formulate the comprehensive system as a linear optimization model. It is built based on the principle of nitrogen material balance, Input and Output table and other macroeconomic indicators to analyze the interrelation between nitrogen material circulation system and socio-economic system. Use the LINGO software to simulate a computer modeling of the nitrogen material circulation system and the socio-economic system. The computer modeling is utilized to give predictions, which can be employed in the process of decision-making.

Key words:

Nitrogen material balance, Input and Output Simulation, mathematical model

1. Introduction

China is a large agricultural country. With 70% of its 1.5 billion people living in rural areas, China faces grave challenges from both global economic integration and global changes in the natural environment. As a developing country with 9.6×10^6 km^2 of land, China must acquire a good understanding of sustainable development; develop scientific methods for evaluating the sustainable capability of its socio-economic development, and deal with the issues of imbalance between economy and environment of socio-economic development in order to devise policies to achieve the goal of sustainable development across the country.

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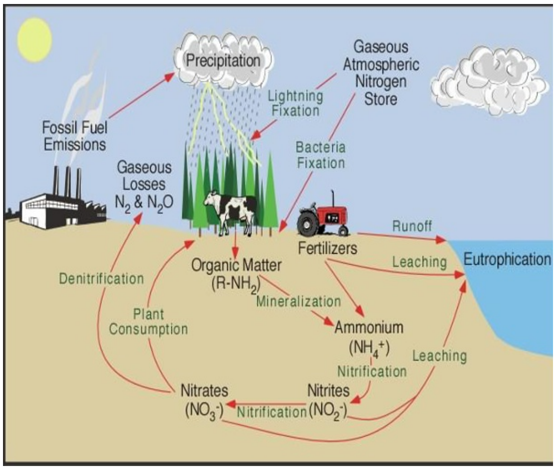

Fig.1 Nitrogen Cycle [1]

The nitrogen cycle represents one of the most important nutrient cycles found in terrestrial ecosystems (Figure 1). Nitrogen is used by living organisms to produce a number of complex organic molecules like amino acids, proteins, and nucleic acids. The store of nitrogen found in the atmosphere, where it exists as a gas (mainly N_2), plays an important role for life. This store is about one million times larger than the total nitrogen contained in living organisms. Other major stores of nitrogen include organic matter in soil and the oceans. Despite its abundance in the atmosphere, nitrogen is often the most limiting nutrient for plant growth. This problem occurs because most plants can only take up nitrogen in two solid forms: ammonium ion (NH_4+) and the ion nitrate (NO_3-). Most plants obtain the nitrogen they need as inorganic nitrate from the soil solution. Ammonium is used less by plants for uptake because in large concentrations it is extremely toxic. Animals receive the required nitrogen they need for metabolism, growth, and reproduction by the consumption of living or dead organic matter containing molecules composed partially of nitrogen.

2. Statement of the problem

The activities of humans have severely altered the nitrogen cycle in Songyuan city of China. Some of the major processes involved in this alteration include:

The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into groundwater. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can lead to eutrophication.

Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion.

Livestock ranching. Livestock release a large amount of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and runoff. Sewage waste and septic tank leaching.

3. Methodology

Present evaluation theories and empirical researches of comprehensive evaluation are mainly focused on developed counties. Baumol and Oates [2] analyzed the political aspects of the environmental problems. Arrow [3] researched the carrying capacity of economic growth and environment. In Japan, Higano and Yoneta[4] constructed simple simulation analyses to evaluate water purification policies. In the recent years, many studies have explored how to protect the environment and improve economic development. Hirose and Higano [5] constructed simulation analyses to integrated environmental policies in the catchment area of Kasumigaura ,Japan. Subsequently, Mizunoya [6] extended and assessed synthetic environmental policies to reduce environmental burdens by biomass technology.

4. Model Structure

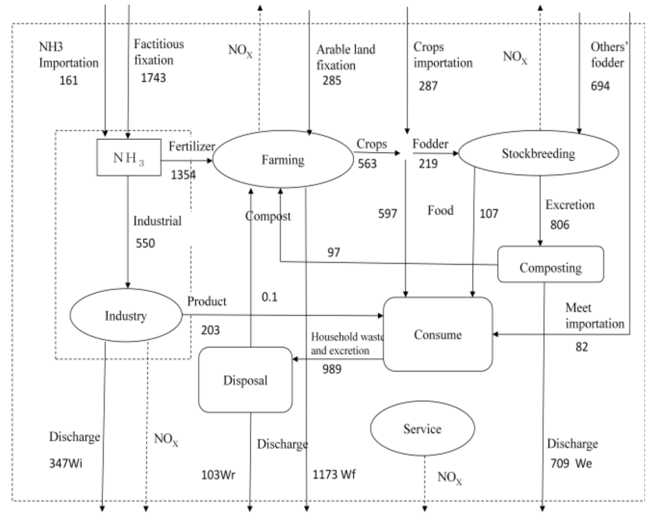

Fig2. The Nitrogen Cycle balance of production in Songyuan city

Nitrogen load of industry in Songyuan city

$$TN = Wf + Wi + Wr + We \qquad (1)$$

TN: Total nitrogen load of industry (fig.2)

Wf: Nitrogen from farming waste

Wi: Nitrogen from industrial waste

Wr: Nitrogen from disposal waste into river

We: Nitrogen from Excretion

Flow balance in commodity market

$$X_i \geq \sum_{j=1}^{5} A_{ij} X_j + C_i + G_i + I_i + E_i - M_i \quad (i = 1 \dots 5) \qquad (2)$$

X_i : Column vector of the total production of each industry (Figure 3)

A_{ij}: Input-output coefficient matrix.

C_i: Total non-governmental consumption

G_i: Total governmental consumption

I_i : Column vector of the total investment of each industry

E_i: Export of each industry

M_i: Import of each industry

Objective function

$$max = \mathrm{GDP} \quad (3)$$

$$subject\ to\ \mathrm{TN} \leq \mathrm{TN}_0 \quad (4)$$

TN_0: Total nitrogen of constraint discharge

4. Result

The expectant result will reduce the nitrogen discharge having maintained GDP.

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Introducing a new and integral EPR system in China: Case study of e-waste in HangZhou city

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Abstract

In this paper, I propose the design of an e-waste collection system that will meet the current waste generation trends. Most of the E-waste in China goes to family-run workshop or other illegal E-waste disposal enterprises where laborers disassembly the wastes manually or with rudimentary tools to recycle the valuable components. These practices are harmful not only for the people but also for the environment. Japan's EPR system has achieved remarkable success in collection and recycling of e-waste. According to the Home Appliance Recycling Law of Japan, retailers and local governments are in charge of the waste collection while manufacturers must recycle the wastes. Consumers pay a fee for the collection, transport and recycling of the e-wastes In China, because of the average per capita income, cheap labor, and lack of environmental awareness, it is unrealistic to make consumers pay for their discarded products. On the contrary, they usually sell the e-waste for informal recycling explained above. Based on the Japan's experience and current situation in China this study proposes a new and comprehensive EPR system which can be suitable for China. The study will chose Hangzhou city as case study.

Keywords:

WEEE; Collection; EPR

1 INTRODUCTION

With the rapid development of electronic information industry and the continuous improvement of people's living standard, the quantity of e-waste keeps growing, and becoming the fastest-growing solid waste in the twenty first century of the world including China.

As the largest exporter of electrical and electronic equipment (EEE) and importer of waste electrical and electronic equipment (WEEE, also called e-waste) around the world, China plays a key role in the electronics industry, producing a significant share of the sector's worldwide output. The total sales revenue for electronic products (e-products) was RMB 5130.5 billion (US$802.4 billion) in 2009. (1) Meanwhile, e-waste has become a serious problem in China both in terms of quantity and toxicity, exacerbated by the growing adoption and shorter lifespan of electronic products. (2)

China has become the second largest producer of E-Waste, producing 2.3 million tons of E-waste every year, following the USA with 3 million Tons. According to statistics, 48 million sets, including Refrigerator, washing-machine, color TV, air-conditioning, computer were discarded only in 2005, and this amount reached 78 million sets in 2007. This means an average annual growth rate of more than 20%. In addition, it is estimated that 80% of e-waste from world is exported to Asia, of which 90% is exported to China. From 1990 to 2000, the inflow of E-waste increased from 0.99 million tons to 17.5 million tons. (3)

Obviously, treatment of electronic waste has been a problem urgently needing to be solved and that cannot be ignored anymore.

2 THE SITUATION OF WEEE RECYCLING IN CHINA

Owing to lack of legislation, recycling often occurs informally in China. (4) The traditional WEEE flow system in China, shown in Fig. 1, Most of the E-waste in China goes to family-run workshop or other illegal E-waste disposal enterprises as well as secondhand market by individual collectors. Part of old products that goes to secondhand market will be repaired and resold to consumers who have demand in. And the rest will go to informal recycling sectors with high revenue in return.

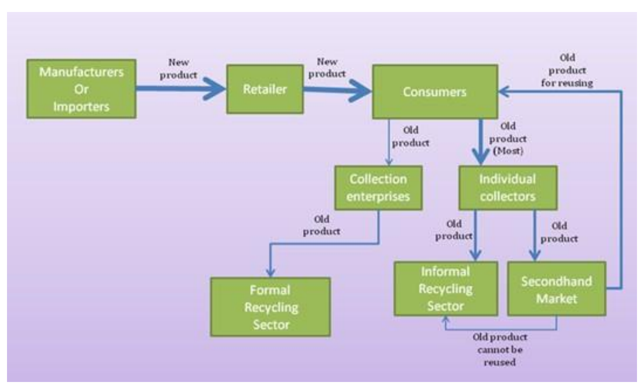

Fig.1 The traditional of WEEE recycling in China

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They can provide high price to collect E-waste is because they can reduce cost more than formal recycling sectors. In order to reduce cost, they usually disassemble e-waste in the fastest and most direct way to recycle the valuable components, such as stripping of metals in open acid baths, removal of electronic components from printed circuit boards by heating over a grill, and recovering metals by burning cables and parts. (5)

These practices have caused severe pollution releases to the surrounding soil and groundwater in informal recycling areas, such as Guiyu in China. Long-time exposure to dioxin and heavy metals leads to human health damage such as the case of 70% of lead poisoning in children in Guiyu. The pollutants also leak into water supplies, making river waters unfit for consumption. The local drinking water has to be transported from neighboring cities. According to the report of Environmental Organization "BAN", the content of Pb in local drinking water is double of European Union's safety standards. (3)

Obviously these practices are harmful not only for the people but also for the environment and the lack of a clear waste management policy has made the situation more serious for the environment and people's health.

To cope with the challenge of financial crisis by expanding consumption demand, a pilot project named "Implementation Measures of the 'trade old for new' of Home Appliances" have been launched since June 2009, which specifies that consumers who trade their old home appliances between June 1, 2009 and May 3, 2010 in 9 pilot Provinces and cities including Beijing, Tianjin, Jiangsu, Zhejiang, etc, will receive 10% rebate of the original product price. Of course there is an upper limit, which is 400 RMB/set for TV, 300 RMB/set for refrigerator, 250 RMB/set for washing machine, 350 RMB/set for air conditioning and 400 RMB/set for PC. The Government will offer retailers the subsidy for this rebate. And the collection enterprises will also receive the Government subsidy for transporting these old products. The total government subsidy will be up to US$300 million throughout the country. (6) The WEEE flow with "Trade old for new" system in China, shown in Fig.2.

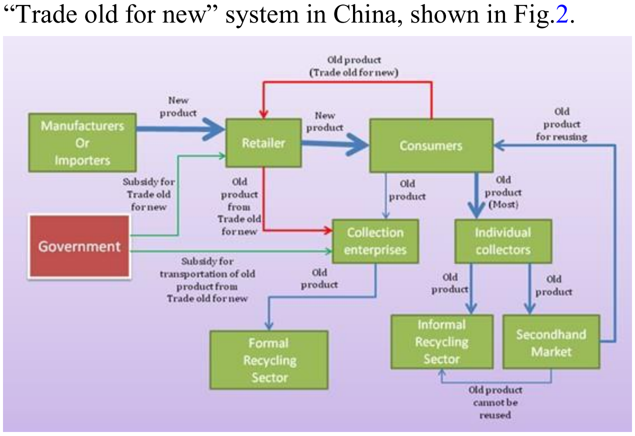

Fig.2 WEEE flow with "Trade old for new" system

Since this project brings about not only a striking effect of market stimulation but also a great influence of post-consumer WEEE collection, the pilot Provinces have been increased from 9 to 19 and the time period extended to December 31, 2011. By December of 2010, there were 30.026 million sets of new product sold and 31.109 million sets of old product collected. (7)

3 JAPAN'S EPR SYSTEM AND THE PROPOSED NEW EPR SYSTEM FOR CHINA

Japan's EPR system has achieved remarkable success in collection and recycling of e-waste. The Home Appliance Recycling Law was enacted in June 1998 and was enforced in April 2001, aiming to realize sound waste treatment and efficient use of resources through reduction of wastes and full utilization of recyclable resources in order to realize a sound material-cycle society. The law introduces a new framework of recycling of which the principle is to place an obligation on manufactures and retailers of home appliances. (8)

According to the Home Appliance Recycling Law of Japan, with regard to the four specified post-consumer use home appliances, namely air conditioners, television sets, refrigerators and washing machines, retailers and local governments are in charge of the waste collection while manufacturers or importers must recycle the wastes. Consumers pay a fee for the collection, transport and recycling of the e-wastes when they discard those appliances. (8)

In China, because of the average per capita income, cheap labor, and lack of environmental awareness, it is unrealistic to make consumers pay for their discarded products directly. On the contrary, they usually sell the e-waste for informal recycling explained above. Based on the Japan's experience and current situation in China this study proposes a new and comprehensive EPR system that illustrated in Fig. 3.

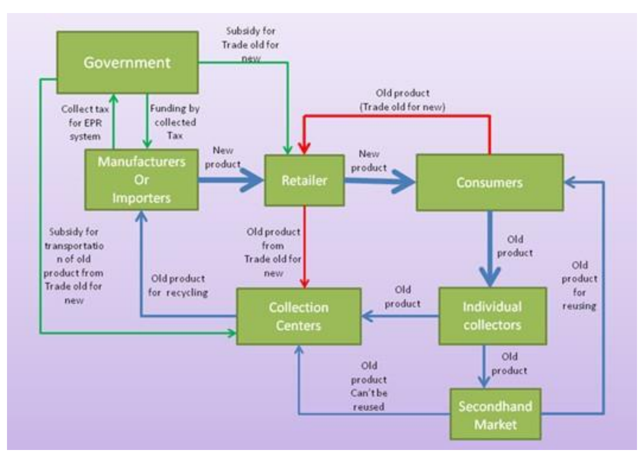

Fig.3 The new EPR system

In this system, the Government provides funding to Manufacturers or importers for EPR system through the collected tax from them. Manufacturers will establish or commission formal recycling centers. And because of the great impact of both economy and e-waste collection, the "Implementation Measures of the 'trade old for new' of Home Appliances" will continue to be implemented as before and expand to the whole country.

Based on this system consumers can pay part of the new product with the discarded one through "trade old for new" system or can sell directly to individual collectors. Individual collectors can either sell the e-wastes to secondhand market sector for repair and resell or sell them to the established central collection centers. The central collection centers, in charge of the local government, will also receive the wastes from retailers or secondhand market and transport them to formal recycling centers established by Manufacturers for recycling.

4 CONCULSION AND FUTURE WORK

Hangzhou locates on the Hangzhou Bay 180 kilometers southwest of Shanghai in Eastern China. It is the capital and largest city of Zhejiang Province, the provincial center in economy, culture, science and education and is one of cities that have highest economic growth rates in China.

Hangzhou city occupies 3068 km² and has 1.269 million households, the total resident population of 4.294 million as of 2009. Hangzhou city's total GDP grew to RMB 406.99 billion (US$63.78 billion) with GDP per capita of RMB 95,342 (US $14,940). (9)

The situation of WEEE recycling in Hangzhou is as same as other city of China. With the rapid development of local economy, electronic industry and demand of e-product in Hangzhou, lifespan of electronic products are becoming shorter and shorter. That means more WEEE will be produced.

There is a large number of manufacturers and importers of home appliance or other e-product, as well as secondhand market of a certain scale in Hangzhou. Moreover there is a large number of floating population individuals who live on the business of waste collection including old home appliance collection. Most of this population is from other depressed area of China. They could play an important role in this new system and make the greatest contribution to it. Besides, Hangzhou city is also the pilot city of the project "Implementation Measures of the 'trade old for new' of Home Appliances". With this background this research will use Hangzhou city as a case study.

This system aims to take WEEE to the formal recycling sectors from informal ones. The Successful Experience of "trade old for new" system shows us that the key point is economic benefit. If consumers can get more benefit from formal sectors than informal sectors. No doubt this system will work well.

So the countermeasure is to pay individual collectors and secondhand market a financial incentive (or fixed price) to turn in old product or unusable equipment and parts higher than that offered by informal recyclers. This incentive price will come from government funding, which is actually the tax collected from manufacturers or importers.

This study will use MFA to analyze the material flow of the new system in Hangzhou city. Introducing this new system in Hangzhou city and investigate the material flow of main home appliance and related valuable substances through MFA will be the future subject.

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Introducing Socio-Environmental Management Policy Guidelines for the Financing of Electric Power Projects in Bangladesh.

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Abstract
Bangladesh is struggling for a long time with her energy sources especially electric power. To achieve the vision of reducing gap of demand and supply of electricity to enhance economic activities in near future Govt. is encouraging the private sector to establish small and medium power plants apart from the govt. basically burning the fossil fuel. This power projects have significant social and environmental impacts which are not much seriously addressed as this sector is considered as priority sector and difficult for the lone governmental agency for several reasons. In this study, a Social and Environmental Management policy guidelines for Financial Institutions (FIs) will be developed to finance electric power projects. As, the private sectors plants are usually set up with financing from FIs, a different approach mechanism to determine and assess future potential environmental and social impacts of electric power projects could be done by the financer of plants as third party, under the guidance and regulation of the Central Bank, the regulator of the FIs.

Keywords
Electric Power, Environmental Safeguard, Social Impact, Financial Institutions, Environmental Laws.

1. INTRODUCTION

The energy related infrastructures in Bangladesh is quite small and insufficient, which is also not well managed by anybody concerned. Even up to last decade the energy was not the prime priority sector for the government. The per capita energy consumption in Bangladesh is 163kg which is one of the lowest amounts in the world (*World Bank, 2010*)[1]. Still today half of the country's total energy consumption is dependent on wood, animal waste, crop residue, leaves and some other noncommercial energy sources. As of following chart biomass is the dominant as primary energy consumption source followed by natural gas, oil, coal etc.(*Tamim et.al. 2005*[2]).

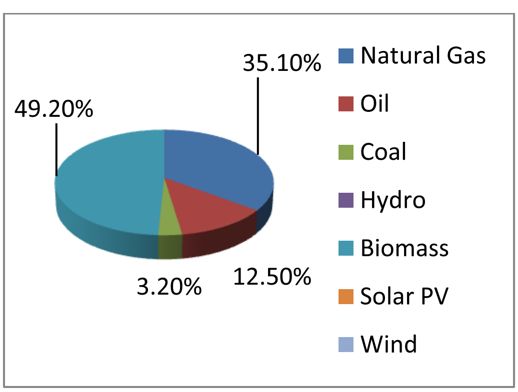

Fig. 1 Primary Energy Consumption Sources.

Historically ancient Dhaka, the capital city of Bangladesh started using of electricity from 1901 introduced by the then Nawab of Dhaka. Later from 1933 commercially the residents of Dhaka city started using electricity (*DPDC 2011*)[3]. After the liberation of Bangladesh electricity became popular as energy source for living and industrial purposes which created huge demand of electricity.

1.1 Background of the Study:

Electricity is the major source of power for country's most of the economic activities. Bangladesh's electric generation capacity was around 5.5 GW in February 2011. Only 47% of the population has access to electricity (*BPDB 2011*)[4]. Following figure will show the electricity production trends after the liberation of Bangladesh in 197.1

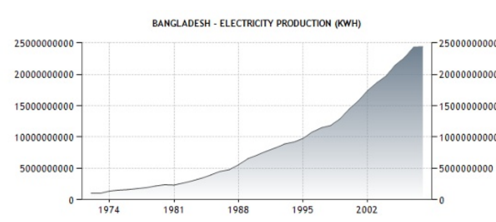

Fig. 2: Electricity Production Trends in Bangladesh.

Bangladesh is not much rich in natural resources. It has very small stock of oil and coal so far but has wide reserve

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of natural gas. Therefore, most of the electric power plants are established using the natural gas as raw material which is more than 88%. From following figure we can see the raw materials that are using to generate electricity at this moment in Bangladesh (*MoF 2010*) [5].

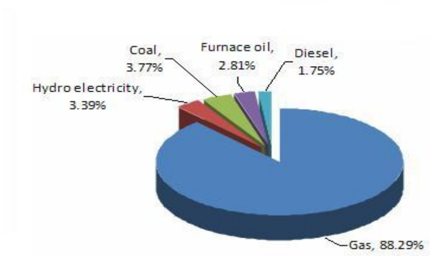

Fig. 3 Fuel Use Types in Power Plants.

Due to the increasing huge demands Government has planned to add 5000MW electricity in the national grid within 2013. Basically as gas reserve is depleting authority is now switching to furnace oil and coal fired plants rather than gas fired. It is obvious that this will require huge budget and government is unable to accommodate this, so they invited private to come forward to help resolving the crisis. Most of the private farms would go as public private partnership (PPP) basis.

1.2 Objectives of the Study:

Thanks to government initiatives of facing the challenge of power a significant numbers of small and medium power plants are established in last couple of years by the private sector including on PPP basis. As these power plants are very crucial for the emerging economy of the country but not free from significant social and environmental impacts which were not seriously addressed earlier leaving necessary to establish a mechanism to determine and assess future potential environmental and social impacts of electric power projects. It is very difficult for the lone Government's environmental agency to monitor and evaluate the socio-environmental impacts of these electric power projects due to the lack of proper laws and guidelines, expertise, man power, corruption etc. Again, most of these projects will be financed by the banks or other financial institutions (FIs), so it would be meaningful to do these socio-environmental impact assessments by these FIs in a different approach under the regulations, guidance and supervision of Central Bank of Bangladesh.

The research is opted to focus on the following issues:

1. To frame out a Social and Environmental Management policy guidelines for FIs to finance electric power projects consistent with Bangladesh Environmental and Social Assessment laws.
2. Apart from possible environmental impacts, the social impacts including land acquisition and involuntary resettlement issues are also considered.

2. METHODOLOGY

This descriptive study is carrying out by reviewing the existing social and environmental laws of Bangladesh. The related literatures those are already published in country and worldwide. Consultation with the stakeholders and by analysis of the gathered information.

3. ENERGY AND EMMISSION SCENARIO IN BANGLADESH

3.1 Carbon Emission Trends in Bangladesh:

Bangladesh is one of the least Carbon-Di-Oxide (CO2) emitting countries. The per capita carbon emission is only 300kg in 2006-07(*World Bank 2010*). The estimated total CO2 release from all primary fossil fuels used in Bangladesh amounted to 5072 Gigagram (Gg) in 1977, and 14,423 Gg in 1995. The total amounts of CO2 released from petroleum products, natural gas, and coal in the period 1977-1995 were 83,026 Gg (50% of CO2 emission), 72,541 Gg (44% of CO2 emission), and 9545 Gg (6% CO2 emission), respectively (*Azad Et.al., 2006*)[6].

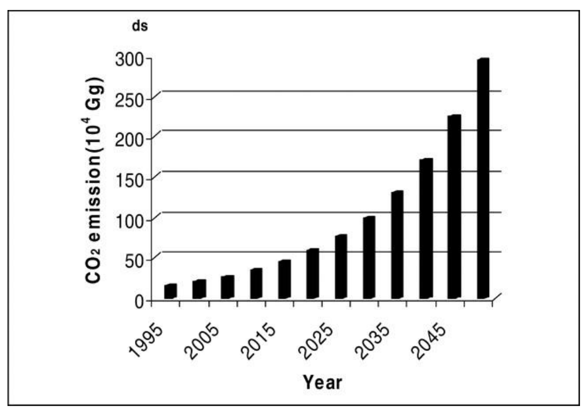

Fig. 4. Future Trend in CO_2 Emission from Fossil Fuel Combustion in Bangladesh (1995–2070(*Azad Et.al., 2006*).

The World Bank has estimated that Bangladesh loses around $1 billion per year due to power outages and unreliable energy supplies. However, Bangladesh is trying to better environmental management by keeping the uptrend of economic activities.

3.2 Current Situation of Electric Power in Bangladesh:

The demand of electricity in Bangladesh is growing and growing everyday for living daily life and all sorts of economic activities due to enhanced economic activities in the country with sustained GDP growth. At present electricity demand growth is 10% which is expected to increase in coming years. However, the generation and distribution of electricity is not increasing in compare to demand resulting huge load shedding and power outage everyday causing problems in daily lives and hampering significant economic losses. Failure of installing new plant according to demand forecasting, lack of maintenance of power plants, faulty transmission and distribution lines, system loss, illegal connection and overall corruption and mismanagement has created today's situation of electric power in Bangladesh from its liberation. As in summer often temperature climbs to around 40^0C increases the power demand in peak but only extends the load shedding hour and frequent power outage leaving people in a miserable situation.

According to the official statistics, the country's electricity shortage gone up 1000 megawatts (MW) to 1259 MW with the demand of 4806 MW on 2006. In 2009 the shortage was about 1400 MW to 1800 MW, which is almost twice more than last year and the country need about 5000 MW. Power Development Board (PDB) sources said while the official power demand was just 5000MW, the unofficial demand was hovering around 6000 MW. The officially estimated power demand is 5000 MW against a generation of around 3500 MW in 2009. Around 1500 MW power could not be generated due to short supply of gas to many power plants (*Saifullah, 2009*[7]).

At present among the total electricity generation capacity the public private ratio is 55% and 45% respectively.

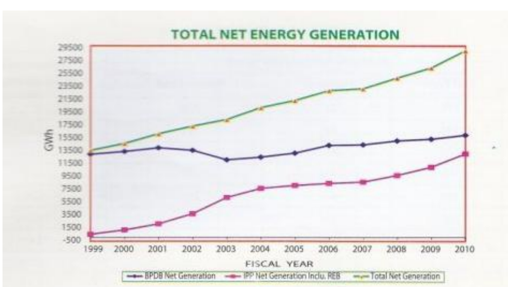

Fig. 5 Net Energy Generation by Public and Private Enterprises

If we analyze the electric power consumption pattern of the country we will see that even today domestic is the leading single user by more than 47% followed by industries, commercial and agriculture.

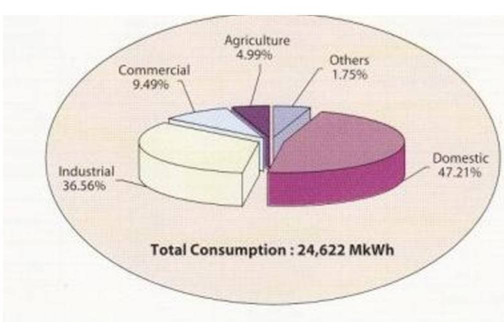

Fig. 6. Electric Energy Consumption Pattern in Bangladesh *(BPDB, 2010)*[8]

3.3 Environmental Concerns of Electric Power Plants

We can understand that the generation of electric energy demand is increasing about 10% every year. To meet up this demand government is increasing power generation. As Bangladesh has natural gas reserve the most power plants have established based on natural gas especially in the private sector because private sector is serious about the supply of raw materials. They took guarantee of continuous supplying of gas in their plant. Recently as gas are depleting government is diverting to other raw sources like furnace oil and coal. Burning of fossil fuel has significant environment and social impact which has to be addressed seriously. Again, in 2010 there were 58 no. of electric power plants in Bangladesh including public and private sector which have a vast social and environmental concern in the country. Another 14 more plants will be come in operation by 2015.

The following figure will show the fuel consumption by only the public power plants.

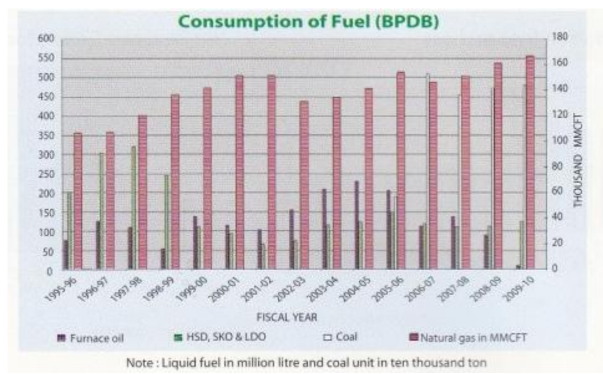

Fig. 7 Fuel Consumption by the Public Electricity Generation Plants

3.4 Major Social and Environmental Concerns

The major environmental and social impacts are triggered due to implementation of electric power projects could be as follows:

- Change of land use pattern;
- Involuntary resettlement issues;
- Surface and ground water;
- Ambient and indoor air pollution;
- Land degradation;
- Forest management issues; and
- Fisheries management issues etc.

Apart from the wider social and environmental effects by fossil fuel burnt electric power generation, The biggest effect of fossil fuel plants have overall is the emission of air pollutants, particularly SO_X, NO_X, CO, CO_2, hydrocarbons and particulates. CO, CO_2, and the hydrocarbons are the "greenhouse gases," believed to be responsible for global warming. SO_X and NO_X produce acid when released into the atmosphere, leading to the production of acid rain.

Following table list approximate amounts of airborne pollutants produced. (*Energy Foundation, 2007*) [9].

Table 1. **Power Plant Emissions (g/kWh)**.

Plant Type	CO	NO_X	SO_2	CO_2
Coal	0.11	3.54	9.26	1090
Oil	0.19	2.02	5.08	781
Gas	0.20	2.32	0.004	490

Apart from these emissions, the noise and vibrations of the plants are also to be considered. Other than these the heat that will released from the plant also need to be cooled down. These emissions can be controlled by taking different measures.

4. ENVIRONMENTAL GUIDELINES FOR ESTABLISHING POWER PROJECTS

In accordance with the Bangladesh Environmental laws, depending on the extent of impact on the environment, the Department of Environment (DoE) classifies all the projects in four categories. These are:

i) Green;

ii) Orange - A;

iii) Orange - B; and

iv) Red

Green Category

Projects, which do not have any negative impact on the environment, belong to Green category. For this category of projects, it is assumed that no significant environmental impacts from these projects will be occurred.

<u>Examples</u>

- Bamboo and cane goods, candle. Watches etc.

Orange A and B Category

This category includes projects that could moderate to significant impacts on environment which could be mitigated easily. Depending on the nature and extent of impacts the projects under Orange category has been sub-divided into Orange A and Orange B. The projects to produce little harmful for surrounding environment and can be managed easily are categorized under "Orange-A".

<u>Example</u>

- Small hotel/restaurant business, weaving factory;

The "Orange-B" category industries are could be a source of moderate significant adverse impact to the surrounding environment, however could be mitigated by taking proper action by the project entity.

<u>Examples</u>

- Processing of fish, meat, food items etc.

Red Category

This category is assumed that significant negative environmental impact could happen if this project is being carried out. This types of projects generally need to undergo by vigorous examination and monitoring and impact mitigation plan by the project proponent and the central environmental agency.

<u>Examples</u>

- Port development Power generation, transmission, distribution and services.

4.1 Institutional Setup for Environmental Safeguard in Bangladesh

Department of Environment (DoE)

The prime governmental institution for environmental concern in Bangladesh is the Department of Environment (DoE), under the Ministry of Environment and Forest. This department was not created very early just 20 years back to ensure the conservation and management of Environment for sustainable development of the country. The principal activities of the department are:

- Defining EIA procedures and issuing environmental clearance permits which is legal requirements before proposed projects can proceed to implementation;
- Providing advice or taking direct action to prevent degradation of the environment;
- Pollution control, including the monitoring of effluent sources and ensuring mitigation of environmental pollution;
- Setting the water quality standard of the country; and
- Declaring Ecologically Critical Areas (ECAs) where the ecosystem has been degraded to a critical state.

Environmental management in Bangladesh is regulated by following laws, rules and regulation and DoE is in charge of these issues:

- National Environmental Policy, 1992
- National Environnemental Management Action Plan, 95
- Environnemental Conservation Act and Rules, 1995
- National Conservation Strategy, 1992
- National Water Policy, 2000
- National Water Management Plan, 2001

Department of Forest

- The Department of Forest is responsible for sensitive area protection in four types of legally protected areas-wildlife sanctuaries, game reserves, reserved forests, and natural forests.

5. ENVIRONMENTAL IMPACT AND MITIGATION MEASURES FOR POWER GENERATION PLANTS

The analysis of the environmental impacts is an important tool to determine the appropriate measures to be taken. The impact assessment is a continuous process which mainly depends upon the activities and need to be updated on regular basis.

5.1 Potential Impacts

Considering the life cycle of a project involving the activities, potential impacts could be classified into following phases:

i) Planning and Design Phase

ii) Construction Phase

iii) Operation & Maintenance Phase

iv) Decommissioning Phase

It is recommended that the impact assessment measures the performance during all the phases against the baseline position.

5.2 MITIGATION MEASURES

Adequate mitigation measures have to taken in different stages of project life cycle like design stage, construction stage, operation stage and decommissioning stage. The pollution level would be different in every stage. Some major impacts and mitigation measures are as follows:

Air Quality

Bangladesh is predominantly dry country which starts huge dust during construction phase, so it would be better to start construction in rainy season, of course it will depend upon the soil properties. In operation stage the burning of fossil fuel will triggered the ambient air pollution by generation of GHG gases and particulate matters which has to be controlled and kept in acceptable level.

Water Quality

Surrounding surface water and ground water could be polluted both in construction stage and operational stages. So adequate measures need to be taken to keep the water quality in acceptable level. The water should not be released to open stream or river without being treated as it also may hamper the fisheries and crop production.

Ecology and Biodiversity:

The construction and operation of electric power plant may have significant impact on surrounding ecology and biodiversity even in generation of green energy like hydro and solar energy.

Waste Water Treatment and Solid waste:

The waste water and solid waste that would generate from the establishment of electric power plant should be treated. The waste water could be treated for reuse within the plant and it has to maintain the standard of the country before releasing to the natural ways. Solid waste materials should be separated at a designated point within the plant prior to disposal in approved local authority waste disposal sites.

Domestic CDM

The electric power plant that will burnt fossil fuel must emit carbon-di-oxide which will increase the global warming potentials of the country though Bangladesh is one of the least CO2 emitting countries in the world. So, if domestic CDM can be introduced, the power plant's emitted CO2 could be purchased by the emission permitting agency. Introduction of an integrated domestic market for emissions trading will be helpful in order to reduce CO2 emissions, it is necessary to utilize the methods to encourage technology development and efforts to reduce CO2 emissions by pricing CO2 and using market mechanisms.

5.3 Environmental Impact Assessment (EIA): EIA will be done by the project entity before starting of the project which has to be cleared by the Governmental Environmental Agency. This EIA should be prepared by the third party recognized environmental consultant.

5.4 Environmental Management Plan (EMP): An Environmental Management Plan, a part of Environment Management Guidelines basically is an implementation plan for mitigation, protection and/or enhancement measures, which were already recommended in the EIA submitted by the project entity. It details:

(a) The measures to be taken during the implementation and operation of a project to eliminate or offset adverse environmental impacts, or to reduce them to an acceptable level.

(b) The actions needed to implement these measures.

6. CONCLUSION

Bangladesh is a small and densely populated country, however very promising in recent economic growth. The energy source and use always play an important role in potential economic activities. In this sense, Bangladesh is very low energy consuming country and facing a huge shortage of energy. To achieve these numbers of power plants are establishing without much considering the environmental safeguard issues. In this paper the rationale and purpose of developing a policy frameworks from the view point of financer is described. As the study is yet to finish, the role and way of doing by the FIs and Central Bank will be accumulated.

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National greenhouse gas reduction policy trends from voluntary agreements to negotiated agreements and its implications.

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Abstract

Since the adoption of Bali Roadmap in 2007, the efforts to reduce Green House Gases (GHGs) Emissions are growing with concern of new agreement against climate change. Under Kyoto Protocol, Annex I parties which have received mandatory target of GHG emissions implement lots of policies for reducing GHG emissions. Beside Annex I parties, many countries set their own GHG emissions target and make efforts to achieve the target in many ways. Each country introduces voluntary agreements and negotiated agreements to reduce GHG emissions in industrial sector that occupies a large part of national GHG emissions. As the demand on reduction of GHG emission is strengthening, climate change policies come up in form of negotiated agreements.

The existence of the obligation affects countries' GHG reduction policies' intensity. According to recent discussion about post-Kyoto protocol, it is expected that some countries as China, South Korea, and India would receive the mandatory target of GHG emission.

In this paper, direction of national GHG reduction policy is suggested for the countries that have large potential to receive the mandatory target of GHG emission by comparing policies of GHGs emission reduction between Annex I parties and Non Annex I parties.

Keywords:

Voluntary Agreements, VA, Negotiated Agreements, NA, policy trends, GHG reduction economy, modular design, LCA, LCC, simulation

1 INTRODUCTION

The companies, which produced, supplied and consumed the energy, have made a contract with the government for effective GHG reductions and energy savings, and the Voluntary Agreement (hereinafter, VA) institutions, which support the setting and implement practices of the participants voluntarily goals through the discussion, have been conducted in various forms from around the world. Although the first introduction of a voluntary agreement was used as a means of supplementation of the shortcomings of the existing GHG emission reduction and energy saving policies, but unlike voluntary agreements, Annex1 countries, which have been assigned the mandatory reduction amount, and the countries, which have set voluntary GHG reduction targets, considered the government scheme (NA: Negotiated Agreements) to bind the target companies with compulsory regulation or the introduction of domestic institutions.

Hence, the transition trend from VA to NA will be reviewed and the implications will be drawn through policy comparison from the countries with the NA institutions.

2 VA AND NA FOR GHG REDUCTION BY COUNTRY

2.1 UK

VA in UK

Making a Corporate Commitment Campaign (MACC) of UK's VA was conducted in September 1991, which is the system that the government released its contents on a regular basis to the press, after chief executive officer in UK's private and public sector organizations set the goal of medium-term energy efficiency for some 3 to 5 years, and disclosed it voluntarily[1]. In this system, the company itself, as the individual body for the energy efficiency enhancement, has set the goal and action plan without compulsion and published it internally and externally and then the government announced it to the press again. This is the institution to promote the strategy of energy saving and to expand the mind of energy-saving to other sectors, as well. To achieve the UK's GHG reduction target to be set under the agreement after the Kyoto Protocol, Climate Challenge Agreements (CCAs) in 2000 was enacted. CCAs are the voluntarily agreement

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between the government and the industries. to reduce the 80 % of Climate Change Levy(CCL) of the group of energy-intensive industry. CCAs have 5 target periods (2002, 2004, 2006, 2008, 2010 year) and grant the facilities and institutions which achieved the goal the eligibility to reduce CCL for the next two years. If the particular sector fails this goal, the facility to fail the goal among facilities or organization that belongs to the sector will be disqualified from CCL exemption over the next two years[2]. This is the system's nature of voluntary agreement and it seem to be an effective system rather than MACC in terms of the achievement of goal through a strong financial incentives and penalties.

NA in UK

UK's Carbon Reduction Commitment (CRC, coming into effect on April 1, 2010), which is similar to the characteristics of NA institution, pushed forward with the achievement of UK's GHG reduction goals to reduce at least 80% GHG emissions reductions by 2050, compared to the 1990's baseline. The target of CRC was the companies which are not regulated by law such as EU Emissions Trading Scheme among the companies over 6,000 MWh of power consumption in 2008, and the target company should need the monitoring of GHG emissions and buy the quota from the government, and an organization's carbon dioxide emissions quota will be offset by purchasing emission credits[3]. CRC is the mandatory nature of the institution, the report on the emission volume or the disclosure of purchasing information of the quota by the government are legal obligation. If they failed to do so, there is a financial penalty.

2.2 Japan

VA in Japan

Japan's VA system is its representative example of Voluntary Action Plan on Environment of the Industrial Federation of Economic Organizations, involving 36 industries in 1997 year. This action plan was solely based on the industry voluntary efforts, each industry set individually 4 action items such as global warming policies, waste measures, environmental management and environmental conservation related to overseas business activities. Among them, carbon dioxide emissions should be reduced to the level in 1991, as the common goal, and the countermeasures are proposed[1].

In order to enhance the transparency and reliability of the action plans, the Industrial Federation of Economic Organizations has set up the 3rd party evaluation committee performed by an external expert since 2002 year and, within the framework of self action plans, the assesment of industry has been conducted, and as of 2011 year, and problem-solving activity by year against the issues has been continued along with the opening of the performance report.

NA in Japan

In Tokyo, with the amendment of the regulation regarding the securement of environment, new goal in June, 2008 was set, reducing 25%by 2020 and 40% by 2030 as compared to 1990. To achieve the goal, with target of large-scale companies, the total reduction obligations of GHG emission and trading scheme was introduced in April, 2010 year.[3] The target companies to participate are about 1,400 of business building with big scaled locations over usage of 1,500 kl of crude oil, equivalent to the amount of fuel, heat and electricity in previous year. The target sites should determined the baseline emissions and created the plan on the global warming measure, and, regarding annual calculation for GHG emissions, it should be verified by accredited third party test agencies.

In the case of the achievement of goal to be failed, the company received the reduction command of that amount plus additional penalty amount.

When a violation of the command happened, Tokyo Governor charged the cost the offender instead of the necessary amount to buy, with public announcement.[4]

2.3 The Netherlands

VA in the Netherlands

Dutch's Long Term Agreement (LTA) is voluntary agreement signed between the government and the representative of the industries from 1991 to enhance the energy efficiency, up 20% by 2000, compared to 1989. LTA in the Netherlands is the voluntary agreement and the role of government and corporate obligations shall be binding by law, which have the features. the long-term agreement & business plan to be terminated in 2000, an average 22.3 percent of the energy efficiency has been improved by using the various subsidies and tax incentives as a means of leverage for the plan period. After the termination of long-term agreement business, Phase 2 project (LTA2, (2001 to 2012) was begun for small business and industry. Although Phase 1 LTA was voluntary agreements between the related authorities and associations, Phase 2 LTA was undertaken by agreement with individual business projects, sectors and authorized institutions (Competent Authorities).[1]

2.4 Australia

VA in Australia

Greenhouse Challenge Program in Australia was that for the reduction of GHG, the Australian Government in March 1995 started a voluntary agreement made between industry and government program, which aimed to reduce GHG 15MT. The goal of this agreement was to reduce the GHG emission by developing the efficiency of process and energy's use, and to enhance the competitiveness of industries as well as the effective response to climate change.

Company's Chief Executive Officer could attend the program by submitting an agreement of the reduction of GHG to the federal government, and the federal government supported the companies by means of varies promotion methods such as the use of logo only for attended companies, the issue of reports as well as environmental and technical support. Currently, this system has been terminated in 2009, the Australian Government tried to introduce Carbon Pollution Reduction scheme (NA) and the introduction of the carbon pollution reduction scheme was also deferred until 2012 because the Act on the establishment of Australian Climate Change Regulatory Authority was failed to pass at the Senate.[3]

NA in Australia

Australia's National Greenhouse and Energy Reporting was introduced in 2007 and GHG emission information institution. This scheme's applied target is a corporate or business center using over 25,000 tCO2eq of GHG emission and 10 TJ of energy usage per year.

2.5 Korea

VA in Korea

The national energy saving promotion committee (Chairman: Prime Minister) in May 1998, in Korea passed a vote of the introduction of a voluntary agreement institution for promoting energy saving in the industry.

Korea's industry's VA target was the much energy consuming industries using over 2,000 toe of energy consumption per year and companies involved should set up the plan of process improvement, new technology introduction, short-and-long term energy and the reduction of GHG, the government supported the technical guidance and funding, which was the a system.

Government leaded to the companies voluntarily for the energy savings through the financial and technical support and various incentives and achieved the energy saving and GHG reduction efficiently. Cumulative basis from 1998 to 2009 of 2,481 companies signed an agreement and 1,300 companies maintained it except for the discontinued companies of business and expiration companies of the agreement. Through a total investment of 7.1492 trillion won, 18,855,000 toe, 6.404 trillion of energy savings, and GHG of 57,961,000 tCO2 were reduced.[5]

NA in Korea

In June 2009, the emergency economy measure meeting passed a vote of the energy demand management measures and, to tackle high oil prices and climate change effectively, GHG 30% reduction goal was set up along with the introduction of goal management system adding a force means of implementation. Since April 2010, in accordance with an Enforcement Ordinance on a low-carbon, green growth basic law, GHG energy target management institution has been performed. GHG energy target management institution, unlike the existing voluntary agreement, needed to attend forcibly the companies and business center with much energy consumption and target companies set up the goal through the negotiations with the government and the government prepared for forced means of implementation (incentive and penalties) for the achievement of cost-effective goals.

3 THE INTRODUCTION TREND OF VA AND NA FOR GHG REDUCTION

3.1 UK

UK has implemented MMCA (Making a Corporate Commitment Campaign) for achieving GHG and Energy reduction target since 1991. In 2010, CCAs and CRC has been implemented. They are differentiated from the ancient agreements in manners of participation and implementation. CRC which is the most recent system can be sorted as NA so that participation and implementation are obligated.

Table 1: GHG reduction schemes in UK

Name	participation	implementation	type
MMCA (1991)	voluntary	voluntary	VA
CCAs (2001)	voluntary	mandatory	VA
CRC (2010)	mandatory	mandatory	NA

3.2 Japan

In Japan, GHG emission reduction agreements can be summarized as 2 agreements which are Voluntary Action Plan on Environment in 1997 and Reduction obligation of total emission of GHG and ETS in 2010. The first one complies with VA. But the other complies with NA which aims to strictly reduce national GHG emissions.

Table 2: GHG reduction schemes in Japan

Name	participation	implementation	type
Voluntary Action Plan on Environment (1997)	voluntary	voluntary	VA
Reduction obligation of total emission of GHG and ETS (2010)	mandatory	mandatory	NA

3.3 The Netherlands

LTA(long term Agreement) is a representative agreements in Netherlands. It has been implemented in 2 phases. The first LTA was established in 1991 and the second LTA in 2001.

It was voluntary to participate in 1st LTA and there wasn't any legal duty to achieve GHG emission reduction target. However, 2nd LTA had been modified before its implementation. Practically it combined VA and NA by setting mandatory GHG reduction target.

Table 3: GHG reduction schemes in Netherlands

Name	participation	implementation	type
LTA1 (1991)	voluntary	voluntary	VA
LTA2 (2001)	voluntary	mandatory	VA

3.4 Australia

Australia has similar trends of establishment of policies with Japan. After implementation of VA in 1991, they moved to NA system in 2001 to accelerate reduction of GHG emissions.

Table 4: GHG reduction schemes in Australia

Name	participation	implementation	type
Greenhouse Challenge Program (1991)	voluntary	voluntary	VA
National Greenhouse and Eenergy Reporting (2001)	mandatory	mandatory	NA

3.5 Korea

Korean government has similar policy trends to government of Australia and Japan. In 1998, 'Voluntary agreement in Industry sector' was implemented in the form of VA. Recently, GHG-Energy target management system was conducted with strict duties on achieving target of GHG-Energy reduction. Korean government expects that this agreement may derive large reduction of national GHG emissions.

Table 5: GHG reduction schemes in Korea

Name	participation	implementation	type
Voluntary agreement in Industry sector (1998)	voluntary	voluntary	VA
GHG-Eergy target management system (2010)	mandatory	mandatory	NA

4 CONCLUSION

We have reviewed introduction trends of VA and NA schemes in five countries: England, Japan, Netherland, Australia and Korea. Despite of differences in management and introduction time among countries, all five countries commonly adopted compulsory NA after introducing VA in advance.

Unlike VA, NA is a scheme with enforcement power. The aspect of introduction of NA or modified VA which has mandatory GHG reduction target proved that NA is being recognized as a powerful tool to derive GHG reduction.

It is expected that introduction of NA scheme may enlarge in accordance with increase in awareness of climate change and response to post-Kyoto Protocol. Therefore, further study for successful introduction and implementation of NA should be conducted.

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Eco-design promotion in SMEs by material flow analysis of supply chain: case studies and modeling

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Abstract

We have designed and implemented a program for the promotion of eco-design that is especially aimed at improving the resource productivity of small- and medium-sized enterprises (SMEs) through supply-chain partnerships. This program was operated as a three-year (FY 2008-2010) project funded by the Ministry of Economy, Trade and Industry. In this project, 58 corporate teams (162 companies in total), typically involving a manufacturer and one or two suppliers, participated. We asked experts to visualize material losses by material flow analysis of a supply chain to help each team conserve more natural resources. On the basis of the case studies considered in this project, we first investigated the supply-chain partnership models in terms of various types of material losses and improvement methods. Further, we categorized these methods to share this valuable information among the companies. Moreover, we discussed extended models that include customers and the expansion of these principles into the carbon management in the supply chain.

Keywords:

resource productivity, material losses, SME, material flow analysis, MFCA, LCA, supply chain

1 INTRODUCTION

Many manufacturers have made serious effort to implement the 3R measures, especially the reduction in the use of raw materials, as part of countermeasures against their rising prices and to encourage cost reduction activities. However, with increasing in the complexity of supply chains, the efforts of a single company are limited. Large companies such as raw material manufacturers and assembly manufacturers have successfully reduced waste. On the other hand, parts and processing companies, called midstream companies, many of which are SMEs, have reported that their reduction measures are outdated.

Even if such small companies are aware of the importance of environmental considerations, there are great obstacles to the implementation of countermeasures. Unless a concrete results is directly obtained, it is difficult to promote the new activities, even if they may prove useful. In general, the cost of raw materials constitute the largest proportion of manufacturing costs, which is why we focused on the reduction in use of raw materials. In this project, we aimed to promote eco-design in order to improve the resource productivity of the supply chain including SMEs by visualizing their material flows.

For example, the generation of waste by a parts manufacturer might be due to inefficient product designs by the product's manufacturer. The program in this project sought to resolve these problems by providing experts familiar with the material flow analysis (MFA), who served as intermediaries between such companies [1, 2].

2 MAJOR FACTORS PREVENTING PROMOTION OF PARTNERSHIP

Figure 1 shows a schematic of loss generation in a supply chain. When midstream companies try to reduce their large losses, they may find that the loss generation is due to their upstream and downstream companies, which may provide only standard sizes of raw materials or inadequate part specifications. In such a case, by creating cooperation with the upstream and downstream companies, significant improvements can be made. That said many factors stands in the way of such supply-chain cooperation.

For this reason, we first investigated the major factors that prevent the promotion of partnership, by conductiong interviews with 35 companies in various product fields that were positioned both upstream and downstream. As a results, we were able to summarize these obstacles in the following three categories:

(i) Factors related to power relationships between companies

1. Part specifications are optimized for use in assembly and inspection lines of the downstream company, so excessive specifications may be required. To change such specifications, a process change is required in the downstream company, and this can be difficult to implement.
2. A higher incidence of inferior products from parts manufacturers may be due to excessive quality requirements, such as the absence of defect that is not directly related to performance.

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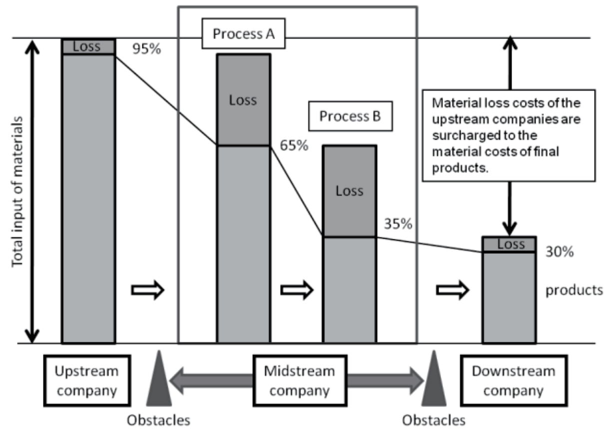

Fig. 1: Expansion of target area for improvement in midstream company

3. Material losses in processing companies can be due to the unalterable standard material sizes and minimum purchase lot quantities.
4. In order to maintain a continuous flow of orders from clients, processing companies tend to follow the client's specifications even if large material losses are generated, and do not propose any changes in the specifications.
5. In general, suppliers gain fewer advantages from cooperation than product manufacturers. Even if suppliers succeed in reducing thir raw materil input, a downstream manufacturer may demand a lowering of the cost to suppliers.

(ii) Factors related to company secrets

1. It is difficult to share information related to material losses in the manufacturing process, such as raw material input and waste generation, because such information is usually related to company secrets, such as its costs, yields, and processing technology. For simple processes, however, the manufacturing cost can be easily estimated from the material name and data about input amount.
2. Even within a group of companies that share capital ties, it is not always easy to advise an other company regarding the improvement of its production lines.

(iii) Factors related to complicated supply chain and business practice

1. Recently, the supply chain has become complicated because of an increase in overseas suppliers, orders to multiple suppliers, concentration purchasing, etc., all of which result in insufficient communication, especially in terms of technical matters.
2. If the materials are supplied by clients, it is difficult to maintain an incentive to reduce material losses.
3. Suppliers manufacture quantities of products that exceed what was orderd in order to compensate for the production of inferior products, which may eventually be discarded.
4. Resource conservation leads to lower sales for raw material manufacturers.

In order to resolve the problems caused mainly by obstacles (i) and (ii), we create a business support program, as shown in the next section. To overcome these obstacles, it is especially impotant to know how they can share information without leakaging of company secrets. Therefore, we provided experts who could act as intermediaries between suppliers and manufacturers. As a results, the communication between companies was facilitated so that useful information could be shared while company secrets were adequately protected.

Moreover, in the program, the advantages obtained by such cooperation were guaranteed through the contracts between suppliers and manufacturers.

3 SUPPORT PROGRAM

The method of visualizing material losses in the supply chain is based on MFA and is combined with Material Flow Cost Accounting (MFCA) and life cycle assessment (LCA), depending on each company's situation and the skills of the experts provided by us.

We provided a total of 128 experts who have professional consulting experience using MFCA. They helped teams reduce their material losses over a period of about four months, by following four major steps:

(1) The material flow was analyzed throughout the manufacturing processes by the team.

(2) Using MFCA analysis, the material losses were made visible as a negative product cost in the process of each company. Some teams also analyzed environmental impacts using LCA.

(3) The team shared the analyzed data using methods that were appropriate to the relationship between companies, to prevent the leakage of company secrets such as cost-related data. For example, some teams that had no mutual capital relationship shared only the ratio of their positive and negative product costs.

(4) By analyzing the shared data, teams were able to clarify the areas that needed improvement. The team then examined such improvements to the manufacturing processes in order to reduce the total material losses of the team. (Following the program, the companies continue to work on the implementation of improvement measures at their own discretion.)

Teams consisted of two to five companies (including SMEs), and involved materials, parts, process, and assembly companies. After extending a broad public invitation to assemble such teams, we formed 58 teams (representing a total of 162 companies) over three years. These companies were selected irrespective of their size, and they belonged to spectrum of industrial fields such as electrical machinery, plastics, textiles, and food.

4 CASE STUDIES

We organized the teams into two groups; teams in which the downstream companies play a key role in cooperation, and teams in which the midstream companies play a key role. We will next discuss the typical results of these two groups as case studies [2].

4.1 Teams on which downstream company plays key role

If the downstream company is in charge of the final product design, the team can expect to receive significant benefits by modifying the design. However, in those cases in which the design is in part determined by the customer's specifications, there may be almost no room for change. In other cases, in which the team targets existing products, the improvement of only the processes is possible, and the cooperative experience can later be utilized in the design stage of new products.

Team from Ohu Wood Works (OWW)

OWW's target products are work tables for cooking lessons and sinks for educational facilities. Ohu Wood Works (OWW) attended the program with their parts manufacturer, which fabricated their sink-tops from stainless steel board on the basis of a design by OWW. The two companies have no capital ties.

The companies first implemented MFCA for their own process separately. They then removed their companies' secret data, such as cost-related data, and the experts then found the relationship between their data within their process flow.

As a result, OWW discovered that the lack of attention to the standard size of the stainless steel in the stainless steel sink's design phase partly contributed to the generation of by-products, namely stainless steel remnants, during manufacturing. OWW then began to consider the standard size of the stainless steel in its design phase, and analyze the amount of remnants generated by each component, and share the results among all concerned.

Team from Panasonic Ecology Systems (PES)

PES's target products are equipment cooling units. In the process of molding products from resin sheets, about 30% of the resin sheets were being wasted as remnants.

By directly sharing information with the resin sheet manufacturer, with whom information-sharing had previously taken place only through the trading company, PES found that the width of the resin sheet could be changed. By reducing its width, PES successfully reduced the amount of resin sheet remnants by 11%.

The company also found that even these remnants could be recycled as raw material for production. Following the program, this team succeeded in building a closed material-recycling system for the remnants.

Team from Omron Relay & Devices (ORD)

ORD's target products are the ferrous parts in magnet relays for machine controllers. The team was composed of three companies that are in charge of press, heat treatment, and plating and that have no capital ties. It was difficult to motivate to reduce losses because the materials are distributed by ORD.

However, ORD played a leading role in the team, based on years of trust it had established. They applied MFCA to the four companies, including cost-relating information, and clarified the areas to be improved in each company.

Consequently, in addition to a reduction in material losses, it was found that it was possible to also reduce water usage and CO_2 emissions during heat treatment. They then worked on improving activities that are beyond the barriers of companies, such as the optimization of materials, molding, processing, and distribution efficiency, as well as the acceleration of communications.

Team from Asics

The Asics team analyzed the processing of walking shoes in activities of their manufacturing subsidiaries, such as changes in their method of molding the rubber soles, and the use of the materials recycled from used shoes. They used MFCA and LCA to evaluate the effects in terms of cost reduction and environmental impact. In addition, recognizing the importance of improving the design stage, they have also worked on eco-design by using the Quality Function Deployment for Environment (QFDE) method.

Team from Ubukata Industries

Their team's target products were the internal motor protectors for compressors used in air conditioners, which are a fairly high-quality finished product that is produced a large production lots. For this reason, design changes are difficult to implement, and no significant improvement was on the horizon.

However, Ubukata, an assembly manufacturer, worked with the two suppliers in charge of pressed parts and ceramic parts, and found that a cost saving of about 4% was made possible by improvement measures such as changes in material.

Since the program ended, they have continued to work on these measures, and have also promoted a process of steady improvement, such as reviewing the inspection process that is duplicated by Ubukata and its suppliers. Even though the effect of such an improvement is small, large benefits can be expected because of the large production volume (about 50 million for a targeted series).

4.2 The team in which the midstream company plays a key role

Parts manufacturers in the midstream often worked to improve manufacturing processes and logistics via cooperation with suppliers and material processors. In many cases, however, the results were limited.

Team from Sadoshima Tech

Their target products were the housing panels of Blu-ray recorders. Their aim was to reduce their losses by cooperating with the three processing companies in charge of cutting, surface-machining, and anodized aluminum treatment. As a result of MFA, in which the cost information was hidden, they found that excessive costs arose due to the reprocessing of marred products.

By reconfiguring their quality standards and sharing the information, the generation of some types of marred products became almost zero, which halved the amount of reprocessing that was needed. As a result, the positive product costs in MFCA could be improved by about 8%.

Sadoshima Tech is also preparing to participate in the design-in of the new Blu-ray recorders, and also intends to propose an optimized back structure of the panel housing, which will further increase productivity.

Team from Shimada Precision

The team's target products are LCD TV cabinets. Shimada Precision, which is in charge of the mold and process design, and three processing companies, which are in charge of plastics molding, assembly, printing and inspection, facilitated productivity-enhancing activities for their input materials by sharing only information related to materials, in the MFA analysis.

They reviewed ways to protect their products during transport between companies, among other topics. As a result, they successfully reduced their use of protective and packaging materials by about 30%.

Team from Asahi

The team's targets are plastic parts for home appliances. Fabless company Asahi and two small "factories in town" which have no capital ties, aimed to distinguish their products from those of the competition by a cost reduction and by highlighting their environmental contributions. They analyzed their processing, such as their plastics molding and coating printing, using MFCA, and shared loss information that included cost information.

The introduction of new indicators for negative product costs made apparent the magnitude of their paint losses. In response, they were able to simulate a 66% reduction in paint use that could be achieved as well as a reduction in ink and foils use. They also set the aim of applying these results to their next products.

Team from Yamatake

Their target products are pressure transmitters for liquid flow. The team focused on improvement in the processing of the IC board supplier, Taishin. Taishin proposed a change in the layout of the IC boards inside the printed circuit board that would reduce the number of scraps produced. Their simulation results showed a cost effectiveness of about 25%. After the assembly manufacturer Yamatake made sure that no changes were needed in Yamatake's inspection and assembly processing, they adopted Taishin's proposal.

Team from Kyousha

Their target products were circuit boards for consumer appliances. The circuit board manufacturer Kyousha collaborated with the two processing companies in charge of cutting and plating. They confirmed that by optimizing the work size of a printed board (the number of circuit boards cut out from the printed boards was changed from 9 to 12), all of the companies would benefit from gains in productivity and reduced losses, and they ultimately realized a loss reduction of 80%.

5 MODELING

Based on the case studies, we first studied a number of models regarding the various types of material losses. Next, we categorized the methods of sharing information regarding the promotion of partnerships, and technical communication in particular. We also discussed the extension of the supply-chain model further downstream. Finally, we explored the expansion of the model into the area of carbon management.

5.1 Types of material losses and improvement method

The causes of material loss generation and methods of loss reduction are strongly connected to the type of material loss. Figure 2 shows the relationship between the types of the material loss generated by midstream manufacturers, their cause in supply chain, and the production stage in a product's manufacture. Improvements in the initial production stages make it possible to resolve problems at a more fundamental level.

Material losses due to design and specifications

Typical material losses involve processing-related scraps such as off-cuts, edge remnants, spruces, and runners. The generation of such scraps is often unavoidable. However, in cases in which there is room for design changes in the downstream company, these losses can be reduced by clarifying the relationship between the quantity of loss and the specifications.

In other cases, losses are caused by differences between the size of a given part and the standard material size. If the material size can be changed, this may lead to more a fundamental improvement than can be achieved by in-house measures. In addition, in the long term, significant benefits can be obtained by working to reduce the number of models or to standardize the design rules.

Material losses due to the method of ordering

Material losses generated by lot changeovers are increased by the production of small lots, emergency production, anticipated production, and so on. These losses can be reduced by planned ordering from downstream companies.

Indirect materials

Indirect materials such as treatment fluids and packing materials ultimately become losses. The quantity of these indirect materials that is used occasionally depends on the in-house fabrication method and equipment. On the other hand, the use of excessive quantities of indirect materials can be reduced through supply-chain cooperation, if this excess reflects excessive specification demands from a product's manufacturer, or is related to the quality of the materials supplied by the material manufacturers.

Inferior products

In many cases, inferior products account for a large proportion of the total material losses in a supply chain. Such inferior products are mainly the result of inappropriate in-house fabrication methods. In other cases, they are the result of excessive quality criteria in the specifications. These problems can be resolved through technical communication between designers and engineers in the production lines of suppliers.

Materials such as plastic and aluminum in inferior products can be returned to the production lines as raw materials; therefore, these may not be recognized as losses. It is important to recognize that additional indirect materials and energy are used in such in-line recycling.

Inferior stocks

In some cases, the reduction of inferior stocks is a more important problem than that of material loss in the manufacturing process. This problem is often caused by insufficient communication about production plans.

5.2 The methods for sharing information

We now discuss the four categories of information-sharing and their relationship to the supply-chain type, as follows:

(i) Sharing all information

This method is possible among teams that have capital ties or that have relationships characterized by deep trust. In some cases, experts can play an important role in building such a trusting relationship. By sharing all information, including cost data, companies are able to analyze their production lines as a series of connected lines.

(ii) Sharing material information

This method is possible in a team that is dominated by its sales force, or that has bonds of trust. The kind of information shared depends on the relationships within the team. In some cases, teams shared the names and quantities of all materials, but excluded cost-related data.

In other cases, the teams did not share detailed material data, because the manufacturing costs could be easily estimated from the names of the materials and their quantities. In such cases, then, they were able to share the total quantities of direct and indirect materials.

(iii) Sharing indexed information

Some of the teams from large companies used indicators related to material loss in order to avoid divulging company secrets. One typical indicator in MFCA is the ratio of a positive product cost to a negative product cost. For the teams concerned the environmental aspects, GHG emission data are also a good indicator of the environmental impact of their products.

(iv) Sharing qualitative information

For teams that have neither capital ties nor relationships of deep trust with their suppliers, it is difficult to share quantitative information. They tended to share only qualitative information, such as the processes by which a large amount of material loss was generated. In this case, it is often time-consuming to achieve improvement.

In general, there are two scenarios by which companies can resolve the problems between them:

(A) To solve the problems, the cost of new investment in other companies is needed.

(B) To solve the problems, there needs to be a review of the design specifications, ordering methods, etc., which is achieved by promoting communication.

In scenario (A), it is important to share the information in method (i) and to correctly estimate the cost-effectiveness.

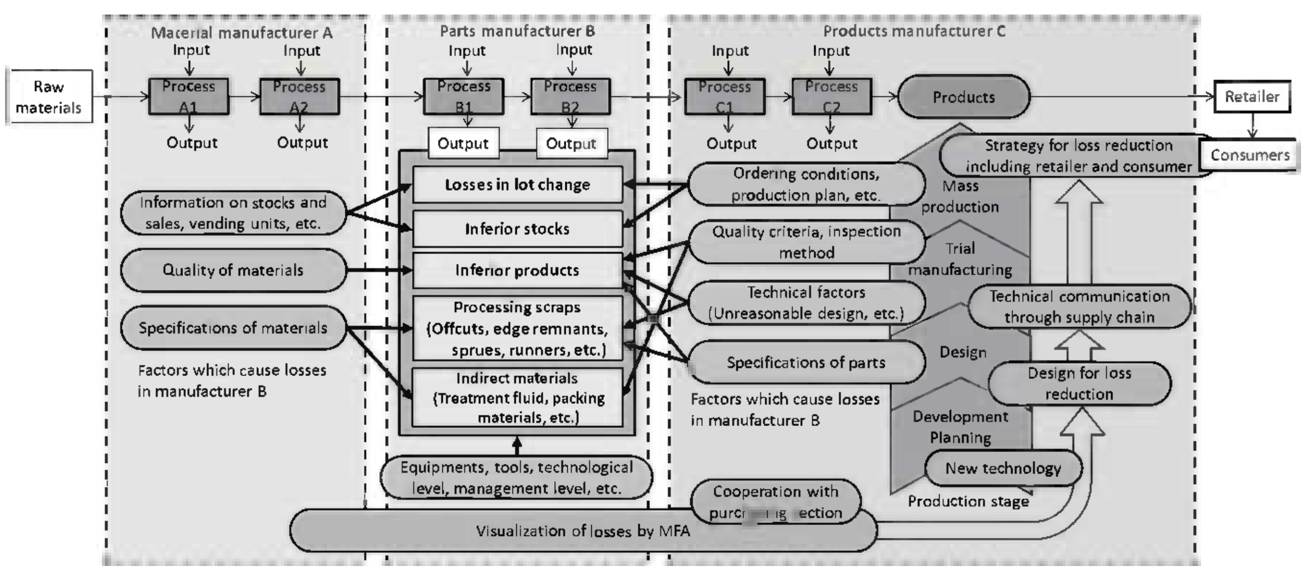

Fig. 2: Diagram shown the relationship between types of material losses, their causes, production stages in products manufacturer, and important factors for supply-chain partnership promotion

It is also necessary to clarify the resulting profit allocation method, including any intellectual property rights. In case (B), resolution does not depend on information-sharing methods (i) - (iii). First, it is desirable to consider scenario (B). Although MFCA is a good tool to visualize the amount of the material losses, MFA is sufficient to promote technical communication in supply chain. Then, first, the case (B) will be desirable to consider.

For there to be cooperation between companies, as well as sharing its methods and skills, human factors are quite important; that is, the top commitment, technical communication which includes engineers, in-house systems for the promotion of improvement activities, and outside experts to mediate between companies.

5.3 Extension of supply-chain partnership model

We now discuss the extension of the supply-chain model to companies that are further downstream. In this project, many teams did not include final product manufacturers, so improvement was limited to changes in processing. In these cases, significant improvement was not expected. If there are even slight changes in the design of parts, this may involve processing changes, such as in the inspection process, as well as additional investment in downstream companies. Moreover, product manufacturers often give orders to more than one supplier, which makes it difficult for proposals from only one supplier to be accepted.

In some cases, however, such as those of Shimada Precision and Sadoshima Tech, they had been preparing to participate in a design-in of final product manufacturers, in this case, major electronics companies, in order to propose new structures of parts that would constitute a fundamental improvement.

In another case, the target area of improvement was extended to a customer who plays a very important role. Some teams tried to reduce the variety of products by offering customers an incentive to choose from a more limited number of products, such as limited colors and designs. For example, OWW offers the incentive of a fast delivery time for particular colored products. They have also successfully reduced the number of edge remnants by reducing the variety of colors of their raw materials.

5.4 Extension to carbon management

Last, we discuss the extension of the models to carbon management, such as the carbon footprint of products and disclosure of GHG emissions. In this project, some teams analyzed their methods of improvement in terms of their environmental impact by using LCA. They confirmed that the methods of improvement had the effect of reducing both costs and GHG emissions.

Moreover, we investigated the possibility of extending the application of these principles to carbon management. Figure 3 shows a model of communication between a manufacturer and its supplier in terms of carbon management. The product manufacturers support their suppliers by leading the effort to evaluate the GHG emissions of each company, and by obtaining GHG emissions data from their suppliers. These data are then utilized in their communications to client companies. We are now developing a simple tool that combines MFCA with LCA in order to provide a good communication tool.

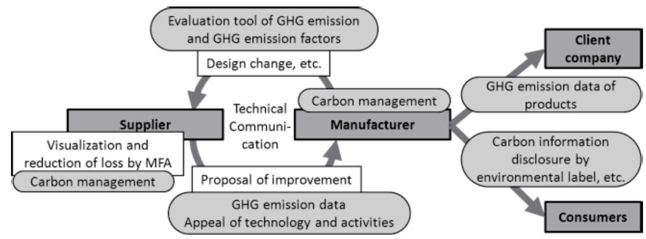

Fig. 3: Expansion into carbon management in supply chain

For communication to a firm's customers, environmental labels such as the carbon footprint of products provide a useful tool. In another approach, many companies disclosed the GHG emissions of their entire company and its products. Such activities have become increasingly important as expressions of corporate social responsibility.

6 SUMMARY

We have implemented a program to help companies conserve resources through collaboration among supply-chain companies. In the course of three years, we carried out case studies of various types of industries, companies of different sizes, and different product fields. We found that material flow analysis was very useful in reducing the material losses in a supply chain, even for teams that lacked internal capital ties. On the basis of these results, we modeled the information about the types of material losses and proposed measures to reduce losses. We also studied various methods for information-sharing and the human factors involved. Finally, as an extension of this model, we examined other models that include consumers and that expand the application of these principles into carbon management in the supply chain.

ACKNOWLEDGEMENTS

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Green Design for Green Business

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Abstract
To solve problems such as pollution and resource depletion and increase industrial competitiveness, green design should meet the requirements of environment as well as business. To achieve this necessity, our major roles are to develop green design method and connect it with policies on green business promotion. For developing green design method, we consider "desirable green" which means better environmental improvement in whole life cycle. We also think of "effective growth" which means more customer value and firmer commercialization of good green business. For connecting green design with policies, we find business models in accord with green growth and study new systematic design model such a PSS, product service system.

Keywords:
green design, green business, green growth, PSS, product service system

1 INTRODUCTION

1.1 Korea National Cleaner Production Center, KNCPC

KNCPC is a non-profit organization established in 1999 under the support of the Korean Ministry of Knowledge Economy (MKE). We became a member of UNIDO/UNEP NCPC Network in 2001; hosted and conducted lots of international symposiums and projects so far. Our major roles are to develop and manage projects, comply with global environmental regulations, and plan national key R&D projects.

1.2 Role of Environmentally Friendly Design

Environmentally friendly design is an approach to product design with special consideration for the environmental impacts of the product during its whole lifecycle. The role of the design has been more expanded from end of pipe to prevention. Furthermore, we should also think the design for sustainability in complex society.

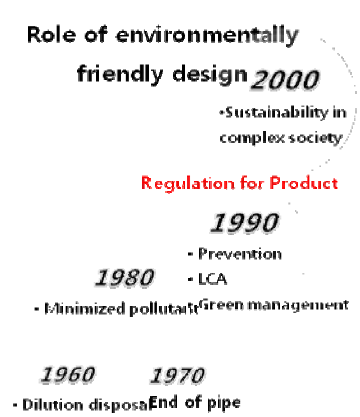

Fig. 1: Role of Environmentally friendly design

2 GREEN TREND OF PRODUCT AND SERVICE

2.1 Marketability of Green Products

To get more result of green growth, we should improve marketability of green product and service. Environmentally friendly product and service have to get high value in whole lifecycle, especially usage stage.

Customers are composed of trendsetter, value-oriented, standard-oriented, and skeptical shopper. To elevate greener result, the product and service should appeal to value-oriented and standard-oriented customers.

For example, Phillips' light bulb named "Earthlight" had failed in the market. After the failure, Phillips changed just product name to "Marathon" without any other physical change. Finally, the bulb has made a hit in the market so far. "Marathon" means long life.

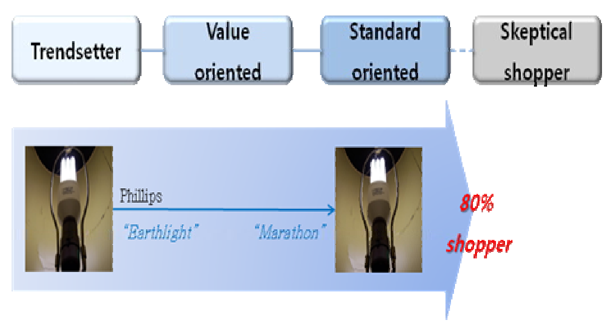

Fig. 2: Improement of marketavility

2.2 Convergence of Product and Service

In Fig. 3, Statistics divide the economy artificially into product and service sectors. (However, in the real economy, value usually created by a combination of product and service). We can see the increasement of value-added from services.

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Globally, many conturies are studying convergence of product and service as green business model. New business model for sustainable material management in OECD report, Smarter and Cleaner Consumption in EU report, 10 Greenservicizing Modes in US EPA, Green Business Model in Nordic, and so on are there.

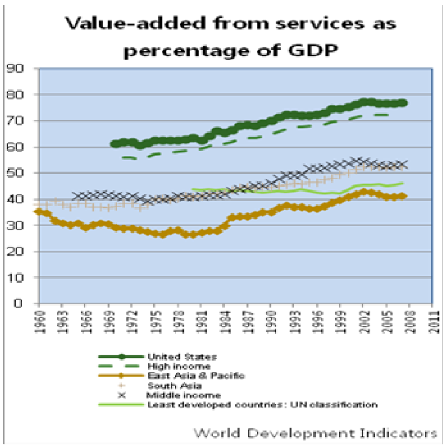

Fig. 3: Value-added from services as percentage of GDP

3 GREEN BUSINESS THROUGH PRODUCT SERVICE SYSTEM

3.1 Product Service System(PSS) as Green Business

All model of convergence between product and service is not green business. Service-led economy is not intrinsically green, for example, pizza delivery and car warranty. We should find out and develop business model having remarkable green effect in its business life cycle. Green design for green business should be realized and can be expressed as PSS design.

3.2 Decoupling, Less Sales More Profit

PSS model can make more and stable profit in usage stage even though not increasing product sales. When we consider product function, product sale is exchanged into service sale. Customers want function instead of product itself. If so, negative environmental effect would be reduced through increased utilization ratio, reuse and so on.

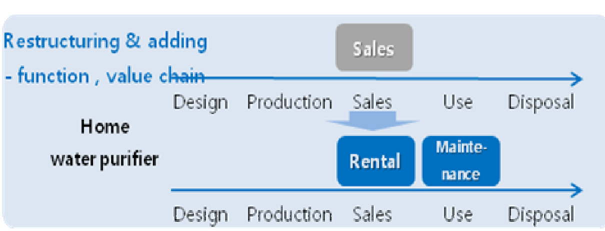

Fig. 4: Product-service change of water purifier

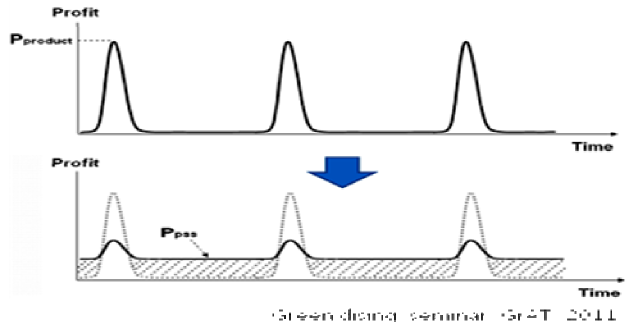

Fig. 5: Continuous profit structure of PSS

4 GREEN DESIGN FOR GREEN BUSINESS

4.1 Concept of Green Design

In this paper, green design pursues green growth policy of government considering harmony of environment, economy, and society.

For greener result of green business, green design method has 4 big items. Fig .6 shows the items. First, "Better" green means a faithful design, combination of environmental and economic success. Second, "Larger" green means whole life cycle design. Each manufacturer of Iron or car product should consider different approach, order of priority, to improve environmental effects. Third, "More" means green product and service have an attractive function beyond just green effect. Finally, "Firmer" is commercialization of the product and service with green design.

Fig. 6: Green design for green business

4.2 Guideline of Green Design for Green Business

To realize green business, business models are developed. And then, system design and technological support are followed. Finally, before commercializing, the model should be checked.

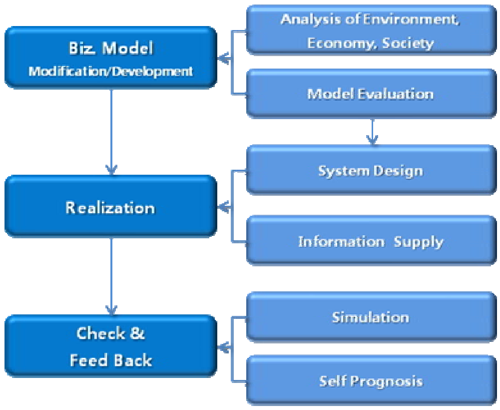

Fig. 7: Guideline for green business

5 TOOL OF GREEN DESIGN

5.1 Model Development

Business model should be considered all effects on environment, economy, and society. In the case of transportation, public transportation is the greenest way from the viewpoint of environment. However, if you think it as new business model, sharing model would be an alternative of it due to service quality.

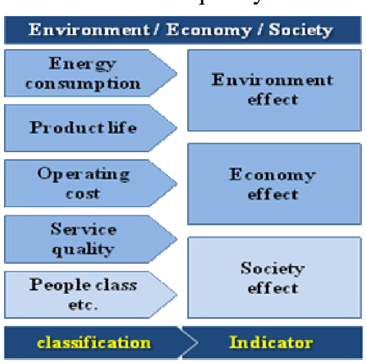

Fig. 8: Business model evaluation

5.2 PSS Design

There are many relationships in PSS design. Developing group as well as its surroundings should also be considered and cooperated.

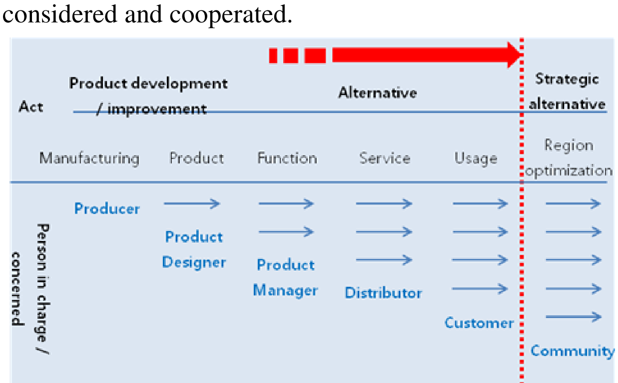

Fig. 9: System design beyond product

5.3 Quantitative Design

Companies can use the design to make attractive product and service by using quantitative tool. Each function and component of product and service is separated and utility value, LCE, and LCC can be calculated. So, companies can select and improve more important part selectively. For green, they can make order of priority easily and accurately.

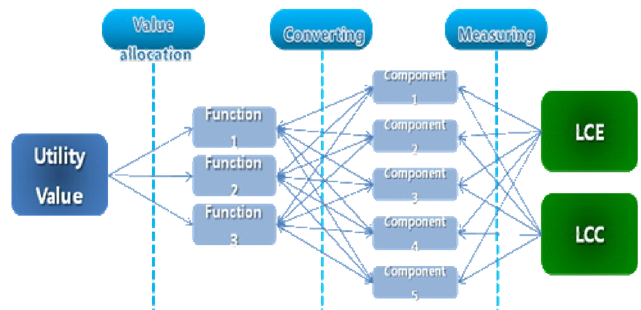

Fig. 10: Quantitative green design

6 MARKET ANALYSIS

6.1 Survey of green business (on-going)

Green business models have been developed by KNCPC, Green Business Association, and companies. Even though the models are being selected carefully, the models must be checked through general public research.

This survey is ongoing and we can present later.

	Experts	General Public
Method	- Gang Survey	- Face to Face Interview - CASI(Computer Assisted Self Interview)
Sampling	- Purposive Quota Sampling	- Proportional Quota Sampling - CASI

Fig. 11: Green business survey

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The Case Study on Carbon Partnerships in Korea

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Abstract
Considering the implications of EU environmental laws and Climate Change, they have been acquired to advance GSCM (Green Supply Chain Management) more and more. The GPs(Green Partnerships) has implemented as a project to promote GSCM by Korean Government. The project is to support SMEs(Small and Medium Enterprises) within supply chain of larger manufacturers. There are two types of program. One is to disseminate green management and cleaner production into SMEs who need support complying with the EU environmental laws such as REACH(Registration, Evaluation, Authorization, and Restriction of Chemicals), ELV(End of Life vehicle) and RoHS(Restriction of the use of certain Hazardous Substances in electrical and electronic equipment). The other is to construct Carbon Partnerships between a large manufacturer and suppliers. The project of Carbon Partnerships is prevailed among companies after enactment of Act on Low Carbon Green Growth in Korea. This article introduced the project of Carbon Partnerships with method and results.

Keywords:
Carbon Partnership, Act on Low Carbon Green Growth, Greenhouse Gas (GHG) inventory, Carbon Footprint, SMEs (Small and Medium Enterprises)

1 INTRODUCTION

Supply chain management is defined as the management of all the activities associated with the flow and transformation of products from raw material acquisition to final product delivery [1]. The whole supply chain related to manufacturing final products is managed such that a particular product is made as an eco-product. The key to lower the environmental impact of business lies in supply chain management [2][3][4]. The new concept of supply chain management is called as the green supply chain management. The Carbon Partnership is one of projects to disseminate green supply chain management for reducing energy use and greenhouse gas emissions from industrial sector in Korea. On 27 November 2009, the Presidential Committee on Green Growth, the Ministry of Knowledge Economy, the Ministry of Environment and the Small and Medium Business Administration jointly developed a plan to expand the green business management model across the Korean industrial sector [5]. The Carbon Partnerships have been spread more and more as a project of the plan. To make effectively low-carbon products and factories, the efforts of whole supply chain including large companies and SMEs are needed. The paper is to share the experience from implementing the Carbon Partnerships comprised of four subjects; 1) establishment of carbon management system, 2) making greenhouse gas(GHG) inventory, 3) calculating carbon footprint of products, 4) checking and improving manufacturing process.

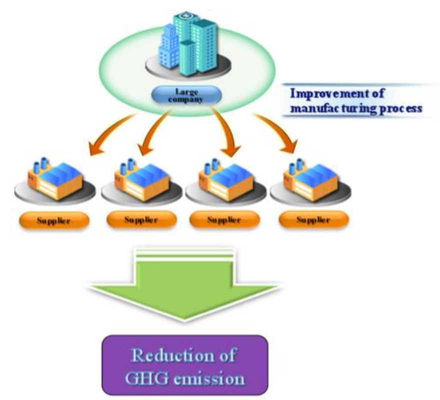

Fig. 1: The concept of Carbon Partnerships

2 METHODS

2.1 Carbon management system

Customers, investors and the public are increasingly demanding information of carbon emissions and activities to reduce it in companies. The carbon management system is a framework composed of structuring organization, making strategy and target, educating workers, implementing to reduce energy use and GHG emission, checking performance, and reviewing. The large company participating in this project should firstly support SMEs suppliers to establish carbon management system for one year. Operating efficiently the system, data of greenhouse gas emission should be measured and managed continuously. GHG inventory and carbon footprint are needed to estimate the amount of GHG emission.

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2.2 Greenhouse Gas Inventory

The aim of GHG inventory is to estimate and account for GHG emissions. GHG inventories are categorized according to scope of emitters, emission source activities and estimation method of the inventory. The inventory of this project is prepared through a six-phase process according to IPCC guidelines.

Phase 1: The boundary of the emitting entity is defined;

Phase 2: The GHG emission sources are identified and categorized, then organized into data tables or worksheets;

Phase 3: The emission estimation methodology is determined, based on the availability and level of relevant data on GHG emissions by source;

Phase 4: The emissions are estimated using the chosen methodology. The resulting emissions from each sector are aggregated to compile an inventory for the emitter;

Phase 5: The inventory outcome is verified through quality control and quality assurance phases to make qualitative improvements before finalizing the inventory;

Phase 6: The credibility of the inventory results is assessed, then directions for improvements and further developments are suggested [5].

2.3 Carbon Footprint

A large company helps SMEs who supply core parts or materials to set carbon footprint of products. The SMEs learned to gather and calculate data of GHG emissions from the whole process of manufacturing parts or materials. The large company can use the result of carbon footprint to set green strategy of final products.

Fig. 2: The case of Woongjin

2.4 Checking and improving manufacturing process

The state of energy use is checked over the manufacturing process before reducing GHG emission. The efficient energy use is directly related with the reduction of GHG emission. The activities of checking and improving energy use are including the several processes; 1) checking the sources of electricity and heat; 2) analyzing the problems of each equipments; 3) advising the improving point and cost-efficiency; 4) advising the technology or methodology to improve energy use and reduce GHG emission.

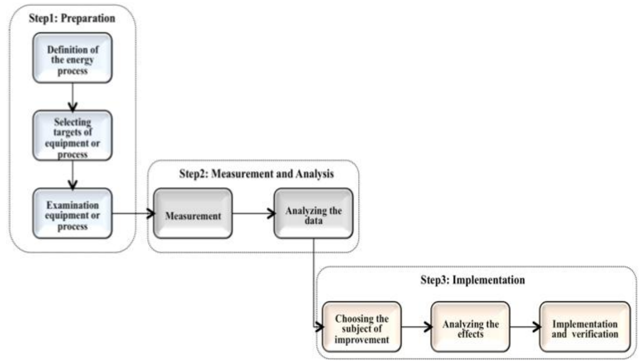

Fig. 3: Flow chart of checking and improving process

3 RESULTS

11 projects of the Carbon Partnerships are driven by the Government since 2008. 11 large companies and 325 SMEs have participated in the projects. Financial benefit was assumed 21,363 million won from reduction energy use of 325 SMEs in 2010. The amount of GHG reduction was calculated over 60,000 ton for one year.

Table 1: The results of Carbon Partnerships in 2010

Projects (Industry)	Financial Benefit (1,000won/year)	Amount of GHG reduction (tCO2/year)
Automobile	2,357,411	5,062
Paper01	250,392	0
Display	773,015	5,744
Chemistry01	7,689,785	0
Steel	4,711,419	29,586
Chemistry02	1,487,121	0.2
Electronics01	547,434	2,640
Paper02	193,787	762
Electronics02	574,266	3,458
Electricity	198,052	456
Semiconductor	2,581,160	15,376
Total	21,363,842	63,084

The results of products carbon footprint are presented as four steps of disposal, use, manufacture, materials. The rate of GHG emission of cosmetics is over 80% from the steps of manufacturing materials or parts. The other hand, GHG of electronics was emitted over 80% from the steps of use by consumers. The results of carbon footprint from each step were used for setting green strategy over whole processes of products.

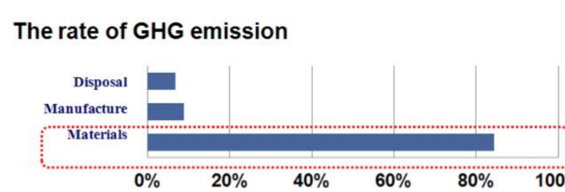

Fig. 4: The results of cosmetics(chemistry02) carbon footprint

4 CONCLUSTION

SMEs have a lack of understanding the importance of greening their business site and products. Most of them are not directly faced with the pressure of compliance with Act on Low Carbon in Korea. However, it is significant that they should be participated in low carbon activities for reducing total amounts of GHG emission. The project of Carbon Partnerships between large company and SMEs suppliers is the best driver to lead SMEs to join Low Carbon activities. Large companies hand down knowhow of GHG management and energy saving technology to their SMEs suppliers. Through this project, over 300 SMEs have formulated the system of managing energy and GHG reduction. However, there are many subjects to be solved in the project. The budget has to be increased to encourage participation of SMEs who are helpful to reduce energy use and GHG emission from various industrial sectors. Furthermore, the method to gain certified emission reduction should be given to participants who look for practical incentives from the Carbon Partnerships.

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The Relationship between Tourism Policy and Sustainable Life-style

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Abstract

Since the rapid development of industry and technology, Human lifestyle has been dramatic change, and with the natural environment, sustainable survival will almost certainly be sidelined, they are on the brink of collapse in spirit and physically for a long time due to busyness. Obviously, human lifestyle is to eventually return to the natural environment for sustainable survival, that is " Sustainable Living " for the basic concept. Sustainable life is a goal to continuously pursuit for human, in addition to life back in the natural environment, but also to re-understanding this island that gestate the development of human civilization. This kind of lifestyle for returning to the natural environment response to tourist-oriented, The Eco-tourism Society and the International Union for Conservation of Nature and Natural Resources (IUCN) all have proposed the tourism policy concept of communal development of the natural environment and recreational activities. (or " Ecotourism ","Eco-tourism"). The concept is identical to tourism policy planning that was proposed by Taiwan Tourism Bureau from 2002 to 2011. They plan to construct multidimensional tourist environment and develop tourism activities of local, ecological diversity, and ultimately to make Taiwan into a sustainable tourism "green silicon island".

The main purpose of this study is to explore the relationship between tourism policy and sustainable lifestyle, and further analysis the effect of tourism policy for the sustainable lifestyle development. This study has made to use Field Methods in its research extensive fieldwork in its research, hope the findings could help the Government in the planning and development of tourism policy, in the "sustainable development " concept, leading the people towards the permanent Continued into the lifestyle goals.

Keywords:

Tourism policy,Sustainable Living,Field Methods

1 INTRODUCTION

Human's lifestyle, along with human civilization, has been changing, and the changes cause the developing of human civilization; however, industrialize boosts the changes over dramatically and rapidly. This crowded and busy social life causes humans on the verge of spirit and physical collapse, and the failure of environmental sustainability; therefore, if human beings would wish to live on this environment sustainably, its lifestyles will eventually have to return to the natural environment friendly, which is concept of "sustainable lifestyle."

Sustainable lifestyle reflects to Tourism. Between 2002 to 2011, ROC Tourism Bureau proposed that "Sustainability" would be the main concept for all tourism policies; the policies include: to build more tourist-oriented environment, to develop rural tourism, to develop diversity of tourism activities. The ultimate goal is to shape Taiwan as "Green Silicon Island." Through the elaboration of research background and motivation, this study can be summarized in the following two research purposes:

1.Reviewing the relationship between tourism policy and sustainable lifestyle.
2.Analysis the impacts from tourism policy to development of lifestyle.

The purpose of this research is to assist the government on tourism policy making, and the "sustainability" concept would lead the people towards the goal of sustainable lifestyle.

2 LITERATURE REVIEW

This study will review the concept of tourism, the evolution of tourism, the concept of sustainable lifestyle, and the relationship between them.

2.1 Tourism Policy Development

Before the twentieth century, the tourism is the combination of religious, scientific, geographic exploration, culture, and anthropology of the research-based eco-activities;

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until the twentieth century, tourism is defined as nature of ecological research activities into the general people's leisure activities. But the essence of what it was changed to enjoy the 4S concept: sun, sea, sand, and sex. For developing countries, this will only lead to imbalance between environmental pollution, over-exploitation, alien invasion of strong cultural and economic dilemma. As eco-tourism expert, Hector Cebsllos-Lascurain, said, on the International Conservation Union, the ecological damage were the result of un-controlled mass tourism, also known as "non-sustainable development."

Continue to promote environmental issues, tourism has evolved in nature but also to make changes along the environmental awareness and eco-tourism Society (The Ecotourism Society) and the International Conservation Union (IUCN) have put forward are the natural ecology and the common development of recreation activities the tourism policy concept ("eco-tourism"). Therefore, the proposed eco-tourism, making tourism back to the original combination of nature and ecology and sustainability, and tourism has become the mainstream, to re-understanding by tourists of all life gave birth to this piece of land.

Taiwan's rich island ecology, biological diversity with rare, very suitable for development of eco-tourism. In fact, often have the wrong strategy led to over-exploitation caused irreparable consequences. Kenting National Park, such as over-exploitation of the entire marine ecological balance is damaged, eventually suffer or humans. This is a natural environment for short-sighted policy of tourism counter attack. It can be by way of eco-tourism for tourism education, so that visitors no longer "predatory, " but to "grow and learn" attitude to the experience and management, and active knowledge of the environment, access to knowledge, with nature, to reach people harmony with the natural realm. Therefore, the Tourism Bureau to develop a "White Paper on Taiwan's eco-tourism", "Taiwan's development of 21st century tourism new strategy" and "Tourism Policy White Paper", the main emphasis in the future of Taiwan's tourism development requires the development of eco-tourism as the main tourism trends, this trend will also become the government each year for tourism policy in the focus of development.

2.2 Sustainable lifestyle

For Earth, the history of human evolution, but the earth which now dominate theecosystem again important species. If because of endless human destruction caused by human extinction, and the evolution of the earth itself will not stop. This is just the evolution of new species on Earth. So for humans, the real "sustainability" concept should be thinking about how human beings should go against the threat posed by humanity itself, leaving humans to the earth's ecological system under a "sustainable." (2011, Chung-Ming Liu)

It is necessary to explore the human lifestyle patterns, Tu,Jui-Che (2005) in the lifestyle design book said: life style is a symbol of people's lifestyle, and culture influence the formation of this symbol, but also record actions of human life and life style. Therefore, the development of lifestyle represents the development of human civilization and the ecological system on earth how to get the dominance of a process. But the development of science and technology, making today's continuous human consumption and destruction of natural resources to meet human consumption of high current privileged life.

If human wish to sustainable survival and development, it must keep the Earth's natural environment to achieve a balanced development. So for human life, is bound to move towards the sustainable direction, and a sustainable concept that will affect the future of human life and cultural development, and to become a "sustainable lifestyle."

2.3 Tourism policy and sustainable lifestyle of the association

Through tourism policy and sustainable lifestyle analysis of relevant literature can be found by the current changes in the environment, tourism policy development, eco-tourism to the main spindle. Hope that through education the way for tourism to the actual experience of human evolution the development of the natural environment, and then operate and take the initiative to understand the environment and with nature. This is the "sustainability" concept. If humans want to survive in this planet sustainable, must follow the "sustainability" idea to change the lifestyle of today, and move towards a sustainable lifestyle. Therefore, tourism policy and sustainable lifestyle does have a close relationship.

3 RESEARCH METHODS

In this study, the structure shown in Figure 1. The development of tourism policy is based on the theoretical point of view, to explore sustainable tourism policy for the development of lifestyle real effects are, for data analysis. Through the writing of data integration, summarize the correlation between the two, and then to the field survey method for field observation and verification, and finally summarize the conclusions and recommendations required for reference.

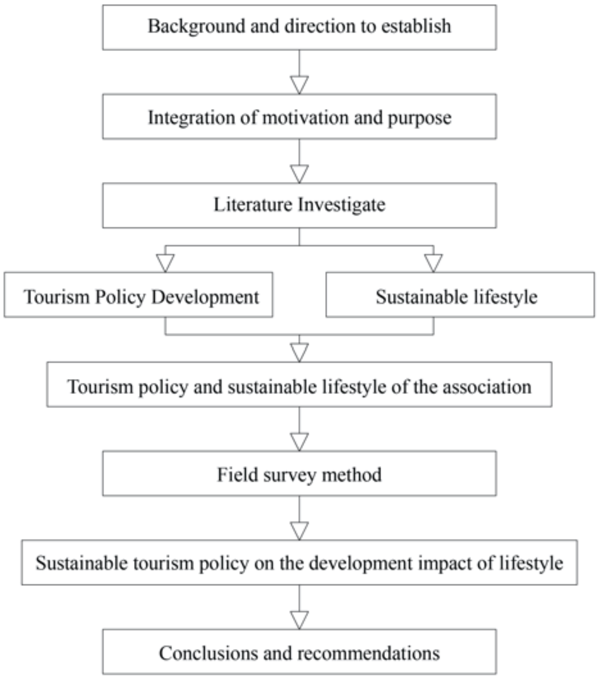

Fig. 1: Research organization chart

4 RESEARCH AND ANALYSIS

First, the analysis of research literature, summarized the tourism policy and sustainable lifestyle of the association, and then observed through field surveys practical way to participate in research. Observed mainly in the way of promoting eco-tourism in Taiwan have the tourist area of field visits, the visits of research results are summarized below in Figure 2.

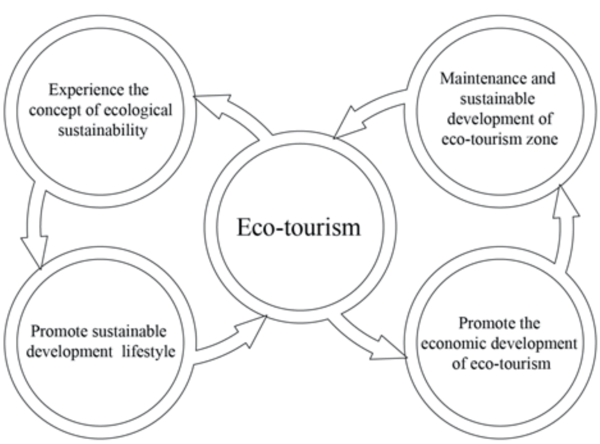

Fig. 2: Research summarized

Through the chart type, today's tourism policy as the main eco-tourism, its impact can be divided into two levels of cycles :

1.practical experience through eco-tourism concept of ecological sustainability, the development of sustainable lifestyles.

2.through improved eco-tourism in the economic development and the income maintenance and sustainable eco-tourism area.

5 SUMMARY

From the literature review and subsequent research showed that : the development of tourism policy, and the country's overall economic, social, cultural, political, and most importantly, the development of sustainable lifestyles have a major relevance. In addition to the country's overall development, but also related to the human in the natural eco-system is able to move under the "sustainable" development. Therefore, appropriate arrangements for leisure time, to experience the natural ecology of nature, so that daily overtime physical and mental exhaustion caused by the liberation of being outside, but also to change attitudes, so that the concept of sustainability in people's minds, the last to step to a truly sustainable lifestyle.

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An Investigation on the Network Governance of the Yilan Museums Group.

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Abstract

Taiwan Creative Living Industries, guided and supported by the Ministry of Economic Affairs, embodies the policy focusing on the culture and creativity industrial development. The present study aims to investigate how such industries create the value of sustainable management among the fields, the museums, and the government's policies through three instruments: the in-depth interviews with industry operators, participant observations, and literature review.

Keywords:

museum, network governance, and sustainable management

1. INTRODUCTION

The term, culture tourism, according to the United Nations Educational, Scientific and Cultural Organization (UNESCO), is defined as a combination of traveling activities and the cultural environment including the sightseeing, vision, performing arts, lifestyle, traditional value, special events, and other activities concerning the communication of creativity and cultural issues. In Taiwan, after issuing the plan, "Challenge 2008: National Development Plan Summary Report", the creative living industries gradually gained much attention. The present industries, combined with cultural creativity elements, became brand new creative industries. With the continuous changes, the enterprises realized it was still hard to achieve the goal with the combination of business management and cultural creativity, and that the cooperation with other practitioners is another essential key to success. Therefore, how to improve and strengthen the cultural creativity industries and sustainably manage it obviously became the lesson of the enterprises. It also implies the importance of the connections among local industries and the network management.

2. LITERATURE REVIEW

Youngsun Culture and Education Foundation and Lan-yang Culture and Education Foundation serve as the two main organizations, trying to create the Yi-lan community and cultural indutries. Youngsun Culture and Education Foundation, established in June, 1989, had devoted itselves to building the community and the cultural policies of Yi-lan for decades. It plays an impirtant role for the negotiation between the authorities and the people. Nevertheless, the rotation of political parties caused the failure of the connections among the museum group members because of the different opinions respectively held by the authorities and the museum group members. Thus, the following literature mainly focus on the trend of musuem development, the network management, and the orientation of culture industries.

2.1. The Trend of Museum Development

With the people's awareness of a better life quality and the changes of culture, the museum is not only a field for display and exhibition, but also an extension for the local people and its culture. However, it is worthy to ponder whether the policy is restricted to the traditional thinking.

No matter which style the museum is, the role of museum became more diversified nowadays. The International Council of Museums (ICOM) defined the museum as the non-profit public organization with the goal of research, education, and recreation, providing the public services, facilitating social development. Besides, it helps to preserve, maintain, research, display the pieces of human beings and the environment, and make them well-known to the world (Han, 2000). The building of community museum is a tendency now. Compared with the functions a traditional museum serves, the community museum heavily relies on the power of the public like the human resources, materials, and the capital. The need of more resources makes it face more challenges in terms of operation. Involving more local people and organizations to join emerged as the lesson to build up the network.

In the process of the cooperation between the museums and the local people, if the museums solely ask the local people to contribute and overlook the importance of their duty, the museums will hardly win the support from the local people. Gradually, such one-way cooperation might be the stumbling block to success. That is to say, in addition to the support from the local, the museum authorities should put how to feedback the local people into consideration.

To become an eco-museum is one of goals for most of contemporary museums. In 1980, the campaign of eco-

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museum in France, known as the birth of New Museum, led this fashion. It was an experimental campaign with a brand new idea, especially with the emphasis on the museum as an public organization, providing services for the society (Chang, 2004). During the period of 1990-1997, the policy that building the whole county full of culture was carried out by Hsi-kun You as Yi-lan County Magistrate. This policy tried to find out the museums, which might own potential for research, preservation, display, and educational functions. Such museums are called satellite museums（www.ilma.org.tw/modules/tinyd1/index.php?id=9）. Afterwards, from 1998 to 2005, the following policies were accomplished by Shou-cheng Liu as the magistrate, the museum group was formally established in May, 2001, with the focus on tourism industry development.

2.2. Network Governance

According to the definition by Lincoln (1982), network management refers to an organization in which the distinct members relate one with another through social relationship. In the process of forming the network, some newcomers might get involved in the relationship, and these newcomers usually have the ability to carry out the decision or the policy. Through the governance reliance, policy network, and partnership, the members exchange and share the resources. In other words, the aim of forming network is to gather the people, who share similar purpose, dream, and needs, to fight together.

2.2.2. The Governance

Many scholars claimed that the reasons why a new term, "governance", emerged was because the focus has been switched to the governance rather than the government. In other words, the current tendency makes the government change into the governance without government (Yu, 2003). Hyden (1999) pointed out the idea of governance refers to the task, managing both formal and informal political affairs with certain regulation. Simlarly, Rosenau shared the similar idea with Hyden, and stated that the governance is a series of management mechanism for activities. It might not be authorized, but it still works (Yu, 2003).

Such a new term – the governance – implied the changes of the government. Moreover, it shows a new ways of governance, including a self-organization system, the share of resources among the network, and a reciprocal relationship (Rhodes, 1997). Based on the definition of Commission on Global Governance, the governance refers to the general ideas about the managment from both public and private organizations. It works as a mediator for the conflicts, and constantly takes action. Furthermore, it forces the people with power follow the regulations of formal organizations, and properly arranges the informal system to reach a beneficial state (Sun, 2003). In addition, based on the various meaning of the government, Rhodes futher defined the governace as a self-managment process among the networks (Shih & Tsai, 2000; Sun & Chung, 2005).

Accroding to the difinition by Commission on Global Governance, the governance was characterized by Smouts. First of all, the governance refers to a process, rather than a set of regulation or activities. Second of all, the governance put much emphasis on the negotiation instead of dominance. Third of all, the governance contains both public and private organizations. Last, the governance indicates the importance of constant interactions among the networks, rather than a set of formal regulations. What's more, Rhodes pointed out the four characteristics of the governance. First, both people from the government and non-goverenmental organization are closely related to each other. Second, the members constantly interact by participating the network, sharing resources, and negotiating. Third, the members interact based on the models they trust and approve. Fourth, the value of the organization lies in its autonomy rather than government's accountability (Rhodes, 1997).

2.2.3. The Concept of Network Management

The domain of the governance could be divided in to four: market, hierarchy, network, and communities. In the market, the operation is all based on competition and price for business transaction. The hierarchy refers to the power for control and management. As to the network, it serves as the basis for the resources sharing, power equality, and mutual trust. The last one, communities, focuses on the group actions for mutual benefits. Basically, these four elements function differently as Table 1 reveals (Sun, 2002; Cheng, 2005).

Table I : The comparison of Market, Hierarchy, Network, & Communities

Mode	Market	Hierarchy	Network	Communities
Relationship	Contract and Ownership	Employment	Exchange of Resources	Shared Awareness
Degree of Dependence	Independent	Subordinate / dependent	Mutually dependent	Mutually dependent
Business Transaction	Price	Authority and Power	Trust	Mutual Benefits
Way of dealing With the conflicts	rgument / Lov	egulations/ Ord	Social skills	Responsibility Cooperation
Culture	competition	Primary and subordinate	Equally and reciprocally	The Community

From Sun, **2002: 18-27**; Cheng, **2005**

The purpose of network management is to prevent the individual management model from being a failure, and a well-operated model should rely on the cooperation between the government and the non-governmental group from the society (Yu, 2003). With regard to the practice of policy, the network would be interdisciplinary to build up a better society with more powerful economics, creating a partnership among more effective enterprise, government, and citizen (Sun & Chung, 2005). Hence, Cheng (2005) stated that the value of the network management lies in a new operating model full of diversity, trust, and a co-dependent relationship, solving the dilemma that the traditional public service generated before.

3. RESEARCH METHODOLOGY

3.1. Research Question

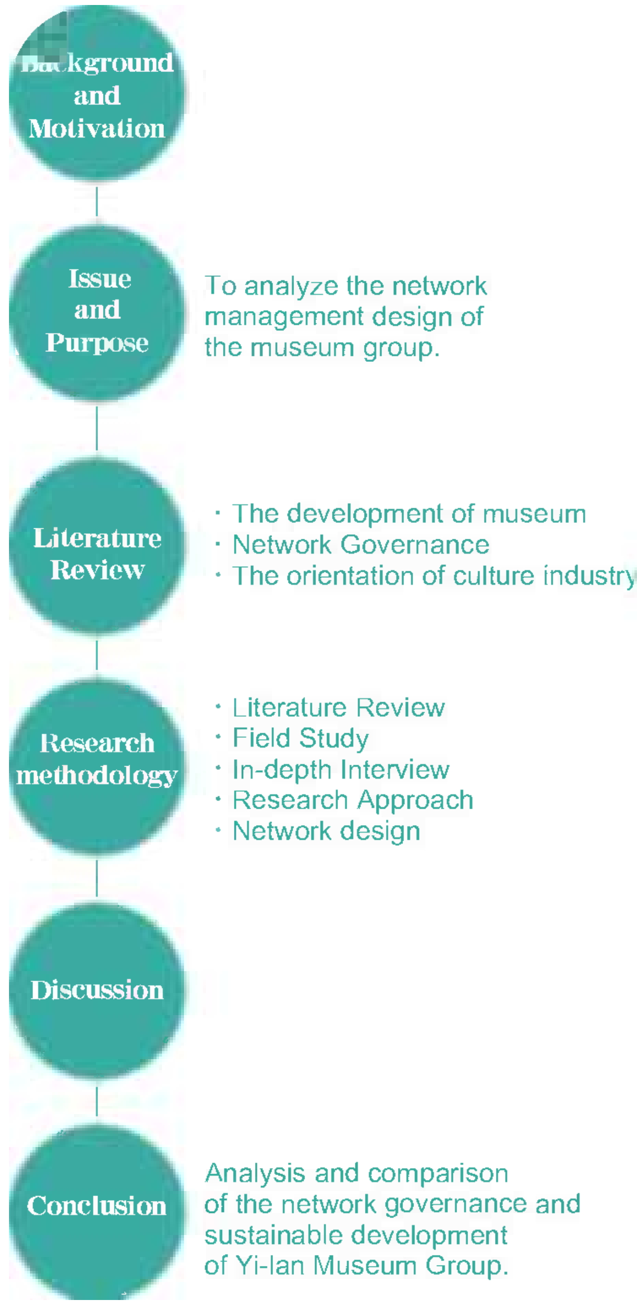
With three cases concerning Taiwan Creative Living Industry, the present study aimed to investigate the network management between Lan-yang Museum and Yi-lan Museum Group in terms of the policy, the local factor, and the cooperation's through in-depth interviews and participant observations. Combined with the literature review, the first-hand data collected from interviews and observations were further analyzed by the orientation of culture industry to understand the role of network management.

3.2. Research Purpose

The purpose of the study is to analyze the relationship between Lan-yang Museum and Yi-lan Museum Group, to examine the effect of policy on the museum group, and to understand how the museum group manage for sustainable development.

3.3. Procedures

Table II: Procedures



From the present study

4. RESEARCH FINDING

THE FINDING OF INTERVIEWS AND ANALYSIS

4.1. To Build up a Museum without Wall is the Ultimate Goal for Yi-lan. (Local)

Since 1990, the plan of building the Lan-yang Museum had been carried out. Originally, the Yi-lan County Government actively promoted the policies related to the local culture, trying to build up an eco-museum and combining both natural and humanities resources together. Meanwhile, the policies carried out by the Council for Cultural Affairs made the number of the satellite museums suddenly grow up. The formal eco-museum operation includes one museum as the core museum and several museums as the satellite. Each museum serves as the connector and manager within this community, and each of those satellite museum, owns either small-scale or large-scale resources, integrated with the modern environment. Above all, this is the ideal of a museum without wall.

The birth of satellite museums enabled the government to realize the non-governmental organization and the enterprises had their own way to manage the museum. On the other hand, some museum, because of the way without a complete arrangement, went out of business. This phenomenon urged those who concerns about this issue think about how to improve the current situation. Hence, those satellite museums were connected together, cooperating and sharing resources to improve themselves. Besides, with the help of the Lan-yang Museum, a national museum supported by the government, these satellite museums and the Lan-yang Museums were all connected with each other. Within this network, the Lan-yang Museum was just like a big hand, holding those hands of satellite museums, providing them with the expenses, and facilitating the local development.

4.2. A Huge Gap caused by Different Governors (Policy)

The support from the Yi-lan County Government is the gas to the museum groups as a vehicle. When Mr. Ting-nan Chen and Mr. Hsi-kun You were the magistrates of Yi-lan County, they actively promoted the establishment of eco-museum. However, different magistrates had different point of view toward the policy, and such gap directly influenced those museums in Yi-lan. If the incumbent cannot broaden their viewpoint and realize the idea of the museum without wall, their impression on the museum still stays traditional. For example, the museum should be the place for exhibition only. Such different attitude toward the museum undoubtedly generated a huge gap. Mr. L from Youngsun Culture & Education Foundation said,

“ After Mr. Li-cheng Lu had finished organizing the Lan-yang Museum and left the museum, the gap between the Lan-yang Museum and other museums was generated.”

It implied Mr. Lu played an indispensable role in negotiating the matters between the public and private organizations. Unfortunately, after Mr. Lu’s leaving, the negotiator between the Lan-yang Museum and the Museum Group has gone. Since then the unfamiliarity of the governors led the government stopped allotting funds, ten million dollars, to the museum group. In addition, the lack of communication made the museums and the Lan-yang Museum in an opposing situation.

4.3. The Museum Heavily Relied on the Government’s Financial Support (Cooperation：Group Members’ co-reliance)

The capital shortage was always a problematic issue between the core museum and the satellite museums. However, didn’t those satellite museum have any budget? Since the county government stopped providing financial support, those museum group members turned to other public organization like the Council of Cultural Affair for applying the budget. In order to successfully apply for the budget, each group member seldom made contact with other group members in a competitive way. What’s worse, the inequality between the Lan-yang Museum and other satellite museums was regarded as the biggest challenge for the sustainable development. Therefore, each museum’s job and responsibility should be clearly identified in order to reach a flat organization. Besides, the idea about the museum without wall should be greatly promoted for every body to clearly understand.

To be the chain museum is the common goal for the Lan-yang Museum and other satellite museums. It is a huge difficulty for those which are short of money to do network management. The Yi-lan Museum Group could be divided in to six categories. It sounds reasonable if they could share resources through network management. Unfortunately, the group members cannot trust each other. Without the cooperation, the network among group members failed to connect each satellite museum and gradually became extinct.

Table III: The Six Types of the Museum Group

Six Types		
1.School	2.Foundation	3.Community
4.Industry	5.Fine Arts Museum	6.Public Organization

From the present study

5. CONCLUSION

To sum up, the data collected through interviews with three satellite museums showed that 1. the network was greatly influenced by the governor’s ideology and the lack of communication. 2. based on the condition for sharing resources equally and friendly, each satellite museum should strengthen their own potential for tourism. 3. Despite the weak connection among the Museum Group members, the tourism in Yi-lan was still successful, and some satellite museum were still prosperous due to their prefect management.

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The motivation toward the environment-friendly daily life; Case studies in Finland

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Abstract
Based on the methodology of group dynamics and the case studies in Finland, this paper suggests the importance of establishing the robust and mutual relationship between residents and the waste management company through the communication. This paper also emphasizes the need of the collaborative activities by residents and the waste management company for the betterment of the environmental communication which leads people to the environment-friendly daily life.

Keywords:
environmental communication, group dynamics, waste management, motivation, daily life

1 INTRODUCTION

Recently, there has been growing interest in a new environment-friendly lifestyle. In response to this gain of momentum, municipalities have launched the environmental policies, companies have provided the sustainable management, and stores have begun selling the eco-friendly commodities. Behind these trends, the increasing and consecutive destruction and overuse of natural resources have been unfolding.

This recent situation has led to researches focusing on people's pro-environmental behavior. Dahlstrand and Biel, for example, explored the propensity levels in behavioral change [1]. Fransson and Gärling considered whether enivironmental concern plays an important role for behavior changes [2]. Stern developed a conceptual framework for the theory of environmentally significant individual behavior [3]. Kollmuss and Agyeman analyzed the factors that have been found to have some influence, positive or negative, on pro-environmental behavior [4]. Little has discussed the communication and the collaborative activitites by waste management companies from the social constructionist perspective.

This paper focuses on the waste disposal from the viewpoint of the communication. We cannot live without the waste disposal, that is to say, the waste disposal is indispensable in our daily life. Incorrect disposal of waste, for instance, is one of the issues that has generated a major discussion in terms of the environmental problems in Japan. One of the underlying causes of this problem is the complexity of the garbage separation. In Japan, the way to separate garbage differs from municipality to municipality. Once he or she moves to the area in a different municipality, he or she has to learn how to separate garbage from the beginning. The imposition of the pro-environmental behavior and activities is insufficient for the change of people's daily life, for the way of life is deeply ingrained in daily habits.

By focusing on the waste disposal, this paper considers what is needed for the environment-friendly daily life as well as the better environmental communication. Based on the methodology of group dynamics and the case studies in Finland, this paper redefines the environment-friendly daily life, suggests the importance of the robust and mutual relationship through the communication which encourages people to spend the environment-friendly daily life, and emphasizes the need of the collaborative activities by the residents and the waste management company for the betterment of the environmental communication which leads people to the enviornmen-friendly daily life.

This paper builds upon the methodology of group dynamics newly proposed by Sugiman. The next section provides an overview of its methodology and its definition of the communication. In the third section, this paper shows the case studies conducted in Finland, which has unique environmental policies focusing on the communication provided by the waste management companies. Following the results of the case studies conducted in Finland, the word, environment-friendly daily life, is redefined in the fourth section. The last section provides the conclusion of this research.

2 METHODOLOGY

2.1 Group dynamics

New group dynamics advocated by Sugiman highly stresses collaborative practice by researchers and people, maintaining social constructionism as its meta-theory [5]. It differs from traditional group dynamics created by Kurt

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Lewin. This new group dynamics emphasizes the nature of the collectivity while the traditional group dynamics underlines the psychological process of individuals [6] [7].

Sugiman defines group dynamics as "a field of study in which the dynamic nature of human collectivities or groups is investigated by examining the collectivities as wholes on the one hand, and the dynamic bilateral relations between the collectivity and the lives, or the psychological states, of individuals who belong to these collectivities on the other" [8].

2.2 Communication

In group dynamics proposed by Sugiman, holding social constructionism as its meta-theory, communication is what produces something communal, provides a basis of meaning and enables our life world to be less ambivalent in the end [9].

Following the definition of the communication above, this paper considers the environmental communication as the communication that provides people with the basis of the meaning of the practice of the pro-environmental behavior and activities.

3 CASE STUDIES IN FINLAND

3.1 Waste management companies

Finland has unique environmental policies which try to instill the environment-friendly awareness into people by the communication provided by the regional waste management companies. As contrasted with the waste management in Japan, the waste management in Finland values a close relationship with residents. Many of waste management companies in Finland have at least one eco-center where anyone can learn about the environmental issues for free and can buy recycled and used items. For the purpose of obtaining the interviews and visiting the sites where environmental communication was taking place, I visited two waste management companies in Finland.

Turun Seudun Jätehuolto Oy

Turun Seudun Jätehuolto Oy (TSJO) is located in Turku, Finland. It is owned jointly by the regional municipalities and its customers include 317,000 residents and businesses located within its operational area. It has a unique slogan: “More From Waste.”

The interview with a waste advisor who was also serving as a public relation officer at TSJO was conducted on 8th of March, 2010.

According to this interview, TSJO puts an emphasis on 1) Communication between TSJO and its customers, 2) Polluter-pays principle, 3) Spurring public knowledge in recycling, 4) Exhibition at recycling center, and 5) Hotline.

TSJO accentuates the importance of the communication with each resident and local groups in its operational area and provides the information on the waste in valid and feasible ways through many activities such as visits to small groups, comprehensible brochures, original goods, and so forth.

The polluter-pays principle states that whoever is responsible for damage to the environment should bear the costs associated with it [8]. TSJO is operated under this principle.

Pupils visit the recycling center to learn the history of the waste and this is strongly suggested by the curriculum. They have to visit TSJO several times between lower-grade and higher-grade. TSJO aims to instill "environment-friendly spirit" to them and it commits to strenuous efforts to spur public knowledge in recycling in multiple ways such as the visits to small groups including home visits upon request.

In addition, TSJO regards exhibitions featuring photos and things which show residents in chronological order how the waste has been dealt with and recycled as one of the most important activities in terms of the environmental communication.

TSJO sets up a hotline for residents in Turku to communicate with them. Waste advisors receive phone calls. Residents in Turku can obtain the best answer out of waste advisors over anything related to their waste management —the way to dispose of garbage, how to recycle things, what kind of things can be recycled and so on—.

TSJO underlines establishing the positive and productive relationship with residents through the communication, realizing and remembering the importance of the locality and motivating residents to the environment-friendly activities in a collaborative way.

Pirkanmaan Jätehuolto Oy

Pirkanmaan Jätehuolto Oy (PJO) is located in Tampere, Finland. It is owned jointly by the regional municipalities and its customers include 416,000 residents and businesses located within its operational area. It has no slogan but it has the targets to be achieved which are to reduce the amount of waste, to improve waste recovery and to take care of safe final disposal.

The interview with a waste communication advisor who was also serving as a public relation officer at PJO was conducted on 11th of March, 2010.

According to this interview, PJO puts an emphasis on 1) Communication between PJO and its customers, 2) Attunement with EU environmental policy, 3) Instillation of the positive attitude toward environment-friendly activities into residents, 4) Landfill as an eco-center, and 5) Foreigner-friendly activities.

PJO also puts an emphasis on environmental communication like TSJO. However, in contrast to Turku, Tampere is too large and too multinational to communicate with each resident and local groups in feasible ways for each like TSJO does. Therefore PJO tries to establish the relationship with each resident in

Tampere with other means such as arranging photo contests for the "waste calendar" it distributes every year.

PJO regards the attunement with EU environmental policy as important, for it shows what should be done as part of pro-environmental activities.

PJO puts high priority on instilling "positive attitude toward pro-environmental activities" into residents in Tampere through various original goods such as video games, CDs, and calendars. PJO believes that the earlier children get the positive information on pro-environmental activities, the more positive and robust their attitude toward pro-environmental activities becomes and the more spontaneously they put them into practice.

PJO owns the two biggest landfills in Finland, located on the fringe of Tampere. PJO strongly recommends residents to call the landfill "eco-center“ because the word "Eco-center" gives people a more positive image toward the landfills and these landfills are not only a landfill but also a center that anyone can visit and learn environmental issues.

PJO provides foreign residents with easy-to-understand brochures written in plain Finnish and English with rich illustrations. PJO is also making an effort to build up the positive relationship with foreign residents. They are often blamed for the incorrect disposal. PJO is afraid they will have the negative attitude toward pro-environmental behavior and activities because of this.

PJO emphasizes that building up the positive attitude toward pro-environmental behavior and activities is the most urgent and crucial.

These two waste management companies stated that they successfully created and maintained a close and good relationship with residents based on the environmental communication. To investigate the environmental communication from the residents' side, the participant observation was conducted.

3.2 The participant observation conducted in two households

I conducted the participant observation in two housholds in Tampere and Joensuu. In Joensuu, I also interviewed twenty-three Finnish residents during the participant observation.

I spent all day long together with the collaborators, video-taped or recorded their behavior and activities under their permission, and kept logs as much as possible.

The collaborator in Tampere was a Finnish single male student in late twenties living in an apartment alone. The collaborators in Joensuu were members of a family of two: a Finnish female woman in late sixties and her nephew who was a single student in mid-twenties.

They all separated garbage in a correct way without reading a guideline or a brochure distributed by the local waste management company about how to conduct the waste disposal correctly. According to them, separating garbage has already become a habit. For this reason, they can always do it appropriately unless the waste management company changes the policy of the waste disposal and they will be able to do it in a correct way even if the waste management company changes the policy of the waste disposal or they move to the area where the different waste management company gives service because they think they have a strong relationship with the waste management company —they can visit it, call it or ask someone from it to come to their houses to learn how to separate garbage in a correct way—. Even the collaborator who was in late sixties separated garbage correctly without any effort. She described the reason as follows; "since I was little, I have done this. I didn't know why I had to do this but I have just done this. It's, like, as if Japanese people don't eat anything before saying something when eating, you know. I just cannot throw the garbage away without separating it."

These two case studies illustrate the pro-environmental behavior conducted spontaneously and it is quite likely that the efforts by the waste management companies to establish a close and good relationship with residents through the environmental communication yeild results.

Twenty-three Finnish residents in Joensuu who volunteered to be interviewed were ranged in age from 15 to 72 years. Eleven of them were male and the rest were female. Each interview mainly focused on the pro-environmental behavior and activities that they thought they had done, how they had conducted the waste disposal and what they thought the environment-friendly daily life should be. According to these interviews, it was found that interviewees had confidence about the way to separate the waste correctly, the relationship between the residents and the waste management company was strong, and the residents believed in the waste management company — "when I forget how to separate the waste, all I have to is to visit the waste management company or call it to ask about how to do that"—. They had been repeatedly told how to separate garbage since they were little and they had an understanding of the environmental issues through the educational visits to the waste management company when they were younger. Moreover, there are eco-centers in almost each municipality in Finland and people can visit there to learn about environmental issues and can buy recycled and used items. It seems quite probable that the pro-environmental behavior and activities are something very familiar to them. Presumably, all these kind of things contributed to their pro-environmental behavior and activities.

4 ENVIRONMENT-FRIENDLY DAILY LIFE

4.1 Definition

On the basis of the case studies in Finland, this paper redefines the environment-friendly daily life as the environment-oriented daily life in which people spontaneously put into practice the pro-environmental behavior and activities that are sublimed to a habit.

People's lifestyle is deeply ingrained in their daily habits which are not easily changed. The waste disposal, for instance, is conducted in everyday life. In general, people conduct the waste disposal without bringing to mind the environmental issues: why do we have to separate the waste and what kind of effects would the incorrect disposal have on the environment? The waste disposal is usually conducted as their habit once they learn how to separate the garbage from the guideline distributed by the local waste management company, their family, their neighbors and so forth.

4.2 Pro-environmental behavior and activities

Following the definition of the redefined environment-friendly daily life, the pro-environmental behavior and activities are explained as follows.

Pro-environmental behavior in environment-friendly daily life

In environment-friendly daily life, people have the robust but flexible environment-friendly habits. Specifically, they separate the waste in a correct way without any effort once they learn how to do it, they know what is supposed to be good under the current knowledge or technology for the environment. People do not even realize that they themselves are conducting pro-environmental behavior because it is nothing special in environment-friendly daily life and it is sublimed to the common practice.

Pro-environmental activities in environment-friendly daily life

In environment-friendly daily life, people willingly take part in the community-based environmental activities such as the cleanup activity in the neighborhood held by the neighborhood association and the environmental workshops held by the local municipality. As an example, in my city in Kyoto in Japan, the cleanup activity in the neighborhood is held by the neighborhood association every two to three months in general and all the residents at any age are supposed to participate in this activity. However, the participants have been decreasing. In environment-friendly daily life, people willingly consent to the participation in this kind of activities.

5 CONCLUSION

The significant conclusion is derived from the thorough case studies and interviews in Finland. It is important to establish the robust and mutual relationship between the residents and the municipality through the communication that spurs people to spend the environment-friendly daily life. The interviews with officers from waste management companies, residents and the collaborators in Finland show the significance of creating the robust and mutual relationship between the residents and the municipality through the communiction which is conducted in a non-coercive way for the purpose of creating the good relationship.

In addition, collaborative activities by residents and the waste management company are needed for the better environmental communication. They can contribute to the betterment of the pro-environmental behavior and activities. The case studies indicate the high possibility that the robust and mutual relationship through the communication and the collaborative activities between the residents and the waste management company bring people to the better pro-environmental behavior and activities sublimed to a habit and to the environment-friendly daily life.

ACKNOWLEDGEMENT

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A business feasibility study on a paprika with carbon footprint label

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Abstract

Recently, the carbon-footprint on the agricultural products such as vegetables would become attractive. Especially, Ministry of Agriculture, Forestry and Fisheries (MAFF) tries to promote eco-friendly scheme to agricultural sector, since they have interests in the global warming protection and/or the abatement of CO_2 emissions by 2011. Also, due to the carbon-footprint for agricultural products, the added value for CO_2 emission reduction might be brought.

In this paper, we propose the greenhouse system for a paprika cultivation in which the required energy would be supplied by the biomass gasification process of Blue-Tower (BT). On the product, we investigated the consumer's behavior and the business condition so that our proposed system is running continuously. Due to the questionnaire results, we examined the relationship between CO_2 abatement and the consumer's willingness to pay (WTP) of a paprika with CO_2 emission reduction label.

Finally, assuming the scale of BT system and/or the cultivation area, we analyzed the optimal combination by which our proposed business would be gone well.

Keywords:

Carbon-footprint, LCA, Blue Tower, Conjoint analysis, Tri-generation

1 INTRODUCTION

Recently, the carbon-footprint on the agricultural products such as vegetables would become attractive. Especially, Ministry of Agriculture, Forestry and Fisheries (MAFF) tries to promote an eco-friendly scheme to agricultural sector, since the organization has interests in the global warming protection and/or the abatement of CO_2 emissions by 2011 [1]. Due to the carbon-footprint (CFP) for agricultural products, the added value for CO_2 emission reduction might be brought. Also, from the viewpoint of food safety, the controlled cultivation system will be absolutely necessary. Unfortunately, on this spring, the disaster which occurred in Japan, and then the cultivation area was polluted by the nuclear accident in Fukushima. Simultaneously, the waste biomass materials which are great amount were discharged. That is, it would be necessary to consider the effective use of the biomass feedstock and the creation of the eco-friendly cultivation system in order to contribute the economic growth on the agricultural sector.

Therefore, we focused on greenhouse using a lot of energy and conducted feasibility study on our system, supplied electricity, thermal energy and CO_2 for growth promotion to paprika cultivation by BT under added-value for CFP. In addition, we estimated 12 cases of BT-cogeneration system (BT-CGS).

2 METHODLOGY

2.1 Outline of our system

The greenhouse for harvesting vegetables requires electricity, thermal energy and CO_2 gas as growth agent. Therefore, for the purpose of reducing the direct CO_2 emission, we proposed the paprika cultivation system so that CO_2 would be abated by the biomass gasification system of Blue Tower (BT). Figure 1 shows the schematic design of our proposal and Table 1 shows the conditions of specification for our case study. Based on the previous study, we designed the combined BT system with gas-engine and/or SOFC, respectively. This time, we used the specifications in order to estimate CO_2 emission in our target facility.

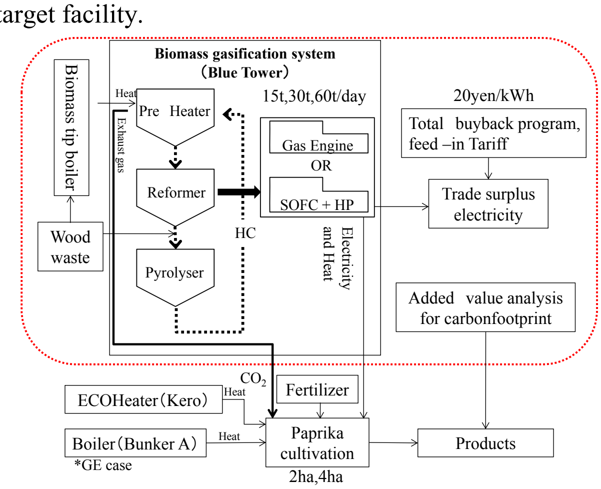

Figure 1 Proposed system

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Table 1 The conditions of specification for our case study

	Gas Engine			SOFC + HP	
	Cultivation scale	BT-plant scale		Cultivation scale	BT-plant scale
GE-Case1	2ha	15t/day	SOFC-Case1	2ha	15t/day
GE-Case2	2ha	30t/day	SOFC-Case2	2ha	30t/day
GE-Case3	2ha	60t/day	SOFC-Case3	2ha	60t/day
GE-Case4	4ha	15t/day	SOFC-Case4	4ha	15t/day
GE-Case5	4ha	30t/day	SOFC-Case5	4ha	30t/day
GE-Case6	4ha	60t/day	SOFC-Case6	4ha	60t/day

2.2 Biomass LCA

LCA is a technique to assess the potential environmental impacts associated with a product or service throughout its life cycle. Figure 2 shows system boundary in this study. Function unit is CO_2 emission per a paprika.

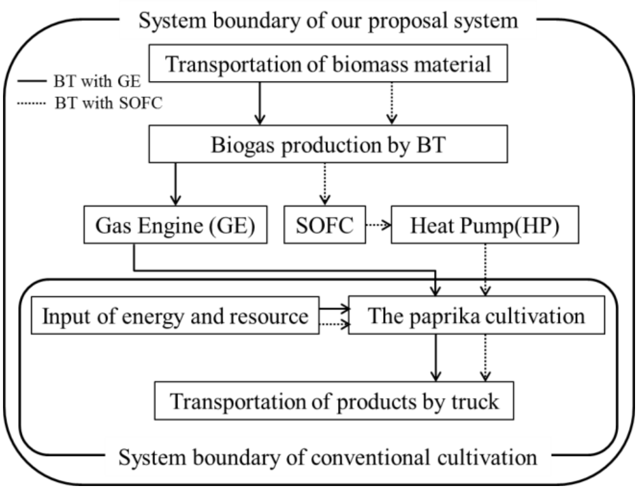

Figure 2 System boundary in this study

2.3 Willingness to Pay due to Carbon footprint

The willingness to pay (WTP) is defined by the maximum amount per a person, and that means a willingness to pay in order to obtain the products by which he or she would be satisfied, or to avoid the undesired such as pollution. In the previous research, it is said that the consumer has a willing to pay for eco-friendly vegetables. This means that there is potential to reduce CO_2 emission by purchasing the product [2]. Therefore, we calculated CO_2 emission per a paprika of the system more precisely, since the carbon footprint would be extremely important factor. After that, we estimated consumer's willingness to pay (WTP) of each case for CO_2 reduction. Note that we investigated the level of WTP through the questionnaire.

Finally, we clarified the sustainable business conditions in the consideration of the additional profit due to WTP besides the public support.

3 ENERGY AND CO_2 EMISSION OF THE CULTIVATION

3.1 Conventional cultivation system

First of all, we designed the system due to an interview to the farmer of paprika cultivation (1.2ha). Using the reference data, we estimated the energy consumption and CO_2 gaseous volume, respectively, assuming that each factor is proportional to the cultivation area.

In this study, we assumed that the cultivation area is 2ha or 4ha.

Here, Table 2 shows the annual production yield and energy consumption in the conventional case.

Table 2 Annual production yield and energy consumption

Amount of yield	240	t/year
Bunker A	240000	L/year
Kero	4300	L/year
CO_2 for growth promotion	58460	kg/year
Electricity	100	MW/year
Fertilizer	23715	kg/year

3.2 CO_2 emission of conventional cultivation

Based on the above data, we evaluated CO_2 emission per a paprika on LCA methodology (see Figure 2). The direct CO_2 emissions are due to a bunker A, kerosene, electricity and CO_2 gas as a growth agent, respectively. Also, we considered the indirect CO_2 emission from fertilizers and transportation of products. Here, we used the CO_2 intensity of transportation process, which is shown by the regression equation on a freight weight [3]. In this study, we assumed that the paprika market location is at *Ota*, Tokyo in Japan. That is, the transportation distance is 449 km.

On the direct carbon balance, considering air infiltration for temperature control, we assumed that loss rate of CO_2 gas of a growth agent is 20%.

In our system, the gas would be available for the exhaust gas through the BT plant. However, it is necessary to verify the acceptability from the viewpoint of sulfur content including the exhaust gas and/or CO_2 concentration.

Next, on the CO_2 emission of fertilizers which are equivalent to the indirect emission, we considered N, P (P2O5) and K (K2O). Table 3 shows the specific CO_2 intensity for each fertilizer.

Table 3 Specific CO_2 intensity

Bunker A	2.8	kg-CO2/L
Kero	2.51	kg-CO2/L
CO_2 for growth promotion	0.2	kg-CO2/kg
Electricity	0.468	kg-CO2/kW
Fertilizer	2.5	kg-CO2/kg

Consequently, the CO_2 emission of 2ha or 4ha would be 582.4g-CO_2/paprika or 573.9g-CO_2/ paprika, respectively.

3.3 The cultivation installing proposed system

We estimated the electricity and heat demand in the target facility. On the heat demand in the cultivation process, we considered the consumption date of a bunker A and kerosene, and the temperature difference between the inside and outside ones of the greenhouse in order to convert to the time series data. On the other hand, on the electricity consumption, it was assumed that 8 hours electricity supply to the facility would be executed at constant.

In this study, the electricity and/or heat is supplied due to a gas engine (GE) or SOFCs with heat pumps (HP). Based on the proposed system, we executed the process design to understand the net energy efficiency and/or the specific CO_2 emission of a paprika. Next, we analyzed the cost balance in consideration of the feed in tariff (FIT) due to the surplus electricity sell to the commercial electricity company. Also, on the cost analysis, the increment of product yield by feeding the higher concentration of CO_2 gas is considered. For instance, according to the interview to the farmer, the CO_2 gaseous concentration in the conventional case is approximately 600ppm to 700ppm. If the concentration would be able to go up to 3,000ppm, the total yield would be three times in comparison to the conventional ones. Thus, we estimated the CO_2 gaseous concentration and increasing rate of yield in the case that the exhaust gas through BT plant was supplied. Here, it is assumed that the upper limitation of CO_2 gaseous concentration is 3000ppm. Table 4 shows the estimation result of CO_2 gaseous concentration and increasing rate of yield in each case. Note that the average weight of a paprika is 180g/paprika.

Table 4 CO_2 concentration and increasing rate of yield

GE and SOFC-HP	CO_2 concentration[ppm]	Increasing rate of yield[%]	Annual amount of yield[t/y]	Annual amount of yield[10^6a puprika/y]
Case1(2ha15t)	1546	200	799	4.4
Case2(2ha30t)	2783	289	1154	6.4
Case3(2ha60t)	5257	300	1200	6.7
Case4(4ha15t)	928	122	979	5.4
Case5(4ha30t)	1546	200	1597	8.9
Case6(4ha60t)	2783	289	2309	12.8

3.4 CO_2 emission balance due to the promotion of BT-CGS(GE) or BT-CGS(SOFC-HP) cases

Next, we explain about CO_2 emission balance in the paprika harvesting facility based on LCA methodology. In the conventional case, the emissions due to fossil fuels of electricity, kerosene and diesel were considered. Also, the chemical fertilizers and the CO_2 gas as a growth agent were fossil fuel origin.

On the other hand, in the BT cases, the CO_2 emission biomass due to feedstock of BT gasifier is equivalent to zero since the biomass material has a carbon neutral. Here, in our proposal cases, the emissions on auxiliary power of the plant, diesel of the transportation sector and chemical fertilizers would be accounted. That is, on the emission on energy supply which would be same or excess against the demand, there is potential to reduce the emission by the alternative effect. Note that we do not consider the CO_2 reduction benefit although the excess power would be able to be sold to the conventional electricity company based of the feed-in-tariff (FIT) scheme. Here, Tables 5 and 6 show the CO_2 emission and reduction per a paprika in every case.

Table 5 CO_2 emission and reduction (BT-GE)

Case name(Cultivation scale,BT-plant scale)	CO_2 emission per a puprika[g-CO_2/a puprika]	Rate of CO_2 reduction [%]
GE-Case1(2ha15t)	104.6	82.0%
GE-Case2(2ha30t)	68.6	88.2%
GE-Case3(2ha60t)	98.9	83.0%
GE-Case4(4ha15t)	257.8	55.1%
GE-Case5(4ha30t)	93.2	83.8%
GE-Case6(4ha60t)	67.4	88.3%

Table 6 CO_2 emission and reduction (BT-SOFC-HP)

Case name(Cultivation scale,BT-plant scale)	CO_2 emission per a puprika[g-CO_2/a puprika]	Rate of CO_2 reduction [%]
SOFC-Case1(2ha15t)	60.6	89.6%
SOFC-Case2(2ha30t)	68.5	88.2%
SOFC-Case3(2ha60t)	98.9	83.0%
SOFC-Case4(4ha15t)	92.1	84.0%
SOFC-Case5(4ha30t)	58.4	89.8%
SOFC-Case6(4ha60t)	66.9	88.4%

4 ANALYSIS OF CONSUMER'S AWARENESS AND ADDED VALUE FOR CO_2 REDUCTION

4.1 Conjoint analysis

In this study, we executed a questionnaire on consumer's awareness for agricultural products with a carbon footprint, so-called "eco-friendly products". The conjoint analysis is a research technique by which the trade-off relationship between products and service providers would be identified. Also, through the analysis, we can estimate the willingness to pay (WTP) of eco-friendly products. Based on the question form, the items are similar to an actual purchase behavior in each consumer and neglected on the selection bias.

4.2 Questionnaire contents and result

The respondents of questionnaire are residents in Miyagi prefecture in Japan. For 1,000 families, we send a questionnaire due to the surface mail randomly, and the responses were 241 mails with the rate of 24.9%. The investigation period was from Oct. 1 to 15, 2010. Note that this area is one of a famous site of paprika cultivation.

In this study, we used 215 mails which were valid for our analysis.

The question content of our questionnaire is as follows; (1) the preference survey of paprika, (2) the survey of environment awareness and (3) the predicable survey.

On the content of (1), Table 7 shows the attribution items by which the price of paprika would be affected. Next, on the item of (2), the following four items are categorized; (a) the consumer's awareness on an eco-bag, (b) the energy-saving of home electronics, (c) the carbon-footprint and (d) organic vegetables. In the item of (3), their gender, ages and work contents etc. were interviewed.

As a result of our survey, the coefficients for each element with the following statistical indexes such T-value and P-value are shown in Table 8. Where, the indexes of X_i (1: Price, 2: CO_2 reduction, 3: Influence of cultivation site (except Miyagi pref.), 4: Influence of cultivation site of Miyagi pref. are the consumer's utilities, respectively. Also, Table 9 shows the marginal WTP of paprika. According to the survey, the WTP would not be affected by the shape of paprika. Thus, we ignored the influence due to the shape. On the other factors, we analyzed the marginal WTPs, respectively. Here, the WTP due to the CO_2 reduction effect would be effective to some extent. That is, due to the recent environmental awareness, it implies that the consumers have the willing to purchase the eco-friendly paprika with an additional cost, by which we would be able to reduce CO_2 emission.

Finally, based on the results of each respondent, we estimated the regression equation on the consumers' utilities (see Eq. (1)).

Table 7 Attribution data of preference survey of paprika

Attribution	Level			
Production area	Miyagi	Other prefecture	Foreign	
Size	Big	Small		
CO_2 reduction	0%	20%	50%	80%
Price	100yen	150yen	200yen	

Table 8 Results of preference intensity

	coefficient	t value	p value	
Price	-0.0325	-18.5788	0.0000	***
Rate of CO_2 reduction	2.6967	12.4823	0.0000	***
Production area (Other prefecture)	1.9930	10.9662	0.0000	***
Production area (Miyagi)	3.8079	20.9529	0.0000	***
Size	0.2744	1.5421	0.1233	
N	1075	215		
Log likelihood function	-730.033124			

Table 9 Marginal WTP

Rate of CO_2 reduction [yen/a paprika CO_2 reduction 100%]	82.9
Production area(Otherprefecture) [yen/a paprika]	61.2
Production area (Miyagi) [yen/a paprika]	117.0

$$V = -0.0321X_1 + 2.6343X_2 + 1.9487X_3 + 3.7551X_4 \quad (1)$$

According to Eq. (1), the effect on pricing up might not satisfy the consumers. However, on the other indexes, the utility would be increased. Especially, from the view point of environmental awareness, there is a good potential to sell the eco-friendly paprika. This point is extremely important. Because the annual operation cost for the environment business in which the eco-friendly paprika cultivation is included would be abated. That is, this additional fee is an equivalent to the new income.

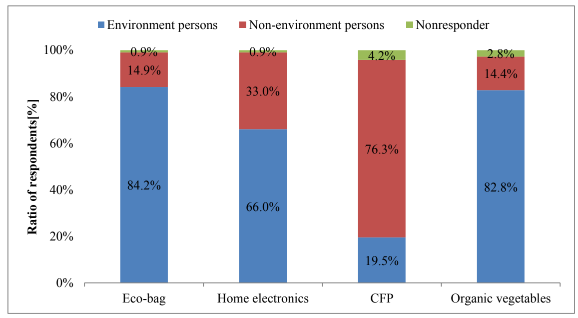

Figure 3 Results of environment awareness

4.3 Estimation of added value

Next, based on the previous studies, from the view point of business operation, we investigated the cost balance. Especially, we estimated how advantageous the WTP of CO_2 reduction is there in our business scheme. In general, it is said that the WTP due to the questionnaire is likely to be large in comparison to that of real status. Assuming that the added value in the real transaction would be 1/3.05 times of the measured WTP [5], we estimated the cost balance. Note that the standard price of a paprika is 200 JPY, which is the average one in seven cities of Japan [6].

On the other hand, at the initial stage, the public support might be necessary. However, in this study, we did not consider any subsidy, since the target cost condition of BT plant was adopted.

5 CASE STUDIES

5.1 BT-CGS(GE)

Finally, we estimated the cost balance in consideration of the income due to the WTP for an eco-friendly paprika and the feed-in-tariff (FIT) scheme, and the outgo of annual depreciation cost on BT system and feedstock cost of 2,000 and 1,000yen/t. Note that the additional income due to FIT would be 20.00 yen/kWh. On the FIT scheme, the Japanese government decided the promotion within a couple of years on the end of August, 2010. This scheme means that the surplus electricity through the eco-friendly energy system will be sellable to the commercial electricity companies in the higher conventional price. Based on these conditions, we estimated the payback time and the internal rate of return on the BT system as Table 10 and Figure 4.

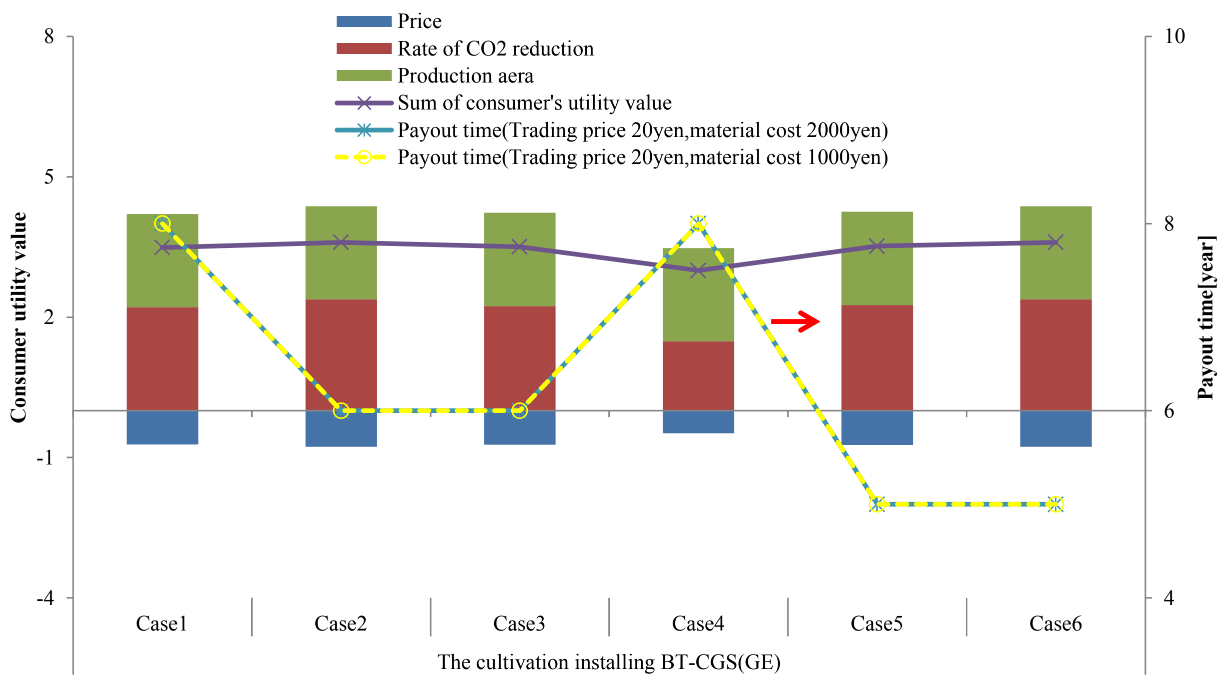

Figure 4 Relation between payout time, internal rate and consumer's utility (GE)

Table 10 payout time and internal rate (GE)

Material cost[2000yen/t] Trading price[20yen/kWh]		Material cost[1000yen/t] Trading price[20yen/kWh]	
Payout time[year]	Internal rate[%]	Payout time[year]	Internal rate[%]
8	10.2%	8	10.9%
6	14.6%	6	15.6%
6	15.3%	6	16.6%
8	9.6%	8	10.4%
5	19.2%	5	20.2%
5	20.3%	5	21.5%

According to Figure 4, we concluded that Case 2, 3, 5 and 6, of which consumer's utilities are comparatively high and their payout times are shorter, would be beneficial for our proposed business. Considering the business contingency, we think it better that the system would be operated by the condition of Case 5. Also, although there is somewhat technological barrier, it implies that the larger plant scale is more advantageous on the payout time and/or internal rate of return.

5.2 BT-CGS(SOFC-HP)

Next, we think about the installation condition of combined BT-SOFC system. The reasons why we focused on SOFC are the comparative high concentration of H2 in syngas through BT system and the higher energy efficiency of SOFC in comparison to the other energy conversion systems. Also, the discrepancy between supply and demand on the thermal energy, which would often happen in the CGS operation, would become small. In this system, there is no waste energy, because the product energy is electricity only. Of course, some heat pumps would be necessary in order to supply thermal energy to the greenhouse facility.

So far, the unit cost of SOFC is high. This means that the subsidy due to the central government is absolutely required besides our proposed scheme. Thus, in this study, the unit price of SOFC was used as of 2015. In this case, we assumed that the subsidy from the central government is available at the 50% rate. Likewise, we estimated the payback time and the internal rate of return on the BT system (see Table 11 and Figure 5).

Through our estimation, we concluded that Case 5 of which the consumer's utility was higher and the payout time was shorter would be beneficial. Compared to BT-CGS (GE), it is suggested that the income of WTP due to much CO_2 reduction would be increase. However, the pay-back time would be expanded.

Table 11 payout time and internal rate (SOFC-HP)

	Material cost[2000yen/t] Trading price[20yen/kWh]		Material cost[1000yen/t] Trading price[20yen/kWh]	
	Payout time[year]	Internal rate[%]	Payout time[year]	Internal rate[%]
Case1	8	9.3%	8	9.9%
Case2	8	10.4%	8	11.2%
Case3	8	9.7%	8	10.8%
Case4	7	11.6%	7	12.2%
Case5	6	14.6%	6	15.3%
Case6	7	13.2%	7	14.2%

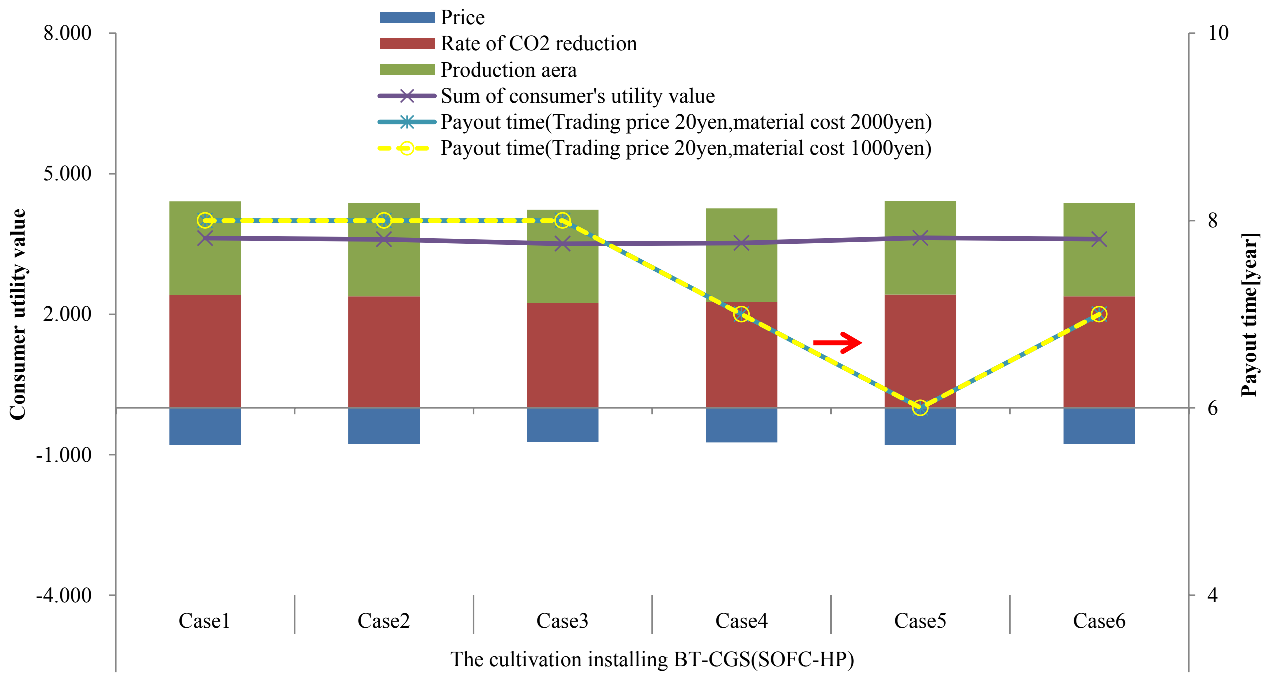

Figure 5 Relation between payout time, internal rate and consumer's utility (SOFC-HP)

6 CONCLUSION

According to the case study of BT-CGS proposed in this study, optimal cultivation scale and BT plan scale is 4ha and 30t. It is highly possible that our system which is a combined system with the agriculture facility would be practically. Also, although there is somewhat cost barrier to install the SOFC unit, from the viewpoint of effective energy use, the combined SOFC system which would be fueled by the bio-fuel of hydrogen would be extremely promising one in the near future.

On the countermeasure of reduction of operating cost, the index of carbon foot print is extremely significant. That is, the consumers have great concerns on the eco-friendly product. They have good potential to pay more money for the products by which their utilities would be raised up.

Soon, the central government of MAFF tries to promote the CFP scheme. Under the circumstances, due to the beneficial combinations, we would be able to reduce the cost relatively while abating CO_2 emission.

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Life Cycle Assessment of Dairy Cow in Korea

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Abstract

Recently environmental impact caused by livestock receives increasing attention. The objective of this study is to estimate the environmental impact of dairy cow in Korea by life cycle assessment (LCA). System boundary is cradle-to-gate from feedstuff production to farm gate. Functional unit is producing 9,000kg of milk and referece flow is one dairy cow. Environmental impact categories considered include global warming, acidification, ozone layer depletion, abiotic resource depletion, photochemicaloxidant creation, eutrophication, eco-toxicity and human toxicity. Four impact categories were identified significant. They are acidification, eco-toxicity, eutrophication and global warming. Manure management affect significantly on acidification, eco-toxicity and eutrophication, while enteric fermentation dominated by CH_4 emission affect global warming.

Keywords:
Dairy cow, LCA, manure management, enteric fermentation

1 INTRODUCTION

The aim of this study was to perform life cycle assessment of dairy cow which produces beef and milk that is important ingredient of food industry in order to identify those parts of life cycle that are important to the total environmental impact.

2 METHOD

2.1 LCA is the basic method for identifying environmental impact of dairy cow in this study. Goal definition

The main goal of the case study was to identify key issues associated with the life cycle of dairy cow.

2.2 System definition

System description

Target dairy farm is imaginary farm which based on statistics of Korean dairy farms belonging to Seoul Milk Cooperative Federation [1, 2]. Fig 1 shows system boundary of target dairy farm.

Function, functional unit and reference flow

The main function of dairy cow is to produce milk. The functional unit is producing 27,000kg of milk and reference flow is one dairy cow which produces 27,000kg of milk during economical life (5 years).

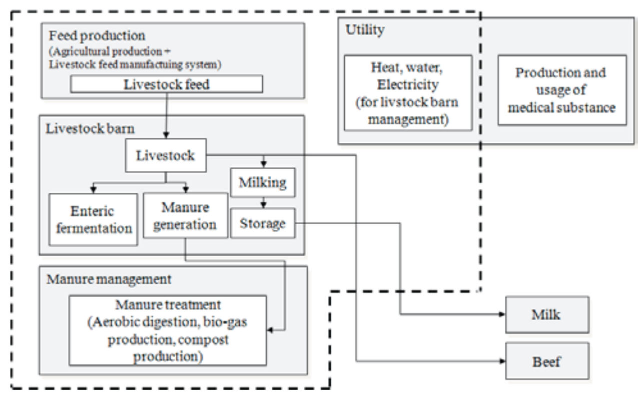

Fig 1: System boundary of the dairy cow

2.3 Inventory analysis

Data collection was based on site investigations, literatures, and LCI DB in LCA software and Korea LCI DB Information Network [3].

Cultivation of feed crop

The input/output date of feed cultivation in Korea is collected from Standard Agriculture Guideline of Korea. LCI DBs of another country are source of the input/output data of imported feed cultivation. The databases of Ecoinvent (Data ver. 2.1, 2009) were used to collect data of imported feed crop cultivation and agricultural goods such as herbicide, pesticide and fertilizer etc [4].

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Production of feedstuff

The input/output data of feedstuff production system is site data of feedstuff manufacturing factory of company A.

Breeding

The input/output data of breeding is collected from statistics of Seoul Milk Cooperative Federation [1]. In addition, the methane emission from enteric fermentation was calculated following the IPCC guideline [5]. Total methane emission of dairy cow was 571.45kg .

Manure management

The methane and nitrous oxide emission from manure decomposition are 65kg/f.u.[1] and 50kg/f.u.

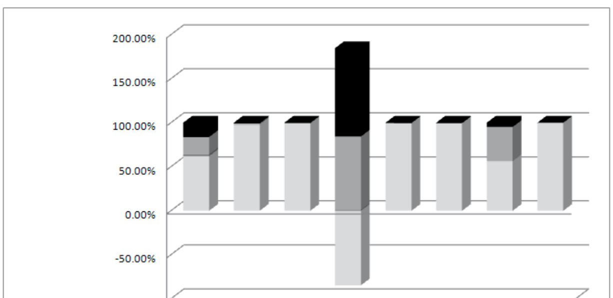
2.4 Impact assessment

The impact categories chosen in this study are: climate change (GWP), stratospheric ozone depletion (ODP), acidification (AP), eutrophication (EP), photo-oxidant formation (POCP), depletion of abiotic resource (ADP), human toxicity potential (HTP) and terrestrial eco-toxicity potential (TETP).

3 RESULT

3.1 Characterization

The characterization results are in Fig 2 shows the contribution of each sub system to each impact category. From Fig 2 it can be seen that breeding and manure management are major contributors to global warming because methane is from enteric fermentation and nitrous oxide is from manure management.



	ADP	AP	EP	GWP	HTP	ODP	POCP	TETP
Manure management	16.26%	0.88%	0.33%	100.28%	0.41%	0.52%	4.80%	0.06%
Breeding	19.73%	1.00%	0.37%	83.37%	0.02%	0.00%	38.76%	0.00%
Production of feedstuff	1.92%	0.10%	0.04%	0.98%	0.00%	0.00%	0.01%	0.00%
Cultivation of feed crops	62.08%	98.02%	99.26%	-84.63%	99.57%	99.48%	56.43%	99.94%

Fig 2: Characterization result

[1]f.u.=One dairy cow which produce 27,000kg of milk during economic life (5 years)

4 CONCLUSION

From the characterization results one can find that minimizing the adverse environmental impacts caused by the cultivation of feed crops should focus on the minimization of the chemical use during the cultivation process.

Manure management and breeding are significant environmental impacts of dairy cow, too. For reducing adverse environmental impact from methane and nitrous oxide, first, one needs to improve digestion efficiency and prevent enteric fermentation process by changing composition of feedstuff. Second, one develops manure management system which can reduce creation of nitrous oxide.

5 ACKNOWLEDGEMENT

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Problematic of estimating GHG emissions in Logistics Company

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Abstract

The global transportation industry firms lag behind 'Global 500 Companies' in reducing greenhouse gas emissions and setting reduction targets, according to a new report from the Carbon Disclosure Project (CDP)[1]. So, the transportation sector could have a major long-term impact on climate change and world energy usage, if strategic investments are not made, according to the research.

According to OECD GHG emission database[2], the transportation sector occupies 13.1% of global GHG emission and 23% of global energy use. Therefore, logistics companies should absolutely struggle with GHG emissions reduction. But, it is practically hard to estimate theirs GHG emissions, even though it is the first step to set GHG emissions reduction target and reduce the emissions.

In this paper, the problematic and the improvement scheme of estimating GHG emissions have been derived through analysis of two Korean representative logistics companies' GHG inventory.

Keywords:

GHG inventory, GHG emission, Logistics, Freight, Transport

1 INTRODUCTION

After the international societies recognized together the global warming as common problem and concluded the United Nations Framework Convention on Climate Change to solve that, the reduction of greenhouse gas has been recognized as the task to be solved by the world. According to the data published by IEA[2], since 23% of the greenhouse gas of entire world emitted during 2005 were resulted from the transportation area, the reduction of greenhouse gas emission in the transportation area. is emerging as big issue. In addition, as the every country is introducing the greenhouse gas reduction policy, the reduction of greenhouse gas emission in the logistic companies is inevitable, too. The most basic stage to reduce greenhouse gas is to identify the current greenhouse gas emission status but by the characteristics of the logistic business, there are difficulties even in collecting the activity data.

Therefore, in this study, the characteristics of the greenhouse gas inventory of the two logistic companies established in Korea will be observed, and the future research orientation will be suggested identifying the problems and providing recommendations.

2 THE NEEDS TO BUILD THE LOGISTIC COMPAMY'S GREENHOUSE GAS INVENTORY

2.1 Greenhouse gas emission status of the transportation sector

According to the data published by IEA, about 23% of the Greenhouse gas emitted in 2005 was resulted from the transportation area, out of which 27% were emitted by the trucks and trains. Out of that emission, the emission of greenhouse gas by the truck occupied 90%, and in the baseline scenario of IEA report, the worldwide transportation volume by the truck is expected to be doubled by 2050. Therefore, to reduce the greenhouse gas emission in the transportation area, it is imperative to reduce greenhouse gas emission in the logistic area, particularly in the inland logistics.

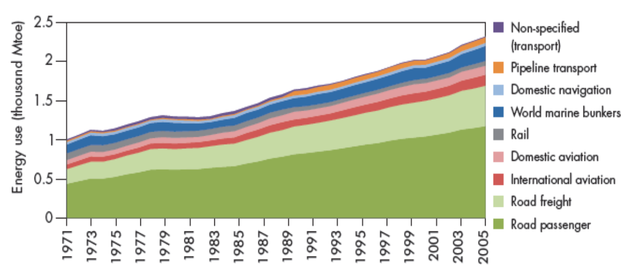

Fig.1: World transport energy use by mode, 1971-2006

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2.2 The needs to build the inventory

The greenhouse gas inventory is a kind of statistical data, which is the list of the greenhouse gas emission sources and volume emitted and is arranged to identify what business entity is emitting how much greenhouse gas at a glance. Therefore, it allows building the base to establish the goals of the energy saving and the greenhouse gas reduction, and indentifying the starting point to measure the reduction volume of the greenhouse gas in future by understanding the volume emitted and volume absorbed accurately and systematically through the inventory.[3]

Therefore, to reduce greenhouse gas in the logistic area, it needs for logistic businesses to build the greenhouse gas inventory, as the most basic stage.

3 THE CASE ANALYSIS ON THE LOGISTIC COMPANY'S GREENHOUSE GAS INVENTORY ESTABLISHMENT

3.1 Inventory Establishment Overview

The greenhouse gas inventory of the 2 logistic companies among 10 major Korean logistic companies were built in 2009 and 2010 based on the data for previous three years, for which the reliabilities were acknowledged through third party verifications.

The guidelines used to build the greenhouse gas inventories for two companies are as shown in Table 1, and the both companies have built the greenhouse gas inventory based on the same guidelines.

For the establishment principle of organization boundary, the operation control approach was used to establish the organization boundary to the extent that the operation control of the company reaches, for both inventories of the two companies.

For the operation boundary establishment, the criteria suggested by the WRI GHG protocol was used to classify and establish Scope1 (direct emission), Scope2 (indirect emission) and Scope3 (other indirect emission).

Table 1: Guidelines used for GHG emission inventory

Country	Organization	Guidelines	Characteristics
International	ISO	ISO 14064-1	Suggested the guidelines focused on the principle and concept. No calculation formula is mentioned
	WRI /WBCSD	GHG Protocol	The most influencial guideline among the greenhouse gas guidelines for corporation
	IPCC	2006 IPCC guidelines for National Inventories	As national greenhouse gas calculation guidelines, emission calculation formulae and emission coefficients, and Global Warming Potential,
Country (Korea)	Law	Enforcement Ordinance of the Fundamental Act on Energy	Provide heat generation by energy source

3.2 Implications of the logistic company's inventory establishment

The noticeable matters observed through the logistic company's greenhouse gas inventory establishment were drawn as 2 items related to mobile emission sources. However, the other emission sources in the greenhouse gas inventory of the logistic company have very insignificant weight in total emission volume and only the emission sources commonly observed in the general corporations are existed.

Classification and Accessibility to the Dara according to the form of mobile emission sources

As shown in Table 2, the types of mobile emission sources can be classified into 6 categories according to the name, ownership, manager, frequency, potentials for other logistic activities. The accessability and reliability are varied depending on each category.

Out of them, the types of vehicles having high reliability and accessibility to the greenhouse gas activity data are A and B because as the vehicles always in use, it is impossible to use for other types of logistic activities and all activities are dependent on the business operations..

Table 2: Mobile Emission Source Classification of the Logistic Company

Type	Name	Ownership	Manager	Frequency	Other Logistic Activities
A	Corp.	Corp.	Corp.	Year-round	Impossible
B	Corp.	Corp.	Ext.	Year-round	Impossible
C	Corp.	Ext.	Ext.	Year-round	Impossible
D	Corp.	Ext.	Ext.	Year-round	Possible
E	Ext.	Ext.	Ext.	Certain Period	Possible
F	Ext.	Ext.	Ext.	Irregular	Possible

The type C is impossible to use for other logistic activities but since the managers and owers are located externally, the data is not considered to be managed completely by the corporation. The type D is same as type C but since it can be used for other types of logistic activities, the fuels consumed cannot be considered to be used in the business activities of the corporation.

The type E and F have lowest reliability and accessibility to activity data, and since the operational rights other than the matters required by logistic activities of the corporation are possessed by outsiders, it is hard to collect the acitivity data such as actual feul consumption. And in case of the vehicle allocation in type F, since the allocation is not fixed and it is impossible to collect the even the vehicle information, it has less data accessibility.

The Prolems in Establishing the Orgaizational Boundary by the Complex Transportation

Although it occurs in the A, B, C types among the vehicle types classified previously, there is the complex transportation, which occurs in types of D, E. F. Since the latters are not actually performed the logistic activities for the specific corporation the types, the fuel consumption cannot be considered for 100% business activities of the specific corporation. The fuel consumed at outside of the boundary shoould be excluded according to the organizational boundary establishment principle[4] but it is actually impossible. Therefore, when the greenhouse gas is claculated based on the total energy consumption ignoring nonconformities, potentials of duplicated calculation with other corporation cannot be avoided

4 CONCLUSION AND SUGGESTION

The establishment of greenhouse gas inventory is essential element as a first stage to reduce greenhouse gas reduction in the logistic companies. The one of the problems observed through the establishment of greenhouse gas inventory of the 2 large companies in Korea is that the reliability and the accessibility to the activity data of the greenhouse gas activity data of the mobile emission sources are varied greatly depending on the type of ownership and the operation style. During the actual establishment of the inventory, the greenhouse gas emission of the E, and F types of vehicles (Scope 3) could be drawn because it was impossible to collect the activity data. Although the emission of the Scope 3 is classified as the matter subject to voluntary report, the reliable emission reduction scenario can be planned only if the emission volume is identified from complete data when establishing the greenhouse gas reduction strategy. Therefore, the reliability of the greenhouse gas emission calculation should be improved by developing new measures such as stating the energy consumption report clearly, etc. when the contract is concluded initially. In addition, another problem in establishing organizational boundary by the complex transportation was found. The problem occurs in the complex transportation cargoes due to external operation, which should be settled down by developing energy consumption estimation methods, etc. (estimate the energy consumption using factors like the payload weight, distance, average annual payload weight, etc).

The greenhouse gas inventory guidelines in the logistic area to be used internationally should be developed in a near future through identifying the problems and improving the corrective measures by studying the actual case of the inventory establishment in the logistic area in addition to the problems identified in this study.

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The study of a product service system for the leasing of a water filtration device

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Abstract

The paper presents an LCA study to discuss the environmental impact and economic performance for the leasing of a water filtration device. A proposed leasing program was evaluated and compared to the traditional sell model. The results show that the most contribution of environmental impacts occurs in the use stage, which contributed approximately 36% of total impact. In terms of economical performance, through maintenance, leasing model extended the life of components and reduced the number of components being manufactured and assembled, which could lower the cost of manufacturing. However, with the increase in service transport stage, cost slightly increased. Consequently, as compared with traditional sell model, leasing model could reduce approximately 24% of total cost which concluded high feasibility of PSS. In EEI analysis, the benefit which PSS enhanced is positive as it compared to the traditional sell model. The proposed leasing model displays the positive benefit in both environment and economic success.

Keywords:

leasing program, PSS, LCA, LCC, environmental impact, eco-efficiency indicators

1 INTRODUCTION

Water is essential in everyone's life. Although more than 90 percent families have been served by local public water works, there is still much concern of water quality in many areas of this island. The product sale model of the household traditional water filtration device aims at increasing the sale volume. This leads depletion of resources and harm to the environment when discarded. Therefore, this paper proposed a product service system (PSS) to meet consumer's demand while reducing the environmental impacts. The product service system is a continuous business model, categorized from product-oriented to service-oriented businesses. Aside from satisfying customers' need to the product function, it may reduce the output and sales of the product via service delivery as well as the depletion of resources and the pollutant output. However, as the service function increased, enterprises may account for extra increased cost and faced the impact of other environment.

This paper presents a proposed renting system of water filtration devices in southern Taiwan area. Integrating service into product manufacturing represents a whole life cycle of water filtration device, since the suppliers also take charge of the maintenance and disposal of. After all, consumers indeed require the services of clean water rather than the devices.

In order to find out PSS environmental and economical performance effectively, this study took LCA, LCCA and EEI as basis. These methods were employed to aim at discussing the using of resources in every stage of water filter device PSS and its impact to the environment. Firstly, the environmental performance was evaluated by LCA case studies. Second, LCCA simulated the cost and economic performance produced at every stage of life cycle.

2 LITERATURE REVIEW

2.1 Product service system

A product service system changes the traditional selling of suppliers and the product use by consumers through a new business model, such as a leasing program. Under a contractor, suppliers provide consumers the function they need. Suppliers own the property of products and take the responsibility to treat and dispose of the waste products, while consumers have the right to use the products. In order to make differentiation in the market, more and more manufacturers turn their business models to the PSS. Especially in Taiwan, many manufacturers used to focus on the cost down and pursue the mass production as the main business models. Under the saturation of the markets, it became hard to get the profits in the business model of mass production. Product differentiation is necessary for the modern companies to improve their competition [1].

The concept of product service system was proposed early in 1970s, and known as service engineering in the college lectures. The contents include product service design, development of service models, and supporting systems. Recent PSS studies are concentrated on the scenarios simulation to develop the new business models and

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supporting software [2]. Through the application of life cycle engineering (LCE), Aurich and Fuchs [3] developed the methodology of implementing the PSS design and innovations. European Union also develops the methodology for PSS to provide the manufacturers to establish their own means and tools and create new business models.

A PSS should consider various aspects, such as demand of consumers, values, delivery and life cycle activities. Combining with the experiences, a PSS also involves the sustainability and social acceptance [4]. Many PSSs have been implemented successfully. In the remote areas, MEI provides the rent of solar cells for the residents to storage the energy at day time and to use it in the night. SCA, a Denmark company, mainly provides the nurse pads to the hospitals and health care centers. Recently, SCA provides a service plan to improve the health care of patients and teach the staffs how to use the products correctly. This plan has reached the reduction of nurse pad use by 20%, as well as the increase of user's satisfaction [5]. Other examples, such as prams leasing [6], car sharing [7], and mop renting system [8], demonstrated the environmental and economic benefits in the PSSs.

2.2 Life cycle costing assessment

Life cycle assessment (LCA) is a powerful tools used in investigating and evaluating the environmental performance for many economic activities, such as eco-design, environmental labeling, waste management, as well as PSS. A complete LCA study should not only discuss the environmental impacts, but also evaluate the costs at every stage from material processing to the product disposal of. In parallel, the life cycle costing (LCC) analysis has been developed. An LCC is a value analysis tool. For many corporations, environmental improvement and economic success are both required in the development of new product and/or a service. It is clear that the data from all stages are important to reduce cost, improve product quality, and enhance decision-making through the LCA and LCC studies.

In LCC, the costs from all life cycle stages should be calculated, including all expenditures and the indirect environmental costs [9]. The direct costs in the development of products and services can be identified from many sources, but the indirect environmental costs are usually intangible and hard to be calculated. Therefore, most LCC studies focused on the direct costs associated with the products and services in their life cycle stages. Wong et al [10] studied the energy saving in various patterns of roof planting and compared them by LCC. Krozer [11] utilized LCC method to identify the costs spent in each stage and to improve the cost down in the design stage. Mahlia and Chan [12] studied the energy structures in Malaysia and give the LCC benefits for the country.

3 METHODOLOGY

3.1 Description of the proposed leasing system

For some reasons, the residents in southern Taiwan did not satisfy the water quality supplied by public water works and pursuit high quality water in the market, i.e., buying bottled water or installing water filtration devices. In the traditional sell model, consumers buy the devices and parts in the supermarket. Consumers own the products and maintain and disposal of the products. According to an investigation, the lifespan of the water filtration is about 4 years. Obviously, many parts are usable after they are discarded.

A proposed leasing program for water filtration devices is shown in the figure 1. The product and service in the program follow the concept of life cycle system, i.e. from the materials processing, parts manufacturing, product assembling, distribution, use and disposal of the device. Consumers have the right to use the devices, but providers have the ownership of the products through signing a contract. The content of a contract usually delineates product specification, a lease term, and lease fee. After the lease term, consumers return the devices to the providers, who will examine the devices and parts. If the parts are usable, then they will be reused in the other devices. Because many parts in a water filtration device are durable, the leased devices could be remodeled and extend their lifespan through a good maintenance and refurbishment. If the parts could not be repaired, then they will be disposed of properly after recycling the secondary materials.

Table 1 lists the basic assumptions of traditional sell model and the proposed leasing program for water filtration devices.

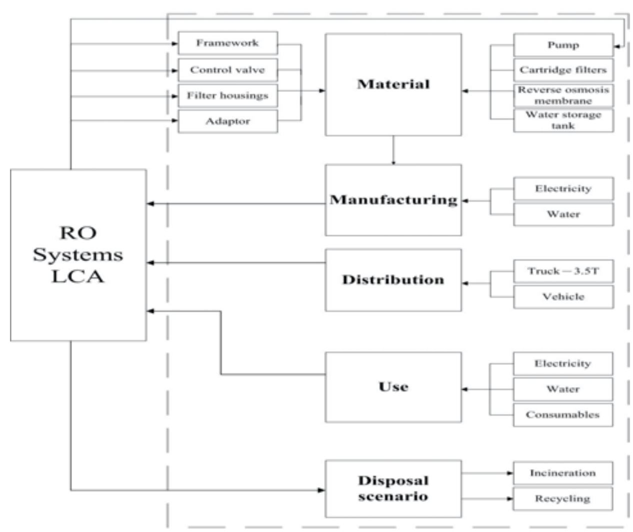

Fig. 1: Scope of a LCA study for the proposed leasing program of a water filtration device

Table 1: Basic assumptions for the study

Case	Conventional sell program (A)	Proposed leasing program (B)
Trading object	Businesses or consumers	Businesses or consumers
Trade type	Buy	Rent
Lifespan	4 years	1 year
Warranty	Limited (1year)	Full
Disposal/ recycling	Customers dispose mops by themselves	Company recycles after they are broken

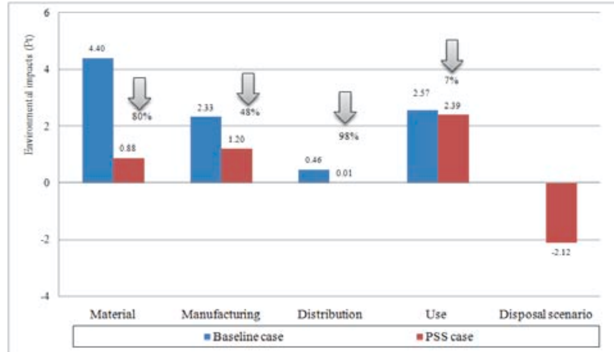

Fig. 2: The environmental impacts of the LCA studies for both business models

3.2 Life cycle inventory

The inventory data was collected through many sources in this study. The data of materials processing were referred to the Swiss-based Ecoinvent database [13] and the amounts of materials used in the device was based on the dismantled parts in the laboratory. A scenario simulation was set in the use stage according to the site survey in the southern Taiwan. The recycling processes were based on Taiwan EPA database and the local market of secondary materials. This collected data was input into the commercial LCA software, Simapro 7.0, and selected Eco-Indicator 99 as the impact assessment method.

3.3 Cost analysis

The price of a product or service in the market is referred to the value concept of consumers, which includes costs of products, service and image. A manufacturer will evaluate all costs of a product or service, including normal profit and tax. A complete LCC should cover all costs in the product life cycle as well as indirect environmental costs. The later is intangible and hard to be monetized. Therefore, there are costs related to parts, assembly, distribution, use and disposal of, considered in this study. Equation 1 shows the calculation of the life cycle costs for a water filtration device.

$$LCC = C_C + C_M + C_D + C_U + C_{Dis} \qquad \text{(Eq.1)}$$

in which, LCC=life cycle costs of the system; C_C=costs of all parts; C_M=costs of assembly; C_D=distribution costs; C_U=costs in the use stage; and C_{DIS}=costs related to disposal of the wastes.

4 RESULTS AND DISCUSSIONS

4.1 Environmental performance

According to the simulation of a 4 year lifespan, the environmental impacts in whole life cycle were scored 9.76 and 2.36 pts for traditional sell and leasing program, respectively. As indicated in the figure 2, the contribution of environmental impacts in the material processing stage dominates in the traditional sell model, while the use stage has the most contribution in the leasing program. The consumption of raw materials in the traditional sell model is the reason that causes a high environmental impact. It contributed about 45% of the total life cycle. If we changed the model to the leasing program, the impact can be reduced tremendously (about 80%). It identified the material processing stage is the environmental hot spot for the designers to improve product performance.

In the leasing program, the use stage contributes 36% of total life cycle impacts. Because of delivering parts and maintaining the devices, the travel trips will increase the environmental impact but not obviously. In the use stage, the impacts from the electricity and water supply were referred to the public utility. There is a space to improve the environmental performance by changing the clean technology in the public works.

The recycling of waste materials was positive for environment. The result of simulation was negative value as a feedback of final eco-points. The leasing program dominates the score due to the reuse of parts. Compared to the traditional sell model, there is 76% reduction of environmental impact in the leasing program for the whole life cycle.

4.2 The evaluation of life cycle costs

The result of life cycle cost analysis is shown in the figure 3. For a lease term of 4 years, the life cycle costs are estimated 13484 and 10212 new Taiwan dollars (NTDs) for traditional sell and leasing program, respectively. Obviously, the leasing program has the advantage of cost down compared to the traditional sell model. Most costs are spent in the use stage due to the replacement of filter every 3 months. For leasing program, there is more cost to pay the trips of service man. It can, however, be compensated in the reuse of the parts in the components manufacturing. The other cost saving is in the disposal of stage. There is about 400 NTDs saving due to the recycling activity.

Life cycle costs represent all costs associated with the stages from material processing to waste disposed of. In the leasing program, the waste materials will go back to the stages of material processing and assembly. It leads to cost saving because of avoiding to build a new one. LCCs

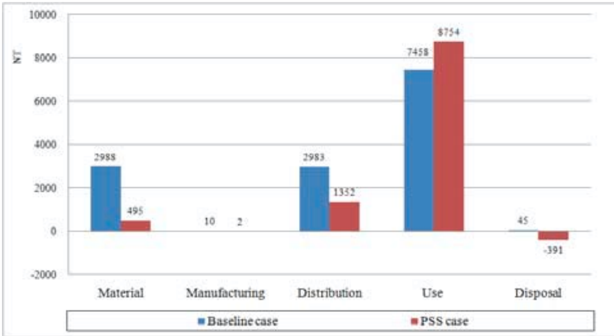

Fig. 3: The evaluation of life cycle costs for both business models

are different from the costs of product that the manufacturer invests.

5 SUMMARY

This paper discussed the environmental and economic performance in a PSS study in the life cycle perspectives. A leasing program of household water filtration devices was proposed and assessed using LCA methodology. The study also included the traditional sell model as reference. The results of LCA studies indicated that the leasing program had advantages both in the environmental and economic performance compared to the traditional model. It is important information for modern company to develop a more competitive business model.

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Consideration of Invigorating Potential Consumers of The Personal Computer Rental Business

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Abstract

Rental business is a new business paradigm that generates revenue by charging fee to the consumers for the use of the product. PC rental business is in its infancy and relatively new to the PC industry.

The objective of this study is to identify factors affecting the rental business paradigm such as reasonable replacement cycle and rental cost, among others. Consumer survey was conducted to identify voice of customers for the PC rental business. The results of the study indicated that PC rental business could be conducive to the reinvigoration of the personal computer industry.

Keywords:

1 INTRODUCTION

The aim of this study is to identify factors affecting the rental business paradigm.

The objective of this study is to derive successful criteria of the PC rental business by conducting consumer survey and analyzing critical factors from the example successful business case.

2 METHOD

Figure 1 describes the whole flow chart of this study to identify factors affecting the rental business of PCs, Firstly, the authors conducted consumer survey to ascertain the potential demand for PC rental service.

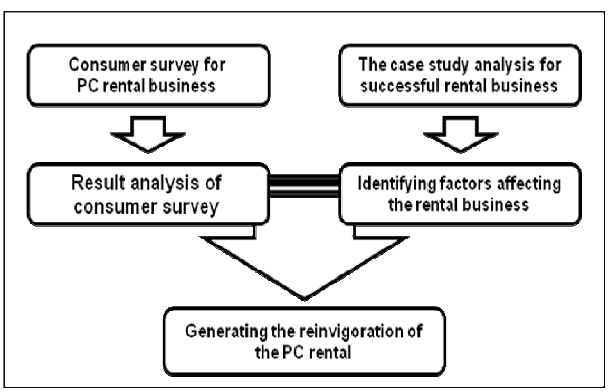

Fig. 1: Flow chart of the study

Secondly, the authors selected successful rental business cases and analyzed strategies. Based on the result derived from two stages, the authors generated factors affecting the rental business of PCs.

2.1 RESULTS

Consumer survey was conducted to identify voice of customers and analyze the potential demand for PC rental market. Criteria for survey was focused on deriving customer's expectation and requirement from the PC rental business. Therefore, the survey form included several questions about the rental cost and replacement.Total 874 different people in sex, age, educational level, and occupation participated in this survey.

According to the survey results, all respondents have possessed one or more PCs and suprisingly of respondents, 9,49% of them own over three PCs. The average number of hours spent on PC is mainly ranged from one to two hours. The cost of the PC rental is set under 10,000 won to over 50,000 won. Cost is the important thing for deciding PC rental. The highest item is under 10,000 won of the rental cost and almost 50% respondents thought that PC rental business is good for eco-friendliness. It indicates PC rental needs to be applied into the rental business.

The result of the consumer's survey is that they want advantage of maintain & management and cost saving. Also they prefer 1 or 2 years of replacement times and under 10,000 won of the rental cost. They consider also PC specification, A/S services. However, the people who do not want to use PC rental responded largely buying PC is better than to rent in point of taking the long view.

2.2 Case analysis of successful rental business

Among various rental cases in Korea, the authors choose three business cases such as car-rental service, water purifier rental service, and baby equipment

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rental service for identifying critical factors of successful rental business. The rationale for selecting these cases is that each case has taken a large share comparing with the other business in the same line.

To analyze the successful strategy of each business case, on/offline searching and interviews were conducted.

Car rental business of k company possesses 30% market share and goal of the total sales in 2013 is 1 trillion won. They applied agent system, membership system management and establishment partner ship. W company sell a wide range of small domestic appliances such as a water purifier, a bidet, and air cleaner and so on. Among them, a water purifier is the biggest selling within its own product line and it has highest market share which is nearly 60%. A rate of growth and the amount of members has risen since it started a rental business. Success strategies are entering the market early, CODY system, unique service strategy and so on. There are many rental compannies for baby care equipment sector and the gap of market share between them is not big. The successful element are package service, accumulated money point system and various options for customers to use rental service.

From the above finding of sucessful strategies, the authors made a check list as presented below in Table 1.

Table 1: Checklist for Success strategy of rental business

Success strategy	Car rental	Water purifier rental	Baby equipment rental
Entered the market early	√	√	
Membership system	√	√	√
Package services			√
Multiple cost choice			√
A/S		√	√
Agent system	√	√	

The checklist indicates the result that membership system, reliable A/S, agent system and timing of business into the market are significant strategies for sucessfully promoting the rental business.

3 IDENTIFICATION FACTORS AFFECTING THE RENTAL BUSINESS

Factors for invigorating the PC rental business are generated by combining the result of consumer survey and analyzed successful strategies of the case examples as shown below.

- **"Providing after service (A/S) of PCs with users by operating membership system**
- **"Customized strategy for meeting the consumer's need such as a product specification and reasonable rental fee." The result of consumer survey shows that a product specification and rental fee is the important factors to rent a personal computer. It needs to be customized.**

4 CONCLUSION

As the survey result says, PC rental business is in its infancy and relatively new to the PC industry and consumers as well. Thus, in order to invigorate potential consumers of the PC rental business, it is necessary to advertise the competitiveness and advantages of PC rental. A company which invest PC rental business need to provide after service(A/S) of PCs with users by operating membership system and customize strategy for meeting the consumer's need such as a product specification and reasonable rental fee. Although the result of this study is not a perfect answer for invigorating PC rental, it plays an important role in establishing basic strategy for rental business in the PC industry.

5 ACKNOWLEDGEMENT

This study was implemented by the support of "2011 Training for Ecodesign experts" funded by ministry of environment.

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Comparison of product carbon footprint between existing and alternative product: A case study of personal computer

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Abstract

Product carbon footprint (PCF) is an ecological profile of a product only focused on greenhouse gas (GHG) emissions. PCF aims primarily at generating environmental profile of a product. Another aim is to identify key parameters of a product in its entire life cycle. In this paper, PCF of an existing personal computer (PC) and alternative PC were quantified and key issues identified. Typical energy consumption during the entire life cycle of the alternative PC was reduced by approximately 15% compared with that of the existing PC. Energy consumption during the use stage was identified as key parameter for both PCs.

Keywords:

Product carbon footprint (PCF), ecological profile, Life cycle assessment (LCA)

1 INTRODUCTION

PCF aims primarily at generating environmental profile of a product. Another aim is to identify key issues of a product in its entire life cycle. The objective of this paper is to quantify PCF of an existing personal computer (PC) and alternative PC (alternative to the existing PC) and identify key issues.

2 METHOD FOR ESTIMATION OF PCF

The study was implemented using the GHG Protocol product standard and ISO 14040 and ISO 14044. The PCF for existing and alternative PC was calculated following the process shown in Figure 1 [1], [2].

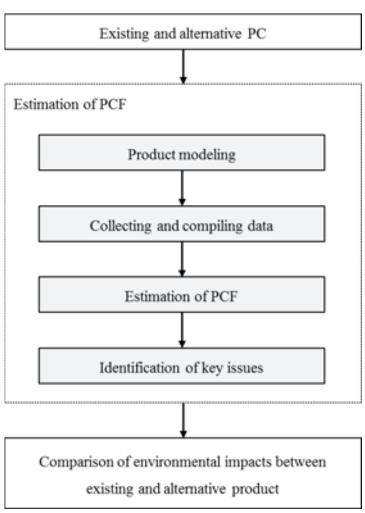

Fig. 1: Process for estimation of PCF in this study

3 CASE STUDY: PERSONAL COMPUTER

3.1 Estimation of PCF

A personal computer was used in a case study to estimate PCF. Product lifespan is 4 years for both PCs. Alternative PC's weight is 12,641g and existing PC's is 11,923g. The functional unit (FU) of the product is one set of personal computer that performs the CPU capacity up to 3.1GHz. Reference flow is one set of personal computer. Cut-off criteria of the product system boundary are 95% (but types of PCB include 100%).

Input and output data from all processes and activities in the defined system boundary are collected. Data for materials and parts on the raw material stage is collected. The data for energy consumption during the manufacturing stage and distribution information during the distribution stage is collected through energy information on the production line and daily record for distribution in Samsung Electronics. According to the Korean carbon footprint label guideline, total energy consumption (TEC) during the use scenario for PC can be calculated using equation (1) [3].

$$\text{Total energy consumption (kWh)} = \text{Typical energy consumption (kWh)} \times \text{Product lifespan (year)} \qquad (1)$$

Product lifespan is 4 years for both PCs, existing PC's TEC is 214.37kWh and alternative PC's TEC is 183.74kWh. Packaging in the end of life scenario at use stage was calculated directly. Also, end of life scenario was applied using recovery factor from the Korean recycling regulation and treatment rate for waste generated and treated in Korea [4], [5].

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3.2 Results for estimation of PCF

In order to calculate GHG emission, emission factors were applied to the Korean carbon footprint labeling factor [3]. Figure 2 showed that PCF of the alternative PC is lower than that of the existing one.

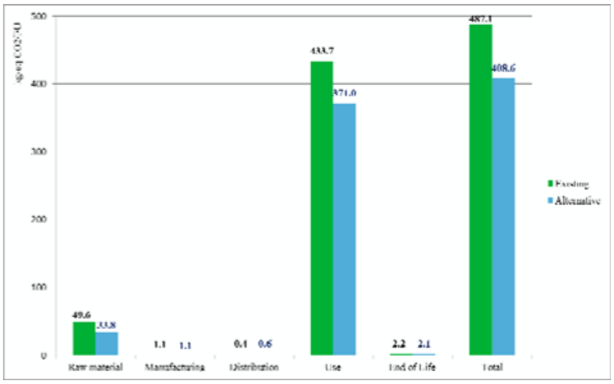

Fig. 2: Results of PCF

4 CONCLUSION

Total GHG emissions during the entire life cycle of the alternative PC was reduced by approximately 15% compared with that of the existing PC. Alternative PC can reduce GHG emissions; however, GHG emissions of both PCs during the use stage were still large. Therefore improvement to reduce GHG emissions during the use stage is necessary.

5 ACKNOWLEDGEMENT

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Application of product function and price based eco-efficiency factors to Washing machine

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Abstract

Higher eco-efficiency can be achieved by delivering to the market competitively priced goods and services that satisfy human needs and enhance quality of life, while progressively reducing ecological impacts throughout the entire life cycle of the product. In this paper, based on the product quality-based eco-efficiency method an ecodesign method that analyzes the relationship between functions, price and environmental impact of a product was proposed. The product function was analyzed using 2 steps function analysis method. A case study was performed using washing machine to assess the applicability of the proposed method.

Keywords:

Eco-efficiency, ecodesign, LCA, LCC

1 INTRODUCTION

Eco-efficiency is a concept indicating ecological efficiency of a company itself, company's activities, or products of a company. The improvement of eco-efficiency can be accomplished by the improvement of product value and the reduction of environmental influence. There is much controversy about what the product value is and how it is quantified. In this paper, eco-efficiency values were identified through representative factors of the product function, price and environmental impact value.

2 METHOD

According to the WBCSD definition, eco-efficiency is achieved through the delivery of "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity." [1]

$$\text{Eco-efficiency} = \frac{\text{Product or Service Value}}{\text{Environmental Impact}}$$

Fig. 1 : Eco-efficiency equation

2.1 Quality and price based eco-efficiency method

This method is representative as 1) Environmental aspect measurement: Simplified Life Cycle Assessment (S-LCA), the environmental impact data is considered depending on its impact on the six environmental impact categories. 2) Product function and economic aspect measurement: selling price analysis for economic aspect, product function analysis for product functions which include main function and sub functions. 3) Eco-efficiency measurement for product value. [2]

2.1.1 Product or service aspect

Product functions and price need to quantify for get eco-efficiency value. The calculation procedure consists of three main step. They are classification, normalization and weighting. This method followed to quality based eco-efficiency method. [2] (Park et all, 2007)

2.1.2 Environental impact aspect

Environmental impact assessment for product is calculated by LCA(Life cycle assessment). , in particular ISO 14044. [3]

3 CASE STUDY : WASHING MACHINE

The target product for case study is drum type washing machines. Five (5) different washing machines that produced in Korea were selected. And the washing machine considered carbon footprint certificated product when we choose the product. It is possible to compare the LCA results of the chosen products. Because the same LCA method applied to all of products for get carbon footprint certification.

3.1 Product function and price quantification

3.1.1 Quantification of product function

Washing machines functions were defined main function and sub functions. That is Capacity of washing machine, volume, washing time, water consumption and power consumption when it use standard mode. It is based on the product literature and a consumer survey.

3.1.2 Quantification of product price

In this study, only selling price applied for economic value of washing machine that were sold on the internet web site (www.bb.co.kr). The selling price of the wahsing machine is shown in Table 1.

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Table 1 : Classification of washing machine price

Price of washing machine						
Function	Direction	A	B	C	D	E
Price	↓	₩ 669,000	₩ 590,000	₩ 650,000	₩ 720,000	₩ 699,000
Price x life span		₩ 4,014,000	₩ 3,540,000	₩ 3,900,000	₩ 4,320,000	₩ 4,194,000

3.2 Environmental impact quantification

The environmental impact result of washing machine was carried out carbon footprint certification.

3.3 Eco-efficiency result

3.3.1 Function based eco-efficiency

Fig. 2 shows the function based eco-efficiency result of washing machine. Product D and E have high value of function based eco-efficiency. Which means that product D and E is quiet competitive product of product function aspect.

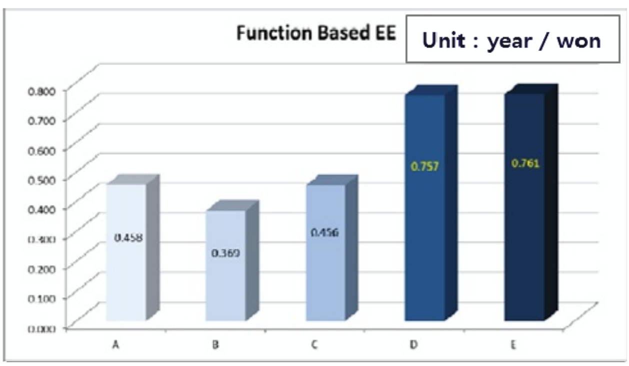

Fig. 2 : Function based eco-efficiency result

3.3.2 Price based eco-efficiency

Fig. 3 shows the price based eco-efficiency result of washing machine. This result also product D and E have high value compared to others. Product D,E values satisfied with low environmental impact and high price values.

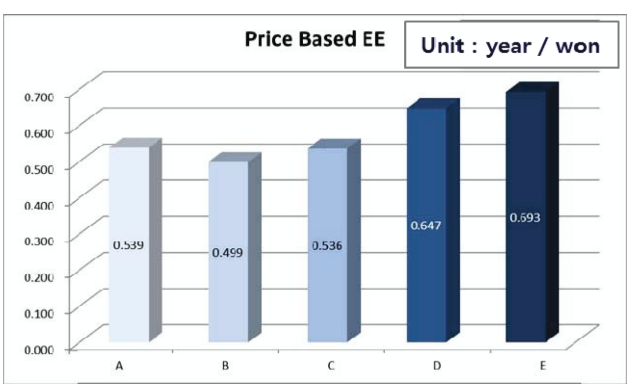

Fig. 3 : Price based eco-efficiency result

4 CONCLUSIONS

The analysis results that product E is the best product function based and price based eco-efficiency. Based on function based product or service aspect shows that product D is the highest value. Price based eco-efficiency shows that product E is the highest value. In this study, we choose only one factor, selling price for economic aspect.

5 ACKNOWLEDGEMENT

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Comparison of the eco-efficiency of the rental and sales business types of receipt printer

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Abstract
The objective of this paper is to compare the rental business type with the sales business type from the economic and environmental performance perspectives. Environmental performance was assessed by life cycle assessment (LCA), while economic performance by life cycle cost (LCC) analysis including product cost and rental cost. Eco-efficiency was calculated using the LCA and LCC results. Receipt printer was chosen as the product for comparison.
Both rental business and sales business type receipt printer exhibited similar economic performance; Eco-efficiency of the rental business type is higher than that of the sales business type in the case of receipt printer.

Keywords:
Eco-efficiency, LCA, Rental Business, Receipt printer

1 INTRODUCTION

The rental business is one of the promising strategies for a producer (a product maker) to shift the paradigm of selling goods toward servicizing. Thus, rental business can reduce environmental impacts throughout the recycling and reuse of the used products. At the same time, consumers of the rental product may end up paying less, while rental service providers can maintain stable revenue structure.

The objective of this paper is to compare the rental business type with the sales business type from the economic and environmental performance perspectives and draw conclusions which type of business paradigm is better with respect to economic and environmental performances to the company as well as consumers. Environmental performance was assessed by life cycle assessment (LCA), while economic performance by life cycle cost (LCC) analysis including product cost and rental cost. Eco-efficiency was calculated using the LCA and LCC results. Receipt printer was chosen as the product for comparison.

2 METHOD AND ASSUMPTION

2.1 Eco-efficiency

Eco-efficiency, as defined by the WBCSD, is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing environmental impacts and resource intensity throughout the life cycle to a level at least in line with the earth`s estimated carrying capacity. [1] In short, it is concerned with creating more value with less impact (see equation 1).

$$\text{Eco efficiency} = \frac{Product\ or\ service\ value}{Environmental\ value} \cdots\cdots eq.1$$

Based on the above underlying formula, the procedure for calculating eco-efficiency has defined in Figure 1.

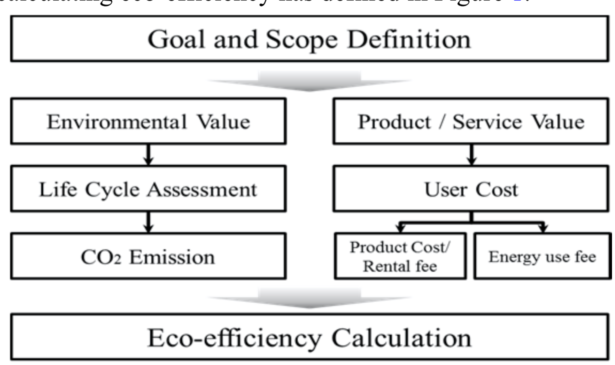

Fig 1 : Process

To identify environmental value, Life cycle assessment (LCA) has been implemented. To calculate economic value, the authors used total user payment and functional performance (see equation 2).

$$\text{Economic value} = \frac{funtional\ value}{total\ user\ payment} \cdots\cdots eq.2$$

As defined environmental and economic value, the paper used the following equation to calculate the eco-efficiency of each business.

$$\text{Eco efficiency} = \frac{1}{\sqrt{CO_2\ emission \times total\ user\ payment}} \cdots\cdots eq.3$$

3 RESULTS

Figure 2 shows the system boundary settings between the sales and the rental case. In case of rental business, a producer collects the wated product and deliver them to

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the recycling center whereas all the wasted are treated by menas of landfill in the sales case.

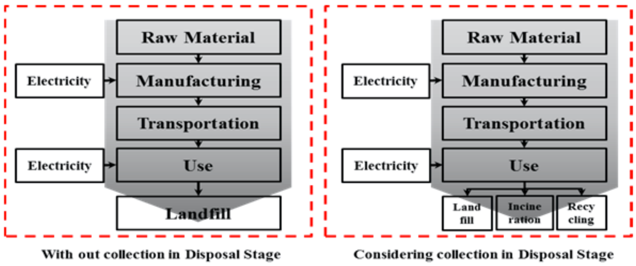

Fig 2 : System Boundary

3.1 Environmental Value

Based on defined scenarios for use and end of life stage and life cycle data, the authors calculated the total CO_2 emission of each type of business as shown in Table 1.

Table 1: Total amount of CO_2 of each type of business

Business type	CO_2 emission (kg CO_2-eq/kg)
Rental	116.7
Sales	119.0

Rental business emitted less CO_2 than sales business did. The result indicates that it can be reduced by 44,656.8kg CO_2 through the rental business if we consider the number of outputs produced for one (1) year.

3.2 Economic Value

As shown in Table 2, consumers who directly buy and use a printer have to pay more than the ones who use rental business.

Table 2: Total User payment

Business type	Cost (Kwon)
Rental	616,071.91
Sales	731,071.91

3.3 eco-efficiency

Table 3 and Fig 3 show the result of eco-efficiency for each type of business.

Table 3: Eco-efficiency

Business type	Eco-efficiency (1/ Kwon·kg CO_2)
Rental	1.179E-04
Sales	1.072E-04

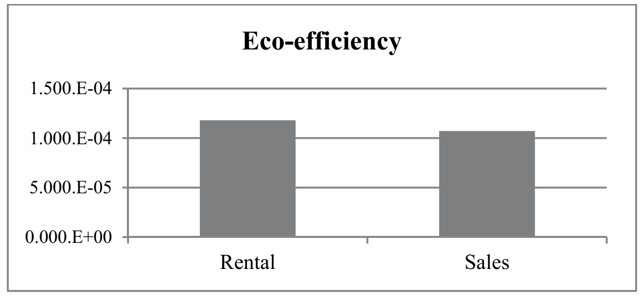

Fig 3 : Results of Eco-efficiency

Eco-efficiency of rental business case is relatively higher than the one of sales business.

4 CONCLUSION

This paper calculated the eco-efficiency of each business types, rental and sales, and offered which business has high eco-efficiency. According to the result, eco-efficiency of rental business is 1.179E-04 per $\sqrt{\text{Kwon·kg } CO_2}$, and this is higher than the value of sales business.

Rental business has lower environmental impacts and economic performance than sales does. Accordingly, eco-efficiency of rental business has higher efficiency than the one of sales. This means that rental business influence low impact to environmental and gives more benefits to consumer.

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Interdisciplinary Communication and Green Design Decisions Making - Case Study of Smart Cane Design

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Abstract
Smart Cane is an RFID based guidance for elderly with visual disabilities. Its main issues are the detection range and correction rate. Some improvement had been proposed but the reader and antenna in front of cane might get damaged during usage. To solve this problem, an approach using Zigbee was also proposed. With a multi-sensory environment the blind people can know and navigate through the surroundings better. The special proximity sensor nodes are embedded in the tactile pavings. The smart cane informs the location or navigation information with the user through his/her PDA via a Bluetooth headset. The environmental life cycle evaluation of these approaches was conducted qualitatively.
Keywords:
tactile paving , smart cane, RFID, modular design

1. INTRODUCTION

Visually impaired people subject to their physical limitation often are unable to balance their life through activities. Blind people are at a tremendous disadvantage when they walk on sidewalks of the streets, where they must somehow detect potential threat from incoming vehicle or dangerous. Pedestrian Safety Legislation has been placed in many countries, tactile paving is one of the most frequently used design to guide the people.

1.1 Related regulations

The U.S. Federal Government has recently started the process to revise the accessibility requirements in public. The guidelines, called Americans with Disabilities Act, wish to address issues like street crossing for visually impaired pedestrians, wheelchair access to on-street parking. The ADA Standards [1] require "detectable warnings" around the curbs to warn pedestrians who are blind or have weak vision. The warning tiles, which are intended to be detected by pedestrians' feet, can alert them when they are about to enter a street.

Tactile paving provide warning and guidance to visually impaired people. The most common surfaces are a series of raised studs, which are used at crossing points, or a series of raised rounded bars which are used at level crossings, at the top and bottom of steps and at some other hazards. The materials used for making the tactile paving tiles are clay, metal or rubber. Its dimension can be around: 300×300mm or 250×250mm. The thickness is 3mm (Fig. 1). Although the tactile paving are useful for warning blind people, in the other hand, it causes inconvenience for pedestrians. Report has shown that women with high heels, or elderly people, have problem with these pavings.

From observation during the project, a local school for the visually impaired has used a thin layer of material as the tactile pavings instead. It is imperatively proven that these can also be effective. The roughness difference between the normal floor surface and the special tactile paving is distinct enough for the students to feel the difference.

From the eco-design's point of view, less material means less processing, transportation and disposal impact to the environment [2]. It is interesting to know the balance between warning the blind, walking comfortably and related environmental impact. Is there a better way to accomplish the task?

Fig. 1 Tactile paving built by rubber

Fig. 2 Guidance by thin surface layer

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1.2 Life cycle of tactile paving

Considering the product life cycle, the scenarios of tactile paving consists of product manufacturing, transportation, installation, product usage (maintenance) and the recycle phase:

1. individual tiles build in factory
2. treatment process
3. assembly and transportation
4. distribution to sale endpoints
5. in site placement and surface preparation
6. maintenance and trouble shooting (replacement)
7. recycle

Although the individual tile is small, the overall amount is huge in the city construction. This results in huge carbon footprints. The qualitative analysis was carried out using the LCA evaluation software. The preliminary results indicate production phase is most significant part of environmental impact.

2 SMART CANE GUIDANCE

Information technologies are increasingly helping to integrate and socially include people with visual disabilities. Through innovative techniques and concept design, we can design products that can reduce the barrier for those people and improve their daily lives. The problems of user location detection is complex, involving aspects such as resolution, accuracy, privacy, and user orientation.

The smart guidance techniques give active warnings through voice or body-touch by information technology to knowing the surrounding environment. This can provide more required information and reduce the number of tiles required. Previous technologies will be discussed here.

2.1 GPS

Recently more cell phones manufacturers start to integrate GPS into their cell phones. It utilized a backpack with aerial receiver which can correct gradual errors in the GPS system. It creates a DGPS-like system by obtaining GPS correction data via the cell phone data network. It is utilized in outdoor space. The major problem in practice of GPS is the resolution and accuracy.

2.2 RFID

The High-Density RFID Tag Space [3] uses active RFID tags on a grid; each placed 1.2 meters apart from each other. Active RFID tags have a battery power source which allows it to transmit a stronger signal. The transmitted ID of each tag is used to look up the known coordinates of that tag.

A footstep based indoor location system was proposed. User simply puts on the special sandals to enable tracking of his/her location relative to a starting point, making it easy for deployment everywhere. The footstep location system is based on dead-reckoning, which works by measuring and tracking displacement vectors along a trail of footsteps.

To make the system transparent to the outside observer and pervasive to the user, a RF-PATH-ID system should be small and non-obvious when worn by the user. The RFID circuitry utilized existing OEM boards from manufacturers and will connect to the cell phone/PDA using serial or Bluetooth links. The RFID reader circuit board is integrated into the shoes or the walking cane [4]. The antenna for the system is critical both in dimension and placement location.

2.3 iCane

iCane [4] creates a supportive environment allowing timely and useful information to be passed to the user, guiding them in and around public facilities such as shopping malls or the MRT stations. Location-encoded RFID tags are embedded in the tactile pavings (Fig. 3). By equipping the standard white cane with an RFID reader, the iCane informs the user about location or navigation information through his/her PDA with Bluetooth headset.

Fig. 3 iCane design [5]

3 INTERDISCIPLINARY COMMUNICATION

The interaction between the engineering and design groups can reveal possible problems. A one-day design meeting was held with both the design and engineering participants, aiming to generate new concepts. Then we interviewed with engineering experts to confirm the technological feasibility within the five years. After that, concepts were built into simple prototype model, and verified design parameters with experiments.

3.1 Design parameters

The domain languages used in engineering and design are different, and this often creates some communication barrier. An appropriate translation is needed between the engineering parameters (such as frequency, physical limitations) and design parameters (size and distance), in order to remove this barrier.

Making design decisions need careful consideration before the detail design stage. In order to create a proper sustainable concept in the initial stage, comparisons and good choice of the technology and components are required.

3.2 green design decisions making

While smart cane require less parts/tiles for guidance, the equipment itself and the necessary parts to convert energy into usable electricity have a carbon footprint. The smart cane also brings environmental impact during manufacturing, product use, and end-of-life periods. From environmental impact's point of view, it is important to consider the possible technology available and related environmental impacts in early design phases [6].

The life cycle framework had been applied to smart cane design based on energies used during material production, manufacturing, and transportation. For smart cane, the supporting network and system which provided information need extra energy [7], consequently, the major parts that can contribute within the life cycle is the use phase. The manufacturing phase impact can also be minimized by proper selection of technology and part. The major green design considering span is shown in Table 1.

Table 1 Green design phases and considering span

	Manufacture	Use	Recycle
System		o	
Circuit	o	o	
Battery		o	
Frame	o	o	o

Small changes at the design stage can have a far greater positive effect than trying to mitigate impact during and after production. The general smart cane consists of four different devices; the network, the control electronics, the battery and the mechanical frame. Environmental impact is related to factors such module size, battery size, frame and electronic packaging material required and control electronics. Minimized environmental impact can be achieved through proper choice of those variables. The judgments can be made based on environmental impact, weight, installation and cost.

4 CONCEPT DESIGN

The design case of smart cane with RFID reader and Zigbee are discussed in this article.

4.1 Concept 1: antenna redesign

iCane with RFID reader has limitation on detection range [5]. There is a desire to increase the sensing distance. For extension of RFID reader's range, the minimum size and energy savings of different antenna technologies are compared. To minimize the damage to the environment, the production and usage phases of RFID-guidance system need to be considered throughout. Therefore energy-saving and reduce battery usage become an important considerations of sustainable design. The HF RFID utilizes magnetic field induction to read. To enhance performance of detection distance, magnetic material or layout change can improve coupling efficiency. We need to consider the miniature electronic configuration, RF antenna efficiency, reliability, materials weight and so on.

An analytical method to compute the power delivered to the RFID tag as a function of the mutual coupling between the loop antennas of the tag and reader was introduced. The concept of improving antenna mutual coupling on the power delivery was proposed in Fig. 4.

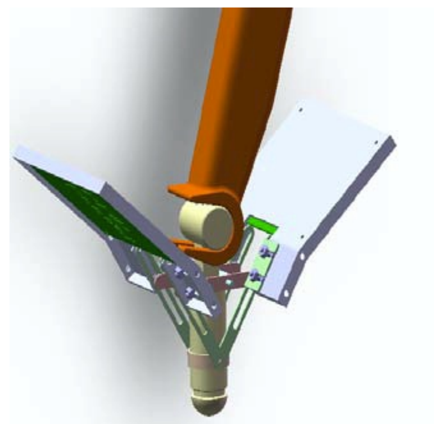

Fig. 4 Antenna structure for improving reading efficiency

An adaptive impedance matching circuit [8] implemented on the antenna reader was used as a solution to mitigate the detrimental effect of the mutual load on the power transfer efficiency [9]. Select the magnetic material as rod structure can also slightly increase effectiveness. This design can extend antenna reading distance to 50CM, but it reveals another problem. The antenna might be damaged by the surrounding structure while moving the cane during walking.

4.2 Concept 2: Zigbee wireless node

The Zigbee multi-sensory environment (Fig. 5) enables blind people to know the surroundings that they are required to navigate through. The specific proximity communication nodes [10] are embedded in the tactile paving path (Fig. 6). By equipping the standard white cane with a Zigbee wireless node, the smart cane communicates location or navigation information with the user through voice signal. While the front part of cane contact these nodes, the information transfer though his/her body (Fig. 7) and the PDA. System can inform the user with Bluetooth headset.

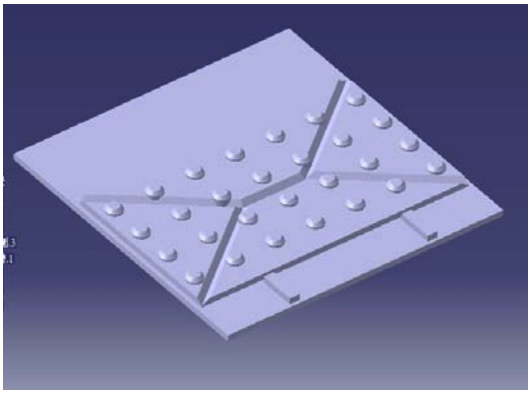

Fig. 5 Zigbee multi-sensory environment, with solar charging node and sound signal

Fig.6 Communicate through the contact of guidance tile

Fig. 7 Proximity communication nodes which transfer signal through metal parts

5 SUMMARY

Comparing with traditional tactile pavings on the street, the use of RFID and Zigbee requires less material, and there is less interference to other people. However, it requires more maintenance and the system extends to the domain of networking. This increases the complexity in LCA evaluation. The life cycle and its related environmental impact need to collect in order to build a basis for evaluation.

The successful sustainable innovation must balance between demand, technology and resources. In order to meet the dynamic balance of environmental sustainability, green innovation is needed in the initial stages of product concept design. Two kinds of smart cane were presented and major considerations were discussed qualitatively. More detail design is needed to communicate with different knowledge domain to further decide the smart cane's design parameters.

ACKNOWLEDGMENT

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Carbon Reduction Assessment of a Product Service System: A Case Study of Washing Machines

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Abstract

Global warming has constantly been regarded as a major threat to sustainable development. Thus, reducing energy consumption and carbon emissions entails committed action through sustainable management practices based on a life cycle perspective. A product service system (PSS) is a new business model that has been adopted by many companies and is currently widely used in developed countries. The PSS model can achieve not just economic benefits, but also many environmental benefits such as carbon reduction. Currently, almost every household owns various types of appliances such as washing machines. Along with lifestyle changes, self-service laundries have become a typical PSS. This study investigates carbon emissions from traditional laundry practices (i.e., washing machines) and PSS modes (i.e., self-service laundries) by life cycle assessment. We compare the life cycle carbon emissions of a community with 360 households, each owning a washing machine, with those of a commercial coin-operated laundromat with five self-service commercial washing machines. Two life span scenarios of washing by a household's washing machine (i.e., 7 years) and a commercial coin-operated laundromat (i.e., 21 years) were considered for comparison.

Results show that for the first scenario (i.e. 7 years) and the second scenario (i.e. 21 years) with 360 households the use of commercial laundry mode share increase in proportion, which will lead to a reduction in total carbon emissions. In addition, the threshold ratio of the number of households (each owning a washing machine) to the number of commercial washing machines that can reflect the minimum value of carbon emissions from the PSS mode is 11:1.

Keywords:

Product Service System, Life Cycle Assessment, Carbon footprint, Washing machine sharing, Carbon reduction

1 INTRODUCTION

The world is facing the challenge of sustainable development. Over the past century, rapid industrial development and the human pursuit of economic growth, along with the corresponding extensive use of fossil fuels, resulted in increased levels of carbon dioxide (CO_2) and other greenhouse gases, which accelerate global warming and cause drastic climate changes. These phenomena are hazardous not just to humanity, but to all life. With the rise of global warming issues, carbon reduction has become a trend. Several governments, businesses, and consumers are presenting their respective policies to address this issue (Poter and Reinhardt, 2007). By 2016 to 2020, Taiwan's government aims to reduce Taiwan's CO_2 emissions to a level similar to that in 2008.

The scope of the carbon subject is vast, and enterprises and government agencies require vast resources and manpower. To meet the challenge of sustainable development, enterprises can reexamine their products and level of organization, and develop sustainable products or become a sustainable enterprise, businesses can adopt the product service system (PSS) concept, which includes physical products and intangible services. PSS can replace products through service, and reduce each stage of a product life cycle (including service) by considering its economic, environmental, and social impact (Bernardini and Galli, 1993; Cleveland and Ruth, 1998; Voet, Oers, and Nikolic, 2004).

For consumers, the washing machine has a family penetration rate of over 90%. In Taiwan, the opening of a self-service automatic laundry caused popularization in the 1980s (Executive Yuan, Taiwan, 2011) The concept of a self-service laundry was used to investigate the development of PSS consumer behavior patterns of different families that regularly use washing devices. Behrendt et al. (2003) considered that "common use" laundries and drying ways have lower environmental impact. The goal of this study is to assess the carbon emissions of both household and commercial coin-operated laundromat washing machines using the concept of life cycle assessment (LCA).

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2 LITERATURE REVIEW

2.1 Product Service System (PSS)

PSS is a combination of the three concepts of the innovation economics model, namely, dematerialization, the Integrated Product Policy (IPP), and the extended producer responsibility (EPR). Lamvik (2002) considered PSS as one of the main approaches to sustainable development. Mont (2002) proposed that PSS requires different societal infrastructure, human structures and organisational layouts; it is designed to be competitive, to satisfy customer needs, and to have lower environmental impact than traditional business models.

According to Tukker (2004), PSS is categorized into three types, namely, product-oriented, use-oriented, and result-oriented , and contains eight kinds of PSS subcategories (Fig. 1). The self-service laundry model is classified as a PSS model of sharing of products, which focuses on increasing the utilisation of products through shared use. Fig. 2 shows the framework of the self-service laundry model.

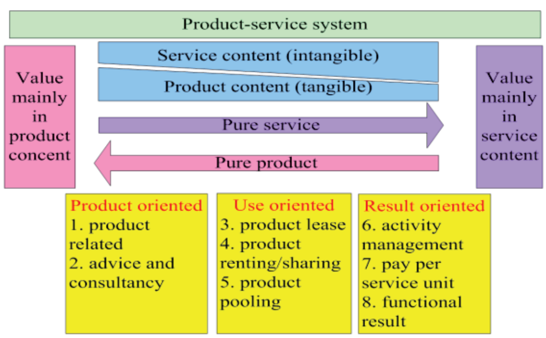

Fig. 1: Main and subcategories of PSS

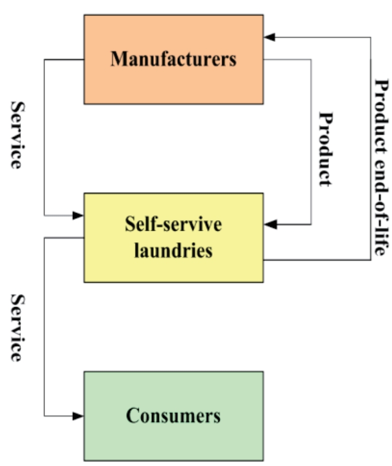

Fig. 2: The framework of the self-service laundry model

2.2 LCA and application of the environmental benefits of PSS

LCA is a tool for examining the total environmental impact of a product through every cycle of its life—from cradle to grave (UNEP, 1996). The United Nations Environment Programme (UNEP) combined the effects of the PSS and the product life cycle in 2001 (Fig. 3).

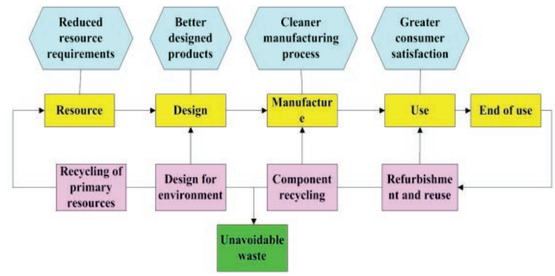

Fig. 3 : The influence of PSS over the product life cycle

Maeda (2005) used the concept of LCA to assess the benefits of PSS. LCA can be used to develop a variety of service delivery methods and increase the industrial efficiency of PSS.

2.3 Carbon footprints

The concept of carbon footprint came from the ecological footprint assessment created by Wackernagel (1996), which considers humanity's energy and resource throughput and converts these data into area units. The ecological footprint and carrying capacity can then be directly compared because they are measured in the same units.

The carbon footprint of a product comprises the greenhouse gas emissions at each stage of the product life cycle. The calculation includes raw material extraction, manufacture, use, and end-of-life or recycling (Fig. 4).

Fig. 4 : Product LCA (includes service)

3 METHODOLOGY

The current study compares the life cycle carbon emissions of a community consisting of 360 households, each owning a washing machine, with those of a commercial coin-operated laundromat with five self-service commercial washing machines. The selection of the two types of washing machines for inclusion into the current study does not include the following:

1. drying clothes and adding hot water;
2. using different detergents;
3. repairs (the machine should be well maintained);
4. washing machine styles (the different scenarios in the study used the same types of household and commercial washing machines); and
5. transportation (the machine should be within walking distance).

The units selected for study were household washing machines with 7 years of life and commercial washing machines with 21 years life (Table 1.) Fig. 5 shows their system boundary. Note, however, that the commercial washing machines does not include the waste phase.

Table 1: Functional units and goal

Types	Household washing machines-Swirl	Commercial washing machines-Drum
Capacity of washing clothes (kg)	10	17
Life span (years)	7	21
Mass (kg)	44.7	253
Number of units	360	5

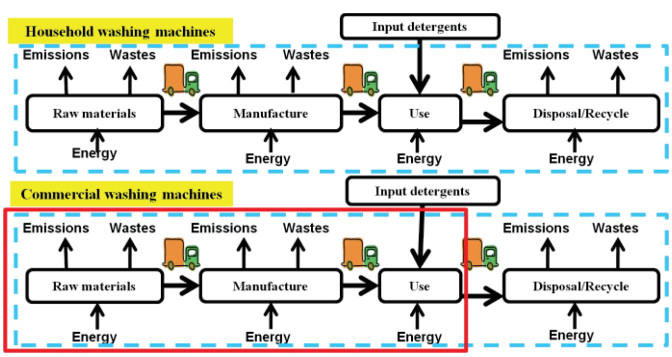

Fig. 5: The research of system boundary

4 RESULTS AND DISCUSSION

4.1 The first scenario (Evaluation time = 7 years)

The first scenario to compares 360 households using traditional laundry practices (360 units of household washing machines) with the PSS model (5 units of commercial washing machines). However, the lifetime of commercial washing machines is 21 years, which does not include the waste phase. The carbon emissions in the raw materials stage of PSS model are smaller than traditional laundry practices, because the PSS model of sharing of products can decrease the manufactures of washing machines. In the manufacturing stage, the traditional laundry practices produce high carbon emissions and need to manufacture a large number of washing machines. Besides, the commercial washing machines have larger capacity of clothing than traditional washing machines so that caused difference with numbers of washing clothing in the use stage (Fig. 6).

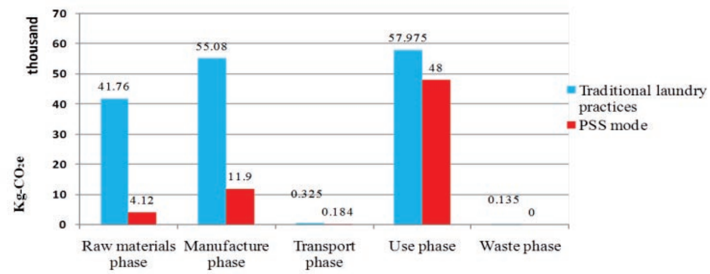

Fig. 6: Results of the first scenario

4.2 The second scenario (Evaluation time = 21 years)

The 21-year lifetime of a commercial washing machine is three times that of household washing machines. Therefore, the 360 households used an equivalent of 1,080 sets of household washing machines. Fig. 7 compares the 1,080 sets of household washing machines with the 5 units of commercial washing machines.

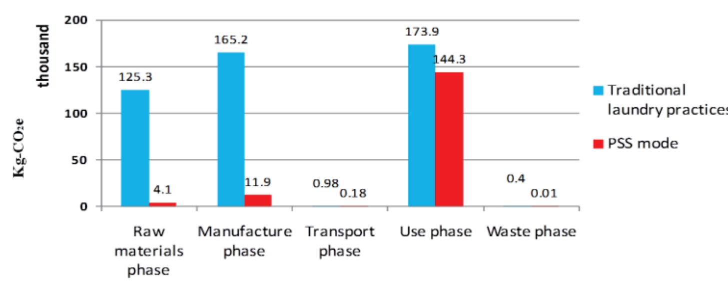

Fig. 7: Results of the second scenario

4.3 Simulated scenario

The use of the life cycle concept in modelling household and commercial washing machines gives the simplest ratios, from 1:1 to 40:1. Total carbon emissions of both traditional laundry practices and the PSS model increase when the number of households increases (Fig. 8). Comparing the ratio of the two scenarios, the two lines intersect to one point, 11 (10.89), and the carbon emissions of the PSS model are lower than the carbon emissions of traditional laundry practices gradually after the points. Accordingly, the ratio of household washing machines to commercial washing machines should be 11:1 for the efficiency of reducing carbon emissions.

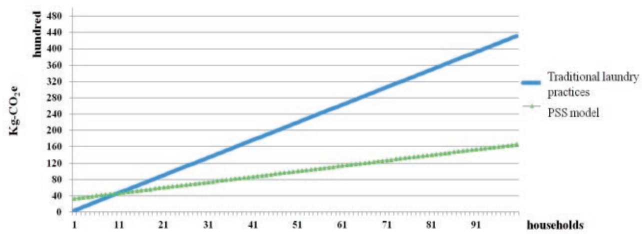

Fig. 8: Results of the simulated scenario

5 CONCLUSSIONS AND SUGGESTION

For the first scenario (i.e., 7 years), total carbon emissions from the traditional laundry practice and the self-service commercial laundry reach 155,276 and 64,310 kg CO_2-e, respectively. For the second scenario (i.e., 21 years), total carbon emissions from the traditional laundry practice and the self-service commercial laundry reach 465,830 and 160,532 kg CO_2-e, respectively. The threshold ratio of the number of households (with each owning a washing machine) to the number of commercial washing machines reflects an 11:1 minimum value of carbon emissions from the PSS model.

To reduce the carbon emissions of commercial washing machines, the manufacturers of commercial washing machines can use high-efficiency motors to reduce power consumption and improve the impact of carbon emissions. There are many residential buildings in Taiwan, so residents can refer to foreign practices to set up the community laundry room for sharing the washing machine and for promoting environmental consciousness. Such measures can also reduce the consumption of raw materials, carbon emissions, and environmental impact.

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Innovative Power Generation System for Harvesting Wave Energy

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Abstract

As a wave power generator utilizing dielectric elastomers can directly drive elastomers by the up and down motions of waves, the structure of the generator is simple and its size can be made small. Using a power generator set on a shore protection, we have proved that it can generate electric power even by fairly small-amplitude waves. Also, we have confirmed that this small-sized device can be utilized for stable hydrogen generation.

The use of significantly larger amounts of dielectric elastomer material to produce generator modules with outputs in the MEGAWATT at range is being investigated for application to ocean wave power systems.

Keywords:
Water Power Generation, Artificial Muscle Actuators, Dielectric Elastomers, Direct Drive, Human & Animal Motion

1 INTRODUCTION

Increase in world population and the accompanying surge in demand for energy, food and water, as well as the sudden increase in energy consumption caused by recent industrial development and betterment of life standards in newly developing countries will accelerate global warming. Among the diverse measures proposed to meet our energy needs, the use of renewable energy is receiving increasing attention. Especially, the wave power generation has attracted attention as one of useful utilization methods for ocean energy. However, the conventional wave generators are large, expensive, and unable to efficiently generate electric power with small amplitude waves, limiting their widespread usage [1]. To solve these problems, this article discusses the possibilities for a wave power generator using dielectric elastomer artificial muscle recently developed as a novel method for harvesting renewable energy [2]).

These artificial muscles enable electric power generation by their expansion and contraction. As dielectric elastomer is very light, inexpensive, and easily formed into multiple layered structures, it can make a very simple and robust direct drive wave power system that is economically viable [2].

The use of significantly larger amounts of dielectric elastomer material to produce generator modules with outputs in the MEGAWATT at range is being investigated for application to ocean wave power systems.

2 BACKGROUND ON DIELECTRIC ELASTOMER ARTIFICIAL MUSCLES

Dielectric elastomer artificial muscle is a new smart material technology with characteristics and properties not seen in other materials [3-5]. The basic element of dielectric elastomers is a very simple structure comprised of thin polymer films (elastomers) sandwiched by two electrodes made of a stretchable material. Dielectric elastomers can operate as an electrically-powered actuator. When a voltage difference is applied between the electrodes, they are attracted to each other by electrostatic forces leading to a thickness-wise contraction and plane-wise expansion of the elastomer.

We have verified [6] that the dielectric elastomer type of electroactive polymer can maintain good operational characteristics even in an ultrahigh-pressure environment by showing that the electroactive strain response to an applied voltage was unaffected by externally applied pressures of up to 100 MPa. Fig. 1 shows the deformation ratio of EPAM at different ambient pressures and applied voltages [6].

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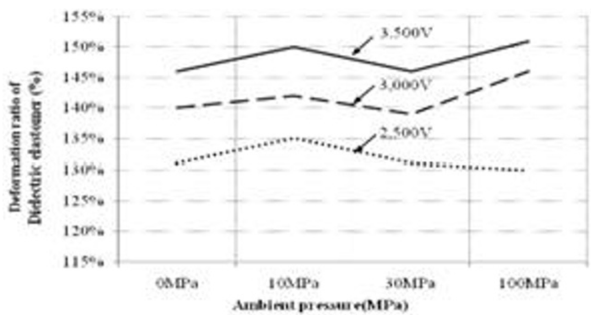


Fig. 1: Deformation ratio of Dielectric Elastomer at different ambient pressures and applied voltages.

More recently, the use of dielectric elastomer actuator in the reverse mode, in which deformation of the elastomer by external mechanical work is used to generate electrical energy, has been gaining more attention [2].

3 OPERATION PRINCIPAL OF DIELECTRIC ELASTOMER GENERATORS

The operation principle in the generator mode is the transformation of mechanical energy into electric energy by deformation of the dielectric elastomer. Functionally, this mode resembles piezoelectricity, but its power generation mechanism is fundamentally different. With dielectric elastomer, electric power can be generated even by a slow change in the shape of dielectric elastomer, while for piezoelectric devices impulsive mechanical forces are needed to generated the electric power [7,8]. Also, the amount of electric energy generated and conversion efficiency from mechanical to electrical energy can be greater than that from piezoelectricity [2]. Figure 2 shows the operating principal of dielectric elastomer power generation.

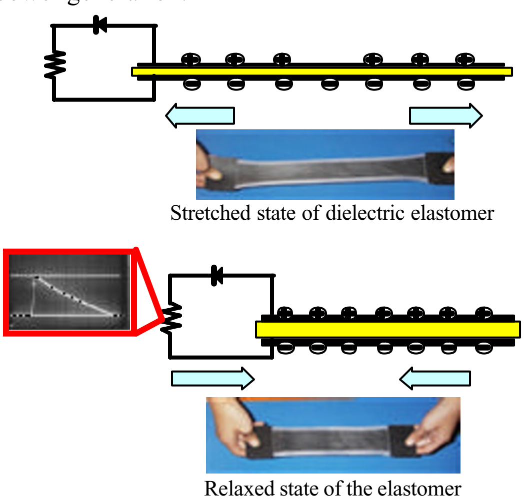


Fig. 2: Operating principle of dielectric elastomer power generation

Application of mechanical energy to dielectric elastomer to stretch it causes compression in thickness and expansion of the surface area. At this moment, electrostatic energy is produced and stored on the polymer as electric charge. When the mechanical energy decreases, the recovery force of the dielectric elastomer acts to restore the original thickness and to decrease the in-plane area. At this time, the electric charge is pushed out to the electrode direction. This change in electric charge increases the voltage difference, resulting in an increase of electrostatic energy.

$$C = e_0 eA/t = e_0 eb/t^2 \qquad (1)$$

where e_0 is the dielectric permittivity of free space, e is the dielectric constant of the polymer film, A is the active polymer area, and t and b are the thickness and the volume of the polymer. The second equality in Equation (1) can be written because the volume of elastomer is essentially constant, i.e., $At = b =$ constant.

The energy output of a dielectric elastomer generator per cycle of stretching and contraction is

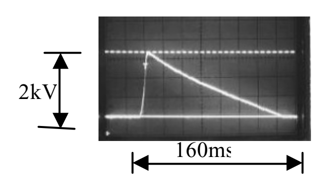
$$E = 0.5 C_1 V_b^{\,2} (C_1/C_2 - 1) \qquad (2)$$

where C_1 and C_2 are the total capacitances of the dielectric elastomer films in the stretched and contracted states, respectively, and V_b is the bias voltage.

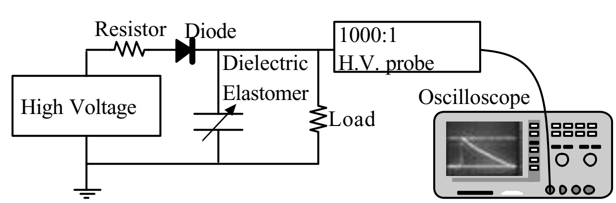
Considering then changes with respect to voltages, the electric charge Q on a dielectric elastomer film can be considered to be constant over a short period of time and in the basic circuit. Since $V = Q/C$, the voltages in the stretched state and the contracted state can be expressed as V_1 and V_2, respectively, and the following equation is obtained:

$$V_2 = Q/C_2 = (C_1/C_2)\,(Q/C_1) = (C_1/C_2)\,V_1 \qquad (3)$$

Since $C_2 < C_1$, the contracted voltage is higher than the stretched voltage, corresponding to the energy argument noted above. The higher voltage can be measured and compared with predictions based on the dielectric elastomer theory. In general, experimental data based on high impedance measurements are in excellent agreement with predictions. When the conductivity is assumed to be preserved in the range of electric charging, Q remains constant.



(a) Typical scope trace from the contraction dielectric elastomer.. Voltage spike occurs at contraction and gradually back to (stretched) voltage due to load resistance.



(b) Measurement circuit of generated energy

Fig. 3: Voltage for the compression of dielectric elastomer and measurement circuit

4 WAVE POWER GENERATORS USING DIELECTRIC ELASTOMERS

We carried out the world's first marine experiment into power generation by natural sea waves using a power generator having 300 g of dielectric elastomer in August 2007 in Tampa Bay, Florida, USA[2].

The power generation unit used in the experiments (See Figure 4) was a cylindrical tube with a diameter of 40 cm and a height of 1.2 m. Inside the tube were two roll-type EPAM modules, each about 30 cm in diameter and 20 cm in height (in the stretched state). About 150 g of dielectric elastomer film (including electrodes) was used in each roll. The maximum measured electrical output capacity, verified in laboratory tests, was 20J for one cycle of operation. However, wave activity was minimal during the test period. Wave heights were on the order of few centimeters, which made it very difficult to carry out tests for wave-powered generators. On occasion the weather generated waves 10 centimeters high. Despite the low wave activity and non-ideal motion of the buoy, the generator was shown to function. Even with the small wave height of 10 centimeters, we were able to generate a peak power of 3.6 J with an average power of 0.75 J. While this amount of power is small, we can extrapolate these numbers to estimate the potential of a dielectric elastomer generator mounted on a buoy.

The generator uses a proof-mass to provide the mechanical forces that stretch and contract the dielectric elastomer generator, as shown in Figure 4.

In December 2008, oceanic tests were also carried out in California, USA, and it was confirmed that generated electric power was constantly stored in a battery [7].

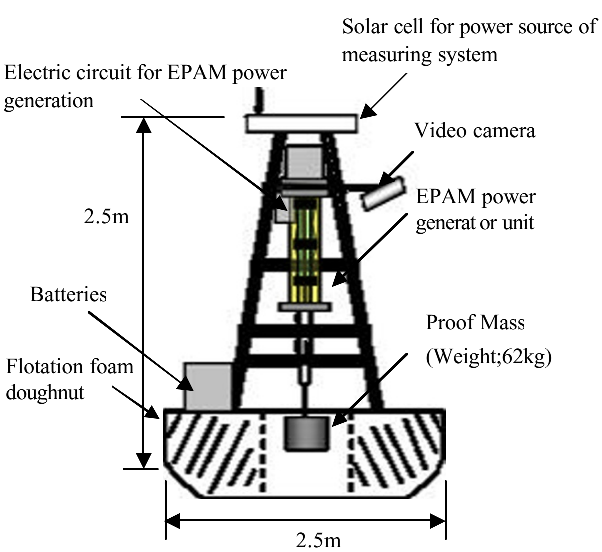


Fig. 4: Buoy generator configuration

Photo 1: Dielectric Elastomer Generator System on the Buoy Used in December 2008

5 FURTHER MODIFICATION ON BUOY GENERATION SYSTEM

In November 2010, we carried out marine tests for electric power generation using a fairly small buoy of 90 cm in diameter at Suzaki Port in Izu Peninsula (which is located 200 km south-west of Tokyo).

As the wave power generator using an artificial muscle can directly drive the muscle by up-down wave motions, the structure is simple and its size can be made small. Moreover, as the generator can induce electric power even from waves of approximately 10 cm high [2], it can be applied to the sea surface of small waves like in-bay and in-harbor waves. To further advance the verification for that, we set the following two objectives for marine tests conducted this time in Japan:

1) To fabricate a portable smaller system for electric power generation that can easily be mounted on the edge of ship, shore protection, seawall, etc. The possibility of megawatt plants using a lot of these modules to generate power was also investigated.
2) To verify that electric power can be generated even by the fairly small amplitude waves which occur near the shore protection. To confirm that even a small-sized device can be used for hydrogen generation.
3) To confirm that even a small-sized device can be used for hydrogen generation.

5.1 Experiment and Discussion

The artificial muscle for the power generation module in this experiment is only 4.6 g, and is formed to be cylindrical (26 cm in diameter and 12 cm in height). When a voltage of 3000 V is applied to the artificial muscle, its maximum power generation is approximately 274 mJ each cycle from 6 cm-stretched to relaxed states.

The power generation buoy was moored by a wire from a water depth of 2.8 m using mooring equipment set on the shore protection (see Figure 5 and Photo 2). The power generation module was set between the buoy and wire, so that the artificial muscle could be directly stretched by the up-down motions of the buoy due to waves.

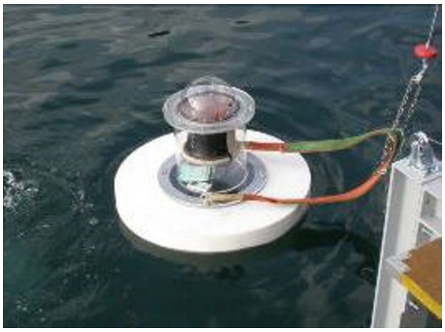


Photo 2: Dielectric Elastomer Generator on the Test Buoy

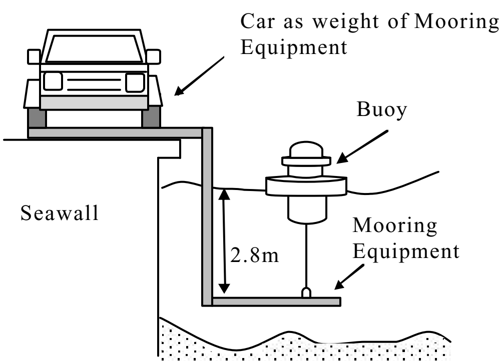


Fig. 5: Mooring equipment set on shore protection

In this experiment, as the height of continuously occurring waves was approximately 14 cm, the electric power generated by each wave was about 131 mJ. At this time, the applied bias voltage was 2100 V, and thus for 3000 V at the same condition, the electric power generated is estimated to be about 274 mJ.

Figure 6 shows the total electric power generated and amount of electric power consumed in one minute. Actually, the energy obtained from generators is the net value of the total energy generated minus the electric power consumed. However, because the total generated energy is expressed in joules, it can be converted to watts by integrating one-second changes.

Figure 7 shows the amount of electric power generated in one minute at that time. In addition, Figure 8 shows wave height values. The maximum momentary power output of 131 mW could be obtained from a wave height of 17 cm, but since the wave cycle was 5 seconds, the average amount of energy produced in one minute was 27 mW. What is noteworthy here is that in the case of small waves with a height of about 4 cm, the cycle was a very fast 1 second, meaning that 52 mW of electric power, or about twice the average, could be generated. These results verify that even more electric power could be obtained because rapid wave cycles of even small waves could be harnessed to power the generators.

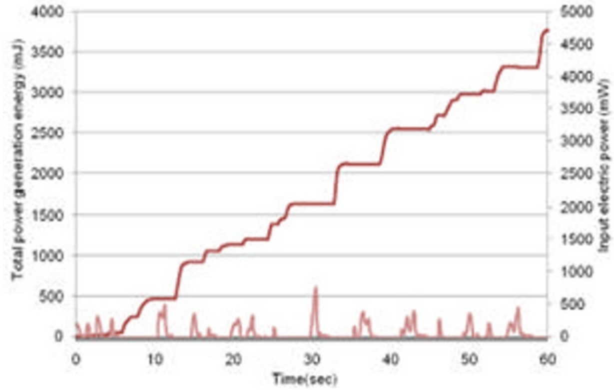


Fig. 6: Total power generation energy and input electric power of one minute

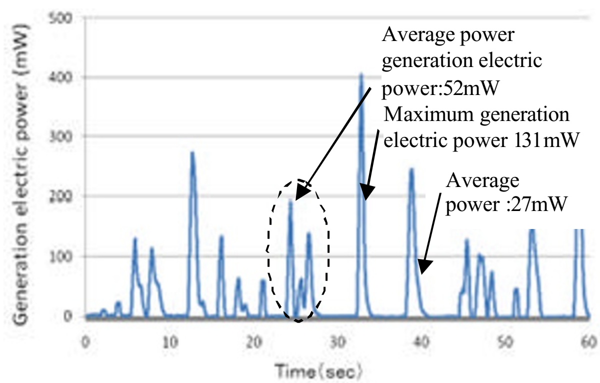


Fig. 7: Power generation electric power of one minute

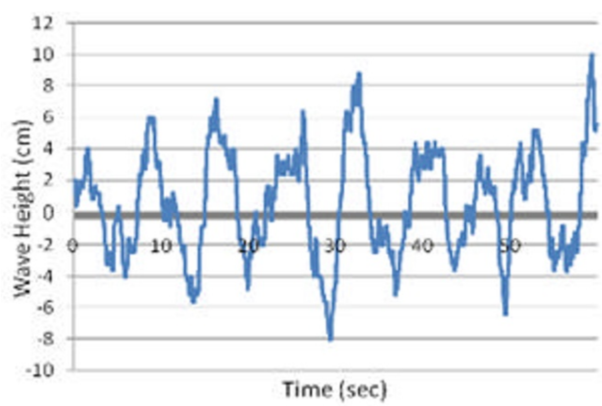


Fig. 8: Wave height variation of one minute

Two displacement sensors having 3 degrees of freedom were also attached on the buoy body to measure the buoy movements induced by waves. As the analysis of the buoy movement, electric power was obtained because of not only its vertical movement but also its horizontal movement.

Moreover, in this experiment, the generated electric energy was stored in a lead storage battery, and an experiment on hydrogen generation by electrolysis using the generated energy was carried out at the same time

Because of spatial limitations, equipment for hydrogen generation was mounted this time on other buoys moored near the power generation buoy, but by improving the shape of the equipment and the design of the power generation buoy, the equipment can be installed inside the current power generation buoy.

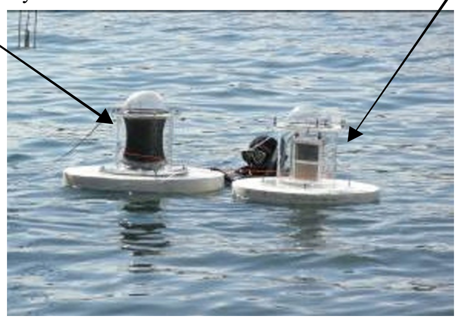


Photo 3: Dielectric elasromer generator system and hydrogen generation equipment

Photo 4 shows a prototype dielectric elastomer generator system with rectangular power generation modules, which can be set in water. This is a very simple power generation system which resembles sea tangle drifting in the sea water. It can be easily set in place, resulting in a significant reduction of equipment installation costs. This system consists of a buoy of 10 cm in diameter and three power generation modules of 12 cm in length, 5 cm in width, and 1.86 g in weight connected in series, that can generate up to 50 mJ of power. In this experiment, electric energy of approximately 40 mJ was generated by waves whose height was about 15 cm.

Photo 4: Sea tangle-type power generation

5.2 Possibility of Mega Watt Plant Using the Generation Modules

As the dielectric elastomer used for the power generator in this experiment is only 4.6 g, the generated power showed a rather small value of 274 mJ. However, the power generation can be drastically increased by increasing the packaging density of the artificial muscle, doubly or triply layering the generation device, and arranging more multiple-layered devices. Also, the enhancement of the power generation efficiency of each artificial muscle sheet itself is a significant subject to be developed [9].

An estimate based on data from our sea trial demonstration experiments has shown that even in seas where the wave height is only 1 m throughout the year (e.g., the sea close to Japan), if there are spaces of approximately 3500 m in length and 15 m in width, the establishment of a sea-based facility generating 8.5MW of power is possible. Fig. 9 shows the conceptual rendering of the dielectric elastomer wave power generator system.

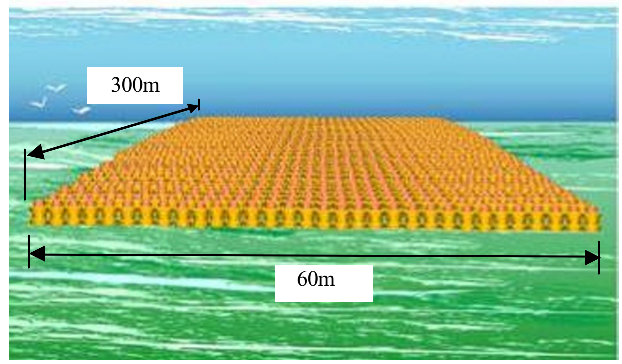


Fig. 9: Conceptual rendering of EPAM wave power generator system

Incidentally, wave power generators using conventional rotors and power generating systems using piezoelectric devices generate AC electric power, and thus for their usage, it must be converted into DC power. On the other hand, as the dielectric elastomer system generates DC power, it can be used without the conversion. This indicates that our system is very advantageous for constructing a high-efficiency, local self-sufficiency electric power system which enables the activation of local industries.

5.3 Cost Analysis of Dielectric Elastomer Power Generation

The power generation efficiency estimated on the basis of the data obtained from in-tank experiments in 2006 [10] and ocean demonstration experiments in 2007 [2], 2008 [11] and Nov. 2010 is approximately 18 US cents/kWh. In the near future, we expect that the electric power generation per unit mass or volume of dielectric elastomer material can double, and that the expected power generation cost per kilowatt-hour is 5 – 6.5 US cents. This value is comparable to that for fossil fuel thermal power plants. Of course, the wave power systems have the additional benefit of not releasing any pollution or greenhouse gasses.

6 CONCLUSION AND FUTUR E PLAN

The small-size power generation modules are compatible with small waves, and are portable. Also, computer simulations have showed that by simultaneously using a lot of modules, offshore plants with a power generation capacity of MW level can be constructed. The plants can generate electric energy even with small waves, and can maintain a certain amount of power generation capacity even if several modules do not work well. And if modules become faulty, they can be easily replaced.

We plan to further investigate more effective structures and methods for water power transmission and realize a power generation unit of 2 kW in the near future. In early 2012, we plan to carry out full-scale ocean experiments using an improved buoy-mounted dielectric elastomer power generation unit that will enable a power output level of several hundred watts.

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Study on a Power Generation System as Distributed Power Supplies in Consideration of the High-Pressure Dissociation Characteristics in the Small Difference in Temperature of CO_2 Hydrate

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Abstract

A fluid mixture of gas and water, pressurized and cooled to a certain pressure and temperature, gas hydrate is produced. By heating the gas hydrate after the formation, extremely high pressure gas can be obtained by hydrate dissociation. This study aims the pressure obtained by dissociation of gas hydrate, drives a high-pressure gas engine generators as distributed power. Gas hydrate has a function of the energy storage capabilities and the working fluid. However, the actuator using the expansion properties dissociation of gas hydrate does not have any examples for previous discussion. This paper focuses on CO_2 hydrate. Then the expansive energy dissociation of CO_2 hydrate formation rate of hydrates storage capacity is investigated. As a result, it is proved an electric power corresponding to approximately 45% of the daily power consumption (4.5 kWh of generator outputs) of an individual house is stored, when 1 m^3 of water is used to generate CO_2 hydrate for 480 minutes.

Keywords:

Distributed Power Supplies, Gas Hydrate

1 INTRODUCTION

The pressure-temperature characteristics of a gas-hydrate include a large differential pressure that is obtained from a small temperature difference. Therefore, therer is a potential of a clean power generation system constructed using the low-temperature exhaust heat of a factory, using the difference in temperature between day and night, such as a green energy created by the hydrate generation cycle, and the gas dissociation of the gas-hydrate. The pressure-temperature characteristics of the gas-hydrate change greatly with types of gas formed from the hydrates.[1] For example, in the case of CO_2 hydrate, a pressure differential (difference between the highest pressure of the gas dissociation and the minimum pressure of the hydrate generation) of approximately 3 MPa can be obtained on the phase equilibrium curve of generation and dissociation of approximately 10 degrees Celsius difference in temperature. Therefore, we were examined the operation of a high-pressure gas engine generator according to the differential pressure obtained from the difference in temperature. In this paper, the basic technology of an engine generator for distributed power supplies by a high-pressure gas is investigated. The high-pressure gas is generated by CO_2 hydrate that involves small risk. Until now, gas hydrates have been examined in many fields, such as the transportation of fuel gas and the undersea storage of CO_2[2]. However, the application of CO_2 hydrate in the working fluid of an actuator has not been studied yet.

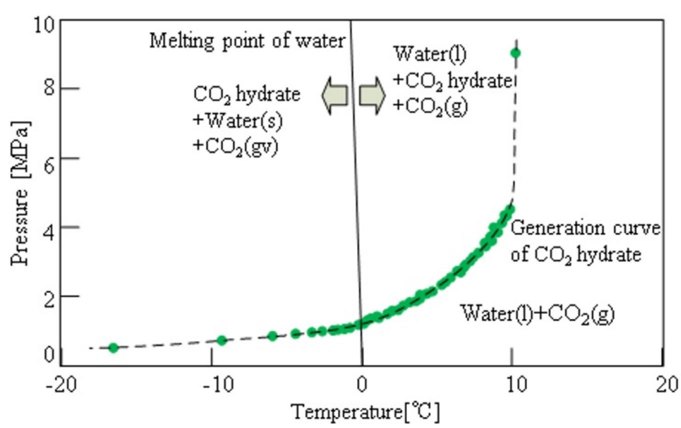

Fig. 1: Phase diagram of CO_2 hydrate

When operating an actuator using the differential pressure produced by the generation and the gas dissociation of CO_2 hydrate, CO_2 hydrate can provide energy storage. However, the energy density of the energy storage, the energy storage velocity, the energy release velocity, etc., of CO_2 hydrate have not been fully investigated. Therefore, in this paper, the generation rate of CO_2 hydrate and the quantity of the dissociation expansion energy to be stored are clarified by tests and numerical analysis.

2 CHARACTERISTICS AND APPLICATION TO DISTRIBUTED POWER OF CO_2 HYDRATE

Figure 1 is a state diagram of CO_2 hydrate [1]. In general, the difference between the maximum pressure when the

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gas hydrate generate and the minimum pressure when the gas dissociate can be obtained several MPa by small temperature differences. For example, the pressure difference can be obtained about 3 MPa by expansion of gas dissociation when Heating CO_2 hydrates 0 degree to 10 degrees, as seen in Fig. 1. Thus, in this paper, we propose to drive a generator by the high pressure gas engine using a pressure difference. In this case, high-temperature heat source and cold source achieved can by using the temperature differences between day and night in cold regions or low-temperature waste heat or natural energy such as solar and wind power. Suppose a CO_2 hydrate engine generator in this study (CH engine generator) proposed in this study is realized, unprecedented clean distributed power generation system can be built. In addition, CO_2 hydrate has a function of the energy storage, but the energy density of CH engine generator is expected to be low because the formation of the hydrate rate is slow. Until now, as there is no examples of applying CO_2 hydrate for the working fluid of the actuator, the feasibility of CH engine generator has not been known. This paper investigates the generation rate of CO_2 hydrate and the energy storage capacity of hydrate dissociation. This paper reveals the energy density of CH engine generator.

3 NUMERICAL ANALYSIS

3.1 Generation of CO_2 hydrate

The amount of CO_2 dissolved in water is very large, the amount of CO_2 dissolves in 100cm^3 of water under 25 °C, 100 kPa is 0.145g. Also in this condition, consumed CO_2 mole divided by mole of water described in Figure 2 ($n_g/n_{w,o}$) value is 0.000593. CO_2 hydrate is generated in condition of the hydrate formation shown in fig 1 after the CO_2 is saturated in water.

Kawamura, et al. reported in 2002[3] that the production rate of CO_2 hydrate is the fastest in the condition of the melting point of ice temperature and pressure conditions .

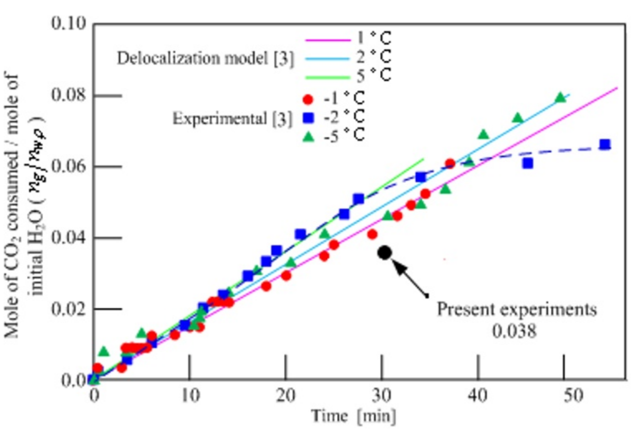

Fig. 2: Experimental and analysys results in the early period of CO_2 hydrate growth

Figure 2 shows the results of experiments and analysis of the rate of generation of CO_2 hydrate on the melting temperature of ice proposed by Kawamura, et al. .

3.2 Generation rate of CO_2 hydrate

The following is expressing CO_2 hydrate formation reaction.

$$\begin{aligned} &\mathrm{CO_2}(gas) + Hn\cdot \mathrm{H_2O}(liquid) \\ &\qquad \rightarrow \mathrm{CO_2}\cdot Hn\cdot \mathrm{H_2O}(hydrate) \end{aligned} \tag{1}$$

Here, Hn is the hydration number theory. Hn in the filling factor of 1 is 5.75. However, the filling factor realy becomes 1 therefore that most of the filling factor, Hn is around 7-8 [4,5]. In addition, the density of CO_2 hydrate is about 1.1, higher than that of sea water, depending on the hydration number when the hydrate generated in seawater[6].

Englezos-Bishnoi model[7] used to calculate the growth rate of hydrate[8]. This model assumes that growth is driven by the fugacity difference between before and after the hydrate generation. Equation (2) is a formula for the amount of CO_2 gas $n_g(t)$ consumed in the growth of hydrate. $n_g(t)$ has been assumed to be proportional to the amount of mol of water, $n_w(t)$, presenting the test space at the sampling time t. In addition, gas-liquid contact area is assumed to be proportional to the water.

$$\begin{aligned} \frac{dn_g(t)}{dt} &= K'\cdot\left(f_{ex}-f_{eq}\right)\cdot n_w(t) \\ &= K'\cdot\left(f_{ex}-f_{eq}\right)\cdot\left\{\, n_{w,o} - Hn\cdot n_g(t) \right\} \end{aligned} \tag{2}$$

Now, assuming Hn and $K'\cdot\left(f_{ex}-f_{eq}\right)$ is constant, the following equations is obtained by integrating the above equations. The hydration number Hn has been obtained from experiments of Hata 8.13 [8].

$$\frac{n_g}{n_{w,o}} = \frac{1}{H_n}\cdot\left[1-\exp\left\{-Hn\cdot K'\cdot\left(f_{ex}-f_{eq}\right)\cdot t\right\}\right] \tag{3}$$

Here, we investigate the hydrate generation process. As shown in equation (4), it is nessesary to correct the the equation (3) for amount of CO_2 dissolved until the generation of hydrates.

$$\frac{n_g}{n_{w,o}} = \frac{1}{hn}\left[1-\exp\left\{-hn\cdot K'\cdot\left(f_{ex}-f_{eq}\right)\cdot t\right\}\right]+\frac{n_{gf}}{n_{w,o}} \tag{4}$$

Here, n_{gf} is the number of moles of CO_2 dissolved in water when hydrate generated at the time. hn is the hydration number during the generation of hydrates. hn is approximately 11 in different conditions according to the experiments from Haneda, et al. [8].

3.3 Work of high pressure fluid

(1) CO_2 gas

As the energy conversion processes due to gas expansion in the actuator, the formula for thermal adiabatic work (5) is used.

$$P_{co_2} \cdot V_{co_2}^{\kappa} = \text{constant} \tag{5}$$

Here, P_{co_2}, V_{co_2}, κ are respectively the pressure, volume, and specific heat ratio of CO_2 gas. When CO_2 gas reaches the exit (state(P_a , V_a)) from the inlet (state (P_b , V_b)) of the actuator, the gas is assumed to be adiabatic expansion. In this case, the gas in the state of P_a , T_a , do adiabatic work until a state of P_b . CO_2 gas temperature at the outlet of the actuator is calculated as follows.

$$T_b = T_a \cdot \left(\frac{P_b}{P_a}\right)^{(\kappa-1)/\kappa} \tag{6}$$

Work obtained by the expansion of CO_2 gas can be calculated as follows. However, R_{CO_2} is the gas constant of CO_2.

$$L_{CO_2} = G_{CO_2} \cdot \frac{R_{CO_2}}{\kappa - 1} \cdot (T_a - T_b) \tag{7}$$

Work of water vapor L_{vp} also can be calculated as above.

(2) Liquid water

Work of high pressure water when changing State (P_a , T_a) to (P_b , T_b) is caluculated by the following.

$$L_w = V_w \cdot \Delta P_{a-b} \tag{8}$$

Here, V_w is the water mass flow, ΔP_{a-b} is the pressure difference between points a and b.

By dissociation of CO_2 hydrate in an enclosed space, work L_{chd} obtained by the pressure of rising water and gas, is the sum of Equations (7) and (8), as shown in Equation (9). Here, L_{vp} the right side of Equation (9) is the insulation work of steam.

$$L_{chp} = L_{CO_2} + L_{vp} + L_w \tag{9}$$

Each the generator efficiency and the mechanical efficiency of the actuator are represented as η_a and η_e . Then, the electrical output W from the actuator (engine generator) can be calculated as follows.

$$W = L_{chp} \cdot \eta_a \cdot \eta_e \tag{10}$$

4 EXPERIMENTS OF CO_2 HYDRATE GENERATION AND DISSOCIATION

4.1 Experiment system

Figure 3 is a summary of the experimental apparatus to study the generation and dissociation of CO_2 hydrate. Figure 3 (a) as shown in the experimental apparatus invention is to supply the heating medium for heating and cooling tube within the heat exchanger double tube, between the inner tube and outer tube of CO_2 and pure water filling the space (test space). This volume of the test space is approximately 100 cm^3. Inner diameter of the outer tube is 21.2 mm. outer diameter of the outer tube is 25.4 mm. Inner diameter of the inner tube is 12.8 mm. outer diameter of the inner tube is 10.2 mm. In addition, outside of the tube length (Fig. 3 (a)) is about 450mm. Figure 3 (b) shows that N_2 can also be supplied to the test space gas exchange in addition to CO_2 in the experimental apparatus.

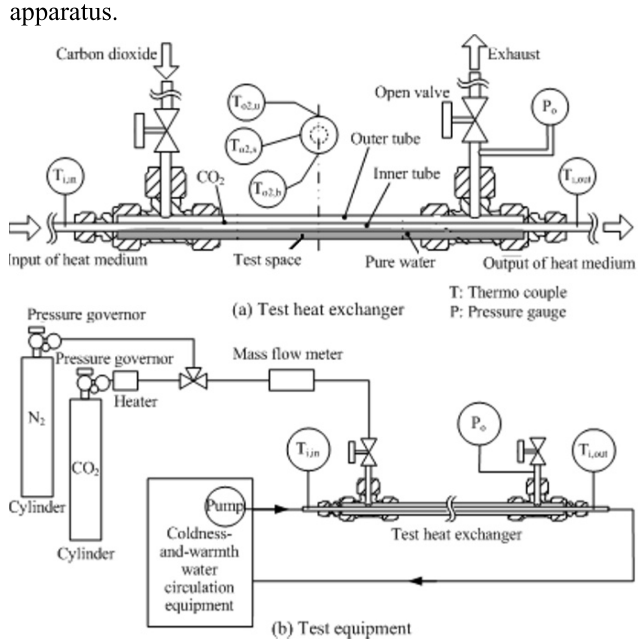

Fig. 3: Generation and dissociation test equipment of CO_2 hydrate

Temperature sensor (thermocouple type covering T) is installed in the entrance of the outer wall of the outer tube and the heating medium to measure the temperatures. In addition, the pressure in the test space is measured using a pressure sensor (Fig. 3 (a)).

4.2 Experimental Method

As described in Section 3.1, amount of CO_2 in water tend to dissolve in water. First, pure water should be filled in a test space. Then, the high pressure of CO_2 was supplied after 30 minutes, adjusted to 3 MPa by the release valve. The test space is filled with $50cm^3$ of pure water and $50cm^3$ of CO_2 each. Also, enough heat for generation and dissociation of CO_2 hydrate was provided for heat exchanger.

5 RESULTS AND DISCUSSION

5.1 Generation rate of CO_2 hydrate

Figures 5 (a) and (b) are the experimental results of Experiment A and B. Heating medium temperature during the hydrate generation in each experiment is -5 ˚C. The heating medium temperature, at the operation of the CO_2 dissociation in Experiment B, is 15 ˚C. In Experiment A, the operation continued for more than 16 hours in CO_2 hydrate generation. In Experiment B, generation and dissociation of CO_2 hydrate repeated a pattern of conducting for 1 hour and 30 minutes. Figure 5 (a) is the experiments of CO_2 hydrate generation of a long time.The generation rate slows down after the first 4 hours seen in fig 5(a). In addition, the generation rate of 30 minutes from begining is faster than the rater times. In Experiment B, we set a generation time CO_2 hydrate as 1 hour from the egining . CO_2 gas dissociation rate is faster than the CO_2 hydrate generation time, approximately 30 minutes in the case of Experiment B. In an ideal gas equation of state, gas pressure is reduced by contraction due to cooling the gas. Thus, in order to clarify the differences of lowering pressure due to the generation of CO_2 hydrate and the contraction of CO_2, similar experiments were carried out with N_2 instead of CO_2 to generate CO2 hydrate. The results are shown in Fig. 6. The natural radiation was 10 ˚C for 1 hour at room temperature after cooling. N_2 of 10 ˚C was cooled, the pressure was reduced to about 0.2 MPa. Therefore, the results of the pressure lowring due to the generation of CO_2 hydrate in each experiment in Fig. 5, indicate that each pressure lowring includes the pressure reduction caused by the contraction of CO_2 due to cooling the gas. The calculated results of the consumption of CO_2 in the generation of CO_2 hydrate on the experimental results A and B, are plotted in Fig. 2. Each results of the two experiments are lower than the results of the literature[7]. The reason is that each literature[7] consideres the rate of hydrate very fast, as the values on the melting point of ice. Furthermore, the rate of generation of

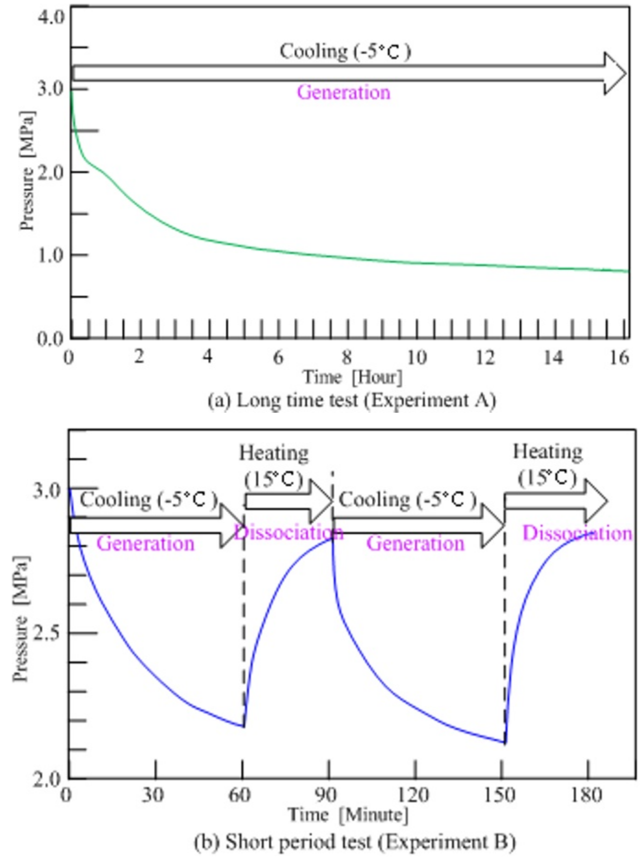

Fig. 4: Experiment results of the pressure of CO_2 dissolution test

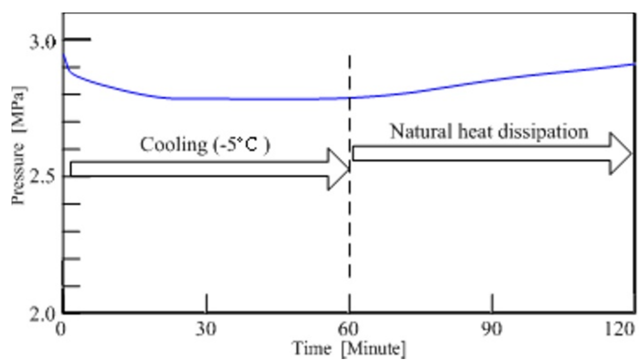

Fig. 5: Results of reference test using N_2

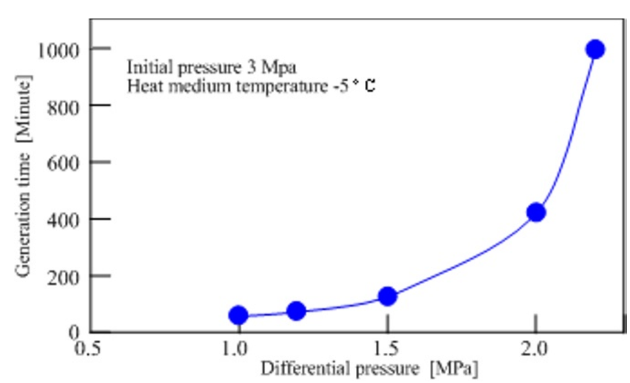

Fig. 6: Experiment results on the generation time for obtaining a pressure differential

hydrates changes easily by factors such as the structure of the test apparatus, stirring conditions and heat transfer.

5.2 Time to generate the CO_2 hydrate

In a Power generation system assumed in this paper, CO_2 hydrate behaviers as the working fluid as well as a energy storage. By generating a CO_2 hydrate, it is possible to store energy during the dissociation gas pressure rises. In this paper, we examined the time required for energy storage and the amount of energy storage of CO_2 hydrate. Figure 7 shows relation of differential pressure (the pressure difference between the minimum of the maximum pressure during hydrate formation and dissociation of gas) and CO_2 hydrate generation time , under the condition of 3 MPa initial pressure and the temperature -5 °C as the medium heat.This result, however, varys greatly depending on the heat transfer and the heat medium temperature setting. The results in Figure 7 indicates the time to produce the hydrate tekes suddenly longer , after the differential pressure exceeds 1.5 MPa.

5.3 The amount of energy storage

(1) Generation rate of CO_2 hydrate

Figure 9 shows the results of the consumption of CO_2 in generating hydrates including the experimental results of the initial pressure of 3 MPa (red curve) and the results from the analysis of initial pressure of 1.5 MPa to 6 MPa calculated by (4). In 120 minutes from the starting of the experiment, the differences between the experimental results at initial pressure 3 MPa and the analytical results is large. In addition, The characteristics of the experimental results between the time of 20 minutes from the beginning of the experiment and the ones after 20 minuites are very different.The causes of the difference suppoused to be insufficient water solubility of CO_2, nonsmooth heat transfar with phase change in double pipe heat exchanger possible. In the early dtage of the experiment, the CO_2 hydrate and ice is generated on the outside of the inner tube. The development of the hydrate is dominated by the thermal conduction, inrich heat transfers faster. However, as the thickness of the hydrate increasing over time, heat resistance increase. The causes of the differences between the experimental results and analysis results up to 120 minutes from the begining of the experiment should be necessary to examine further.

(2) Time required for energy storage

Figure 10 shows the relation of the energy storage rate and the generation time when generating $1m^3$ CO_2 hydrate in water. In figure 10, the curve of 3 MPa initial pressures is the experimental result and the curves of the initial pressure of 5 MPa and of 6 MPa are obtained from the analysis.The method of calculating the analysis is as follows.First, the amount of CO_2 hydrate is generated based on the $n_g/n_{w,o}$ shown in Fig. 9. Then, the storage

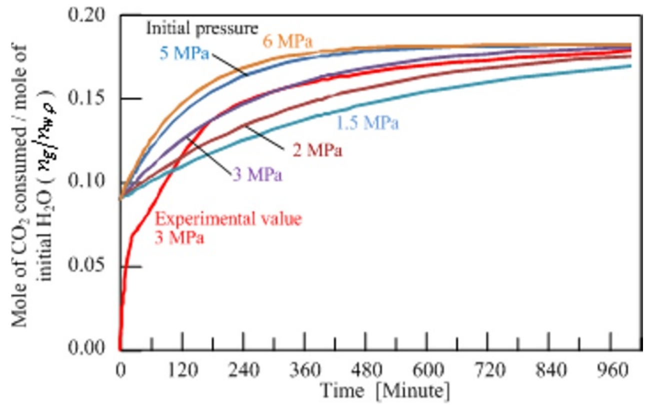

Fig. 7: Generation characteristics of CO_2 hydrate

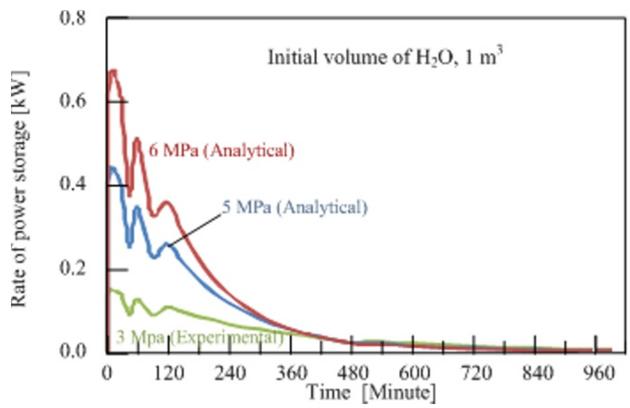

Fig. 8: Analysis results of the rate of power storage

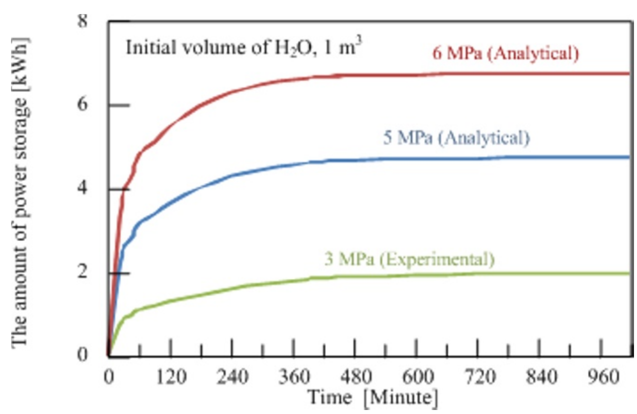

Fig. 9: Analysis results of the amount of power storage

pressure is calculated based on the value expected. Finally, the expression is obtained by calculating Equation (6) ,(7), (8), and (9). However, the K' in the formula (4) is obtained using each sampling time of the initial pressure of 3 MPa. Therefore, the experimentally observed initial pressure of 3 MPa variations up to 120 minutes from the begining of the experiment also appeared in analysis of 5 MPa and 6 MPa. Energy storage rate per hour by generation of CO_2 hydrate, after 360 minutes, is almost the same regardless to the initial pressure. Figiure 11 is the amount of CO_2 hydrate energy storage that can be stored in $1m^3$ of water. Like Fig. 10, curve of 3 MPa initial pressures is the experimental result, and 5 MPa and 6 MPa are analitical results. The results in Figure 11 shows after approximately 480 minutes, the energy storage doesn't increase. Without the air conditioning load, power consumption of a house for a day is about 10 kWh. Therfore the energy storage by the CH generator engine under 6 MPa initial pressure is approximately 45 % (4.5 kWh end power output) of power consumption of a house. This result is calculated from Eq. (10), the values of η_a and η_e ,are caluclated as 0.85 and 0.8 respectively.

6 CONCLUSIONS

The goal of this study is to drive a high pressure gas engine generators as distributed power, focusing on the pressure difference obtained by a temperature differences of CO_2 hydrate. In this paper, we investigated generating characteristics, the generation rate, the amount of energy strage of dissociation expansion of CO_2 hydrate.

As a result, the following conclusions were obtained.

(1) The pressure difference between generation and dissociation of hydarete incres as the temperature of the hydrate decreases.However, when the temperature of the hydrate falls below 0 °C , the increasing pressure difference becames very small. Instead, it is believed that the concentration of CO_2 hydrate in water increases.

(2) Energy storage rate per hour by generation of CO_2 hydrate, when after 360 minutes, is almost the same regardless to the initial pressure.

(3) Without the air conditioning load, power consumption of a house for a day is about 10kWh. Therefore the energy storage by the CH generator engine under 6 MPa initial pressure is approximately 45% (4.5 kWh end power output) of power consumption of a house. However, experiment results and analysis results are significantly different, the causes of the differences between the experimental results and analysis results up to 120 minutes from the beginning of the experiment should be necessary to examine further.

NOMENCLATURE

A : Gas-liquid contact area [m2/mol]

f_{eq} : Fugacity of gas in the three-phase balanced condition [MPa]

f_{ex} : Fugacity of gas in experimental condition [MPa]

G : Mass [kg]

H_n : Theoritical hydration numbers

K : Rate constant [/(MPa・min・m^2)]

K' : Overall rate constant [/(MPa・min)] ($K' = K \cdot A$)

L : External work [J]

L_{chd} : Work obtained by the pressure of rising water and gas [J]

n_g : Amount of CO2 captured in the hydrate [mol]

n_w : Amount of wator [mol]

$n_{w,o}$: Initial number of moles of water [mol]

P : Pressure [Pa]

R_{CO_2} : Gas constant of CO_2 [kJ/(kg・K)]

T : Temperature [K]

t : Sampling time [s]

V : Volume [m^3]

W : Electrical output of the generator [W]

Roman character

κ : Specific heat ratio

Subscript

a : Inlet of actuator

b : Outlet of actuator

ch : CO_2 hydrate

w : Water

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Combustion Characteristics of Bio-Mass Gas as Utilizable Energy

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Abstract

Some of biomass gases are produced by the gasification in the gas furnace and by sewerage processing. Recently, it is required that the low-calorie bio-mass gas is utilized as a renewable energy. It is remarkable that the bio-mass gas is used as a substituted fuel. The gas includes various species of components which are such inert gas as Nitrogen N_2 ,carbon dioxide gas CO_2 and such flammable components as hydrogen H_2 ,methane CH_4 and carbon monoxide CO. The calorific value of the fuel depends on the ratio of each component. Holding the flame is an important pole in the burning technique but there are many obscure points of the flame structure, the burning characteristics, extinction and so on. It is not easy to hold the stabilized flame. The stability mechanism for holding the flame has been studied. It is found that the parameters for holding the diffusion flame are fuel velocity, co-flowing velocity, nozzle diameter (curvature of nozzle), condense of the fuel. Bio-Mass Gas is used as a utilizable energy.

Keywords:

bio-mass gas, renewable energy, diffusion flame, low calorific fuel

1 INTRODUCTION

Gasification gas produced in gasification furnace and low calorie bio-mass gas collected from sewerage processing are receiving attention as renewable energy(1). The bio-mass gas of which the release calorific value is about a tenth of methane calorific value is the low calorie gas that contains much inert gas (N_2, CO_2). It is important that the bio-mass gas is utilized as one of renewable fuel. In this study we research into combustion characteristic and stability limits of the diffusion flame. The simulant gas whose component ratios are similar to the components of the bio-mass gas collected from gasification furnace is used as fuel of the experiment. The relation between the inside diameter of the burner nozzle and the stability limits of flame is investigated.

2 EXPERIMENT EQUIPMENT

Fig.1 shows the flow diagram of experiment equipment. It contains gas vessels, flow-meter, and burner.

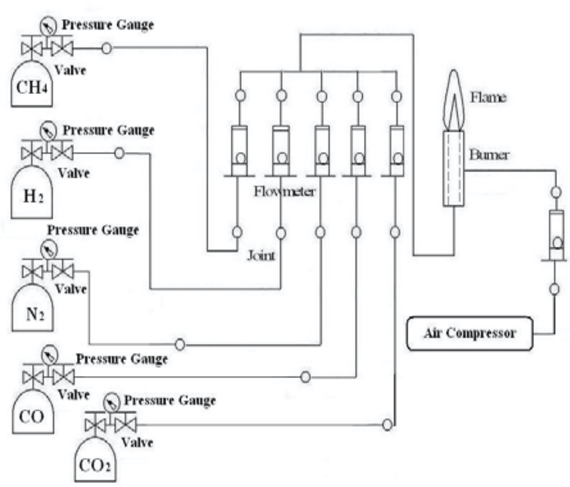


Fig. 1 Flow Diagram

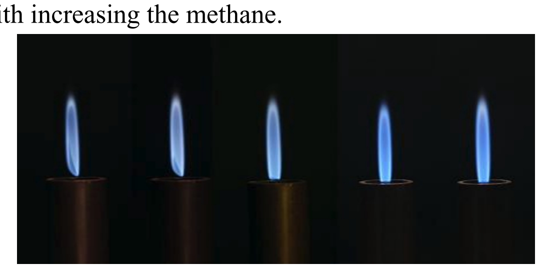
The simulant gas which is similar to the bio-mass fuel gas collected from gasification furnace is used as the fuel. The ratios of the components are CH_4:2.48%, H_2:12.13%, CO:8.91%, CO_2:12.92%, and N_2:63.56%. The lower calorific value is 3.322[MJ/m3] (But the lower calorific value of methane is 35.79[MJ/m3]). Flow-meter with precision needle valve is used for controlling the fuel flow rate. Using the burners of eight different sizes, the experiment is executed. The inside diameters are 0.34mm, 0.51mm, 0.60mm, 0.94mm, 1.21mm, 1.94mm, 3.40mm, and 5.00mm. And the combustion air is supplied by the compressor. The temperature of the internal flame is measured by R type thermocouple (Pt-PtRh13%) and it is moved in the vertical direction and in the radial direction.

3 RESULTS AND DISUCCUSION FOR FLAME STABILITY OF SIMULANT BIO-MASS GAS

Bio-mass gas contains various gas components. The effective utilization of the biomass is required. Flame stability of simulant bio-mass is researched regard to the flame stability (2).

3.1 Stability and Structure of bio-mass flame

Fig. 2 shows the flame structure of bio-mass gas 0.6[L/min] with adding methane. The flame is stabilized with increasing the methane.



0.01 0.02 0.03 0.04 0.05

Flow rate of Methane [L/min]

Fig.2 Flame configurations with adding Methane

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Fig.3 shows the flame configurations of bio-mass gas flame with increasing the air velocity of the circuit flow,. when the bio mass gas rate is 0.1 L/min and0.02L/min of methane is added to the biomass gas

. When the circuit air velocity is higher, the flame is not stabilized .

0 0.07 0.14 0.21 0.28 0.35

Circuit Air velocity [m/s]

Fig. 3 Flame configurations of bio mass gas to add methane with increasing the circuit air velocity

Fig.4 shows the flame configurations when the rate of bio-mass gas is 0.2[L/min] and 0.011[L/min] of hydrogen is added with increasing the circuit air velocity.

0 0.35 0.70 1.05

Circuit Air velocity [m/s]

Fig.4 Flame configurations of bio mass gas with hydrogen with increasing the circuit air velocity

Figure 5 shows the circuit air velocity when the flame blows off.

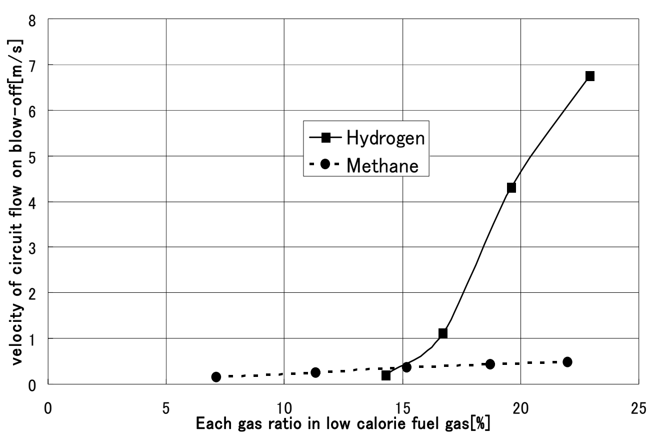

Fig.5 Blow-off velocity for mixture ratio in bio-mass gas with increasing Circuit Velocity

Hydrogen is more effective for flame stability of bio-mass gas than methane.

3.2 Hydrogen flame stability

When hydrogen H_2 is diluted with nitrogenN_2, the stability limit[3] of the diluted hydrogen is investigated with increasing the spout velocity of the fuel which is the diluted hydrogen. When the ratio of hydrogen is 20, 25,30,and 35%, the blow off velocity is shown in Fig. 6 When the ratio of hydrogen is over 30%, flame stability is gone up. The blow off velocity increases, when the nozzle diameter is 0.34 to 1 mm. when the burner inside diameter is around 1mm, the bow off velocity decreases. It is necessary that the reason is will be discussed.

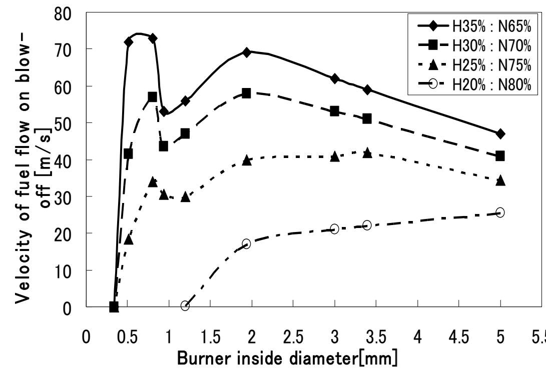

Fig. 6 Velocity of fuel flow on blow-off for each burner inside diameter

When hydrogen H_2 is diluted with carbon dioxide CO_2, the stability limit of the diluted hydrogen is investigated with increasing the spout fuel velocity. When the ratio of hydrogen is 20, 30,and 35%, the blow off velocity is shown for the burner inside diameter in Fig. 7 . The blow off velocity increases, when the nozzle diameter is 0.5 to 1 mm. When the burner inside diameter is around 1mm, the bow off velocity decreases as the bow off velocity of the diluted hydorogen with nitrogen.

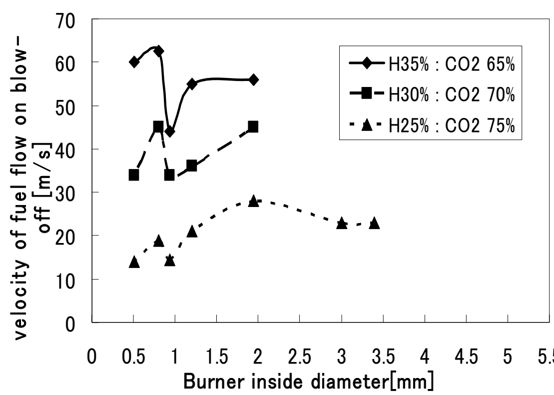

Fig. 7 Velocity of fuel flow on blow-off for each burner inside diameter

Fig.6 and Fig.7 are combined into Fig.8. Fig.8 shows that the blow off velocity of the diluted hydrogen with nitrogenN_2 is 20~30% less than the blow off velocity of the diluted hydrogen with carbon dioxide CO_2

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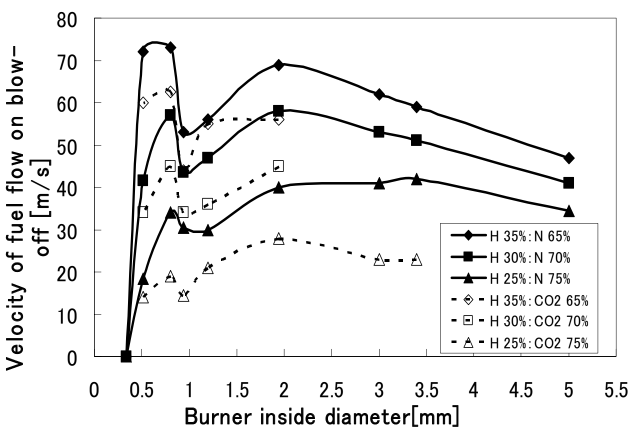


Fig. 8 Velocity of fuel flow on blow-off for each burner inside diameter

3.3 Methane flame stability

When methane CH_4 is diluted with nitrogenN_2, the stability limit of the diluted methane is investigated. When the ratio of methane CH_4 is 30, 35, 40, and 50%, the blow off velocity for the burner inside diameter is shown in Fig9. When the burner inside diameter increases, the blow off velocity increases for every burner diameter. That is the flame stability increases. And when the ratio of methane CH_4 is over 40%, the blow off velocity is up rapidly as the burner inside diameter is over 3.5mm. The fuel gas is not ignited under when the burner inside diameter is less than 1mm.

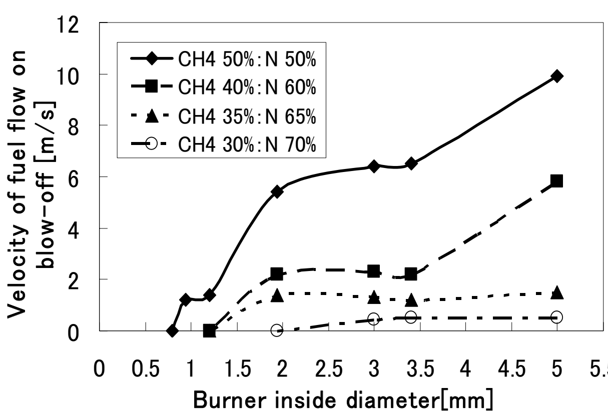


Fig. 9 Velocity of fuel flow on blow-off for each burner inside diameter

When methane CH_4 is diluted with Carbon dioxide CO_2, the stability limit of the diluted methane hydrogen is investigated. When the ratio of methane CH_4 is 40% and 50%, the blow off velocity for the burner inside diameter is shown in Fig10. When the ratio of methane CH_4 is over 40%, the blow off velocity is up rapidly as the burner inside diameter is over 3.5mm.

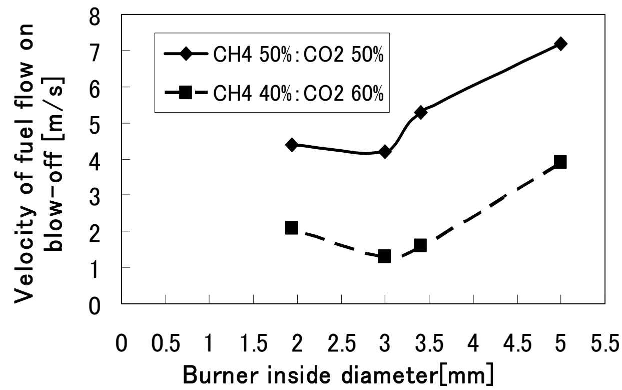


Fig. 10 Velocity of fuel flow on blow-off for each burner inside diameter

Fig.9 and Fig.10 are combined into Fig.11. Fig.11 shows that the blow off velocity of the diluted hydrogen with nitrogenN_2 is 20~30% less than the blow off velocity of the diluted hydrogen with carbon dioxide CO_2.

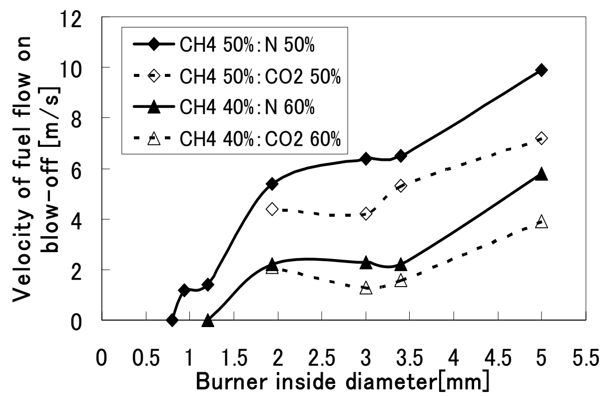


Fig. 11 blow-off velociy for each burner inside diameter

3.4 Effect of Carbon monoxide for Profiles of Flame Temperature

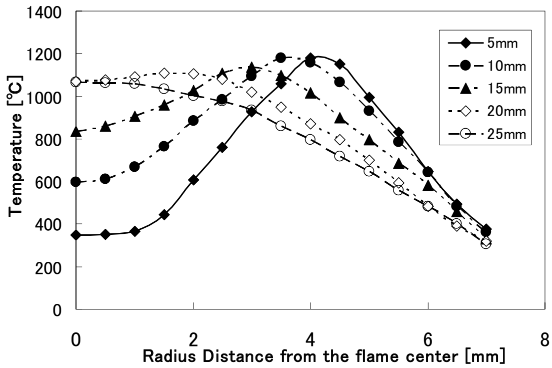
Bio-mass gas contains Carbon monoxide CO. The combustion characteristics of Carbon monoxide are studied. The profiles of flame temperature are measured by the R Type thermocouple.

Fig.12 (a) shows the radial profiles of the internal flame temperature of the simulated bio-mass gas (CH4:11.3% H2:11.0% N2:57.8% CO2:11.8% CO:8.1 %). It is measured at each cross section, which is located at 5, 10, 15, 20, 25 mm from the top of the burner nozzle.

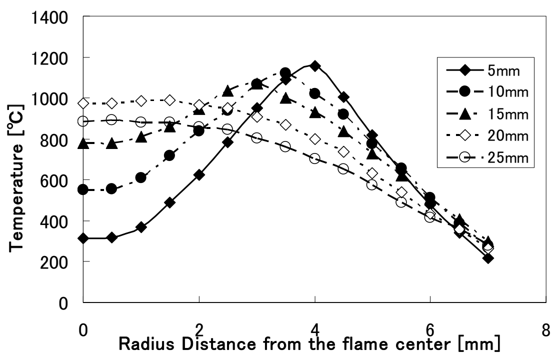
Fig.12 (b) shows the radial profiles of the internal flame temperature of the simulated bio-mass

gas which excludes CO (CH4:11.3% H2:11.0% N2:57.8% CO2:11.8% CO:0%).

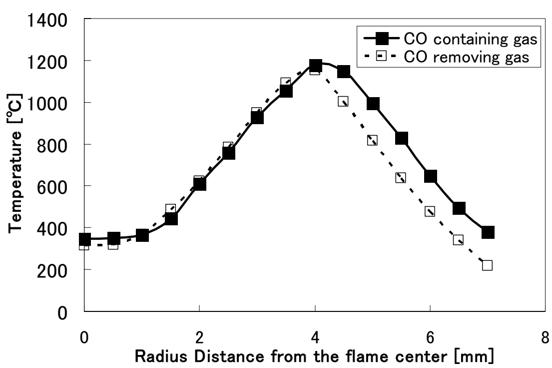
Fig.12 (a) and Fig.12 (b) are compared for the profile of temperature on the cross section at 5mm from the burner nozzle in Figure 12(c).



(a) H_2:7.4% CH_4:17.6% CO_2:11.3% N_2:55.8% CO:7.9%



(b) H_2:7.4% CH_4:17.6% CO_2:11.3% N_2:63.7% CO:0%



(c) Comparison

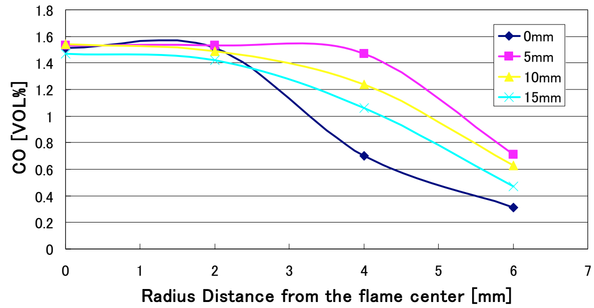
(Spout biomass velocity is.467[m/s] The burner inside diameteris5.00[mm])

Fig.12 Radial profiles of Flame Temperature

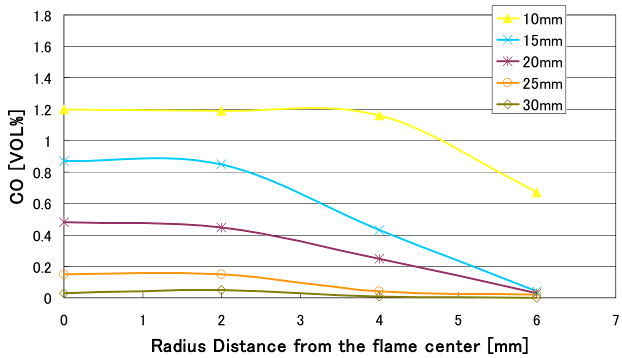
The maximum of flame temperature is 1180℃ in Fig,12(a) and is 1150℃inFig.12 (b). Flame temperature is increasing when the ratio of CO increases. And the flame surface moves outside in the radial direction.

3.5 Combustion of Carbon monoxide

Bio-mass gas contains Carbon monoxide CO. Fig.13(a) shows the radial profiles of Carbon monoxide CO concentration of the simulated bio-mass gas at each cross section which are located at 5, 10, 15, 20, 25mm from the top of the burner nozzle in unburned flow. Fig.13(b)shows the radial rofiles of CO at each cross section which are located at 10, 15, 20, 25, 30mm from the top of the burner nozzle when the flame is formed.



(a) unburned flow



(b) Flame Inside

Fig.13 Radial profiles of CO

It is indicated that the combustion of Carbon monoxide in the flame is completed

4 CONCLUSION

(1)The stability of the diffusion flame depends on the fuel velocity. The flame is stabilized when a bit of hydrogen and/or methane is added to bio-mass gas. It is found that the biomass gas is utilized as a renewable fuel.

(2) CO is effective to raise the flame temperature.

(3) Stability of bio-mass gas flame depends on burner inside diameter. And the flame is stabilized with increasing the inside diameter of the burner nozzle

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Life Cycle Assessment of CdTe Photovoltaic System

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Abstract

In this study, life cycle assessment (LCA) of Cadmium Telluride (CdTe) photovoltaic (PV) system is carried out to analyze its environmental impact on global warming (GW) and abiotic resource depletion (ARD). The CdTe PV system consists of CdTe PV module, power conditioning system (PCS) and balance of system (BOS). The global warming potential (GWP) of CdTe PV system is 11.1g CO_2 eq./kWh under the condition of 1,810.4 kWh/m^2/yr, 11.2% of conversion efficiency, 80% of performance ratio. The ARD of system is 1.20E-02/yr/kWh. The CdTe PV module accounts for 62.9% and 59.3% of the GWPs and ARDs of the entire CdTe PV system, respectively. And energy payback time (EPBT) which is the time required to compensate the energy used during the life cycle of PV system with avoided primary energy reduction by using PV system is estimated. The EPBT of CdTe PV system is 0.69 years, meaning that the electricity generated by the PV is regarded as net energy profit.

Keywords:

CdTe PV, photovoltaic, LCA, EPBT

1 INTRODUCTION

The renewable energy technologies such as PV have gained a reputation for being sustainable and environmental compatible and protect the environment from risk and damaging impacts [1]. However, all anthropogenic means of energy production such as PV system generate pollutants when their entire life cycle is accounted for [2]. Thus, it is essential to know the environmental performance of PV system which consists of CdTe PV module, PCS and BOS during its life cycle.

2 METHODOLOGY

LCA is defined as the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [3]. In this study, GWP and ARD of the CdTe PV system were assessed by using the eco-indicator methodology developed by the Ministry of Knowledge Economy (MKE) of Korea.

3 GOAL AND SCOPE DEFINITION

3.1 Goal of the study

The goal of the present LCA study is to analyze the environmental impact and identify the significant environmental issues associated with the CdTe PV system.

3.2 Scope of the study

Description of target system

The CdTe PV system in this study is 100kW PV system of First Solar, Inc., Malaysia. The specification of the system is explained in Table 1.

Table 1 : Specification of the system

Category		Information
PV module	Total area	893 m^2/EA
	Total weight	14,883 kg/EA
	Conversion Efficiency	11.2 %
	Performance ratio	80 % [4]
	Operation Life time	30 years [4]
PCS	Generator maximum power	110 kW
	Maximum input voltage	1,000 V
	Maximum input current	235 A
	Rated output	100 kW
	Weight	1,120 kg

Description of system boundary

The system boundary defined in this study includes resource extraction, manufacturing of CdTe PV, use stages. Recycling and disposal stage is excluded because of the lack of disclosed information for representative recycling process. Fig. 1 shows the system boundary of the study.

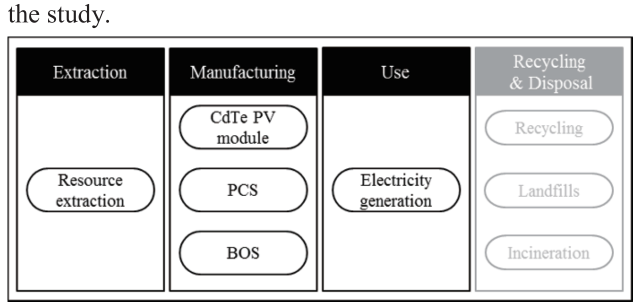

Fig. 1 : System boundary of the study

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Functional unit

A functional unit is the quantified performance of a product system for use as a reference unit in LCA [3]. The functional unit in this study is defined as the electricity of 1kWh generation from 100kW PV system.

Environmental impact categories

The production of energy by burning fossil fuels generates pollutants and carbon dioxide. Since current electricity production heavily relies on fossil fuels, it is envisioned that expanding generation technologies based on renewable energy sources would dramatically reduce future greenhouse gas (GHG) emissions [2]. Hence, the impact categories of GW and ARD are considered.

4 DATA COLLECTION AND CALCULATION

4.1 Data quality requirements

The time-related, geographical, and technical boundaries of data

Descriptions of data quality are important to understand the reliability of the results and properly interpret the out com of the study. Table 2 shows the data quality requirements defined in this study.

Table 2 : Data quality requirements

Boundary	PV module	PCS	BOS
Time-related	2005	2010	2010
Geographical	Malaysia	Korea	Korea
Technical	Techonology in 2005	Up-to-date technology	

Data collection

For the data collection, questionnaires as well as on-site visits to relevant facilities, industrial complex, and public corporations with a large market share are used. Table 3 shows type of data collection used in the study.

Table 3 : Type of data collection

Category	PV module	PCS	BOS
Type of collection	Questionnaire	Onsite visit	Onsite visit
Data source	First Solar, Inc	KACO New Energy	Woo-ri energy bank

Cut-off criteria

Since more than 500 inputs are used in the CdTe PV module, it is necessary to apply appropriated cut-off criteria. 99% of the cumulative mass contribution and environmental significance by Toxicity Release Inventory are considered.

PCS has more than 260 inputs and 99% of cumulative mass contribution is applied for PCS, too.

Data calculation

Data for CdTe PV module and PCS are calculated based on mass and energy balance, respectively. Since there is no installed CdTe PV system in Korea, the amount of BOS for CdTe PV is calculated based on other types of PV system.

5 RESULTS

Total electricity of 4,344,812 kWh is generated by 100kW CdTe PV system under the conversion efficiency 11.2%, performance ratio of 80%, an annual average radiation of 1,810.4kWh/m^2/yr and life time of 30 years.

5.1 GWP

The GWP of CdTe PV system is 11.1g CO_2 eq./kWh. The GWP of CdTe module is 7.0g CO_2 eq./kWh which accounts for 63.4% of the total GWP. The GWPs of PCS and BOS are 2.8g CO_2 eq./kWh (25.4%) and 1.3g CO_2 eq./kWh (11.2%), respectively. Fig.2 shows the results of GWP.

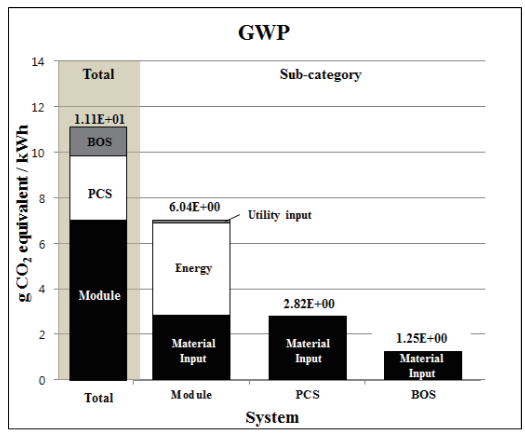

Fig. 2 : The GWP results of CdTe PV System

The electricity used to produce CdTe PV module is the main cause for the GWP of the system and its contribution to the total GWP is 36.6% (4.06 g CO_2 eq./kWh). And, 25.3% (2.81 g CO_2 eq./kWh) of the total GWP is due to the parts of PCS. The contribution of material input is significant because the raw materials of CdTe module such as CdTe and CdS have considerable amounts of life cycle CO_2 emissions.

5.2 ARD

The total ARD of the CdTe PV system is 4.30E-05/yr/kWh. The ARD of CdTe module is 3.08E-05/yr/kWh which accounts for 71.7% of the ARD results for the CdTe PV system. PCS and BOS are 3.08E-06/yr/kWh (18.8%) and 4.09E-06/yr/kWh (9.5%), respectively.

Fig. 3 shows the ARD results of the CdTe PV system. The electricity of CdTe PV module is the main cause for the ARD results of the system and its contribution to the total ARD of CdTe PV system is 37.6% (1.61E-05/yr/kWh). The raw materials of CdTe module such as plate glass and ethyl vinyl acetate (EVA) have considerable amounts of ARD values. The contribution of BOS is caused by the raw materials such as different shapes of steels.

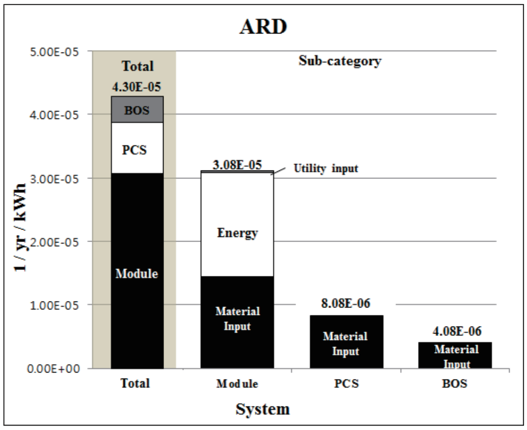

Fig. 3 : The ARD results of CdTe PV System

5.3 EPBT

The concept of EPBT is introduced based on that the alternating current (AC) electricity produced by a PV system displaces an equal quantity of the primary energy input for existing electricity generation. EPBT is calculated from the following equation;

$$\text{EPBT (yr)} = \frac{\text{Total energy input[MJ]}}{\text{Avoided annual primary energy reduction by using PV system } [\text{MJ}/\text{yr}]}$$

where, total energy input means total energy input throughout the life cycle of the 100 kWp CdTe PV system. Avoided annual primary energy reduction is the total primary energy reduction by electricity generation. Primary energy input of Malaysia grid is 7.96MJ/kWh.

The amount of total enery input for 100kWp CdTe PV system is 7.98E+5 MJ (module 5.06E+5 MJ, PCS 1.90E+5, BOS 1.02E+5 MJ), whereas the annual primary energy input reduction by CdTe PV system is 1.15E+6 MJ. Fig.5 shows the EPBT of the CdTe PV system. After passing the EPBT as 0.69 years, the amount of electricity generation is regarded as net energy profit.

6 CONCLUSION

From the LCA study of CdTE PV system the GWP and ARD results are obtained for 1 kWh electricity generation from 100kW CdTe PV system. In addition, the EPBT for 100kW CdTe PV system is estimated.

(1) CdTe PV system has very low GWP which is 11.1g CO_2 eq./kWh. CdTe system consists of CdTe PV module, PCS and BOS. Those are accounted for 63.4%, 25.4% and 11.2%, respectively.

(2) ARD of the CdTe PV system is 4.30E-05/yr/kWh. CdTe PV module accounts for 71.7% of whole impact of the system. PCS and BOS account for 18.8% and 9.5%, respectively.

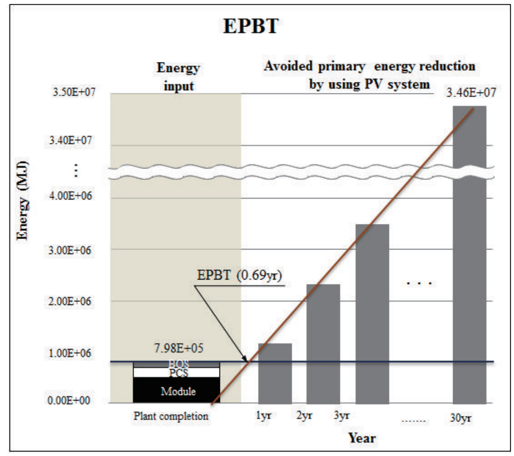

Fig. 4: Results of EPBT

(3) EPBT for the present 100 kW CdTe PV system is 0.69 year. The amount of electricity generated after 0.61 year from the PV system is considered as net energy profit.

7 ACKNOWLEDGEMENTS

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Service System Design and Evaluation for Battery of Electric Vehicles

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Abstract
Service system design for battery is very essential for promoting electric vehicles in building a low carbon society. This study focuses on generation as well as evaluation of new service designs for electric car's battery. Morphological analysis is used to generate service design concepts with selected dimension and shape parameters. On the other hands, conjoint analysis with carefully selected attributes and attribute levels is used to model customers' preference. After part worth utilities of these attributes are estimated for each customer, total utilities of generated service design concepts can therefore be estimated. With utilities of all customers, overall market responses to various service designs could be therefore simulated. Not only preference of customers could be ranked, but potential customers who favor designated design concepts are identified. Market segments and competition among promising design concepts are also analyzed and discussed.

Keywords:
battery, conjoint analysis, electric vehicle, morphological analysis, system design

1. INTRODUCTION

Global warming has become an essential issue worldwide and influenced industry and business management. Almost all countries have declared that carbon reduction and energy saving are and would be one of the most important policy making directions. Some companies have aggressively taken this as a great chance for developing new product and technology. Electric vehicle is one of the most promising products with sustainability concept. However, energy supply for electric vehicle is very different from conventional gas station service because (1) battery is relatively expensive and (2) recharge time is much longer than conventional fuel refill. How to build a proper service system for electric car battery becomes an important issue. Since battery is very expensive, nearly half price of a vehicle, service types other than simply recharge like rental and swap for a charged battery are considered. Many experimental projects have been conducted on infrastructure of service system for electric vehicles. For example, a "Better place project" has been conducted across several nations, developing and demonstrating different types of battery service systems. Taiwan government also selects demonstrative counties to find better operating systems for promoting electric vehicle in large area.

This study focuses on both generation and evaluation of service system designs. With conjoint analysis, customers' preference of service designs is modeled with multiple attribute utility function. Various system design concepts are generated with morphological analysis and technology feasibility. Adoption and preference on each system design concept of each customer can be modeled with the results of conjoint analysis. Not only preference of various types of system design can be obtained, but market shares of selected designs can be estimated.

In general, service design has to include several steps such as (1) detect customers' need, (2) generate new design concept, (3) evaluate candidate designs, (4) detail design and modification, and (5) implementation [1], [2]. Morphological analysis has been used to help generate new design concepts in many literatures. Examples include [3], [4], and [5]. After reviewing all feasible technologies in battery service, morphological analysis is used to generate potential service designs with dimension parameters and shape parameters.

On the other hand, conjoint model has been widely used in new product development ([6], [7]) to estimate customers' utility function and find the preference structure. The part worth utility (PWU) estimation of important attributes could be helpful in detecting customers' responses to new designs. There are three major parts in conjoint analysis. First, important attributes that are major concern of customers for the new product must be carefully selected. Secondly, hypothetical product profiles (so called stimuli) that are combinations of different attribute levels are presented to customers to collect their ratings or choice. Finally, regression analysis is conducted to estimate respondents' part worth utilities of all attributes.

The regression model is as follows, where X_{iks} is attribute level s of kth attribute that presented in profile i and A_{ks} is PWU of attribute level s of attribute k.

$$y_i = \sum_{k=1}^{K}\sum_{s=1}^{S_k} A_{ks} X_{iks} \qquad (1)$$

S_k : total attribute levels of attribute k $(k=1, 2,\ldots, K)$

y_i : Rating on the ith product profile, i.e. willingness to adopt the ith stimuli.

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Reference [8] proposed a method of calculating relative importance of attributes, RIA). The larger range of attribute's PWUs, the more important the attribute is.

$$RIA_k = \frac{[A_{k(\max)} - A_{k(\min)}]}{\sum_{k=1}^{K}[A_{k(\max)} - A_{k(\min)}]} \times 100\% \quad (2)$$

RIA_k : Relative importance of attribute i

$A_{k(\max)}$: the max PWU in attribute k

$A_{k(\min)}$: the min PWU in attribute k.

2. Attributes Selection and Morphological Analysis

After studying literature and conducting small sample survey, four attributes are selected to represent customers' concern on battery service. They are (1) price, (2) service time, (3) time to reach a service station, and (4) time to other nearby services like reaching theater or department store. The range of service time covers both recharge service and battery swap since differentiation of the two types of services is necessary. Time to reach a service station implies density of service station. In Taiwan, for example, time to reach a conventional gas station is generally within 30 minutes. Attribute levels are determined so that all possible levels for potential service designs are covered. Table 1 shows the selected attributes and attribute levels.

Table 1: Attributes and attribute levels

Attribute	Attribute Levels
Price per service	(1) 200 NTD
	(2) 600 NTD
	(3) 1000 NTD
Service time	(1) 5 min
	(2) 120 min
	(3) 360 min
Average time to reach	(1) within 5 mins.
	(2) 6~30 mins.
	(3) more than 30 mins.
Time to other service	(1) within 5 mins.
	(2) 6~15 mins
	(3) more than 15 mins or No other service available

A questionnaire survey is conducted via both field interview and internet. The questionnaire includes two parts: (a) basic information of respondents, including gender, age, residence, education, vocation, and income, and (b) hypothetical service profiles that are basically combinations of attribute levels and are obtained via orthogonal arrays to collect respondent's rating in adopting the specific service. Reference [9] has detail discussion on questionnaire design. The ratings on service profiles were used in regression analysis to estimate part worth utilities of four attributes for each respondent via SPSS. Information of respondents is used to conduct further statistical analysis to describe customers' characteristics.

On the other hand, morphological analysis is used to generate new service design concepts. Table 2 shows the results of morphological analysis, where dimension parameters include service type, equipment type, location area, accessibility, and time to other service and shape parameters include several possibilities of dimensional parameters. With combinations of dimension and shape parameters, 78 design concepts are generated representing service designs that could be considered in the near future.

Table 2: Morphological matrix

Dimension Parameter	Shape Parameter			
	1	2	3	4
Service type	recharge	swap		
Equipment type	ordinary charge	rapid charge	automat ic swap	manual swap
Location area	commerci al	residenc e		
Time to station	within 5 min	6~30mi n	more than 30 min	
Time to other service	within 5 mins	6~15 mins	more than 15 mins or not available	

3. Customer Preference and Customers Grouping by Relative Importance

A survey was conducted during November of 2009 to January of 2010. Totally, 253 effective responses were collected. PWU of four attributes were estimated using regression analysis of SPSS software. Table 3 shows the PWU and relative importance of four attributes.

Based on relative importance of each respondent, cluster analysis was conducted to group potential customers. Two groups of customers were identified with significant difference on relative importance. Group 1 concern more on "time", while group 2 puts more emphasis on "price". Table 4 shows the PWU and relative importance of two groups. Group 2 puts most of weighting on price (59%), while group 1 put more weight on service time (51%). After checking on respondents' background information, Group 1 (concern on time) tends to be single, younger, living in metropolitan area, and occupation including commerce, independent worker, and student.

Table 3: PWU and relative importance of all respondents

Attribute	Level	PWU	RIA
Price per service	200 NTD	-0.908	41.7%
	600 NTD	-1.817	
	1000 NTD	-2.725	
Service time	5 min	0.975	40.3%
	120 min	-1.191	
	360 min	-0.784	
Average time to reach	within 5 mins.	0.323	
	6~30 mins.	-0.910	12.7%
	more than 30 mins.	-0.232	
Time to other service	within 5 mins.	0.152	5.3%
	6~15 mins	-0.079	
	more than 15 mins	-0.072	

Table 4: PWU and RIA of two groups

Attributes	Group 1 (56.13%)		Group 2 (43.5%)	
	PWU	RIA	PWU	RIA
Price	-.501	23.59%	-1.429	59.13%
	-1.002		-2.859	
	-1.504		-4.288	
Service time	1.208	51.66%	.677	24.84%
	-.221		-.152	
	-.987		-5.25	
Time to station	.356	13.87%	.280	10.56%
	-.123		-.050	
	-.233		-.230	
Time to other services	-.243	10.88%	.034	5.47%
	-.024		-.149	
	-.219		.115	

4. WILLINGNESS TO PAY FOR VARIOUS SERVICE TIME LEVELS

Willingness to pay from one attribute level to another attribute level can be estimated by transforming the utility of price and the specific attribute levels. Table 5 shows the willingness to pay for difference between various service times for all respondents, while Table 6 shows the willingness to pays of two groups of respondents. The levels of service times include (1) swapping battery in 5 mins. (automatic) and 20 minutes (manual) and (2) recharging battery in 37, 180 and 360 minutes. On the average, comparing to manual battery swap, customers are willing to pay 67 NTD more for automatic battery swap and willing to pay 78 NTD more for rapid recharge (with advanced equipment).

Table 6 shows the willingness to pay for the two groups. For example, group 1 (time concern group) is willing to pay extra 148 NTD for automatic swap instead of manual swap, while group 2 (economic concern group) is only willing to pay 30 NTD more for automatic swap (the service time is 15 minutes shorter). These estimates can be used in pricing policy for different services while more accurate estimates can be expected with larger samples.

Table 5: Willing to pay for service times

Extra Willing To Pay (NTD)		Swap	Recharge		
		Manual	Rapid	Ordinary 180 mins	Ordinary 300 mins
Swap	Automatic (5mins)	67	145	578	709
	Manual (20 mins)	—	78	512	658
Recharge	Rapid (37.5 mins)	—	—	433	564
	Ordinary 180 mins	—	—	—	131

Table 6: Willingness to pay for various service times of two groups

Extra Willing To Pay (NTD) For Group 1 (More Concern On Service Time)		Swap	Recharge		
		Manual	Rapid	Ordinary 180 mins	Ordinary 300 mins
Swap	Automatic (5mins)	148	322	1293	1598
	Manual (20 mins)	—	174	1145	1450
Recharge	Rapid (37.5 mins)	—	—	971	1275
	Ordinary 180 mins	—	—	—	305
for	Group 2				

Swap	Automatic (5mins)	30	66	258	310
	Manual (20 mins)	—	36	228	280
Recharge	Rapid (37.5 mins)	—	—	192	244
	Ordinary 180 mins	—	—	—	52

5. Simulation of Market Responses on Various Service Designs

For each respondent, total utility for each design of the 78 design concepts is calculated. To compare the customers' preference on the 78 designs, we gave top three design concepts (with top three largest utilities) 3, 2, 1 scores respectively. Then by calculating the total scores that summarize scores from 253 respondents, customers' preference can be quantitatively expressed. Table 7 contains the top ten design concepts that with highest total scores among 78 designs. Top three designs are all with battery swap, while rapid recharge (in the first row) with easy access of service station ranks 4.

Table 7: Top ten service design concepts with highest scores

Service Type	Equipment	Area	Access	Other Service	Total Scores	Ranking
C	R	R	< 5min	< 5 min	99	4
C	R	R	<5 min	6~15min	41	9
C	O	R	< 5 min	> 15 min	40	10
S	A	R	< 5 min	> 15 min	296	1
S	A	R	6~30 min	> 15 min	140	3
S	A	R	> 30 min	> 15 min	42	8
S	M	Com	<5 min	< 5 min	40	10
S	M	R	< 5 min	< 5 min	227	2
S	M	R	< 5 min	6~15min	44	6
S	M	R	6~30 min	< 5 min	62	5
S	M	R	> 30 min	< 5 min	43	7

Note: C: charge, S: swap, R: rapid charge, O: ordinary charge, A: automatic swap, M: manual swap, R: residential area, Com: commercial area

Three service designs including rapid recharge (number 28), automatic battery swap (number 67) and manual swap (number 70) are drawn for competition simulation. Expected market shares are presented in Table 8. Automatic battery swap would have the largest market share: 48%, while the other two have 33% and 19% respectively. Table 8 also shows the market shares in groups with different gender and income. For example, male customers would prefer rapid recharge (21%) than female customers (14%). High income customers prefer automatic swap (61%) than medium and low income customers.

Table 8: Market shares of three competing designs and market shares in different genders, income and time

	Number	#28	**#67**	**# 70**
Overall		19.37%	47.83%	32.81%
Gender	Male	21.3%	50.0%	28.7%
	Female	13.8%	41.5%	44.6%
	Chi square =5.818 p =0.055			
Income	High	19.6%	60.8%	19.6%
	Medium and low	19.3%	44.6%	36.1%
	Chi square =5.636 p =0.060			

6. Conclusions

Battery service system design is very essential for promoting electric vehicles. This study tried to generate service design concepts and make evaluation. Morphological analysis is used to generate new service design concepts, while conjoint analysis is conducted to estimate customers' preference with part worth utility. With morphological matrix, 78 service design concepts are generated and evaluated. Using part worth utility from conjoint analysis, preference of customers can be quantitatively expressed and ranked, while most promising service designs can be identified. Willingness to pay among different attribute levels like service times are estimated so that pricing policy could have reference base. With calculated utilities, market shares of competing service designs could be estimated. Background information of customers can be used to find characteristics of market segments with statistical analysis like cluster analysis.

Marketing strategy for different groups of customers can be made accordingly.

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A Design System for Layout of Charging Infrastructure for Electric Vehicle

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Abstract

We introduce a design system of layout of the charging infrastructures for an electric vehicle (EV). The design system consists of a traffic simulator for EVs and charging infrastructures, and a pre-post tool, which produces the input files into and the resultant figures from the traffic simulator. The traffic simulator can analyze the location of the dead EV (which means the EV running out of electricity) and the number of charging EV at each charging station (ST). We also have proposed the search algorithm for the effective layout of charging STs based on the location of the dead EV by the road traffic simulator. That algorithm has been installed into the traffic simulator. The layout of charging STs is successfully determined to reduce the number of the dead EV.

Keywords:

EV, charging infrastructure, traffic simulator, layout optimization, fast charge

1 INTRODUCTION

The promotion of EV spread in the transportation system is supposed to be based on the two viewpoints: one is the viewpoint from EV users, the other is from the management of the infrastructure. For EV users, sufficient placement of the charging infrastructure along the traffic road is certainly an important incentive to buy an EV, because of its shorter electric drive range. On the other hand, for the infrastructure management, a prospect of the steady EV spread in the market is a trigger to start or invest in the charging infrastructure. There is the chicken-and-egg question among above two viewpoints. The EV spread and the infrastructure network are supported each other, and some evaluation tool on those relationship should be helpful to promote the introduction of EV.

This paper introduces a design system of layout of the charging infrastructures for the EV. The design system consists of a traffic simulator for EVs and charging infrastructures, and a pre-post tool, which produces the input files into and the resultant figures from the traffic simulator. The traffic simulator has been developed to analyze the convenience of EV users such as possible drive range supported by charging infrastructures, and the management information of the charging infrastructure such as availability and sales of electricity [1,2]. We also have investigated the search function for the effective layout of charging station (ST) to reduce the number of the dead EV (which means the EV running out of electric energy of the battery on its way to the destination) by the road traffic simulator. The layout of charging STs is successfully determined to reduce the number of the dead EV. This approach is different from the layout optimization method based on the Voronoi diagram [3]. The system and the algorithm developed in this study are described in the following sections.

2 MODEL FOR DESIGN SYSTEM FOR LAYOUT OF CHARGING STATION

2.1 Outline of design system

Fig. 1 shows the overall of the design system for layout of the charging infrastructure for EV: EV-OLYENTOR (EV-Optimizer for LaYout of Electric infrastructure Network by Traffic simulatOR), and it consists of two tools: one is the traffic simulator to analyze the effectiveness and layout of charging STs, and the other is the pre-post tool to produces the input files into and the resultant figures from the traffic simulator. The multi-agent simulator "artisoc" is applied to develop the traffic simulator [4,5].

2.2 Road map model

We have employed Digital Map 25000 (Spatial Data Framework) as the basic database for the map model in the traffic simulator. Digital Map 25000 is a Japanese whole map database, which is used as the basis for

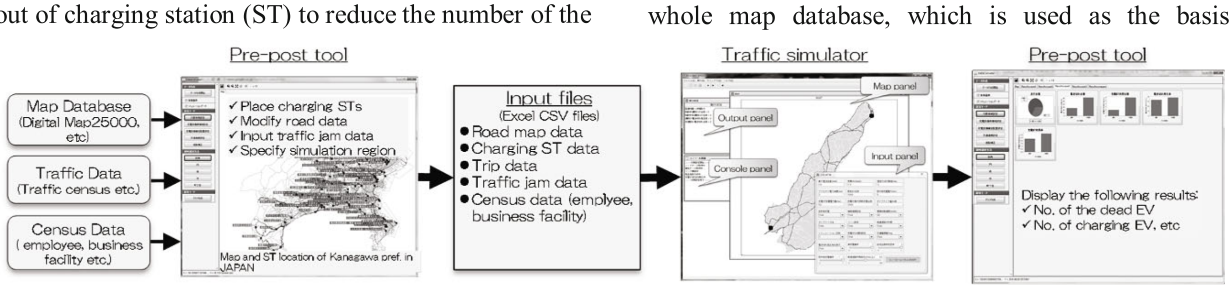

Fig. 1: Overall of design system for layout of the charging infrastructure for EV : EV-OLYENTOR

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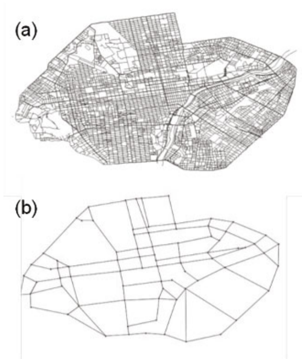


Fig. 2: Modeling the road data for the traffic simulator, (a) original data from Digital Map25000 and (b) road map geographical information system (GIS) [6]. We pick up the road data from Digital Map 25000 (Fig. 2(a)), and simplify it for the traffic simulation (Fig. 2(b)), because of the upper limit of the PC performance. We select all express highways, all national roads, and several major local roads for the road map model. In this study, energy consumption by accessory such as an air conditioner is considered for analysis on the EV fuel mileage. The energy consumption by the accessory use depends, NOT on the travel length, BUT on the travel time. Hence, we also install the travel speed data during the traffic jam into the road map model. Normally, an EV moves at the speed of 45 km/h (at the speed of 80km/h only for the express highway). When the option of the traffic jam condition is switched on, the EV moves at the speed recorded in the road map model. The travel speed during the traffic jam is available in the road traffic census database [7]. Finally, the location of ST is fixed in the road model by the pre-post tool.

2.3 Algorithm for origin and destination of EV

In this traffic simulator, the number of employee and business facility are applied to determine the origin and destination (OD) for each EV. Fig. 3 shows the relationship between zones and the number of employee, and business facility. In the traffic simulator, the road model map is divided into zones as shown in Fig.3. Roughly speaking, a city or a ward has a number of zones. It is assumed that the number of EVs generated in zone i (N_i^{EV}) is proportional to the number of the employee living

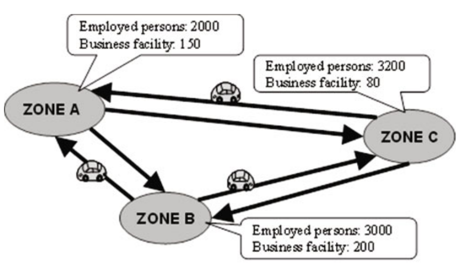


Fig. 3: Relationship between zones and the number of employee, and business facility

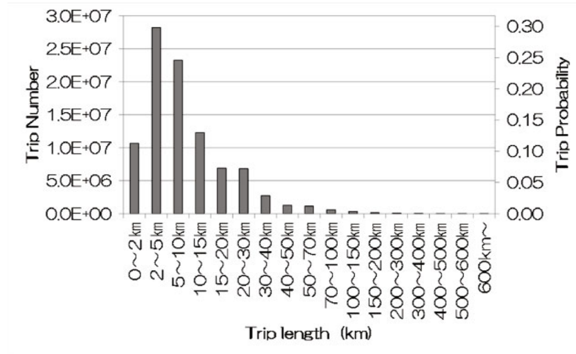


Fig. 4: Distribution of the trip number per day against the trip length on weekdays for the Japanese household car

in zone i (N_i^{ep}) as follows:

$$N_i^{EV} = \frac{N_i^{ep}}{\sum_j N_j^{ep}} N_{all}^{EV}$$

where $N_{all}^{EV} (= \sum_i N_i^{EV})$ is the total number of EV in the traffic simulation. The number of the employee for each zone are available in the population census [8]. Once N_i^{EV} is determined, the origin points in the zone i are randomly and uniformly selected among the nodes of the road in the zone i.

Next, the trip length is determined according to the Japanese traffic database such as the survey on motor vehicle transport [9] and the road traffic census [10]. Fig. 4 shows the distribution of the trip number per day against the trip length on weekdays for the Japanese household vehicle by the road traffic census. Based on Fig.4, we can derive the probability of the trip length for the household vehicle shown in Fig.4. Using this probability distribution, the trip length is determined.

Finally, the destination point has to be selected among the nodes in the road model. It is assumed that the number of EV's destination in the zone i is proportional to the number of the business facility in the zone i (N_i^{bf}). The numbers of the business facility for each zone are available in the population census [8]. The candidate nodes for destination are selected within the trip length from the origin. Here, the number of candidate nodes within the zone i is defined as N_i^{cd}. We introduce the selection probability for destination zone (P_i^{dz}) as follows:

$$P_i^{dz} = \frac{N_i^{cd} \times N_i^{bf}}{\sum_j N_j^{cd} \times N_j^{bf}}$$

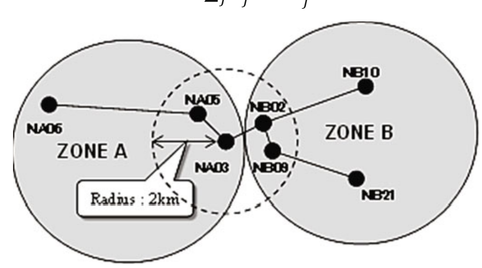


Fig. 5: Selection method of the destination point. NA03 is the origin. NA05, NB02 and NB09 are the candidates for the destination.

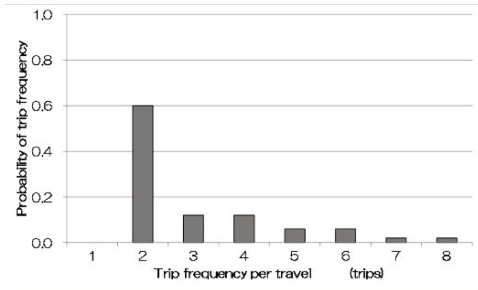


Fig. 6: Probability of the trip frequency per travel.

For example, in Fig.5, the node NA03 is the origin and the nodes of NA05, NB02 and NB09 within the trip length 2 km are selected as the candidates (i.e. $N_A^{cd} = 1$ and $N_B^{cd} = 2$). Here, we have to determine the destination zone, A or B according to the selection probability P_A^{dz} and P_B^{dz}. After selecting the zone of the destination, the destination node is selected among the candidate nodes in the selected zone, randomly.

A one-trip route of each EV is determined so that the traveling time from the starting point to the destination point becomes shortest among the candidate routes. We employ the Dijkstra's algorithm to select the one-trip route [11], which is widely used in the network routing protocol, the car navigation system, and so on. The number of the trip for each EV is determined based on the traffic database shown in Fig. 6, which is based on that data for Imabari-city in Japan [12].

2.4 Algorithm for charging behavior of EV

We define several temporal functions for electric energy of EV: the remaining energy charged in the battery of i-th EV $E_i^{chrg}(t)$ kWh, the state of charge (SOC) $SOC_i^{EV}(t)$, energy consumption $E_i^{loss}(t)$ kWh. The i-th EV stating from the originated point has a certain level of SOC, SOC_i^{start} of a battery capacity C_i. SOC_i^{start} and C_i are input parameters in the simulation. The initial energy charged for the i-th EV is defined by $E_i^{chrg}(0) = C_i SOC_i^{start}$ kWh.

The fuel mileage L^{fm} km/kWh and the power consumption by accessory device such as an air-conditioner P^{ac} kW are conostant parameters. The accumulated length and time of running of the i-th EV is defined by $L_i^{EV}(t)$ km and $t_i^{run}(t)$ hour, respectively. The temporal energy consumption of the i-th EV is evaluated as follows

$$E_i^{loss}(t) = \frac{L_i^{EV}(t)}{L^{fm}} + P^{ac} t_i^{run}(t)$$

, and the remaining battery energy $E_i^{chrg}(t)$ is

$$E_i^{chrg}(t) = C_i SOC_i^{start} - E_i^{loss}(t) + E_i^{add}(t)$$

where $E_i^{add}(t)$ kWh is the additionally recharged energy of the i-th EV by ST and the normal charge equipment. When the charged energy of EV become less than a constant E^{alarm} (which is an input parameter), the fuel warning sign is lit on and EV has to choose which the better action is, going to the destination as planed or changing the destination to the nearest ST to recharge the battery. The decision of the EV action depends on the travel time to the original destination and to the nearest ST. When the travel time to the nearest ST is shorter than that to the original destination, the EV will change the destination from the original one to the nearest ST, and recharge the battery by 80% of SOC in 15 minutes. After recharging, EV will move again to the original destination.

2.5 Validation of the traffic simulation

Before the traffic simulation for EV, we have validated the traffic simulation itself in comparison with the traffic database. Fig. 7 shows the road model for the traffic simulation. This road map model corresponds to that of 10 cities (A-J), where the area and population are 2600km^2 and about three million people, respectively. The traffic simulation for 3000 of the internal combustion engine vehicle (ICEV) was carried out in this road model.

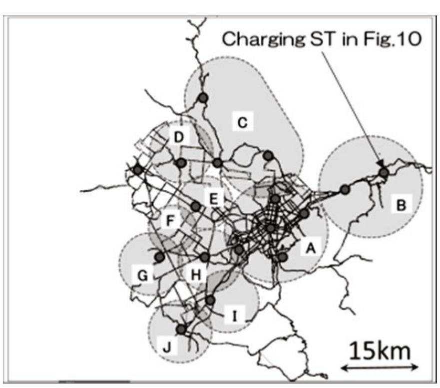


Fig. 7: The road map model of the model cities(A-J) and 17 charging stations.

Fig. 8 shows the simulation result and the data of the person trip survey [13] on the trip number inside a city

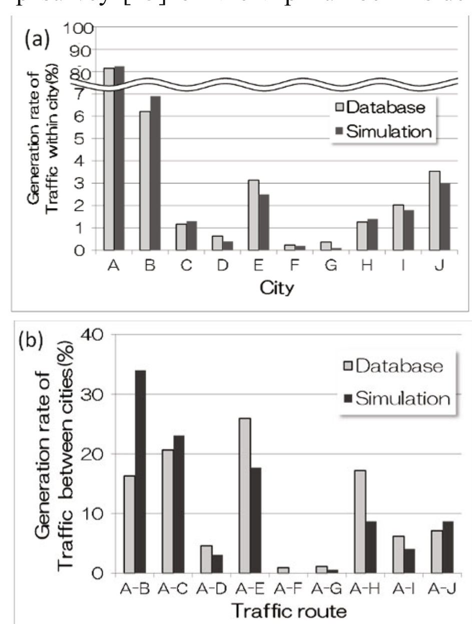


Fig. 8: the simulation result and the data of the person trip survey on the trip number (a) inside a city and (b) between cities.

(Fig.8(a)) and between cities(Fig.8(b)). The trip inside a city means that the origin and the destination are located in the same city. The generation ratio of the traffic number inside city i ($ftrip_i^{ins}$) is defined as follows:

$$ftrip_i^{ins} = \frac{Ntrip_i^{ins}}{\sum_j Ntrip_j^{ins}} \quad j = A - J$$

where $Ntrip_i^{ins}$ is the trip number inside the city i. The trip between cities means that the origin and the destination belong to the different cities, respectively. The generation ratio of the traffic number from city A to city k ($ftrip_{Ak}^{inter}$) is defined as follows:

$$ftrip_{Ak}^{inter} = \frac{Ntrip_{Ak}^{inter}}{\sum_l Ntrip_{Al}^{inter}} \quad l = B - J$$

where $Ntrip_{Ak}^{inter}$ is the trip generation number from city A to the city k. Both of simulation results on the trip generation number inside city and between cities are generally consistent with the person trip survey.

3 VIFUALIZATION OF EFFECTIVENESS OF CHARGING STATION

3.1 Simulation conditions

The road model applied here is the same as Fig. 7. Simulation conditions for EV are summarized in Table 1. The number of the generated EV is 3000. We consider three battery capacities of 8, 14, 20 kWh, and the initial SOC SOC_i^{start} is 1.0, i.e. fully charged state at the generated point. The fuel mileage 7.5km/kWh is applied to the EV traffic simulation. During traveling in the road model of Fig.7, the energy consumption by accessory use such as the air conditioner is assumed and the accessory power $P^{ac} = 3.0$ kW is applied here. While the effective fuel mileage including the accessory power use depends on the respective travel route of EV, the averaged effective fuel mileage results in about 5.0 km/kWh in this EV traffic simulation. In this EV traffic simulation, the traffic jam is considered. The traveling speed of 45km/h (80km/h only for the express highway) is considered as the reference speed. The traveling speed under the traffic jam condition for each road is specified according to the database of the road traffic census [7]. In Fig.7, the location of the charging ST is also delineated for the case of 17 STs. Those locations of the ST are selected uniformly.

Table 1. Simulation conditions for EV

Simulation condition	Parameters
Total generation number of EV	3000
Battery capacity C_i (kWh)	8, 14, 20
Initial state of charge SOC_i^{start}	1.0
Fuel mileage L^{fm}(km/kWh)	7.5
Accesory Power use P^{ac}(kW)	3.0
Threshold energy for fuel alarm lampE^{alarm}(kWh)	3.0
Traveling speed (km/h)	45
Traveling speed for express highway (km/h)	80
Option of traffic jam	effective
Number of ST	0, 8, 11, 17

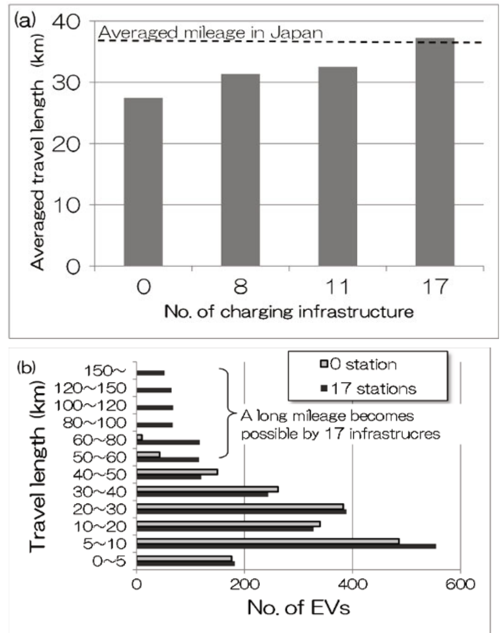


Fig. 9: Effectiveness of charging infrastructure (a) dependence of EV's averaged mileage on No. of charging infrastructure and (b) mileage distribution of EV

3.2 Effectiveness and availability of charging ST

Fig.9 shows the simulation results on the effectiveness of the charging ST. Fig.9(a) is the dependence of the averaged travel length on the number of the ST in case of the battery capacity 14kWh. With increase of the ST, the averaged travel length becomes longer. For the case of 17 STs, the averaged travel length is larger than 37km, which corresponds to the average travel length per day for the Japanese household vehicle [9]. This result implies that 17 STs are required to keep EV drive mileage similar to that of an ICEV. Moreover, this result also suggests the area responsible for a ST is about 150km^2 per ST(i.e. one ST in the area of about 12km square). This result is similar to the ST development target in Kanagawa prefecture proposed by the Kanagawa EV promotion council in 2008 [14]. Fig. 9(b) shows the distribution of EV travel length for the battery capacity 14kWh with/without 17 STs. Support of 17 STs enables long drive range over 60km. That is why the averaged travel length becomes longer.

Fig. 10 shows the simulation results on the time evolution of the number of the charged EV at the ST specified in Fig.7. The number of the charged EV in the morning is less than in the afternoon, because of the initial SOC=1.0. The dependence on the battery capacity (i.e. 8kWh, 14kWh, 20kWh) also shown in Fig.10. In case of the battery capacity 8kWh, the maximum number is about 25 EV per hour. This implies that several rapid charge device in this ST may be required for 3000 EV usage in this model cities. It is interesting that the charged EV numbers per day for 14kWh and 20kW are similar each other. Especially, the maximum number of the charged EV per hour for 20kWh is larger than for 14kWh. This may

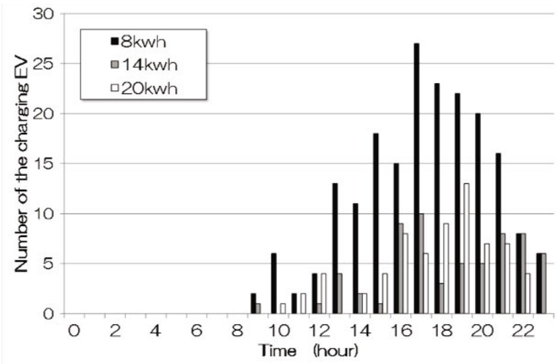


Fig. 10: Number of the charging EV at the charging ST shown in Fig.7

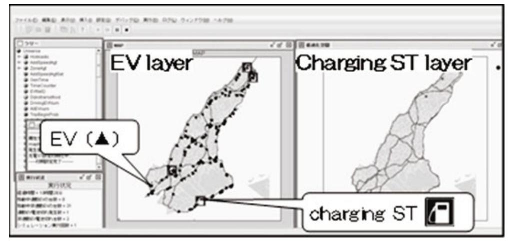
suggest that the ST location likely to charge the EV depends on the battery capacity.

4 LAYOUT ANALYSIS ON CHARGING STATION

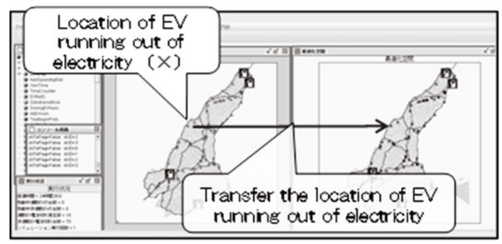
The basic concept of the search argorithm of effective layout is that the charging ST should be located in the area where there are a lot of dead EVs. This search algorithm is installed into the traffic simulation shown in Fig. 11. Two layers are assumed, the EV layer and the charging ST layer in Fig. 11. The calculation step is as follows: (a)Step1:A traffic simulation is carried out with an arbitrary location of charging STs, and the location of the dead EV is analyzed in the EV layer. (b)Step2: That location of the dead EV in the EV layer is transferred to the ST layer. (c)Step3: The location of STs is arranged to spread uniformly the area. (d)Step4: The location of STs is rearranged to be close to the area where there are a lot of dead EVs. (e)Step5: The rearranged location in the ST layer is transferred to the EV layer, and the EV traffic simulation with a rearranged location of STs are carried out. To minimize the number of the dead EV, the above calculation steps of 1, 2, 4 and 5 are iterated in the next traffic simulation.

In the calculation steps of 3 and 4, the ST moves autonomously. Here, we have applied the concept of charged particles motion in the electric field. We consider the ST and the dead EV as a free floating positive charged particle and a fixed negative charged particle. STs move under the control of the attraction force from EV and on the repulsive force from other STs.

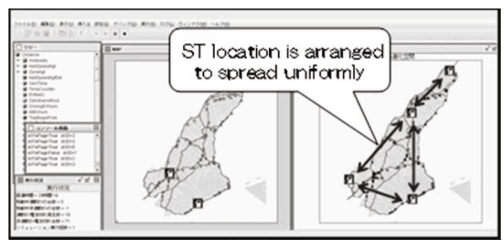
Finally, we applied this algorithm to the more complicated road map. Fig. 12 shows the result on the 6 charging STs on the more complicated road map. Fig. 12(a) corresponds to the large city of one million population, and its road network. Fig. 12(b) clearly shows that the iteration of the search algorithm is effective to reduce the generation ratio of the dead EV. Those results show the effectiveness of the search algorithm for layout of charging STs proposed in this paper.



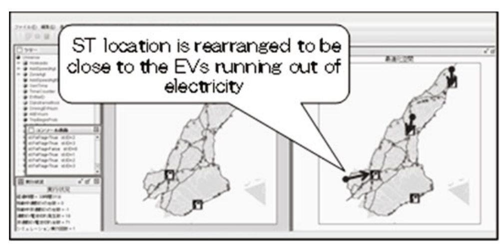
(a)Step1: A traffic simulation is carried out with an arbitrary location of charging STs in EV layer.



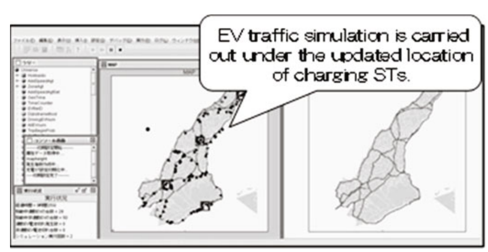
(b)Step2: Locations of EV running out of electricity are transferred to the ST layer.



(c)Step3: The location of STs is arranged to spread uniformly in the area.

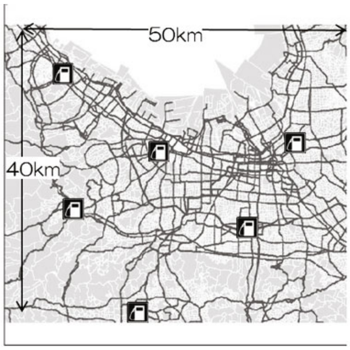


(d)Step4: The location of STs is rearranged to be close to the area where there are a lot of EVs running out of electricity.

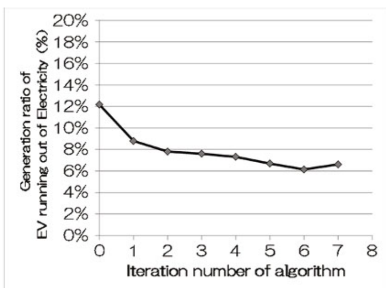


(e)Step5: The rearranged location of STs is transferred to the EV layer, and the EV traffic simulation with a rearranged location of STs is carried out again.

Fig. 11: The calculation steps (a)-(e) of the search algorithm for the effective layout of charging STs based on the EV traffic simulation.



(a) location of STs after 6 iterations of search algorithm



(b) generation ratio of EV running out of electricity

Fig. 12: Application of search algorithm to the complicated road model on 6 charging STs (a) resultant location of the charging ST and (b) generation ratio of EV running out of electricity during iteration of the algorithm.

5 SUMARRY

A traffic simulator has been developed to analyze and to visualize clearly the convenience of EV users such as possible drive range supported by charging infrastructures, and the management information of the charging infrastructure such as availability and sales of electricity. We also have proposed the search algorithm for the effective layout of charging STs to reduce the dead EV by the road traffic simulator. That algorithm has been installed into the traffic simulator. In case of a simple road map, the layout of charging STs is successfully determined to reduce the number of the dead EV. Finally, we have applied this search algorithm to the more complex road map, which corresponds to the large city of one million populations. The result shows that the iteration of the search algorithm is effective to reduce the number of the dead EV. Those results clearly indicate that the design system for the charging ST for EV in this study is effective for the EV spread.

ACKNOWLEAGEMENT

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A Study of a Realistic Dissemination Policy on the Electric Full-Flat Buses in Japan

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Abstract
In a society where drivers and users are older than ever, the combination of universal design and eco-design is needed for the prevalence of electric buses. We have revealed what types of electric buses are better for the companies and users through a social survey. Concretely speaking, we carried out a fact-finding survey intended for bus companies in eight prefectures including Tokyo metropolitan area and sent questionnaires to 216 users in eight prefectures including Tokyo metropolitan area. We have classified the results of the survey into three types of electric buses as dissemination bus models.

Keywords:
Electric Low and Full Flat Floor Bus (ELFB), Universal Design, Ecological Design, Component Built-in Frame, and In-wheel Motor.

1 INTRODUCTION

The application of electric car technology to public transportation is a short cut to the spread of electric cars. Above all, with the application of the technology to a big size city bus it is possible to protect the environment to give new service to passengers, and to make the quality of an electric bus gain wide publicity. An electric low and full flat floor bus is a vehicle which has made it possible to lower a floor, to get rid of exhaust gas, and to prevent noises by using electric car technology. Therefore, it is significant to carry out research on the application of electric car technology to a big size city bus. Our research has revealed what citizens and bus companies in Japan think of the application of the electric car technology to a big size bus.

2 THE BACKGROUND OF THIS RESEARCH

2.1 The Development of a Grand-up Type of Electric Car with Basic Auto Parts Concentrated under a Floor

We have developed an electric car called "Eliica" with basic auto parts, for example a lithium ion battery, a tandem wheel suspension system, concentrated under a floor (Photo.1). And a motor is kept in each of eight wheels. As a result, an electric car has more room and passengers can enjoy roominess. A sport car which can do more than 300 kilometers an hour can accommodate only two passengers because of a big size engine. But "Eliica" can accommodate four passengers. Mere alteration of the form or size of an electric car makes it easier to apply the technology to buses, trucks, and so on. We have certified that a grand-up type of electric car rides better than an electric car now in use. We have tried to make the maximum speed of "Eliica" 400 kilometers an hour. At present "Eliica" can do 370 kilometers an hour. The quality of "Eliica" is very high speed and very high level of function of acceleration.

2.2 More Interest in the Next Generation's City Buses Designed Universally and Ecologically

Nowadays Japan is facing an aging society. We predict that people aged over 65 years will account for 25 percent of the population of Japan by 2025. The number of physically-challenged people is increasing. In this aging society we are more and more interested in city buses. But recently

Photo 1. Grand-up type of electric car "Eliica"

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DOI 10.1007/978-94-007-3010-6_218, © Springer Science+Business Media Dordrecht 2012

buses have been facing serious problems about exhaust gas, noises and so on. But Electric Low and Full Flat Floor Buses are highly appreciated in accessibility and low emission. To solve these problems, we have developed an electric city bus. It is a means of transportation designed universally and ecologically. There is a growing need for a big size electric city bus which can accommodate more passengers.

2.3 Greater Interest in Big Size City Buses Useful for Promoting the Spread of Electric Motor Buses in Japan

Japanese people are getting more and more interested in the development of emission-low vehicles to cut down on carbon dioxide. Nowadays, Japanese municipalities are adopting a policy about assuming a part of the rent for a parking lot, which is paid by a driver of an emission-low car and are trying to spread emission-low vehicles all over Japan. Under the present condition of Japan, people are not very interested in an electric car because of its low efficiency involved in going up a slope. But electric cars are gaining wide publicity because a lithium ion battery can be charged more efficiently now. In spite of its publicity, electric cars have not come into wide use because it costs more to produce a lithium ion battery. But we have proved the high speed and the high acceleration of “Eliica”. So, Japanese municipalities and various bus companies are showing greater interest in applying “Eliica” technology to city buses. Scientific societies are showing interest in “Eliica” technology, too. As a trigger for popularizing electric cars, applying the quality of a grand-up type of electric car to a big-sized city bus is worth noticing.

3 DEVELOPMENT OF ELECTRIC LOW AND FULL FLAT FLOOR BUS AND THE PURPOSE OF THIS RESEARCH

3.1 R&D’s Core Technology

The Electric Vehicle Laboratory of Keio University has been working on the development of EVs for years. The laboratory’s basic concept is to build a dedicated platform for EVs from scratch, instead of the conversion type that involves retrofitting an engine with a motor. This innovative design technology, called integrated platform, stores all equipments required for operating a vehicle, such as batteries, motors (in-wheel motors), and inverters, beneath the vehicle floor. The application of this technology makes it possible to concurrently achieve expansion of usable cabin space in EVs, extension of the mileage on a single charge by using in-wheel motors, and a greater number of lithium-ion batteries, as well as improvement in universal design performance, which has a brisk demand (Fig. 1). Based on the assumption of using the above concept, the Electric Vehicle Laboratory of Keio University has developed a prototype ELFB (the Trial Electric Low and Full Flat Floor Bus) (Photos 2/3/4).

3.2 Prototype ELFB by Keio University

Keio University has developed a prototype large sized ELFB. The development of ELFB was pushed forward based on a framework of the industrial sector (Isuzu Motors Limited), public sector (Kanagawa Prefecture and Kanagawa Bus Association, along its member bus companies that operate public transportation services), and academic sector (Keio University). In the development project, Keio University has worked on creating a practical bus by expanding the opportunities to exchange ideas with industrial and public sectors. In manufacturing a route bus to be used as a public transportation vehicle, it is important to construct a safe, secure, and strong body. Aluminum and polycarbonate are used for the body in order to reduce as much weight as possible. The newly developed direct drive in-wheel motors are mounted on the chassis in order to achieve high-efficiency vehicle operation without loss. The specifications of the large-size ELFB that was developed through this project are summarized in Table 1. The major concern of bus service companies regarding ELFB is the mileage on a single charge. As the results of a field test conducted in Yokohama City, Kanagawa Prefecture in Japan, mileage per charge was 121km. The author of this article conducted an interview survey with 12 bus service companies that are the members of Kanagawa Bus Association. The survey revealed that vehicles of the member bus service companies run an average distance of

Photo 2. The Front-View of Electric Bus

Photo 3. The Rear-View of Electric Bus

about 120km per day between departure from and return to the bus garage. Taking the field test results into consideration as well, it is also revealed that ELFB has the specifications to meet most of the existing bus service requirements (vehicle driving range required for a normal bus service and various other services provided by bus service companies). Introducing the concept and technology of the integrated platform can lower the minimum height from ground to floor, construct a full flat cabin, and improve the universal design performance. According to the Kanagawa Bus Association, the fuel cost per kilometer for the existing large size non-step bus (10.5m overall length and 2.5m overall width standard) is ¥38 (US$0.47). On the other hand, the prototype ELFB of the same large size can run on ¥8 (US$0.1) per kilometer (when using nighttime electric power). In other words, a fuel economy merit of ¥30 (US$0.38) per kilometer can be achieved by replacing the existing non-step buses with electric ones. The route buses run a distance of about 120km per day and 300 days per year, which means using electric buses can result in an annual fuel cost reduction effect of ¥1.08 million (US$13,500) per vehicle. In addition, electric buses contain less number of components and thus, about 50 percent of the remaining running costs (mainly components-related maintenance costs) after subtracting the fuel cost from the total running cost can be reduced from the present expenses. Calculations made based on this fact indicate that the amount of components-related maintenance costs that can be reduced annually is about ¥770,000 (US$9,625) for a large bus. Therefore, based on the above calculations, approximately ¥1.85 million (US$23,125) can be reduced annually for each bus. The electric bus offers a great advantage to Japanese bus service companies because about 80 percent of them are presently operating in the red. Furthermore, the amount of carbon dioxide emissions from existing large-sized internal combustion engine buses is 0.61kg/km (FY2009 data of Ministry of Land, Infrastructure, Transport and Tourism). EVs do not emit carbon dioxide during operation. EVs can reduce 90 percent of carbon dioxide emissions even when emissions during power generation are taken into consideration. In addition, EVs do not produce any noise when they are operated. Therefore, they are better for the environment in areas along the bus route.

3.3 The Purpose of Our Research Study

In our research study, a fact-finding survey on the spot was conducted on bus companies and a questionnaire survey was conducted on citizens to clarify how we can bring electric buses into wider use. Taking the management of bus service and passenger's needs into account, we have aimed at gaining wider publicity by classifying electric full-flat buses based on integrated platform technology into these types, visualizing them. We dealt with only buses with a regular route, excluding sightseeing buses and intercity bus services

4 AN OUTLINE OF THE SURVEY CONDUCTED ON BUS COMPANIES

4.1 An Outline of Fact-Finding Survey Conducted on Bus Companies in Japan

(1) An Object of the Survey

27 bus companies (13 companies in big cities and 14 companies in the suburbs).

(2) The Time When the Survey Was Conducted

From October, 2010 till December, 2010 (For two hours convenient to bus companies).

(3) The List of Interviewers

Toshiki Nishiyama, Seijiro Noda, and Manabu Ishikawa.

(4) The Contents of the Survey

We have clarified how we can bring electric full-flat buses into wider use by conducting a fact-finding survey of the following three items.

A. An item about the maintenance of Buses.

B. An item about the practical use of Buses.

C. An item about the operation of bus companies and merits which they can give to passengers.

4.2 About Social Some Effects Which the Introduction of Electric Full-Flat Buses have on Passengers

We explained objectively what we mentioned in 3.2 about the introduction of electric buses to bus companies in order to obtain objective information in our survey, demonstrating the difference in power source, the

Table 1. Specifications of the Electric Bus

Photo 4. The Interior of Electric Bus

maintenance of a bus, and so on between a non-electric bus and an electric bus.

5 AN OUTLINE OF THE SURVEY CONCERNING WHAT PASSENGERS NEED ABOUT AN ELECTRIC BUS

A bus with an integrated platform can supplies passengers with enough space and power source which will bring new merits to passengers. We did a research study on what kind of merits passengers need. Keio University conducted a questionnaire survey on 216 citizens in big cities in Hokkaido, Tokyo and two prefectures called Hyogo and Fukuoka and in the suburban cities in four prefectures called Niigata, Shizuoka, Kagawa, Yamaguchi and Okinawa at the rate of 24 citizens in per 12 prefectures. 24 citizens consist of 12 men and 12 women. 12 men consist of 2 men in their twenties, 2 men in there thirties, 2 men in their forties, 2 men in their fifties, 2 men in there sixties and 2men in their seventies and more. 12 women consist of 2 women in their twenties, 2 women in their thirties, 20 women in their forties, 20 women in their fifties, 20 women in their sixties and 20 women in their seventies and more. We succeeded in collecting the results of our research study through close cooperation with researchers in each prefecture. The questionnaires deal with some problems about a bus with a regular route and new merits which an electric bus can bring to passengers.

Table 2. What Citizens in Big Cities Need about Electric Buses

(Big Cities)	20	30	40	50	60	70	合計
Space for Baggage	6	5	9	8	9	9	46
Battery Charging	8	3	6	1	0	0	18
Big Chairs	1	3	3	4	4	3	18
Desks	5	5	3	3	1	1	18
Space for Bicycles	1	3	3	2	3	6	18
More Seats	1	3	2	4	0	3	13
Space for Children	4	4	0	0	0	0	8
Enough Standing Room	2	1	1	0	0	0	4
Floor Warming	0	0	1	0	0	0	1
Enough Space for Wheelchairs	0	0	0	0	0	0	0
Refrigerators	0	0	0	0	0	0	0
Chairs for Massage	0	0	0	0	0	0	0

Table 3. What Citizens in the suburbs Need about Electric Buses

(Suburbs)	20	30	40	50	60	70	合計
Space for Baggage	11	8	9	10	10	17	65
Space for Bicycles	8	7	10	10	3	6	44
Space for Children	3	9	2	2	0	1	17
Battery Charging	3	7	3	1	1	0	15
Big Chairs	0	0	3	3	4	2	12
More Seats	1	2	2	2	1	1	9
Desks	5	1	0	1	0	0	7
Enough Space for Wheelchairs	0	1	0	0	0	1	2
Refrigerators	0	0	0	1	1	0	2
Enough Standing Room	0	1	0	0	0	0	1
Floor Warming	0	0	1	0	0	0	1
Chairs for Massage	0	0	1	0	0	0	1

What citizens need is summarized in Table 2 and 3.

6 THE CLASSIFICATION OF ELECTRIC BUSES

We have clarified electric full-flat buses into three types which will be in great demand in the near future, giving some examples of their characteristics and visualizing them. The results of the survey were highly values by 27 bus companies. The following three types will have much possibility of coming into use as bus service.

6.1 Model A : An Urban Type of Electric Full-Flat Large Size Bus (The Front Door – The Middle Door, An Amount to Be Borne by a Bus Company is 23,600,000 Yen)

Mileage on a single charge is 200 km (including electric power for air conditioners, equipments indispensable to a one-man-operated bus and subsidiary ones). This type of bus is designed to leave enough standing room by decreasing seats in number in order to accommodate many passengers. Moreover, to satisfy passengers' needs it has some space for baggage. Figure 2. represents the exterior of a model A. Figure 3. represents the interior. A large size electric full-flat non-step bus can supply passengers with enough space for baggage, large chairs, desks, and so on, with an integrated platform installed. Moreover, it is possible to get power source for welfare equipments under a wheelchair. In this way this type of electric bus which runs in cities makes it possible to combine universal design with eco-design because of enough space.

6.2 Model B : An Suburban Type of Electric Full-Flat Large Size Bus (The Front Door – The Rear Door, An Amount to Be Borne by a Bus Company is 23,600,000 Yen)

Mileage on a single charge is 200 km (including electric power for air conditioners, equipments indispensable to a one-man-operated bus and subsidiary ones). This type of bus is designed to leave as many seats as possible, with little standing room. Moreover it is possible to secure enough space for baggage and to make room for bicycles by using jump seats. Figure 4. represents a model B. of an electric bus. In our survey many bus companies hoped that

Fig 2. The exterior of an urban type of large-size electric full-flat bus with a low floor (Width=2.5m, Length=10.5m, Height=2.8m, The front-door – the middle-door type, Mileage on a single charge is 200km) a bus with the front door and the rear door would survive in suburban cities. Concerning a non-step bus with a rear engine installed, the rear engine makes it possible to adopt "the front door and the rear door" system. But many bus companies like a bus with the front door and the rear door better than a bus with the front door and the middle door because a bus with the rear door can accommodate more passengers and passengers are used to taking the bus. We visualized a bus in Figure 4. as a model of a suburban type of bus. As represented in Figure 3. the seats in half of the forward part of the bus are arranged in two rows. The position of space for baggage, bicycles, children, and so on is subject to change according to what characteristics of buses with a regular route have.

6.3 Model C : An Small Size Electric Full-Flat Bus (The Front Door – The Middle Door, An Amount to Be Borne by a Bus Company is 12,800,000 Yen)

Mileage on a single charge is 200 km (including electric power for air conditioners, equipments indispensable to a one-man-operated bus and subsidiary ones). This type of bus is designed to increase seats in number with little standing room by using larger seats and by holding subsidiary equipments under seats because many elderly people will take the small bus. We have confirmed that electric buses will be classified into a large-size buses and small-size buses through interview with bus companies.

Fig 3. The interior of an urban type of large-size electric full-flat bus with a low floor

Fig 4. The exterior of a suburban type of large-size electric full-flat bus with a low floor (Width=2.5m, Length=10.5m, Height=2.8m, The front-door – the rear-door type, Mileage on a single charge is 200km)

On the other hand, middle-size buses will cease to be used from now on because of halfway transportation. So we visualized a small-size electric full-flat bus which elderly people and physically challenged people can take easily in order to any places with poor access, as represented Figure 5. and 6. Moreover the bus can be loaded with wheelchairs. This community bus can contribute to combining eco-design with universal design.

7 CONCLUSION

It is urgently necessary to enhance further practical utility of EVs through research by evaluating the prototype vehicles. One of the reasons why EVs are being spotlighted in recent years is that they can be driven right to the inside of a building. In the case of electric route buses, they can be driven right up to the front of the ticket gate of a station, medical treatment facilities, or shopping malls, which can reduce the moving distance for the elderly or persons with disabilities. In the future, the research would like to take the moving distance into consideration while studying scenarios of low-carbon town development that utilizes EVs. The research also intends to continue studies on the construction of future environments that are created through a fusion of eco design and universal design. In addition, the plan to embark on the development of electric trucks by making the most of the integrated platform structure is underway as well.

Fig 5. The exterior design of a grand-up style community bus

Fig 6. The interior design of a grand-up style community bus

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Eco-Design: Development of Metabolic System

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Abstract

Eco-design with the major focus on environmental aspects attempts to improve performance and eco-efficiency attributes through covering different dimensions of production process concerns. Biomimics or imitation of natural systems with the highest levels of compatibility would be one of the concerns pursued in eco-design in order to mitigate harms and burdens onto the environment. Since such approaches provide higher levels of compatibility with nature, therefore they would be in accordance with human nature and would more efficiently fulfil other contextual frameworks of design.

Based on these theories, this paper investigates the cores in organic systems and their metabolisms. Then the feasible ideas applicable in industry and eco-design approach are extracted, analyzed and studied. In the next stage, it is explained how the concepts proposed could create metabolism required for creating eco-balance. Afterward the implication of eco-design development is discussed. In the final stage numbers of benefits achieved through eco-design approach are listed.

Keywords: Biomimics, Eco-balance, Eco-design, Eco-efficiency, Metabolism, Performance

1. Introduction

Industrial activities such as building process have caused serious ecological and environmental problems over the past century. Global warming, acid rain, ozone depletion, natural resource scarcity, air pollution, toxic waste, loss of biodiversity, and industrial accidents are assumed as the negative impacts of industrialization over recent decades. Buildings as a multi-disciplinary industry, from the pre-construction phase to the post-construction phase affect the environment. Boussabaine and Kirkham (2004), classify the environmental impacts into two main groups: atmospheric related and resources related [1]. The atmospheric impacts embrace problems such as the green house effect and the impact on the ozone layer while the resource impacts refer to air, water and earth pollution.

2. Natural Systems

Nature is considered to be a zero net system. This means that the organisms existing in this whole system have achieved a sort of compatibility in order to create a consensus balance among them. In other words, all subset systems of this total system are working in accordance with each other, with no burdens on other systems. This level of compatibility and eco-balance are the result of constant synchronisation over millions of years. Hence, conservation of this valuable balance is the responsibility of human kind towards the environment. Sustainable design process as a dynamic approach should be able to present ideas, policies and strategies for developments which are benign to the natural environment and its ecological balance.

3. Eco-Balance

Eco-Design is a result of interconnectivities challenging to balance rational design attributes and existing contexts in a design framework as a dynamic system. Values, scopes and agendas developed in the early stages of design, in addition to activities performed throughout the process, conclude the outputs including results and side effects.

In Figure1 below design and its contextual frameworks are illustrated. The upper body of the illustration relates to when a balance is established through design process and all systems are working soundly in the environment. The lower part of the diagram shows a level of imbalance having occurred when design is not in accordance with its contexts.

The outcomes of such an imbalance are environmental impacts, emissions, customer dissatisfaction, loss of

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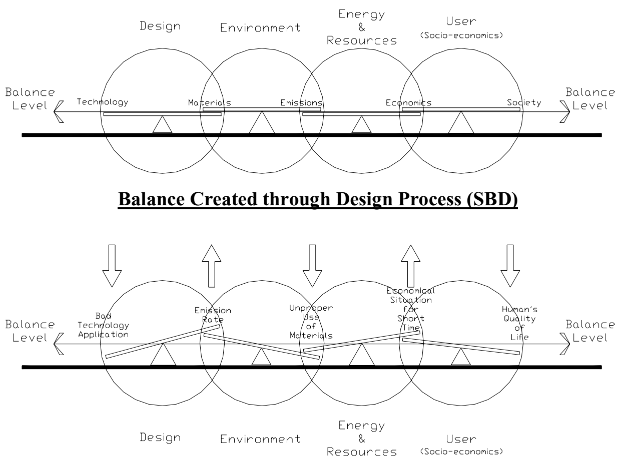
resources and energy, as well as poor performance and poor quality.



Imbalance in Design; Design not in Accordance with Existing Contexts

Fig 1 Sustainable Design/Eco-Design and Balance in Design [2]

4. Emergence of Design of Systems with Metabolism

A good design is always made based on context; otherwise it produces more problems rather than solutions. "When attempting to describe sustainability and by implication sustainable construction [building] … it is necessary to understand the developmental priorities as well as cultural context…" [3].

Design of metabolic systems is considered as a set of actions carried out in order to improve the compatibility issue to the highest levels in design. Eco-design focuses on compatibility of system with its existing contextual frameworks over the WLC of product. Creation of metabolism over the product's life span can be considered as the highest level of adaptability/compatibility of a system with its surrounding systems over its WLC over all stages of product development.

5. Ecological Building Design (EBD) Implications

EBD implications are addressed in two levels:

- ***Waste Management***

A Chinese proverb describes waste as something which is not in its original place. As mentioned nature by itself is considered as a zero net waste system which means that it is automatically able to perform a waste management process.

Waste management in the natural environment is carried out in different ways:

1. No waste/burden is created by a system for other systems; or
2. The waste/burden generated by one system can be used by other systems. In other words one system feeds another system or systems.
3. A system can transform to another system and is able to set a new balance with other systems.

- ***Resource Management***

As mentioned previously, the ecological balance has been achieved over millions of years. Therefore any exploitation of resources can be considered as creating imbalance in the natural system/s. This means that there should be a limitation on the exploitation of natural resources. This issue can incorporate the concepts such as rematerialisation (recycle and reuse), dematerialisation (lower use of materials and energy), intensity of use (IoU) and local and vernacular materials application addressed by the SBD process.

7. Conclusion

Eco-Design, as a performance management process, should be capable of presenting solutions for product development process complexity and dynamism over a product's entire life span. The solutions proposed are derived from views towards existing design objectives with reference to existing context; also, it was concluded that with fewer retrofits and retrospect in our expectations and perception of needs, we might be able to perform more efficiently when dealing with eco-design concerns. Since design dynamism is a result of change occurring in the real world, dynamic and up-to-date solutions remain responsibilities of eco-design. Product design should anticipate upcoming concerns in order to be capable of dealing with dynamism existing in a building's WLC.

Here, it was pointed out that eco-design's new agenda should cover subjects such as eco-balance endorsement, waste management, service and eco-service life design, lean and clean energy generation, design of systems and developments of biomimics in accordance with product's users' needs. The new agenda could lead towards a ***win-win situation*** as a prerequisite for consistency of eco-design movement.

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Long Life and Low Consumption System for Sustainable Development

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Abstract

To reduce material consumption is mandate to construct sustainable society. To reduce environmental burden is another mandate subject and the environmental burden is increased by material consumption and disposal. Even if recycling systems such as recycle plants for home electric appliance in Japan are useful to reduce the burden and increase material supply to the industry by recycled material, still there are very tough issues to be solved from the view of sustainability of industrial system. In this research we found the contradictory relations involved in recycling system is resultant of divided (venous and arterial) operation of recycling. Improving IIDPS (Integrated inverse distribution and production system) we can stave off explosive material consumption. By this mechanism, long time usage of products in the market reserve higher profit of the organizations. As a result we can deaccelerate material consumption of industry and get longer time for sustainable innovation or long life low consumption system for sustainable development. We also show technical issues to improve lifetime of products in the market. Lifetime of product is the most effective mean to reduce material consumption.

Keywords:

Recycling, value increase, low consumption, lifetime, impact coefficient, sustainability, IIDPS

1 INTRODUCTION

Industry consumes material to make products. Increasing demand on industrial product results in shortage of material supply. At the end of use, material in products damages environment if simply disposed. EPR and concept of inverse manufacturing is considered to overcome the above issues. Up to now many solutions are proposed to make recycling systems. But still we cannot have a self sustainable recycling system. The major reason is that the venous part of recycling system does not create enough value for sustainable operation. We will summarize our past study on economical characteristics of recycling system and propose a model that will contribute to make self sustainable system.

2 IMPACT COEFFICIENT

2.1 Material

Sustainability of industry depends on the performance of resource. To evaluate material, we introduce evaluation indices. They are M_{IC} (Material Impact Coefficient) for qualification of material utilization performance of equipment design and M_{LT} (Long term Material Impact Coefficient) for qualification of material utilization performance of industry.

$M_{IC}=Q_m/T_{LM}$

Where Q_m denotes material used in an equipment, T_{LM} is lifetime of the equipment.

M_{IC} can be used to evaluate required material supply for equal service. For example, an equipment of short lifetime must reduce material usage. The direction of technology must be targeted to get lower M_{IC} by reducing material in equipment or prolonging the lifetime of equipment.

$M_{LT}=\Sigma(Q_{mvi}/T_{LMi})*N_{Mi}$

Where Q_{mvi} is material used – recycled material used in equipment i, T_{LMi} is lifetime of equipment i and N_{Mi} is produced number of equipment i.

M_{LT} can be used to evaluate required venous capacity for equal service.

The direction of technology must be targeted to get lower M_{LT} by reducing material in equipment or increasing recycle rate or prolonging the lifetime of equipment or limiting the number of production for higher M_{IC} equipment.

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2.2 Energy

The similar indices can be introduced for the performance of energy consumption in production phase combining the performance of energy consumption in using phase. They are E_{IC} (Energy Impact Coefficient) for qualification of energy utilization performance of equipment design and E_{LT} (Long term Energy Impact Coefficient) for qualification of energy utilization performance of industry.

$E_{IC}=E_u + Q_E/T_{LM}$

Where Q_E denotes energy used for producing equipment, T_{LM} is lifetime of the equipment. E_u is energy consumption in using phase.

E_{IC} can be used to evaluate required energy supply for equipment as of lifecycle. For example, an equipment of short lifetime must reduce energy for production. The direction of technology must be targeted to get lower E_{IC} by reducing energy usage for production or prolonging the lifetime of equipment or improving energy consumption in using phase.

$E_{LT}=\Sigma(E_{ui} + E_{mi}/T_{LMi})*N_{Mi}$

Where E_{ui} is energy consumption of equipment i and Emi is energy used for producing equipment i, T_{LMi} is lifetime of equipment i and N_{Mi} is produced number of equipment i.

The direction of technology must be targeted to get lower E_{LT} by reducing energy usage for production or prolonging the lifetime of equipment or limiting the number of production for higher E_{IC} equipment.

3 MATERIAL SUPPLY BY RECYCLING

3.1 General

At the former section, we mentioned on M_{IC} and M_{LT}. These coefficients are relative indicators but useful to drive system development. If material usage in equipment cannot be reduced then prolonging the lifetime of equipment can reduce M_{IC}. M_{LT} can be reduced by this action. Improving recycling rate will reduce M_{LT}.

3.2 Ceiling of supply

It is very simple concept to utilize used material again and again by recycling. If recycling rate is α then usable amount of material is 1/(1-(α/2)) for one time recycling and 1/(1-α)for multiple recycling. The recycling rate α for the major material used in electric home appliances in Japan is around 0.85[1]. Then usable material quantity is increased 1.73~6.67 times of that for no recycling. Whether it is a good indicator or not but it should be in mind on the ceiling of material utilization.

Apart from the principle of 2nd law of thermodynamics that governs the limit of recyclability, the above estimation is based on a priori system operation. That is, a recycling system is operated on a business mechanism without difficulty.

3.3 Economical feasibility

Fig.1 shows the mechanism of value-up in production (arterial part of recycling system) business model[2],[3]. This mechanism is cascaded in many steps until final product. Therefore value-add in arterial can be increased with no limitation. Fig.2 shows one example. Value-add

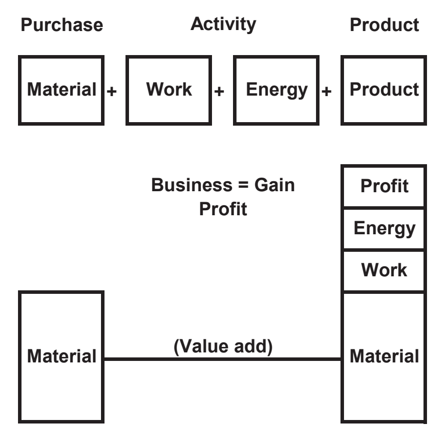

Fig.1: Production Business Model

mechanism in inverse production (venous part of recycling system) business model is similar to Fig.1. But material must be changed to discarded product and product must be changed to material. Very tough business condition for the venous system is pricing of material. The price is not decided by the company in inverse production process but decided by market of material. Therefore value-add of the inverse production process is small. For example, the value is about 1/20 to 1/200 of product for electric home appliances.

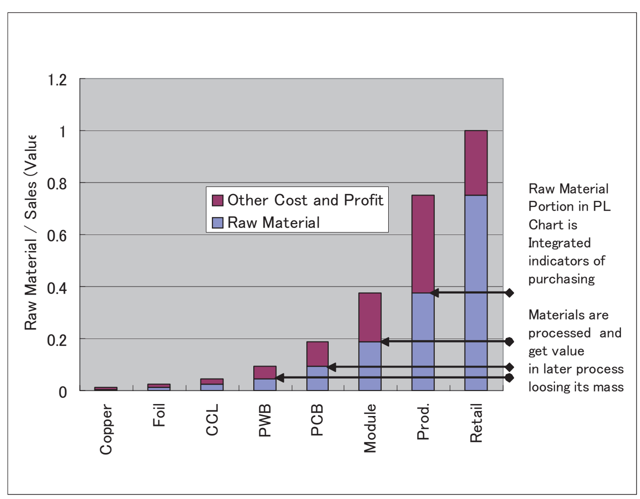

Figure 2: Material portion in sales value (Electronic product model)

The material portion in a product is determined by product (arterial part of recycling system, therefore the venous part cannot increase) and recycling method. Recycling method is sensitive to the quantity of abolished product. The bigger the quantity the more effective recycling method is applicable. Therefore venous system is contradictory system to material saving in nature.

3.4 Compensation of contradictory relation

As venous operation has little margin for adding value, it is a contradictory operation in economical base. To release this situation, a value-add operation must be combined. We can make recycling system if the adding value operation is properly managed to add value to venous operation. We proposed one solution as IIDPS (Integrated Inverse Distribution and Production System) in 2006[4],[5].

4 IIDPS

4.1 Outline of operation

This system is combined recycling system and 2nd hand market. Material flow in this system is shown in Fig.3. In this system the distributor, the manufacturer and the collector for redistribution are functionally incorporated to give maximum life time for EEE.

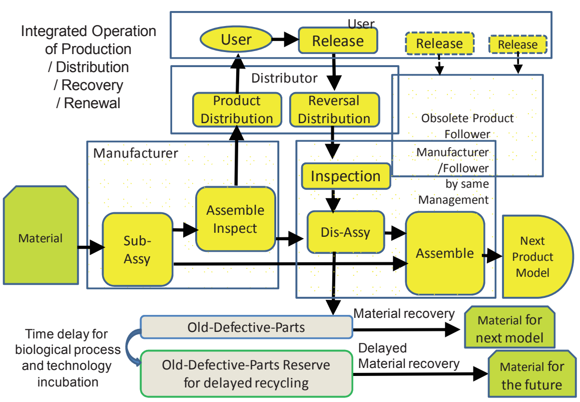

Fig.3 Material flow of integrated inverse distribution and production system (IIDPS)

Material recovery system is also incorporated. Time delay recovery is the very unique approach for material recycling to compromise technological performance of recovery system to economical requirement. Key issues to operate integrated inverse distribution and production system are effective collection, inspection and replacement of degraded parts of EEE. This system can supply products for the consumers of low buying power with a little material consumption and low increment of environmental burden [6],[7]. We can transfer value that is completely lost in simple material recycling and save human work and energy and contribute to improve M_{IC} and M_{LT} [8][9][10].

4.2 Combination of operations

There are many choices to form combined operation in terms of combined operation arterial part and venous part. The manufacturer and venous, venous and assembler, distributor and assembler are typical combinations that can transfer value from arterial part to venous part. One of the important conditions to form these combinations is manufacturing IP at least partly. Therefore manufacturers are key players in IIDPS. But it is very natural situation as manufacturers are main body of EPR. For refurbishing product, it is mandate to transfer EPR to refurbishing organizations.

5 SELF GOVERNING SYSTEM TO SUPPRESS EXCESSIVE MATERIAL CONSUMPTION

5.1 General

The only and challenging subject for the sustainable society is a self governing mechanism that can lead industry to low material consumption system. IIDPS can improve M_{IC} and M_{LT} very much by the combined operation of arterial and venous part in the recycling system. This combined operation opens the way to self governing mechanism.

5.2 Legal system to promote combined operation

The combined operation arterial and venous gives us very advantageous to increase value. In separate operation adding value in arterial part does not make profit of venous part. So the clue of making self governing system is provided by tax system. We propose an allowance reserve for recycling with no tax. The limit of this reserve is about 1% of sales revenue per year. This reserve is not subvention but gained by business. The company that receives this reserve must accept all returned product without fee or buy from consumers. The company can sell accepted product by refurbishing or recycle to material. The mechanism will promote supply of high value-add products. The reserve is used for all venous operations. A product with longer lifetime is favorable for keeping profit because the reserve is accumulated long time. Reducing material portion in a product is also favorable because reserve is counted by sales value (Fig.4). Reducing material portion is also favorable to reduce M_{IC}. Venous operation could be out sourcing.

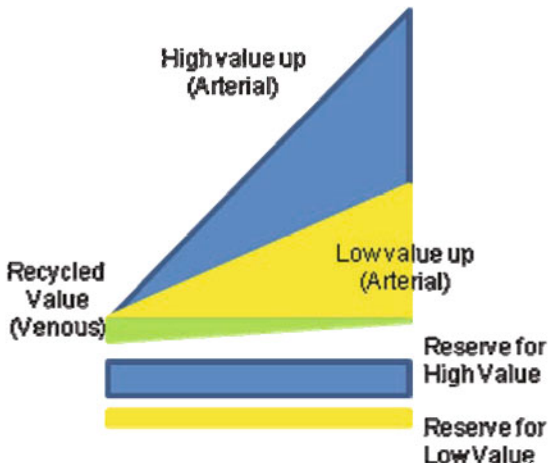

Fig.4 Related reserve for recycling to value-add

5.3 Additional consideration

Distributers can be the position of manufactures because they can supply their own brand to the market. In this case the distributors can receive the reserving right. A business association must be established in preparation to closing company.

6 TECHNICAL ISSUES

To support IIDPS the following technical issues are listed. Modular design categorized by material group, power consumption, reliability of components, IP. Flexible expandable circuit structure, adjustable patch circuit, power recording module are useful to increase life time of products[11],[12].

7 SUMMARY

In order to construct sustainable society, the inverse manufacturing concept is useful. But it is not easy to construct an industrial system under the economical restrictions. To establish the system, a self governing mechanism must be introduced to suppress the material consumption in economic framework for long term. This research showed that separate operation of arterial and venous operation promotes increasing quantity of products and disposal. We showed a combined arterial operation and venous operation by the same business organization is easier approach to realize a sustainable system. A proposed solution is supported by taxation framework but it is not like subvention. Applying this framework, a business organization can transfer operating cost for venous operation from their arterial operation in ordinary business activity. A torrential product supply to the market will be suppressed. Products of longer lifetime will be advantageous to keep bigger reserve for venous operation. A supplier with higher value-add products receives higher reserve for venous operation. The higher motivation to reduce material portion in their products will be stimulated by this mechanism. There are engineering issues such as module technology for prolonging products in the market is useful to realize sustainable system. But they are not mandate to be solved. The engineering achievement will be applied according to the timing of realization and will contribute to reserve time for the further innovation.

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Planning Sustainable Social Infrastructure in the Green New Cities of Azerbaijan

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Abstract
The article is discussed formation of green new cities structure and the planning sustainable social infrastructure in Big Baku region. The author pays special attention on necessity of the system, complex decision of tasks in the Regional plan for development of the green new cities in region. Thus are allocated the basic aspects which decision will allow to defining directions of region development. It is supposed, that the General plan of the Big Baku and green new cities for long years will fix the spatial organization of region. The theoretical findings of this article are useful guidelines for designers and managers.

Keywords: planning, sustainable, social infrastructure, green new cities, Azerbaijan

1 INTRODUCTION

New cities usually symbolize the origins of the city. While these areas are usually endowed with a multitude of new social infrastructure, they are also the areas that are most prone to the undesirable and consequential effects of growth and urbanizations, including overcrowding, air emissions and poor environmental quality [1]. Urban planning of green new cities serves as a fundamental catalyst for change, improving environmental quality of the natural and built environments, and upgrading conditions in new areas [2]. This paper analyses strategies that have been used in the planning sustainable social infrastructure in the Green New Cities of Apsheron, Azerbaijan. This study is aimed at providing on the strategies that have been used to upgrade the environmental quality of this green new cities as a case from which many lessons can be learnt, thus attempting at diminishing undesirable effects and improving the urban, social and environmental quality of its urban spaces for the well-being of citizens. This paper focuses on the role of planning sustainable social infrastructure in the green new cities of Azerbaijan. It proposes a more nuanced approach to understanding of that complex phenomenon, which would include the possibility that some of its forms may represent the much needed transfusion of new and healthy energies into the tired urbanities. The examples of planning sustainable social infrastructure presented in the paper indicate that some of the outcomes of sustainable planning are superior to well theorized examples of urban planning.

Those examples are from Big Baku, one of the fastest-changing cities in the world. The chosen locations are in the precincts of Alyat, Gobustan, Sangachal, Dubendi and Pirallachi - future green new cities of Apsheron, where living connections with the past coexist with practices of the oil power World City [3] [4], located between the West and the East, on a new Silk way [5]. The paper advocates locally attuned approaches to cultural sustainability, and careful balancing of planning with urban self-regulation. Authors of article offers creation on Apsheron urban planning systems of new type - “Eco-cities” which, on its belief, will be capable to provide sustainable development of capital Baku and the existing occupied places of region.

Sustainable development of new cities - “Eco-cities” in the Regional plan of the Big Baku is planned to be carried out due to ecological corridors and the uniform "linearly-strip" communication structure uniting in interconnected moving system all settlement of peninsula.

2 RETROSPECTIVE VIEWS ON FORMATION OF NEW CITIES IN THE BIG BAKU

In order to comprehend the nature of new cities, it is essential to look back into history and identify their beginnings, growth, development and the multiple layers time has bestowed upon them. It is interesting to note how the new quarters of the city tend to represent their origins. The beginnings of most world-famous cities, such as Alexandria, Egypt, Istanbul in Turkey and Baku in Azerbaijan [6] [7], were originally constructed in the area that nowadays represents the historical beginnings of these cities. Over the centuries, the city's new urban fabric began to articulate with respect to this historical centre, and urbanization accordingly occurred in a peripheral direction, as depicted in the diagram in Figure 1 below.

The importance of new centers is that they serve as a place

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of identity, memory and belonging [8]. New city centers of the Big Baku tend to forge an urban identity for the rest

Fig. 1: Diagram to show New Urban Expansion that Radiates out from the City Centre, in a Concentric, Linear or Polycentric Direction

of city, and for surrounding districts to adopt. In many cases, new districts are representative of the entire city, the result of the outstanding multitude of new buildings, social infrastructure and heritage and archaeological sites, which manage to endure time, contradicting new functions and development that take place around them, at expeditious rates. New cities of the Big Baku usually tend to serve as the city's central business districts, or the information and new technologies centers, as they are often referred to. This is owing to the high percentage of commercial functions, public buildings and offices that exist within. In this way, the new cities tends to both represent a great deal about the city's economic performance and success, thus adding notable eminence and value to it.

3 CHALLENGES FACING NEW CITIES

While new centres are real periphery to the city both historically and geographically, they are also subject to many challenges and obstacles. The explosion in urban population is partly to blame for this. In 2007, the world's urban population had exceeded its rural population, and by the year 2050, the world's urban population is expected to increase by up to 65% [9] [10]. New cities of Azerbaijan and all over the world tend to witness a multitude of undesirable effects, the result of the overwhelming waves of rural migration taking place. Overcrowding and consequential unplanned growth of the new cities have resulted in environmental degradation on a variety of scales. This is inclusive of localised environmental health problems, such as indoor air pollution and contamination of drinking water, and city-regional environmental problems such as ambient air pollution, inadequate waste management and resultant pollution of water-bodies such as rivers and lakes. this persistence and the overall laissez-faire attitude that is usually adopted by city administrations may contribute to pollution on a broader scale, and have extra-urban impacts such as ecological disruption, resource depletion, emissions of undesirable greenhouse gases and subsequent rise in anthropogenic heat in the ambient atmosphere.

4 PLANNING OF GREEN NEW CITIES AS A CATALYST FOR CHANGE

Urban planning and the formation of green new cities contribute largely towards upgrading environmental quality as the vast umbrella, thus serving as a fundamental catalyst for change. Development projects taking place in new districts tends to attract a variety of economic activity and competition, therefore encouraging both new inhabitants and visitors to revisit and rediscover these restored vicinities of their cities. Moreover, upgrading the physical built environment, social fabric and urban spaces within the new urban structure all contribute towards increasing their adoption as places for public congregation and activity. This consequently increases social interaction and cohesion between citizens. Furthermore, planning and the formation of green new cities tend to re-affirm residents' feelings of identity and sense of belonging. Furthermore, urban planning is often witnessed as an approach towards sustainability. According to Stren and Polese [11], one of the main aims of sustainable urban policy is to *"bring people together, to weave parts of the city into a cohesive whole, and to increase accessibility (spatial and otherwise) to public services and employment."* in addition, sustainable areas and green new cities are those which are created to support sustainable living, with a prime focus being placed on economic, social and environmental sustainability [12].
This is of distinguished importance in new districts which tend to represent and symbolize a diverse set of ideals of the green new city's identity, including its history and culture on one hand, and its local economic viability on the other. This paper aims at scrutinizing the green new cities on the Caspian seaside of Apsheron peninsula, in Azerbaijan, which is also known as the Baku city agglomeration (Fig. 2).

Fig. 2: (Left) An Aerial View of the Core City of Baku's Caspian Location. (Right) Metropolitan rings surrounding the Core City.

The paper sheds light upon recent attempts that have been made at urban planning by the Azerbaijan architecture and construction university (architecture projecting and urban planning chair) and the society of Urbanists of Azerbaijan together with executive power of Baku city (architecture and town-planning head office). The strategic plans that have been made for the green new cities development of this area are discussed further in this study.

5 PRECONDITIONS OF PLANNING SUSTAINABLE SOCIAL INFRASTRUCTURE IN THE GREEN NEW CITIES

The core of Baku city agglomeration is considered the central hub of the Metropolitan Region of Baku (MRB), the capital of Azerbaijan Republic [13]. As shown in Figure 2 below, the core of Baku city agglomeration is situated directly along the Caspian Sea. It is bounded by natural elements in several directions; the Great Caucasus Range mountain ranges to the North-East and lakes Jeyranbatan and Beyukshor to the North-West and North-East respectively [14].

The map of the Azerbaijan Republic is shaped somewhat like an eagle in flight with Baku for its head. The Big Baku is situated on the Apsheron Peninsula, which juts about 64.4 км out into the Caspian Sea, at the point where the slopes of the Great Caucasus Range descend to the sea.

The low shoreline with its historic coastal road is protected here by the mountains. Hills, about 350.5-396.2m high form a natural amphitheatre with a convenient harbour – an ideal location for a city.

Baku has a moderately warm and dry subtropical climate, with a hot summer and short mild winter. Frosts occur once in 10-15 years. The average temperature is 3-4°C above zero in January, 25-26°C in July. On the same latitude as Greece and Italy, the Apsheron Peninsula is warmer and drier. Incidentally, its average yearly temperature of 14.4°C coincides with that of the Earth. It has the greatest number (284) of fine days in the year of all places in the Caucasus, and the least amount of rainfall (180 mm in the south, 322 mm in the north) [14].

The prevailing winds are either from the south – *Hilavar,* or the north – *Hazri,* i.e., Caspian. The *Hazri* is in fact a very strong sea wind channelled onto the Apsheron Peninsula by the mountains.

Baku today is a city of gardens and parks. Each citizen is required to plant a certain number of trees. As a result there is now 20 sq.m. of greenery per head, a ratio higher than in London, Rome or Bucharest.

Present-day Baku with suburbs, their complex of oil-wells and refineries, industrial, agricultural zones social infrastructure and holiday belts, extends over the whole peninsula, as well as to the numerous offshore islands, both natural and artificial, where the oilmen live and work. It includes, for example, the steel platform township, known as Oil Rocks, 97 km out to sea. The Big Baku thus occupies an area of 220,000 ha (as compared to the 22 hectares of the historical centre of the town) together with the social infrastructure.

Administratively Baku is divided into districts in which there live over 2.6 million people, or about half of the republic's total urban population. In terms of population Sumgayit satellite-city ranks third among Azerbaijan cities after Baku and Ganja, and it occupies second place – coming ahead of Ganja – in economic potential.

Apsheron's medieval castles were built in three lines for defence purposes – along the north-east coast, the centre of the peninsula, and in the south near Baku. Maiden Tower and probably some other towers (now lost), were included in the latter line of defenses. The castles stretch north to Beshbarmag Mountain and south to Gobustan. They are linked by some historians to the Roman expeditions which built forts and observation posts along the strategic Caspian coast. This is confirmed by local tradition: one of the oldest villages on the peninsula is called Ramana.

Alongside with Baku and Sumgayit, there is on Apsheron about 50 city settlements with a population from 1,5 up to 75 thousand people. Among them: Khyrdalan, Alyat, Gobustan, Sangachal, Buzovny, Mashtagi, Pirshagi, Mardakan, Bilgah, Zagulba, Nardaran, Gousan, Dubendi, Pirallachi and others [15]. Today these cities are considered as green new cities - elements of the future sustainable settlements system of the Big Baku.

It is important to identify Baku as an historical city, whose urban structure and social infrastructure has evolved over time, until it reached the present state. As depicted in the diagram shown in Figure 3 below, the city began as a medieval town bounded by the sea, with a series of peripheral villages around it.

Fig. 3: Evolution of Baku from a Medieval City to the Urban Metropolis Known Today

Throughout the 20th Century, however, notable development began to take place in a concentric direction, one which is highly characteristic of many cities in the Caspian region. This has consequentially resulted in the urban fabric found today; with the Core City at the centre, and several metropolitan rings surrounding it together with the social infrastructure. This Core City currently covers an area of 175.7 km², and serves a population density of 382 people/ha [16].

6 CREATION SUSTAINABLE URBAN SYSTEMS OF NEW TYPE - "ECO-CITIES" ON APSHERON

A variety of planning strategies have been adopted by the Baku City Council, aiming at both urban regeneration and upgrading the ecological performance of the green new cities of Baku city agglomeration, which is considered the historical settlements. As part of the research conducted by the researchers looking at urban regeneration; environmental and ecological development conducted in some Apsheron green new cities are classified under different strategies. These strategies for creation urban systems of new type - "Eco-cities" can be classified under six main areas, as shown below:

– Improvement of natural and manmade environments;
– Enhancing socio-economic equality;
– Optimization energy consumption and generation, and waste management;
– Improvement of ambient air and water quality;
– Social Infrastructure Development and Transportation;
– Preservation and regeneration of a cultural and architectural heritage.

Creation urban systems of new type - "Eco-cities" provides the account preconditions of planning sustainable social infrastructure in the green new cities of the Big Baku on Apsheron, in Azerbaijan.

7 PLANNING SUSTAINABLE SOCIAL INFRASTRUCTURE IN THE GREEN NEW CITIES - "ECO-CITIES"

Significant growth in green areas has taken place between the years 1995 to 2010, as part of the Region's Strategic Plan to protect natural spaces and biodiversity, and increase the breathable areas of green spaces within the city [15]. The table 1 reveals increases in green spaces that have taken place between the years 1995 and 2010.

Table 1. Growth of the city's green areas between 1995 and 2010 in hectares (ha).

Green Areas	1995	2000	2005	2010
Urban Green	912.6	923.4	933.4	939.4
Trees along Streets	79.0	79.8	81.0	82.4
Parks and Gardens	16.5	17.5	22.4	27.0
Total	1014.4	1027.0	1043.1	1055.1

Furthermore, being Caspian cities, the beaches of Baku are considered an integral part of the historical city of the Big Baku. Thus, the beaches located within the Core City of Baku undergo regular checks, under the Integral Management Programme of the Social Infrastructure Development for the Big Baku Coastal Area that was set up in 2009. This Programme of the Social Infrastructure Development incorporates measures such as sand and water analysis, ecological sifting of sand and collection and recycling of waste materials found both in nearby waters and on the beaches.

The example of planning for green new city in Big Baku, is shown in Fig. 4.

The first stage	The second stage
The third stage	The fourth stage

Fig. 4: Planning for formations stages for Gobu-San green new city – "Eco-city" on the basis of existing Gobustan and Sangachal settlements

Moreover, environmental audits and checks are performed to ensure that environmental laws are strictly enforced. A large part of the city council's commitment towards sustainability, involves protection and improvement of social infrastructure and public spaces within the green new city - "Eco-city", as man-made elements integrated within both the natural environment and the built one [17]. Social infrastructure and public spaces in Baku follow a distinct style and tradition that date back to Ivaniskiy, Semenoff and Ilyin's planning [18]. The need for development of the green new city's social infrastructure and public spaces was initially recognised during the 2000s, and improvement began prior to the 2011 for "Eurovizion'12", in an attempt to transform each green new city - "Eco-city" of the Big Baku into the *"City of Public Space"* [19]. Consequently, entire districts, such as Multifunctional Inhabited Complex "Ag Lepeler", where designed, and existing urban areas such as the "White City", were further developed [20] [21]. The "White City" continues to stand as an important aspect in the green new cities of the Big Baku social infrastructure and public space design, giving priority to pedestrian activity, providing a meeting point and enhancing social interaction between citizens and tourists alike.

8 SUMMARY

This paper summarized the results of research in the field of planning a sustainable social infrastructure for green new cities - "Eco-cities" in capital region of the Big Baku, in Azerbaijan. The Caspian cities and the Apsheron beaches have been considered as an integral part of the Big Baku.

Green new cities of Azerbaijan must make the best of its inherent capacity to see a sustainable planning. What made the original neighbourhood function, from a human and social point of view, is only vaguely taken into consideration. We approve that when planning a built environment it is crucial to study how the place has worked from a human and cultural point of view, rather than to merely focus on its use. To re-qualify cities Baku city agglomeration for new uses is thus not a project but a process, which means that planning green new cities and them sustainable social infrastructure must leave city for humans to develop and adjust the cities to a functions appropriate for human ways of being and living. The green new cities - "Eco-cities" of Azerbaijan must in other words allow people not only to stay but to dwell. Our paper has been focused on ideas and examples of how to use a approach of sustainable development for planning of social infrastructure as part of the creation of a long-term, livable green new cities.

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National Taipei University of Technology Development of Ecological Campus

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Abstract

National Taipei University of Technology (NTUT) is located in Taipei city the capital of the only green axis tertiary institutions which also in the heart and hub for the city transportation, and people around here makes activities happened frequently ; NTUT is a typical of the urban university, It should be play an important role in Taipei of process building the eco-cities. The development of eco-sustainable campus since 1980, it's divided into four periods: one, the germination period (1980-1999). Second, the integration period (2000-2002). Third, the practice period (2003-2008). Fourth, the vision of (2009 - present).

NTUT completed at the Eco-sustainable campus of the current implementation, like removing walls to create eco-friendly stream interface and the urban street space to reach the campus, community and city links; construction of compound wall and provision of urban green roof carbon adsorption function, balance urban carbon dioxide emissions; to reach a comprehensive permeable pavement of the campus, effectively improve the city water cooling, dramatically reducing the heat load of the city; To build ecological demonstration house with solar energy, ecology and campus landscape, and provide education and demonstration platform for the heat load; The implementation of the above construction of ecological campus, National Taipei University of Technology to "humanities, ecology, science and technology campus, " the development of long-term vision for the campus

, Keep going with the efforts to attempt and try to break through the existing interface with the surrounding environment constraints, the future campus will implement a series of long-range planning, the Greeley campus community of ecological, sustainable development in the surrounding urban environment, with one complete planning, the establishment of culture, ecology, science and technology Trinity metropolitan open campus will create a sustainable green axis of the University of New York reached a more ecological benefit, healthier, more environmentally friendly urban environment.

Keywords:

Ecological、Ecological Campus、Ecological Environmental Design

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1 INTRODUCTION

Located at the heart of downtown Taipei and the Green axis of nucleus,**(Fig.1,2)** of the transportation network, NTUT is surrounded, with major arteries, the most actively place in the city central, as typical of the Metropolitan University in Taipei, the school continued to attempt to break through the elder interface limit , and reach the goal to eco-city , combined with the surrounding environment, the implementation of a series campus planning stage to play an integrated role as the center sustainable eco-campus.

2 NATIONAL TAIPEI UNIVERSITY OF TECHNOLOGY DEVELOPMENT OF ECOLOGICAL CAMPUS

Campus Development Goals has been gradually building a community toward symbiotic sharing of eco-functional multi-campus, divided into four periods:

1. Budding Stage of Eco-Campus Planning Concept (1980-1999)
2. Eco-Campus Planning Concept Integration Stage(2000-2002)
3. Eco-Campus Construction Stage(2003-2008)
4. Prospect for Development of Humanistic Eco-Campus in the Community (2011-so far)

2.1 Budding Stage of Eco-Campus Planning Concept (1980-1999)

The starting was to increase a corner that student could have more activities, to improving the campus cultureal environment**(Fig.3)**.In2003,concern about the eco-environment and Humane care will be "eco-campus" was renamed "human ecology Campus" .Department of Architecture Garden in 1989 was the first space that integrated design education with practices and took both humanistic activities and ecology into consideration.**(Fig.4)**In 1994 “Innovation Science Garden” Department of Architecture was relocated to the new building (Design Hall) next to a wet and shaded vacant lot, which was designed and constructed by students of the architecture design program. To preserve the original environmental features, again, only flat bricks were laid. Since the place was rarely used by students, we were hopeful that moss would show up here. Currently, ferns are being planned.**(Fig.5, 6)** In 1996 (“NTUT School Plaza” **(Fig.7)**) have been reform to (“Humanities Plaza”**(Fig.8)**). Upon completion, vines were planted. At present, creeping figs have covered the half-perforated wall that connects the plaza and Chinese banyan garden. The openings of the wall were so arranged to allow branches of the red cedars behind to stretch out. The third education building had also been covered by Boston ivy. This core of humanities had been approaching the image of green valley.

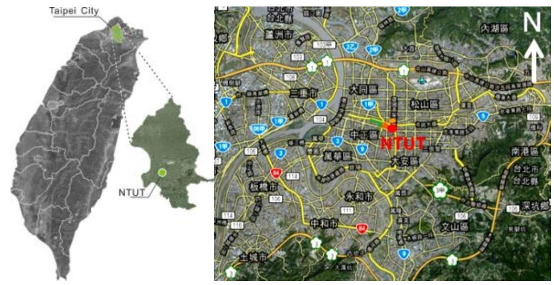


Fig.1:Situated at the heart of downtown Taipei and the Green line of nucleus

Fig.2: NTUT is surrounded, with major arteries, west near to Taipei station and east to MRT Zhongxiao-Xinsheng Station, it is where 5 transportation intersection place, Located near the northwest corner of the campus, Huashand gallery section and Guanghua Mall is an important information technology outlet in Taipei City.

Fig.3: NTUT Eco-Campus Image

Fig.4: Department of Architecture Garden

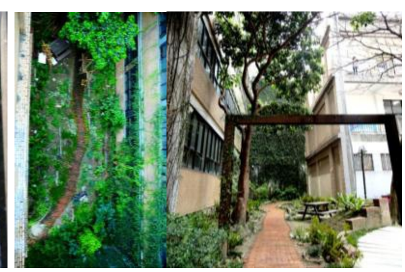


Fig.5:Innovation Science Garden Fig.6: Fern Park

Fig.7:Humanities Plaza Fig.8:Humanities Plaza

2.2 Eco-Campus Planning Concept Integration Stage (2000-2002)

Upon its inception in February 2000 NTUT Water Environment Research Center began to introduce water ecology issues. The following idea was proposed:

"Eco-idea concept of education, creat multy eco spaces, urbanlized humanity eco-persepective, to construction new permeable pavement, and become a zero energy campus". An open eco-campus space must be connected to the urban area through ecological interface, to expand eco-campus idea to city planning.

2.3 Eco-Campus Construction Stage（2003-2008）

2.3.1 NTUT Green Campus Building and Campus Restructuring Plan

In older to achieve "Eco-Campus", since 2003, NTUT execute the reform plan to Green campus, setting up the "Site Revegetation", "Wall Revegetation and Rainfall Eco-Reservoir Project" **(Fig.9)**, "Site Water Conservation Improvement Project", "Integrated Opto-Electronic Exterior Shade" and "Energy Conservation Improvement Project", "Air Conditioning Energy Conservation Improvement Project", several eco- project have been done. eco-reservoir and building the water eco-space could soften the campus space. One year after completion of the project, there had been numerous visits of nightingales to the small area of the pond;white egrets also showed up every now and then to surprise many, and walk on the new permeable pavement **(Fig.10)** will be and joy experience even in the rainy day.

3.3.2 NTUT Eco-Campus Construction Project

Since 2003 Ministry of Education, "Appropriation of 2003 grants program to promote Sustainable University" to promote, further proposed "eco-Greeley School Project Plan" implementation.

1."Eco-Balcony Project" was one of the implement **(Fig.9)**"Since mankind has occupied a large area of land that belongs to the living creatures, it would only be ecologically ethical to return the balcony as part of its repayment to the creatures as habitat.

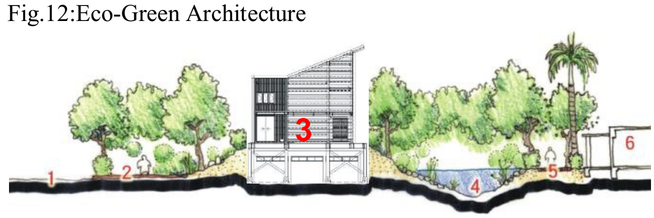
2."Campus Waterscape Project"**(Fig.11)** was completed in 2000 to fulfill a dream. It has connected the eco-reservoir with the outside world making regional ecology more enriched and diversified.

3."Technology Greenhouse (Eco-GreenArchitecture)" **(Fig.12)** combined with design and implementation of teaching, international cooperation, to complete a self-eco-cultural integration between. In accordance with Taiwan's hot and humid climate, it utilized environmental conditions to plan a comfortable indoor environment that is in harmony with nature and energy-effective.The Eco-Green Architecture is situated between the Campus Waterscape and the Eco-Reservoir to demonstrate the fact that ecology and humanities are one. **(Fig.13)**


Fig.9:Eco-pond landscape bird watch photo
Fig.11:close to the Chung-Xiao Rd. building roof eco-terrace

Fig.10:The permeable pavement in front of Design department building panoramic view


Fig.11:Campus Waterscape Project
Fig.12:Eco-Green Architecture



1. Zhongxiao E. Rd. Vehicle Lane
2. Eco-Sidewalk to Expand Experience of Space Esthetics
3. Eco-Green Architecture
4. Eco-Reservoir Landscape
5. Eco-Sidewalk
6. Revegetation of the Roof of Convenient Store

Fig.13:Eco Green Building relationships with the surrounding environment section diagram

3.3.3 「Rice Garden」 Reconstruction

July 2007, to expaned the eco campus iedea, we set the "Rice Garden" project by the "campus scenes to experiment and innovate" in Practice**(Fig.15,16)**. The concept it introduced integrated history and humanities at the MRT exit near the campus.This is the best spot to advocate humanistic eco-campus. Each year when the rice crops ripen we intend to celebrate it as an important event on campus **(Fig.14)**

3.3.4 Xinsheng Green Axis Landscape

Xinsheng axis was the historical axis of the campus – we planning concepts of the original image to eliminate parking on the axis **(Fig.17)**, changed into a people-oriented line of moving lines, construct a model of ecological landscape of the road, ecological diversity and the delicate nature of the landscape planting, to enhance the campus pleasure of walking, and strengthen ecological green space on campus link up "the image of ecological green corridor", Shape a green axis for humanities eco-campus **(Fig.18,19)**

3.3.5 The Green Gate construction project

Since Mar. 2010, following the completion of the MRT after the two-lane, the Green Gate has become the main pedestrian entrance, located at the southwest corner of the National Taipei University of Technology, an ecological campus that emphasizes the integration of technology, humanities and ecology, and at the intersection of ZhongXiao East Road and XinSheng South Road, **(Fig.20)** an area of intensive pedestrian traffic, combines an ecological green wall with the biggest public art in Taiwan, **(Fig.21)** overall efficiency 3600 m^2 , it shows capture the environmentally friendly spirit of NTUT.

3.3.6The Chung Xiao axis permeable pavement structural reform project

This project will be the main school entrance road, "Chung Hsiao axis" of the new permeable pavement with structural chain, improve splicing of permeable pavement, grass brick used on the grass at the seam **(Fig.22,23)**, on the grass curb eco-design, make sure permeability coefficient of rainfall beyond the pavement surface without water collect, and water features to provide protection. After the facilities for shooting and infrared thermal imaging analysis of surface temperature, sunlight diarectly irradiate in the summer after the permeable pavement to improve the road surface temperature can be reduced up to 7 degrees C. **(Fig.24)**

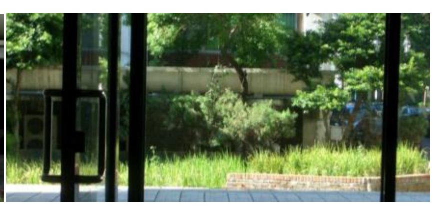


Fig.14: Professor Tsai Jen-Hui harvested the first fruit of the Rice Garden

Fig.15:The Ripening Rice Garden in front of the Design Hall

Fig.16:Rice Garden

Fig.17: Old time Xinsheng axis parking lot image

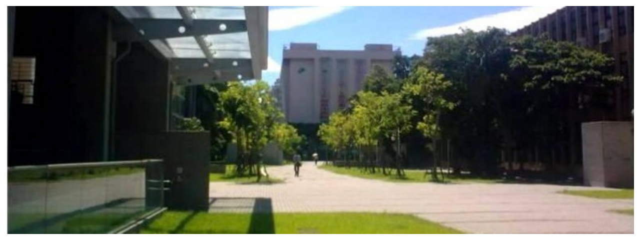


Fig.18:Nowaday Xinsheng axis photo

Fig.19:Nowaday Xinsheng axis bird watch photo

Fig.20:ecological environment link map of the City and campus

Fig.21:The Green Gate located on Xinsheng South Rd.

3.3.7 Xingsheng water corridor that integrates ecology with technology

Along the west sidewalk of campus is the second largest Taipei MRT station and link representatives of science and technology, education, humanities section of Guanghua business area. Plans to remove the wall of this section this technological and ecological water-corridor concept integrates water resource environment, public arts and technology. Through observing the street that serves as the urban-campus interface, it looked for traces of urban living esthetics in NTUT's eco-campus planning and became the spokesman for eco-city. **(Fig. 25,26)**Oct.2011 the Chung Xiao River and Liu Kung River will be more completely integrate urban interface along the west side of campus.

2.4 To create a campus community's vision of human ecology period (2011 - present)

Eco-environment is included all survive of the human ability and care, long-operating this environment, this concern for the environment that the human performance. Eco-campus not only the normal reconstruction project, but also need a long period of people's careness and Careful pampering the eco-environment. A successful eco-campus, urban ecology or ecological community, the residents should be created by long-term out of humane care. Greeley's vision that the future development of the campus is a campus community to create a human ecology.**(Fig.27)**

Fig.22:The orighinal impermeable pavement reform to new permeable pavement with structural support

Fig.23: The orighinal side drains differient with new swales on the side could conserve water

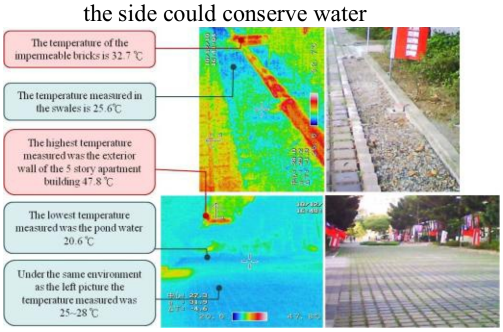


Fig.24:The experment of infrared heat imaging equipment

1. Gather the corner of the campus water systems of the node
2. Strengthen the effectiveness of three-dimensional eco-green
3.Use of natural resources integrated public facilities
4. Extension the Xing Shan axis of aquatic green street
5. With the opening of the new gate of the street
6. Water and technology image combined with the Guanghua business circle
7. Use Water and river to repopulation Liu Kong river irrigation
8. Provide urban rooftop farms

Fig.25:Xinsheng South water-plane ecological corridor planing configure

Fig.26:Xingsheng water ecology with technology corridor status view

Fig.27:The eco-campus planing configure

3 CONCLUSION

Taiwan's efforts in ecological environment have begun to bear abundant fruit in recent years. The government's endeavor in "Challenge 2008 Water and Green Program" signifies it's time for harvest and review, for formulating the direction for the next wave. Eco-campus design is an important link in the nation's effort to construct eco-environment. As NTUT's important indicator in eco-campus development, "Zhongxiao East Road Campus Waterscape" took 7 years to complete, from conceptualization, planning, fighting for budget and winning the support of the administration to communicating with sponsors during the construction, participating to landscape contest and appearing in international magazines.

Tough as it is, each ecological system requires at least a decade to establish a balance. Careful pampering, therefore, is necessary. Humanistic care is demonstrated in the concept that we should try what we can to preserve nature if what it brings about is worth cherishing. This is where delicate culture begins.

This Research Lab is committed to eco-campus planning and management. In addition to the dedicated efforts of the graduate students, I am grateful to the approval and policy support of the administration whose funding has made implementation of many projects possible. I am also indebted to Professor Lin Chen-Yang for introducing NTUT to the concept of water ecology. In the 21st century when environmental protection is assuming ever-increasing importance, NTUT needs to appreciate what has been accomplished and manage the eco-campus it has with more delicate care. The primary task right now is to formulate guideline within the administrative system to systemize the endeavor. In this decated eco-campus have been operating properly, the legisters deeply experice the enviroment have been changing so well, they strongly promoted the idea to city development and communities, shared with all resiidients.

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Design of Green Wall System of Western Façade at College of Design in National Taipei University of Technology

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Abstract

The incorporation of green wall systems is able to lower indoor temperature and beautify the city. There are two major methods for a green wall system: direct wall attachment and independent system, the latter provide better insulation than the former. After the completion of Metro Rapid Transit the entrance between two buildings in National Taipei University of Technology – Department of Design building and Department of Materials and Mineral Resources Engineering building - has become one of the main entrances with large pedestrian traffic, the west façade of design college building therefore is pulled up and become the main façade toward Taipei City. This paper is centered on the design of a magnificent green device using the independent green wall system as a design method to extend existing green wall which runs along Xinsheng South Road, thus offer room for imagination of nature at the heart of city center.

This paper intends to deduce six pints of design concept through literature review: 1. A pivotal space that connects campus ecology; 2. A green impact that has immediate effect to the surroundings; 3. Landscape art that promotes integrity of ecology; 4. A cultural gate for the city and natural ecology; 5. A sustainable life form that follows seasonal change; 6. An initiation of education for participation to the eco-route.

Keywords:

green wall system, façade design, eco-campus, urban greening

1 INTRODUCTION

Vertical green wall has the advantage of lowering indoor temperature and adjusting micro-climate. When applied on an urban campus, it is able to form image of clear character and to increase green coverage. Urban development of high intensity has disrupted the connection of ecological area, resulted in a uneven spread of ecological texture. If the intensity of vertical green wall is increased, with joint effect of urban green belt to merge into ecological network, as a result, urban ecological system will become a dynamic one. The "Green Gate" is a combination of ecological green wall and public art, situated at the south west corner of the campus of National Taipei University of Technology, an area of intensive pedestrian traffic – the intersection of Zhong Xiao East Road and Xin Sheng South Road – to express the central goal of Eco-Campus Scheme that is the integration of technology, humanity and ecology.

2 CHARACTERISTICS OF THE DISTRICT AND SITE

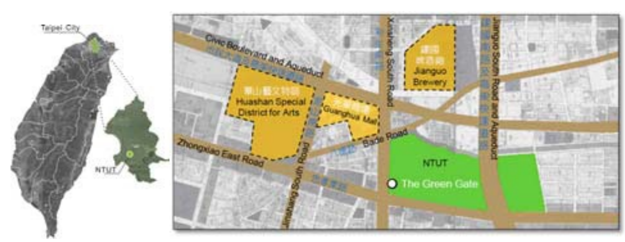

Fig. 1: Site context

The installation of "Green Gate" is founded on and around spaces of Department of Design in NTUT, which is the origin of creative design thinking and concept, it plays an influential role that has direct impact on the environment and paradigms of the university. The spaces utilized include: west façade of Department of Design, pedestrian entrance between Department of Design and, and west terrace of Department of Design. Due to the cross-impact of destruction of Guanghua Bridge and the location of new MRT (Metro Rapid Transport), the site has recently

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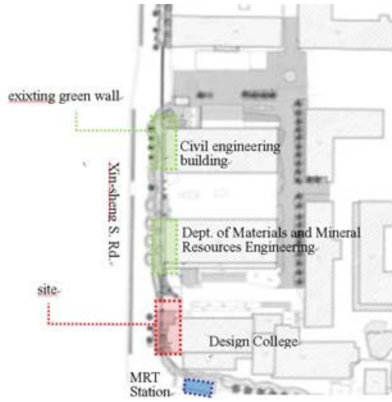

Fig. 2: Site location

become major pedestrian entrance, giving way daily to crowd coming from MRT station and the bus station near by, thus the effect of crowd redirecting, mass containing, and its landmark property, can be distinguished.

3 DESIGN CONCEPT

Through site analsis, collecting and subsequent re-interpretation, this research incorporates 6 design concepts regarding the subject "Design of Green Wall System of Western Façade at College of Design in National Taipei University of Technology"

3.1 The Pivotal Point that Connects Campus Ecology

In the process of planning for green wall systems in the setting of an urban campus, factors that relates to ecology must be considered. Green spaces within the campus are distributed in the form of districts, its marginal status as a habitat crucially lowers its ability to preserve biological species. In response to this, the integration of vertical green wall systems that act as media to connect inner campus ecology effectively construct a complete eco-system. The site is bounded by both ecosystem of the land and water: the land eco-system is consisted of the street front along Xinsheng South Road and roof terrace of Department of Design, and the water the Xinsheng/ Zhongxiao Eco-water landscape; thus with the advantages of flexibility and adaptability, the green wall system joins together the above-mentioned systems to form a continuous and complete one.

3.2 Direct Impact of the Green

Vertical green wall systems has the advantages of directly raise level of comfort, economic soundness, thereby comply with the essence of landscape architecture, also, value of aesthetics. Furthermore, the overall environmental quality is improved to meet the desired functions of an eco-city. Efficiency is one of the key emphases in construction of campus design, where direct impact is preferred to encourage thoughts of awakening for common metropolitans; when overall time for construction is taken into consideration, time for plants to spread across the whole installation takes longer and is unable to satisfy actual requirements for need of speed. Therefore precast modules are used to achieve the effect of greening as soon as construction is complete.

3.3 Land art that nurtures ecology

NTUT has promoted ecological campus for nearly a decade, and has already constructed numerous ecological spaces for educational purposes. The site is a landmark of campus, and should display the campus's ecological spirit.

Installation art has the effect of interacting with the viewer, and can create lifelike qualities for specific spaces; besides the creation of artistic meaning from "site" and "time," this interaction is signified through symbolism. Therefore we can use concepts of installation art to adopt an approach that nurtures ecology, and display qualities of the era in terms of site and time, creating a visual impact that symbolizes nature in the city.

3.4 A cultural gate for city and nature

Urban campuses imply integrity of living, cultural and educational locations for citizens. The university entrance should be an epitome of the campus, and is a type of "intermediary space" that serves as an interface with separation functions, while facilitating the continuation of space inside and outside.

The goal of urban campus planning is to incorporate potential lessons on ecology, culture and social relations that can be offered by the campus into "environment" education, fusing "physical space" to link together the urban environment and serve education functions.

The site is a main pedestrian entrance and should be developed into a cultural square for crowds to stop or walk by; green walls are as if dancing amongst buildings, and create an image of nature, culture and technology coexisting in prosperity.

3.5 Growth and decline through the four seasons

If wall greening is to achieve sustainability, then it must make a breakthrough from relying on maintenance and management to stay in an ideal state, and develop abilities to self-adapt to the environment and evolve. Building walls, animals and plants used for greening should reach a dynamic state of balance, and show different appearance in different seasons or even different ages. The original green walls of NTUT have existed for nearly 30 years, they do not require special maintenance, and even have different appearances in the four seasons; the project site should adopt this simple greening method to achieve sustainability.

3.6 Initiation for participation in an educational ecological tour

The site's location is a hinge of ecological tour stops, and can become a starting point for educational ecological tours, spreading into the campus and posing as an "attractive" natural image to the city.

This natural image aims to arouse a yearning to return into nature's embrace, providing guidance to achieve this goal.

Wall greening can utilize natural factors familiar to human beings, such as valuable crops and reducing the use of artificial colors, to pull people close to nature once again.

4 TRANSFORM OF SPATIAL STRATEGY

Base on previous concepts, 7 space-making strategies are acquired:

4.1 The use of techniques of installation art to create a visually penetrable, air filtering and noise insulating tree structure

Incorporation of techniques of installation art is considered, to create a visually penetrable, air filtering and noise insulating tree structure. Finally, to build an ecological tree, creating NTUT's ecological spirit for the era, as well as a visual focal point in the city. The image of the structure is consisted of lines to compose the natural tree structure, achieving visual guidance effects that are neither aggressive nor estranged. At the same time, after the grid shaped tree is covered in vines, it will act like a mask to filter the city's polluted air and noise.

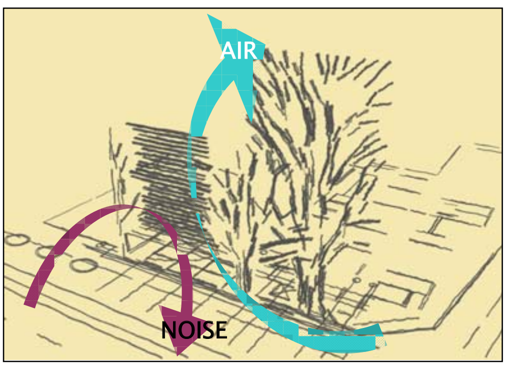

Fig. 3: visual penetration and air filtering effect

4.2 Linkage between green walls of the material and information building and the ecological platform of the design pavilion into an ecological system

The site utilizes horizontal linear structure to link together the green walls of the Civil Engineering building and Department of Materials and Mineral Resources Engineering building, which further extends to the ecological platform on 8F of the design platform, allowing wall greening plants to extend to surrounding ecological systems. This enhances the continuity and completeness of NTUT's ecological campus, forming a larger, stronger "green image."

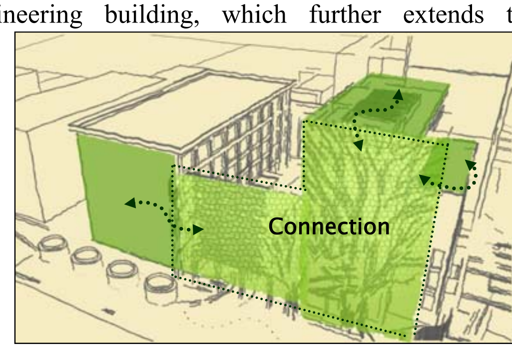

Fig. 4: Connection of existing green wall

Tree branches extend through empty spaces between the Department of Design Building and the Department of Materials and Mineral Resources Engineering building; three trees are the background to contrast the other, forming an intricate, complete one.

4.3 Detached green wall system that requires low maintenance

This design uses fiber reinforced plastic that is light weight, acid resistant with long life span, composing tree branches using articulated mount boards; soil is placed inside along with plants. Module planters and plants are attached behind the ecological tree's structure, which has a light weight steel structure design.

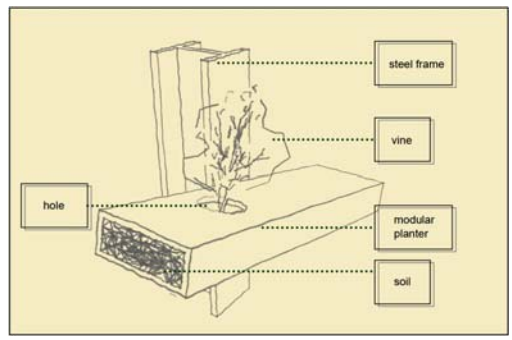

Fig. 5: Components of detached green wall system

4.4 Seasonal change created by multiple layers of vegetation.

Building walls and the plants and animals of wall greening should reach a dynamic state, with different appearances depending on the season and time. After the wall is covered with climbing plants, it will become a small biologically diverse, porous hidden habitat.

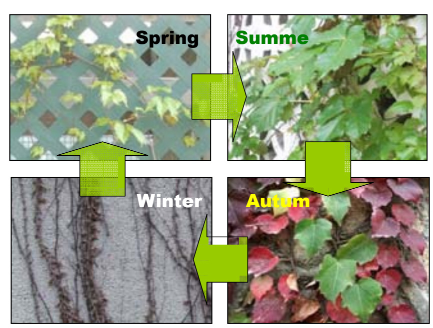

Fig. 6: Seasonal change

4.5 To establish a "hanging" farm to attract citizens to come in contact with nature

" Vertical fruit garden" and an "organic cucumber canopy" is incorporated and is connected to the ecological platform on 8F of the design pavilion. In vertical fruit garden, trailing plants are grown, such as grape vines, for urban citizens to harvest and draw close to nature. The organic cucumber canopy has seasonal crops, such as sponge cucumber and string beans, allowing students to learn to cultivate crops and joy growing own food in a safe, free environment.

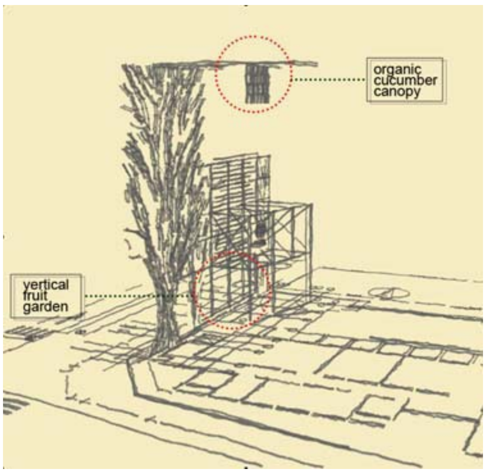

Fig. 7: Location of farms

4.6 Build a space for citizens to rest and experience the cultural and ecological environment

The site acts as traffic hub of Zhongxiao East Road and Xinsheng South Road, where people most frequently meet and interact. Street furniture is installed under the ecological tree, and a mobile platform is built at the entrance of the rarely used underground parking lot of the material and information building; the coffee seats express different behavioral models in the space and show the site's acceptance and tolerance of citizens. People living busy urban lives can relieve their physical and psychological pressure in this ecological scenario, allowing NTUT, an ecological island, to spread and encourage ecological thoughts in the city.

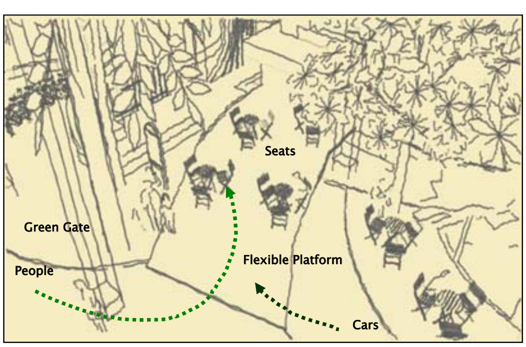

Fig. 8: Interaction with the user

4.7 Set up a starting point for an urban campus ecological tour to attract the public and promote ecology

The site's location is a hinge of ecological tour stops, and can become a starting point for educational ecological tours, spreading out into the campus and posing as an "attractive" natural image to the city.

This natural image aims to arouse a yearning to return into nature's embrace, providing guidance to achieve this goal. For example, wall greening can utilize natural factors familiar to human beings, such as valuable crops and reducing the use of artificial colors, to pull people close to nature once again.

5 CONCLUSION

5.1 Value and Benefits toward Urban Landscape

Urban open space is an important indication of city life. The final outcome of this research establishes new co-relation and human interaction between user, campus and urban environment, with a purpose of opening enclosed campus realm to provide spaces and places that offers public value. Thus giving an opportunity for people from various backgrounds to interact, and to experience and learn the insight of the surrounding environment, so that in the process of travel, metropolitans obtain places to stop by with lower pace and rest. With the above goal, the "Green Gate" intends to initiates a new form of urban living art, in order to remodel on the basis of eco-city, and to improve the quality and imagery.

The outcome of this research is embodied by a tree-shaped public art. The main component is consisted of fiber-reinforced plastic, with vines planted in the light-weight soil; each component is is connected to the ground so when the roots reaches the ground, clocked trickling system for watering can be stopped, and the installation art will become a living life-form. The final result connects the existing green wall on the side of Xinsheng South Road, the farm on the roof terrace. The overall green effect will reach 3,600m2 – the largest in the nation.

Fig. 9: The Green Gate

5.2 Sub-sequential research and future prospect

This research includes a concise monitorial plan, through measurement and computer simulation to record the lowering of indoor temperature and the improvement of indoor air quality of the Department of Design. Since the completion of the “Green Gate”, it can be observed that parts of the “branches” have not been spread by vines as expected. This is possibly due to the effects of natural factors such as sunlight and wind, and properties of the material of the components, result in slower growth. For resolution, a net for the plants to climb will be installed in the future. Besides, the “Green Gate” has accidentally become a large vertical ecological container: ferns and a few aboriginal plants intervene in the same medium and are competing with each other. The above natural and artificial factors in relation to the climbing characteristics of plants and the co-relations between different plants species is worth analyzing in depth.

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Participatory Design Application in Green Campus Interface - Taipei Elementary School Case Study

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Abstract

A School is not only a learning place for students but also a living space. At the same time, they act as the center of a community. Since students and instructors have different images of a school, this project is executed in a participatory way for the campus fence design. Starting from a green, ecological view, both students and instructors will be able to build the ideal campus fence. Taipei City Government is advocating "Observable Loves – Bright Green Campus Smile." Remodel design has been requested for 18 schools in Taipei. This proposal takes Min Quan Elementary School for example, schedules a series of events for "Participatory Design" of the campus and the community interface. First of all, analyze the fence feature which students expect by surveys. Second, develop the fence print that fits user's expectations by students' concepts and models. During the construction, "Participatory Design," "Participatory Construction," and "Participatory Maintenance" can be satisfied by inviting both students and instructors to join together. Along with the participatory design, students, instructors, parents, and residents will develop an affection with the environment. The pleasant experience can further encourage them to manage the campus environment voluntarily. Consequently, the campus fence will become a green interface with ecology, humanities, and landscapes that is shared with students and instructors, community residents, and citizens.

Keywords:

Participatory Design, Green Interface, Elementary School, Green Campus

1 INTRODUCTION

A school is not only a place for learning, but also a space for living. It remains a responsibility for education and plays as a social center of a community. Instructors and students have different images of a school. Therefore, in this project, participatory design is applied to both instructors and students. With participatory design, instructors and students will be able to realize their own imagination and expectation of a school fence in a green way.

Taipei City Government is advocating "Observable Loves – Bright Green Campus Smile." Remodel design has been requested for 18 schools in Taipei and divided into 4 design teams. Our design team, team D, was responsible for the arrangement of 5 of the schools. In this essay, Min Quan Elementary School is demonstrated to look into the interaction between the instructors, students, parents and residents during the progress of participatory design. This experience will be provided as a reference to the design team for future learning.

2 RESEARCH AREA AND METHOD

2.1 Research Area

Min Quan Elementary School locates at Sec. 4 Minquan E. Rd., Songshan Dist., Taipei, Taiwan since 1971 with a total number of 85 classes. The campus occupies 2.5761 hectare. "Variety, Energy, Vision and Eminence" is the prospect of the school for accomplishing Grade 1-9 Curriculum. Min Quan Elementary School is next to Min Quan Park at west and Song Shan Airport at north. The surrounding public facilities are sufficient and well-maintained. Post offices, banks, swimming pools, tennis and baseball courts, underground parking lots, etc. are well-distributed. Because of sitting in the middle of a residential area, abundant cram schools, after schools and talent classes are founded. The campus is in Minshen community- a quiet, simple, pure residential area. Therefore the campus surroundings are extremely clean. However, some of the residents ride motorcycles on sidewalks, turning into an enormous threat of children's safety.

2.2 Research Method

"Participatory Design" was applied in this research. A series of activities interacting with students was proposed to let instructors, students and parents involve in the design of the campus and community interface. Participatory design is originated in 1960s, while communities in England and the United States requested to participate in the environment design (Newman & Thomas, 2008). The process of participatory design is divided into "Design Participation," "Construction

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Green Gate	Ecology Campus	Castle	Sporty Casual
Under the Sea	Colorful	Cartoon	Art Pieces

Fig. 1: Participatory Design- Students' works.

Participation" and "Maintenance Participation." Through the positive experience obtained by joining the process of developing the environment, users will build identification with it (Hung-Er Zheng, 2002；Nick Wates & Charles Knevitt, 1987). Because of the connection towards the campus surroundings, users are consequently more willing to maintain the environment.

3 PARTICIPATORY DESIGN

First of all, several design workshops and orientation combining with school courses were held to build primary understanding for administrators and instructors about the participatory design. Following with distributing surveys to discover students' ideal fence, the topic from their design concept and model can be created. Consequently, a fence design that fits user's expectation was developed. Meanwhile, "Participatory Design," "Participatory Construction," and "Participatory Maintenance" were realized by inviting both students and instructors to join the construction together. The outlines of each step are listed in the following:

3.1 Participatory Design

School Orientation

School administrators and instructor representatives were invited to provide the expectation and needs for the campus fences. Choices of plants as well as possibility of applying to Science courses were discussed with Science instructors too. Meanwhile, the guidelines regarding integrating fences plants to courses as well as developing student surveys were discussed.

Student Survey

Project CDs including related fence construction cases were distributed to instructors. Instructors were requested to help explain to students before filling surveys. In Min Quan Elementary School, students from each grade revealed their expectation of the campus fences by essays and paintings. Phonetic notations were noted on the surveys for students at lower grades to have easier reading. Total 280 surveys were distributed. The design team selected some unique designs from the survey to contribute to the main topics of workshops.

Design Workshop

Topics including "Cute and Fun," "Ecology Green," "Brightness and Happiness," "Architecture Flavor," "Sporty Energy," and "Colorful," etc. were defined from students' surveys. Students were grouped into 6 teams to focus on designing topics they are interested in. Recycled corrugated papers, ice sticks, Styrofoam boards and foam boards, etc. were provided for students with full authorization to create their ideal campus interface. 25 students, 2 instructors, 7 design team members together with 3 recorders have joined this workshop. Pieces named "The Dream of a Fish," "Brightness and Happiness," "Casual Architecture," "Basketball Plaza," "Beautiful Garden," and "The Wall of River," etc. were completed. Finally, students are assigned to explain their design goal as a team and provide their advices as well as creativities for the campus interface design（Fig. 1）

3.2 Participatory Construction

Starting from students' concepts, design teams established detailed designs and blueprints. During the construction process, the principle, directors, Science teachers, parents and students (40 people), design team (7 people), construction unit (5people) and recording team (3 people) were invited to grow plants together in flower stands of the west fence. The species of plants were discussed and decided by Science instructors. Plants suitable for the weather of Taiwan and bloom all seasons such as common tree frens, white mulberries, Chinese ixoras, bananas, papayas, etc. were selected. Hibiscuses and azaleas were added with the plants to build an integrated green fence（Fig.2）.

3.3 Participatory Maintenance

Instructors were able to let students observe Taiwanese original plants through fences buy course assignments. Students could also have better understandings of the growth of a plant and obtain knowledge from Science courses more clearly. At the same time, students' identification with the campus environment were built by joining maintenance and arrangements including watering and weeding.

4 SUMMARY

This research was operated in a participatory design art. Following "Open Campus, Close Neighbors" as the design starting point, the tall and sealed, ordinary fences of a school was replaced by open and green interfaces. While students are participating in the construction process in person, identification with the campus and surrounding areas is developed. An exceptional environmental education space is therefore accomplished（Fig.3）.

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Fig. 2:Primary school Participatory Construction

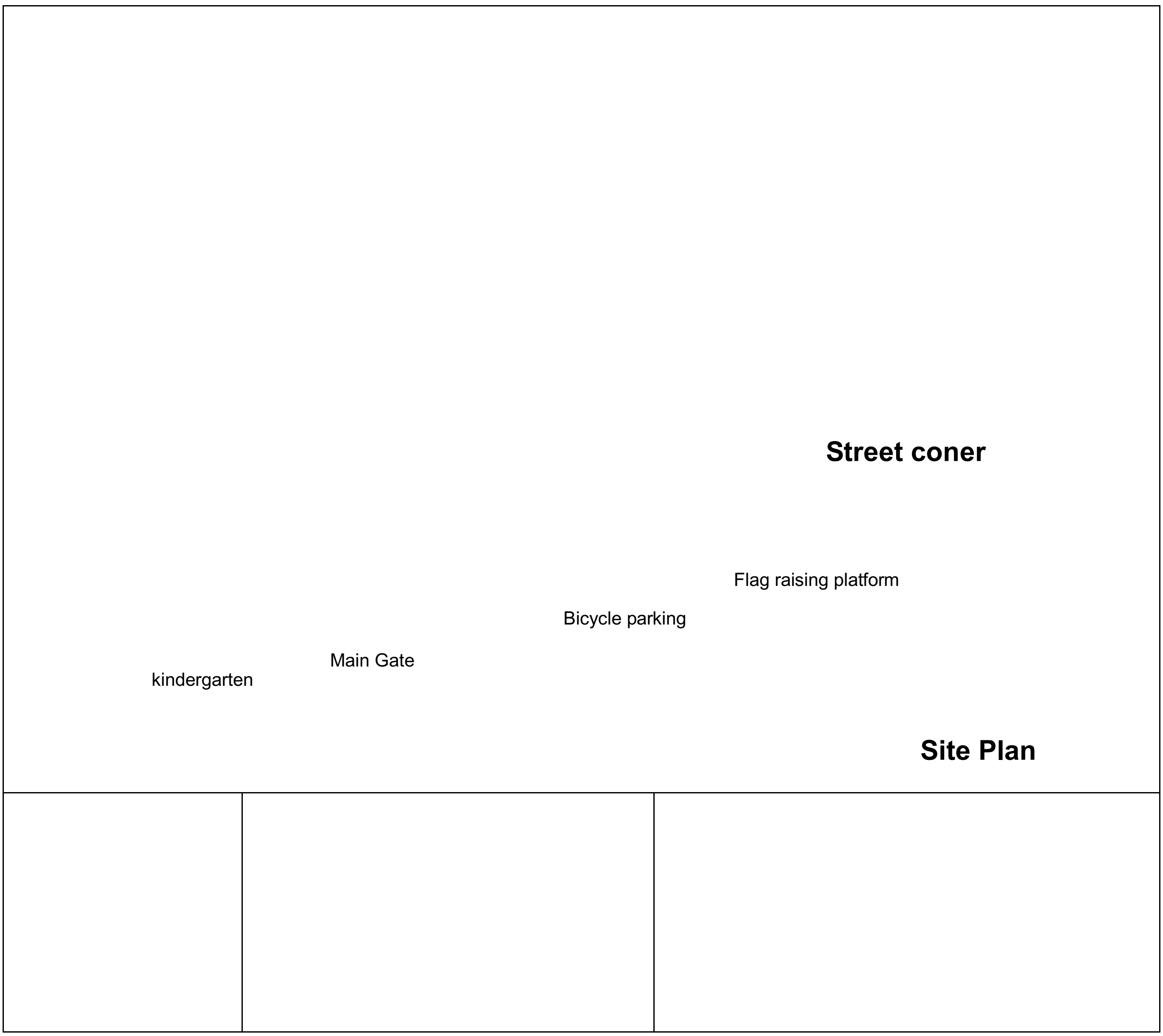

Fig. 3: Completed Campus Green Interface.

Taiwan's Green Design Aspects: Case Studies on Phenomenographic Research

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Abstract

Taiwan is an island situated in East Asia of the Western Pacific Ocean, and our culture was rooted in the East and expanded with the inclusion of Western influences. Throughout the process of colonization, the external cultural influence had made powerful impacts on Taiwanese culture. It is also the processes of assimilation during our history that merged these divergent cultures in terms of coherence, hybridity, identity and allegiance. As Taiwan's contemporary society has been facing the development of cultural transition, Taiwan showcased its soft power to the international community in its creation of a sustainable cultural creative industry, especially focusing on a variety of green fashion and architecture design featuring Taiwan's unique cultural identities. This is often reflected in the themes for design courses. Therefore, the main purpose of this research is to address contemporary process of green design and cultural cluster in Taiwan by way of applications. The reason why we take Taiwan's green design aspects as the main analytic subject is because of its uniqueness and necessity that represents one of the interpretations of the process of post-modern approaches. We would argue that this present study, which draws on phenomenographic research methodology and post-modern theories to investigate the subject, will help us maintain a positive approach in hope to develop a broader perspective and to establish the "green cluster" in connection with Eco-Design society. Moreover, the sustainable consciousness is becoming increasingly important, and gradually had become a trend in the postmodern era in Taiwan. This study realizes the key factor of solving environmental problems relies on human's awareness on the importance of cherishing tellurian resources. By researching and categorizing the forms of the cultural and creative transition. Our research will take several "green cluster" examples in Taiwan as the core cases to investigate and analyze the unique landscape, such as 2010 Taipei International Flora Exposition and Taichung CMP Elite Bookstore. We would stress in this paper of the green design concept, cultural cluster, cultural creative and our understanding of Taiwanese history to show the inspiration of green design aspects. Furthermore, the study will be using case study and Phenomenography as the main methodologies; we hope to explore the development of our relationship with nature and implement creative ideas to our lives. Finally, we plan to develop the concept of "green cluster" and give adaptive guidance to the design field. We will also make efforts to put relevant theories such as these into practice to improve Eco-Design concept in Taiwan. It is very true that we should also have a deeper understanding of green topics, including the origin and prevalence of green concept. Hopefully, the cultivation of a new Taiwanese green design trend will attain ethnic harmony locally and globally, and then amalgamating them into a new and unique form.

Keywords: Green Fashion, Cultural Cluster, Green Cluster, Phenomenography

1. INTRODUCTION

1.1. Background to the Problem

The need for people to adopt more ecologically sustainable and socially responsible ways of living is evidenced by increasing concern over the state of the world's environment (e.g., Rio-Earth-Summit 2002). In many past situations, environmental effects were ignored during the design stage for new products and processes. It was also regarded as a fringe activity. However, in recent year, the concept of green design was accepted by the general public, and has gradually become the ideal development trend. People are demonstrating their feelings through their voting preferences, by joining environment campaigning groups, by changing their behavior to accommodate recycling or energy efficiency, and by using environment criteria in their purchasing decisions as consumers (Mackenzie, 1991). The purpose of this paper is to contribute to the environmental issues and green design concepts in the postmodern era in Taiwan.

As several researchers state, "Designers are in a position to reduce use impacts by purposefully shaping behavior towards more sustainable practices" (Bhamra et al., 2008). Nowadays, more and more designers are creating variety of modern and fancy designs, but the most important goal is to maintain the ecological equilibrium, and increase the living quality of human beings. The designer can have a major influence over how things are made; the materials that are used; how they are constructed; how efficient they are to use; their ease of

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maintenance; and even their recycling/reuse potential(Whiteley, 1994). As Victor Papanek States:

> *Designers shape the development of products and services which directly impact upon society and the environment.(1971)*

Hence, the main purpose of this research is to address contemporary process of green design and cultural cluster in Taiwan by way of applications. The reason why we take Taiwan's green design aspects as the main analytic subject is because of its uniqueness and necessity that represents one of the interpretations of the process of post-modern approaches. By using Phenomenography and case study as our main methodologies, this research will follow the use of cultural cluster and green fashion as our research theories. We hope to explore the improvement and development of green design in the most efficient way through an analysis of papers and cases. We also plan to develop the concept of "green cluster" and give adaptive guidance to the design and education field. In fact, the concept of "green cluster" owns the characteristics of being sustainable, economic, well shaped with good quality and also has low impacts to human health and environment. Furthermore, it will be a harmonious integration between the nature and the human habitat. Finally, the paper will put relevant theories such as these into practice to improve art and design education in Taiwan.

1.2. Rationale and Significance of the Study

In the last decade, a growing interest in the natural environment has been one of the drivers behind there designing of existing products and the creation of new ones, making them more energy efficient or less material intensive (Shrivastava, 1995). For this study, we expand the idea of cultural cluster to "green cluster", and the concept of green fashion is important because this innovative intersection allows a new positioning to emerge and its accompanying perspectives, attitudes, and emotions are likely to generate a new form of culture.

Specifically, this study employs green design concept and "green cluster" to show the principles of social, ecological and aesthetic sustainability. This will be achieved by: 1) analyzing green theories in terms of three "green cluster" cases, including 2010 Taipei International Flora Exposition and Taichung CMP Elite Bookstore, showing the inspiration of green design aspects, 2) analyzing the utility of qualitative research methods such as phenomenography and case study to study meanings of "green cluster", and 3) suggesting how green fashion might link to design aspects and contribute to cultural and creative industries in Taiwan. We believe that this present study, which draws on phenomenographic research methodology and post-modern perspectives to investigate green cluster, will help us maintain a positive attitude in developing a broader perspective on green design.

2. LITERATURE REVIEW

2.1 Defining the Concept of green cluster

Before defining the concept of "green cluster", we have to understand the meaning of cultural cluster. The term, "Culture", is arguably one of the richest and most complex concepts in many languages (Williams, 1976). It is actually material and symbolic, belonging and being, pattern and process, macro and micro, corporate and public, commodity and a public good (Zukin, 1995). In addition, cultural activities are of growing significance to urban and regional economies in the age of the creative city (Landry, 2000; Scott, 2000). When we took Taiwan as an example, we observed Taiwan was rooted in the East and expanded with the inclusion of Western influences. Despite the fact that Taiwan was exploited by the West, and by the time been, the western influence absorbed by Formosa culture and became part of it; she treated the external influences as a cultural plus (Peng et al., 2008). During the past few years, the creation of cultural cluster in Taiwan has been increasingly taken up as an alternative source for cultural development. As Mommaas stresses, "Sometimes, the cultural clusters began their existence in the minds of cultural managers, searching for ways to strengthen the market position of their amenities within a more competitive cultural and leisure market" (2004).

In other words, the broad definition of cultural cluster can be defined as "a system of relations set in a territorially-bounded area, which integrates the process of valorization of material and immaterial cultural resources with infrastructures and different productive sectors associated to the process itself" (Cooke & Lazzeretti, 2007). Therefore, we state the concept of "green cluster" as the development of green design in Taiwan. Coming in a variety of cultural, organizational and developmental forms, "green cluster" emphasizes group cooperation and individual responsibility towards green life. It can also be defined as a trend of group consciousness of living green.

2.2 .Green Design in Taiwan

Climate change has brought increasing attention to the concept of green design. Whiteley monitors the use of the word "Green" in newspapers and magazines 3,617 times in one month during the mid-80s. By the end of the decade the rate was up to 30,777 (1993). As a consequence, in recent years, quite a few experts have placed special emphasis on the environmental problems arising from certain environmental aspects linked to the evolution of society as well as that of the economy (Blomquist & Sandstorm, 2004; Siebenhuner & Arnold, 2007). However, while green design offers the potential to improve the sustainability without sacrificing performance, developing and bringing such concepts to market is a big challenge. Thus, we can see that environmental issues are explored on many levels for individual interpretation from ecologically intelligent design principles and environmental responsibility in design.

With the support of government policies, Taiwan has integrated green design into national projects and many efforts have been made to promote the concept of green. Besides, the development of related regulations of green design is being mature. To catch up the main stream of green, many designers infuse more concepts of environmental protection strategy during the process of design. Recently, the Taipei City Government is promoting Taipei International Flora Exposition. By observing and learning from the exhibits, people will be encouraged to improve their relationship with nature and protect the environment.

3. PHENOMENOGRAPHY AND CASE STUDY APPROACHES TO STUDYING MEANINGS

3.1. The Significance of Phenomenography

For the purposes of this study, we will focus on two commonly cited methodologies- Phenomenography and case study, that are claimed to provide direct access to individual meanings. The first approach used in this research is Phenomenography, which observes phenomena within their real setting. In fact, Phenomenography is similar to phenomenology in that both are concerned with describing a phenomenon. For both, the end results are descriptions that are relational, experiential, contextual and qualitative (Marton, 1986). Besides, phenomenographic research aims to characterize how things are perceived by people rather than describing things as they occurred. The study has a descriptive qualitative design with a phenomenographic method, which is used to describe different ways in which individuals experience a phenomenon. In other words, the basic assumption underlying Phenomenography is that there are differences between how individuals perceive a phenomenon. The analysis, therefore, results in a description of the differences of perception rather than a description of the shared common experience (Dahlgren & Fallsberg, 1991). In this research, we will apply Phenomenography to conduct green design and cultural background on the peculiar phenomena of "green cluster".

3.2. Using Case Study as a Research Approach

This paper is uses methodology in the discipline of cultural studies. While researching on Taiwan's cultural subjects, we discovered that cultural difference is an important issue. Owing to the diverse historical background of Taiwan, we had studied and developed a variety of styles in green design. They not only integrate particular customs with environmental phenomena, but also stand for memorable landscape with historical accounts of Taiwan.

Case study not only helps us understand the evolution of green design in Taiwan under the integration of green fashion and "green cluster", but also by collecting the data we can analyze the facts emerging as a basis from which to work. An aspect of this process is the need to contextualize the study. A literature survey and analysis of the relevant data, using visual and textual information, will be conducted within the fields of aesthetics and cultural theory to clarify how "green cluster" will develop and analyze what we should do to examine improvement. Moreover, as Taiwanese, the process of establishing meaning and positioning ourselves as intermediate persons to carry out this research is an important issue. This will be used to illuminate the process of cultural exchange.

4. CASE STUDIES

4.1. Case Study of green cluster in Taiwan

In recent years, "green cluster" has become the green industry's best way of promoting the green life, for example, Taichung CMP Elite bookstore serves as one of the cases of "green cluster" with the vertical garden. Except for its visual effects which can attract the audiences, its originality of combining the green image of the architecture with the temporal traces of the traditional architecture brings out unique architectural renovation as well as the green impression. 128900 plants are planted on the external wall with the total area of 1850 square meters for the vertical garden of the CMP Elite Bookstore. Before the plantation, we should first understand the sunlight intensity and exposure time and then select appropriate plants. The specially designed drip irrigation system inside the room provides sufficient water to the vertical garden in a water-saving way. The 150000 plants covering an area of 0.2 hectares can absorb 200 kg of carbon dioxide per day and at the same time produce 150 kilograms of oxygen, bringing real positive effects to the environment. The merging intelligence from architect, designer, landscape sculptor etc…, emerged a new tendency in design which showcased the living example of "green cluster" concept.

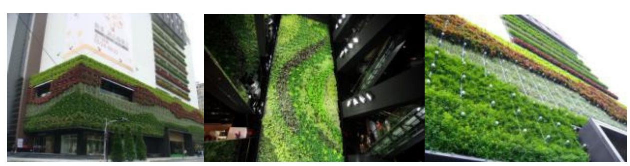

Figure 1. Sequences of Taichung CMP Elite bookstore

Another example we analyzed is 2010 Taipei International Flora Exposition. It is actually the first international certified standard exposition that Taiwan has ever held, and the basic design concept of 2010 Taipei International Flora Exposition was based on the symbiosis theory mentioned previously which merges humanity's basic needs in the desire to pursue happiness and extends the boundary of imagination thus creating a future full of countless possibilities. (Taipei City Government, 2010) It not only highlights the potential of green industry in Taiwan, but also forms a "green cluster" between mankind and nature. To be frank, sustainable development is a forward looking concept. It is therefore not enough to merely look at present performance (Figge & Hahn, 2005). As Son argues,

> *Sustainability is a worthy goal, but can be achieved only through the efforts of everyone involved. Furthermore, to make a signify cant impact, sustainability must be incorporated into the entire life cycle of a construction project, starting with the concept phase, because different environmental, social, and economic considerations come into play at different stages in the development of a project.* (2009)

Therefore, the achievement of Expo can be shown in tourism, gardening and science. It is significant because it is held in the city center and it conveys the essence of human and environment through design methods.

Figure 2. Views in 2010 Taipei International Flora Exposition

4.2. Outcomes and Future Work

By using Phenomenography as the main methodology and the use of ecological material into this project, we hope to explore the improvement and development of sustainable fashion in the near future. The term, green fashion, also can be called "Eco-fashion" can be defined as clothing that is designed for long lifetime use; it is produced in an ethical production system, perhaps even locally; it causes little or no environmental impact and it makes use of eco-labeled or recycled materials (Joergens, 2006; Fletcher, 2008). The most important is, when working with sustainable issue is conviction, the knowledge that has engaged with it as fully as possible, that one has emerged from the creative struggle with a feeling of rightness.

Based on the analysis of the data of this study, the main points concerning the application of "green cluster" as the means of Taiwan's green educational aspects are as follows:

(1) The green visual impression of "green cluster" brings students closer to the space, and enhances the sustainability of the architecture. By combining a focus on sustainability with principles of aesthetics, function and comfort, "green cluster" concept enables designers to make sustainability possible and attractive.

(2) The theory of green fashion proves that human beings should coexist with the nature. The two examples classified by this study are all about the "green cluster" artificially brought to the green space.

In terms of the efficiency of the application of "green cluster" in Taiwan, Taipei International Flora Exposition and CMP Elite Bookstore in the commercial space have successfully brought out the impression of green fashion to the masses. In fact, the effect of environmental greening has been achieved in Taiwanese government in terms of the green fences on the construction site, and they also cast certain positive influence. However, during the implementation of the regulations, the government agencies should manage in a more effective way and make a set of more complete regulations for the execution of the "green cluster" in the city.

5. CONCLUSTION

Generally speaking, this research proposes an integrating framework, based on theoretical concepts from the fields of green fashion and "green cluster", to enhance our understanding of sustainable competitive advantage. The study also realizes the problems, needs, and behaviors of "green cluster" for current condition through reference investigation and analysis. In fact, we are entering a period when environment performance, together with a wide range of ethical and moral issues, will be on the agenda for business, government and individuals (Mackenzie, 1997). Sustainable design takes into account on environmental, economic and social impacts enacted throughout the product lifecycle (Bhamra & Lofthouse, 2007).

Environmental issues are difficult to grasp. They involve "complex overlapping ecological, physical and human systems", and thus require a systems approach to analysis and problem solving (Roome, 1992). Besides, any discussion of green design has to deal with the question of society's values (Whiteley, 1993). Hope through this study, we can spread this fresh seed of green idea into design education, and inspiring more green awareness to awaken more hearts to cherish our precious global resources. At last, we hope the explanations will help the people and our design students in Taiwan to have the awareness of "green cluster" while designing their work.

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Case Studies of Energy Saving and Smart Management for the Small and Mid-size Offices

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Abstract
Energy saving and lowering the greenhouse gas emission is now the major agenda not only for the large scale offices but also for the small and mid-size offices. The result of case studies on energy savings by implementing a facility control system named "BX-Office" was presented at the international symposium on Eco-design in December 2009[1]. This time, the result of case studies shows that "Ubiteq Green Service (UGS)" brings energy savings by automatic control for air condition with setting the pattern of motion detection and reservation status, which extends the collaborating capabilities of "BX-Office" with lighting, air conditioning and various sensors such as power meter.

This study is a continuous research activity of the study on the BX-Office, it shows the result of case studies on energy savings. This study shows the effects of energy savings by implementing the IT system to control office facilities more systematically. The study has conducted in two seasons, one in summer and another in winter.

Results of the two cases show 50% more power saving possibilities, and show the double or more of the target 25% reduction target for corporate and enterprises by the regulation required by the total emission. And the automatic control of the air conditioner by the pattern setting brings the energy saving effect as same as the expectation in summer and winter. In addition, it was able to be confirmed to obtain the energy-saving effect even when not controlling it automatically by indicating the conservation of energy experiment to the facilities user.

Keywords:
energy saving, green, ICT, facility management

BACKGROUND

For global warming measures, a number of international actions including the post-Kyoto Protocol and U.N. Framework Convention on Climate Change are advancing. The energy saving law was enforced from April, 2009. Grasp, improvement and report of the energy use in actual situation that had to grasp it every business establishment every company was obliged to so far by this revised energy saving law.

Therefore a system such as BA (Building Automation) and BEMS (Building Energy Management System) which could manage the amount of energy with utilizing IT was introduced in recent large-scale buildings, and energy saving control came to be practiced [2]. On the other hand, the number of medium size or small size buildings less than 10 stories that an small-mid size enterprise office and a sales agent of the big company seem to rent as a tenant occupy approximately 80% [3] in Japan, and there are few cases which BEMS which is high-cost in such a medium size or small size building is introduced into, and it makes the difficult situation to grasp the energy consumption actual situation of the whole company. In order to push forward energy saving of the whole society in such situation, it is demanded that a system is capable to measure the energy use actual situation of the discrete office in the building where is lower than a middle scale, and a measurement function needs to be handled without experts of the facilities management, and a system is capable to handle multiple office measurement so as to plan a total energy saving. In addition, because energy-saving is the most important social problem since a East Japan great earthquake that occurred domestically on March 11, 2011, an effective energy-saving solution is requested further more.

System Overview (what the UGS is)

Ubiteq developed a system called UGS with the facilities control function that could be introduced into a medium or small size building and/or the tenant office. UGS is located between an IP network and a network for facilities equipments, and it is a device able to communicate all in IP. The network protocol of the existing facilities equipments uses proprietary serial communication and wireless communication, but UGS absorbs those different protocols and provides connectivity and the information acquisition functions from the outside to facilities systems by an IP based coherent method. In addition, UGS enables that IP surveillance camera cooperation, email automatic

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transmission by the pre-defined trigger, and confirmation of the meeting room reservation with a groupware scheduler *1. In addition, UGS brings energy savings by automatic control for air condition with setting the pattern of motion detection and reservation status

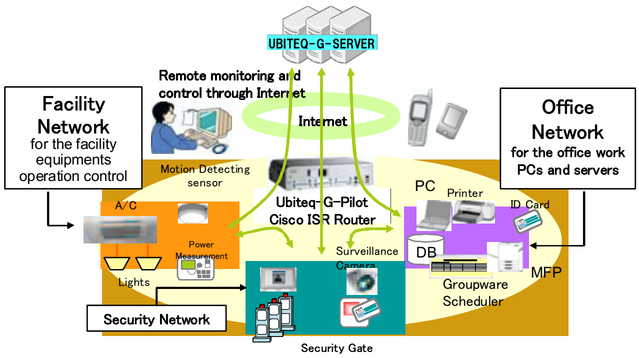

Figure 1: Ubiteq Green Service System Concept

UGS is application software installed on AXP module of the router "Cisco ISR series" made in Cisco Systems, Inc. UGS communicate with a pc terminal and/or a handheld unit of users with IP network via ISR router, and communicate with the facilities equipments such as sensors and illumination equipment, air conditioner, power measurement device *2 using a serial port equipped with on ISR router.

To enable the equipment control and data acquisition jointly between two or more offices, UGS was divided into Ubiteq-G-Server and Ubiteq-G-Pilot. Ubiteq-G-Server provides the control of the facilities equipment, the function of the accumulation of data, the total, and the analysis, and the function services to the user. Ubiteq-G-Pilot acquires the control command communication, the electric power measurement data, and status information.

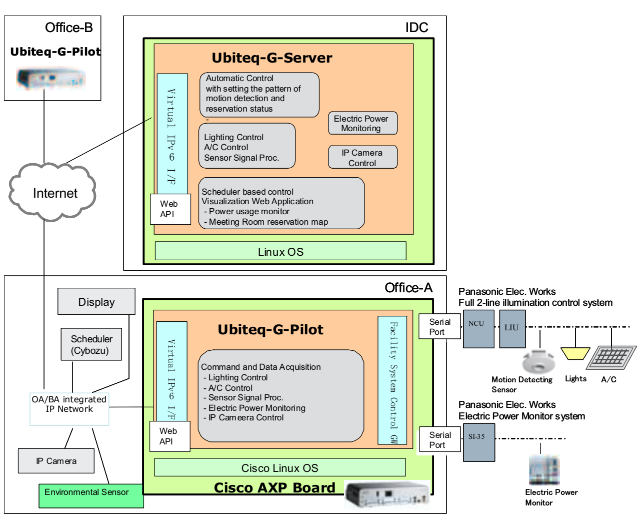

Figure 2: Ubiteq Green Service System

*1: support Cybozu Office8

*2: Support model:

- illumination: Full 2-line type lighting system (NMAST) of Panasonic Electric Works, [4]

- Air Conditioner: Device which equips JEM1427 of the Japan Electrical Manufacturers Association, so-called JEM-A (HA) terminal [5]

- Electrical Power Measurement Device: Product made by Panasonic Electric Works, Multi-circuit Energy Monitor (MEWTOCOL) [6]

Case Study 1: Study of energy effect conducting by UGS (in summer)

The analysis conducted to know the installation effect of this system in the Ubiteq office. The effect of the introduction of the automatic control for air condition with setting the pattern of motion detection and reservation status was analyzed in summer.

[Issue]Up to now, the energy-saving of the air-conditioning of the meeting room by the scheduler cooperation had been operated in Ubiteq. It was operation to lack the comfort for the energy-saving strengthening. Then, the automatic control of air-conditioning was applied to the meeting room in the office and the energy-saving effect was conducted.

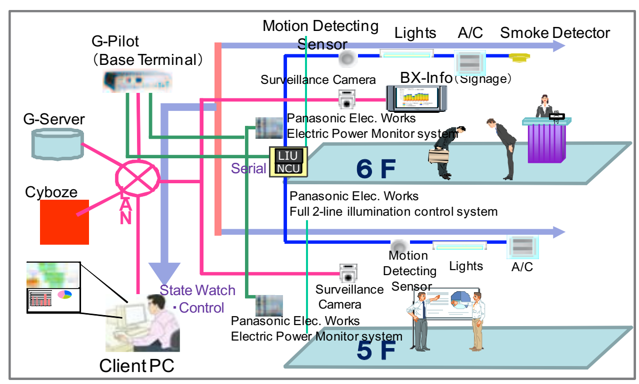

Figure 3: System Overview at the Ubiteq office

[Testing procedure]

・The energy-saving effect of the air-conditioning of the meeting room that applied a different automatic control setting ("hard" setting and "mild" setting) is conducted.

・Because the electric power of the air-conditioning of each meeting room cannot be measured, operating time of air-conditioning is measured.

・Air-conditioning is controlled automatically turning on and turning off air-conditioning with Figure 4 by the shown set sequence by controlled "hard" setting and "mild" setting. % numerical value in figure shows the ratio that occupies it at the reservation time.

- The facilities user is not notified to be conducting energy-saving.

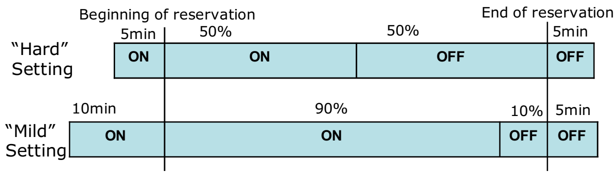

Figure 4: Set sequence of air-conditioning automatic control setting (in summer)

[Result] The calculation result at the air-conditioning operating time by the automatic control of the air-conditioning of UGS in the Ubiteq office is described as follows.

In the office, the test applied to three meeting rooms. The automatic control of air-conditioning was not applied to the second meeting room, the "hard" setting was applied in the third meeting room, and a "mild" setting was applied to the president meeting room.

The result of monitoring the use state on two months, September 1, 2010 - October 31, 2010 is shown below.

The data collected:

- The reservation time with the scheduler (Cybozu)
- Daily records of an air-conditioning operating time in UGS

1. Energy-saving effect comparison with timer management in two months

Air-conditioning is controlled automatically by using the scheduler cooperation. The energy-saving effects were compared from the state of the reservation of the scheduler by the scheduler cooperation of UGS and the timer management such as BEMS.

The reduction rate was calculated at the air-conditioning operating time in the timer management and the air-conditioning operating time in the scheduler cooperation at work hour (For 11 hours: 9:00-20:00).

1.1 Air-conditioning operating time in timer management

Air-conditioning is operated always ON during the office hours for approximately eleven hours from 9am till about 20:00 on weekdays. (In September - October: 40 days)

1.2 Air-conditioning operating time (reservation time) in scheduler cooperation and reduction

- meeting room #2: Air-conditioning operating time 232.50 hours/two months (47.2% of reduction)
- meeting room #3: Air-conditioning operating time 236.00 hours/two months (46.4% of reduction)
- president meeting room: Air-conditioning operating time 66.50 hours/two months (84.9% of reduction)

In Figure 5 the operating time of the lighting is shown in a red graph and the operating time of air-conditioning is shown in a yellow graph.

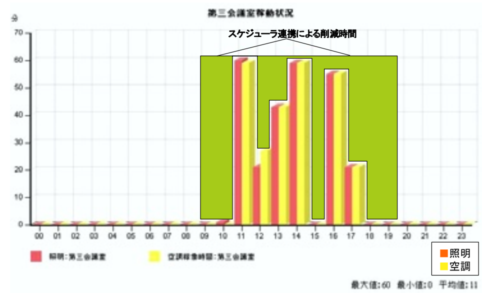

Figure 5: Graph of air-conditioning operating time at meeting room #3

2. Energy-saving effect by automatic control of air-conditioning in two months

The reduction to the scheduler cooperation when the air-conditioning automatic control is applied to the meeting room is shown below. In the air-conditioning automatic control, a "hard" setting and a "mild" setting were applied to the third meeting room and the president conference room respectively. The air-conditioning automatic control was not applied to the second meeting room.

(reduction in air-conditioning operating time to reservation time)

- meeting room #2: Air-conditioning operating time 168.53 hours/two months (27.5% of reduction)
- meeting room #3: Air-conditioning operating time 109.52 hours/two months (53.6% of reduction)
- president meeting room: Air-conditioning operating time 38.87 hours/two months (41.6% of reduction)

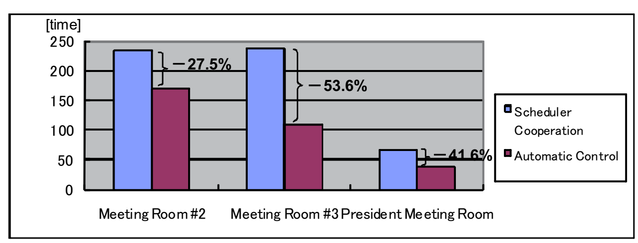

Figure 6: Graph of "hard" setting of air-conditioning automatic control

3. Expected effect of cost reduction

The electric power amount reduction can be foreseen without using the electric power meter when the air-conditioning operation log data is used at operating time. The amount of the reduction electric power in the third meeting room was provisionally calculated at the operation time of the air-conditioning of the automatic control setting ("hard" setting). The amount of the expectation reduction electric power in the entire meeting room was simply provisionally calculated by the area conversion, and the expectation reduction cost during year was calculated provisionally based on the electricity cost.

[Estimation method]

- Reduction electric power amount (year) = (area of the entire meeting room/area of the third meeting room) × the thirdmeeting room power consumption amount (two months) × 6
- Reduction electric power cost (year) = reduction electric power amount (year) × electricity cost

The following are applied to the above-mentioned estimation.

(1) Theoretical value of power consumption in air conditioning facilities in the third meeting room

(2) Amount of reduction electric power in the third conference room (two months) = theoretical value of power consumption × reduction time (two months)

(3) Electricity cost = 21.24 yen/kWh

[Result]

(1) Theoretical value of power consumption in air conditioning facilities in the third meeting room

= 0.52kW

(2) Amount of reduction electric power in the third meeting room (two months)

= 0.52 kW × (236.00h - 109.52h) = 126.48 kWh

- Amount of expected reduction electric power (year of the entire meeting room)

= (172.36 m^2/15.19 m^2) × 126.48 kWh × 6

= 8,610.96 kWh (53.6% of reduction) (comparison for scheduler)

- Expected reduction electric power cost (year)

= 8,610.96 kWh × 21.24 yen/ kWh = 182,896 yen

Case Study 2: Study of energy effect conducting by UGS (in winter)

The automatic control of air-conditioning was analyzed about the effect of the introduction of this system in Ubiteq office as well as summer in winter.

[Testing procedure different factors from case study 1]

- Because the sample operating time of the president meeting room was a little in the conducting in summer, a "mild" setting is applied to the fourth meeting room for general. The second meeting room and the third meeting room are set as well as summer.
- Air-conditioning is controlled automatically turning on and turning off air-conditioning by a set sequence of Figure 7 by controlled "hard" setting and "mild" setting. % numerical value in figure is comparatively shown at time occupying at the reservation time. This is a setting change in the conduction in summer to the demand on a comfortable inclination from the facilities user.
- It notifies the facilities user of the energy-saving conduction.

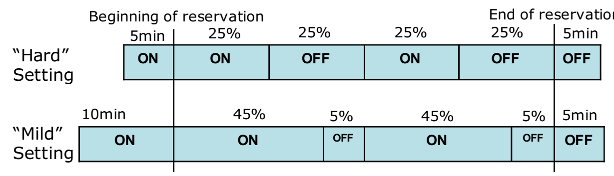

Figure 7: Set sequence of air-conditioning automatic control setting (in winter)

[Result] The calculation result at the air-conditioning operating time by the automatic control of the air-conditioning of UGS in the Ubiteq office is described as follows.

The result of monitoring the use state on two months, December 1, 2010 - January 31, 2011 is shown below.

The data collected:

- The reservation time with the scheduler (Cybozu)
- Daily records of an air-conditioning operating time in UGS

1. Energy-saving effect comparison with timer management in two months

The reduction rate was calculated as well as summer at the air-conditioning operating time in the timer management and the air-conditioning operating time in the scheduler cooperation.

1.1 Air-conditioning operating time in timer management

Air-conditioning is operated always ON during the office hours for approximately eleven hours from 9am till about 20:00 on weekdays. (In December - January: 38 days)

1.2 Air-conditioning operating time (reservation time) in scheduler cooperation and reduction

- meeting room #2: Air-conditioning operating time 189.00 hours/two months (54.8% of reduction)
- meeting room #3: Air-conditioning operating time 174.20 hours/two months (58.3% of reduction)
- meeting room #4: Air-conditioning operating time 196.25 hours/two months (53.1% of reduction)

2. Energy-saving effect by automatic control of air-conditioning in two months

The reduction to the scheduler cooperation when the air-conditioning automatic control is applied to the meeting room is shown below.

- meeting room #2: Air-conditioning operating time 51.63 hours/two months (72.7% of reduction)
- meeting room #3: Air-conditioning operating time 60.65 hours/two months (65.2% of reduction)
- meeting room #4: Air-conditioning operating time 74.07 hours/two months (62.3% of reduction)

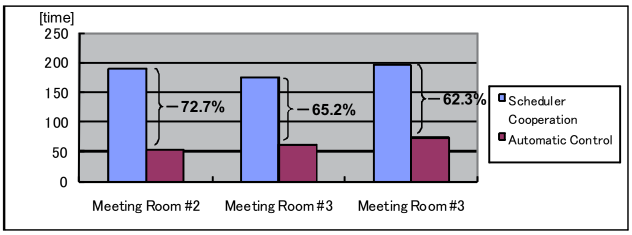

Figure 8: Graph of "hard" setting of air-conditioning automatic control

3. Expected effect of cost reduction

[Result]

(1) Theoretical value of power consumption in air conditioning facilities in the third meeting room

= 0.52kW

(2) Amount of reduction electric power in the third meeting room (two months)

= 0.52 kW × (174.20h - 60.65h) = 113.55 kWh

- Amount of expected reduction electric power (year of the entire meeting room)

= (172.36 m^2/15.19 m^2) ×113.55 kWh × 6

= 7,730.67 kWh (65.2% of reduction) (comparison for scheduler)

- Expected reduction electric power cost (year)

= 7,730.67 kWh × 21.24 yen/ kWh = 164,199 yen

Consideration:

As two case studies said above, this analysis was able to be realized by unifying the motion detecting sensor signal of the air-conditioning control system, air-conditioning operating log data and the reservation data. The energy-saving effect of the automatic control of air-conditioning by the pattern setting of the scheduler cooperation was able to be confirmed.

The effect of the reduction at operating time was achieved in the scheduler cooperation compared with the timer management used with BEMS etc.

The effect of the reduction of 40% or more was achieved in the meeting room for general in summer, 40% or more was achieved in winter, and 80% or more was achieved in the meeting room for VIP in summer and winter.

It was able to be confirmed to achieve the effect of the reduction of 40%-50% by the automatic air-conditioning control by the pattern setting compared with time only for the scheduler in summer, and to achieve the effect of the reduction of 60%-65% in winter while providing a comfortable environment.

In addition, it was able to be confirmed to obtain the energy-saving effect even when air-conditioning was not controlled automatically by indicating to the facilities user the energy-saving conduction.

Summary:

The result of two case studies was able to lead the electric power saving by 50% or more, and the results was able to show the twice or more of the requested reduction amount for the enterprises under the total emission regulation, and the automatic control of air-conditioning by the pattern setting obtained the energy-saving effect the same as the expectation in summer and winter.

It is scheduled that the variation of the pattern setting is increased in the future because energy-saving is possible by the combination of information into which the IT system and the equipment control are unified, and thus the equipment control matched to various purposes is provided. Therefore, the function to provide a comfortable environment to control air-conditioning automatically for instance according to the state of power generation is considered.

Moreover, because UGS is composed of the system that can manage energy with server (Ubiteq-G-Server) and base terminal (Ubiteq-G-Pilot) over the Internet, the energy management can be operated remotely. Therefore, the energy management in the office distributed to two or more places can be consolidated, and the energy-saving effect cooperating by comparing, and analyzing each of energy use actual condition can be obtained.

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Organic Herbal Farming and its relation with the Environment

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Abstract

Nepal has a vast variety of landscapes: mountains, hills, plain, valleys etc. This is the main reason why it is very likely to find herbals anywhere in the country. Indeed the soil of Nepal is very rich (mostly clay soil) and there are a lot of virgin lands. As community development practitioners, our responsibility is to alert people of what and how we can grow and use our local resources. If we protect and mobilize our natural resources, it will support Nepal to keep a sustainable healthy environment. This paper reviews UNEP-EPLC and some other organizations' experiences with organic herbal farming and its connection, directly or indirectly, to the environment. Also, this paper studies the importance of protecting the soil with good fertilizer as well as the importance of organic herbal farming to enhance the farmers' social-economic status. Finally, the paper identifies major challenges and draws key learning in developing sustainable herbal farming system and practices that could be applicable in the context of participatory herbal farming for healthy environment.

Keywords:

environment, organic, herbal farming, lemongrass, holy-basil

1 INTRODUCTION

1.1 Project Background

The **Organic Herbal Production and its relation with the Environment** project's activities have been implemented in two rural communities of *Nawalparasi*. *Nawalparasi district* contains 73 Village Development Committees (VDC) and 1 municipality with 688,483 habitants (Source: Intensive Study & Research Centre, 2008). It covers some parts of hills and some plain areas named *inner terai* and *terai*. Thus, it is known as a district with diverse characteristics. Among these, this project is run in *Town Bhagar* of *Ratanpur* VDC and *Thumsi* of *Gaindakot* VDC. The distance from district headquarter to *Gaindakot* VDC is 102 km. The total number of households is 146, covering 880 people. The traditional way of life (farming for self-sufficiency) reflects their livelihood.

With more than seven years working experience in community development in grass-root level as a social worker, I am aiming to explore the potentialities for the community revival. The direct beneficiaries of the project are local farmers and entrepreneurs. Besides, the development practitioners, field workers and students can also benefit from this project.

The research project has been started since October 2009. By August 2010, the final report of the project has submitted to UNEP-EPLC and presented in Asia-Pacific Environment Forum 2010 in South Korea.

1.2 Map & outline of project areas

One of the study areas, *Town Bhagar*, is a rural village of *Ratarpur* VDC and the other study area, *Thumsi*, is a rural village of *Gaindakot* VDC. Both are located in *Nawalparasi district* the western part of Nepal within *Mahabharat range*. The area receives an annual average rainfall of 2117 mm (*Dumkauli* station) (source: Dept. of Hydrology & Meteorology) and is [1]535ft. (*Thumsi*) & [2]573ft. (*Town Bhagar*) in elevation

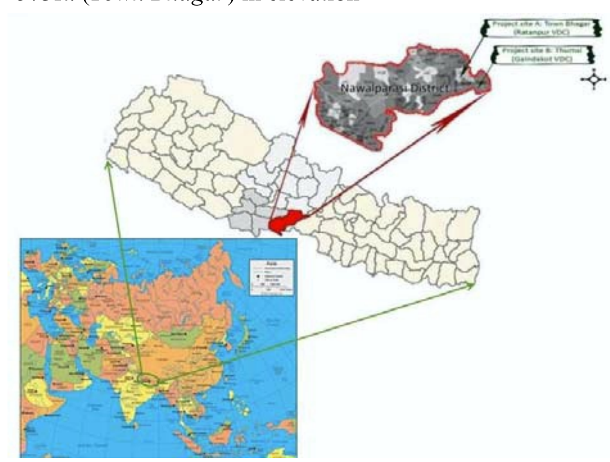

Fig. 1: Map of project areas

[1] N 27.70702˚ & E 084.36792˚

[2] N 27.70675˚ & E 084.27085˚

Both area's elevation and the directions were checked by Garmin (gew201) machine on 21 June 2010 by myself during field visit.

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Table 1: Outline of project areas

OUTLINE: GEOGRAPHICAL OF PROJECT			
Nearest Intl. Airport & its Distance from the Visiting Site	*Kathmandu* / 168 Km	Area	*Town Bhagar* and *Thumsi*
Estimated time	5 Hours (by car) 20 minutes (by plane)	Population	880
Mode of Transportation	Car & air-plane	Number of Households	146

1.3 Objectives of the study

Below are listed the objectives of the study. They have been developed with good consultation of the advisor Prof. Soon-Kwan Hong.

I. To find the importance of organic herbal production
II. To compare between organic and non-organic production and its effect with environment
III. To find out various organic herbal plants which are used to human health
IV. To motivate the farmers towards organic herbal production
V. To motivate the entrepreneurs towards organic herbal business.

2 METHODOLOGY: RESOURCES, INPUT AND METHOD

The research study has mainly been done based on social aspects. As regards to the methodology, the process of collecting information from the *Town Bhagar* and *Thumsi*'s community by using tools such as focus group discussion (baseline survey), [3]PRA/RRA tools, experiences/idea sharing, study and discussion of previous study reports and ideas, informal interviews, home visits, transit walk and observation are major activities.

[3] **PRA/RRA:**

Participatory Rural Appraisal (**PRA**) means development of tools that helped farmers to collect, analyze, and present their own data and information (developed out of RRA in the early 1980s).

Rapid Rural Appraisal (**RRA**) means rapid collection of data by outsiders to achieve a more comprehensive understanding of the complexity of rural societies (Began in the late 1970s)

3 RESULTS AND DISCUSSIONS

Main dominance casts in *Thumsi* are mixed ethnic groups (*Magar, Kumal, Darai, Bramin* and others) and in *Town Bhagar* is an ethnic group called *Magar*. Most of them were born in one of the two places, others migrated from the hilly areas of Nepal. Farm labors is a main livelihood option of those people. They own a small piece of land where they cultivate rice, maize, wheat and other common crops. They also grow small quantities of herbal plants for medicinal uses.

The historical information has been explored through the study project. Since January 2006, *SAHAMATI* (a national level NGO) has been working to produce herbal plants in *Thumsi* and *Town Bhagar* through their Medicinal Plant Production (MPP) project.
After the MPP program was launched, the community members increased the quantity of herbal production in their fields.

The major activities implemented by MPP project are mentioned below:

- Herbal plant production
- Herbal tea production
- Formation, registration and functioning of the 'Community Herbal Producer's Cooperative'
- Installed of a distillation plant and production of essential oil
- Sensitization process for the protection of environment through organic farming

3.1 Organic herbal plants found in Nepal and their valuable importance

Herbal plants have always been part of human life on earth. Plants and human beings have a close relationship and people depend on plants for their existence, so the relationship must be sustainable. Herbs have saved men's life on innumerable occasions; therefore, the reasons and effects of their over-use concerns everyone. A very fact is that herbal plants in Nepal are mostly found in natural forests. Nepal is a natural diversified country and herbs adapt to its environment: some plants prefer very cool climate while others will only grow in warm places that enhances their germination, maturation, flowering and fruiting. For example *Yarsagumba* (*Cordiceps sinesis*) needs caterpillar. Besides, there are some practices to employ natural-based farming which means to grow herbal plants organically in the own garden.

Some medicinal herbs are being exported from Nepal, Mostly under the form of raw materials. All over the world, herbs are highly demanded to cure the human being and to increase longevity. To ensure that herbal plants will always be available, we must learn to grow them on our own in a sustainable way that will preserve the environment in the long term. Moreover, we have to proceed in a way that will permit Nepalese rural community members/farmers to directly benefit from cultivating and growing herbal plants.

A good harvest depends on factors such as the type of soil, climate, availability of irrigation and pest management.

3.2 Things to consider when growing own herbal plants

1. Choose suitable sources for the plants through herbal expertise
2. Have planned the nursery well
3. Avoid unnecessary stress for the plants
4. Prepare the planting field based on natural farming/organic farming
5. Look after newly planted plants until they are well established
6. Stay in touch with your herbal plants on regular basis

Herbals cannot only cure our ailments but can also be a potential economic source for the community. Some of the herbs are already much sought after by pharmaceutical companies.

3.3 Environmental Sustainability, Ethical Values and Considerations

If carefully managed, organic herbal farming is a sustainable industry. The continued growth of herb sales can also help to protect and increase the biodiversity of many ecosystems around the world which are presently declining, due to problems such as over-farming and pollution. 75% of our herbs are grown locally, in lush fertile organic and bio-dynamic soil. The other 25% mostly comes from the rest of Europe and a small percentage from America (source: Herbs Hands Healing 2010). We are specially concerned about environmental consciousness, since our relationship to Mother Nature is naturally a close one.

A review of recent scientific investigations of the environmental effects of organic farming in comparison to conventional farming will then provide a realistic picture of organic farming contribution to an environmentally sensitive and sustainable use of resources.

If the herbal plants are produced by community members avenues in cultivation, processing, packaging, marketing and industrial application will be opened. Through this way, the rural people, particularly unemployed woman and children, will benefit from this activity.

The demand for herbal plants is increasing as people are more and more fascinated by herbals. However, the extraction from natural forests has its own problems and risks. For a larger production and authenticity we need to cultivate the wild herbs. This will help to conserve some of our medicinal herbs that are pushed into the danger of extinction. It is ecological but also economically successful.

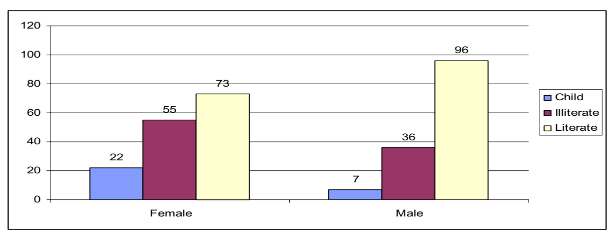
It is highly a motivated matter for the community members to be engaged into herbal farming and to establish herbal enterprises as an alternative to the traditional farming work. The farmers are now oriented and motivated to engage in organic production and they understood the medicinal value of herbal plants. Moreover, in the second step, their motivation towards micro-enterprise development grew up. As a result, they have started a collective business of herbal tea. Additionally, they supply with some other herbals in the small scale. Specially, the lemon grass production has gained a lot of popularity.

3.4 Socio Economic situation

3.4.1 Demography

The demographic features of *Town Bhagar* and *Thumsi* play a major role to understand and adopt technology improvements. It also determines the labor force required. The study sample size was 42 households which represents 30% of the total herbal farmers.

3.4.2 Literacy



Note: Disabled are included in literate and illiterate figure.

Fig. 2: Literacy rate

3.4.3 Livestock

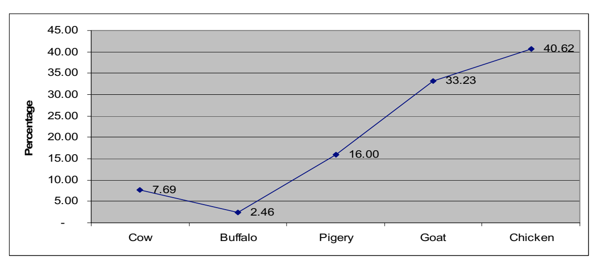


Fig. 3: Livestock status

On average, a mountain/hill household raises six to 10 head of livestock, including large and small ruminants (*Shrestha and Sherchan 1998*). Yet, the average cattle holding per household was VERY FEW only, being this is one of the major causes of poor fertilization trend in the herbal farm.

3.5 Organic Herbal products: Potential of plantation

The community people are motivated towards organic herbal plant cultivation because they know from their past experience that the profit of herbs (especially lemongrass) is three times higher than that of traditional crops. From a financial point of view, herbal farming is more profitable than cultivating traditional crops such as maize, rice, wheat and others. The following calculations show the difference between traditional and herbal farming costs and income ratio.

3.5.1 Total cost of production for cultivating lemongrass in one Kattha land (1 Kattha is 333 m^2)

Table 2: Cultivation exploration of lemongrass

S. N.	Particular	Amount NRs.
1	Land Rent for 12 months	1,200
2	Compost Fertilizer 12 Sacks	1,000
3	Ploughing Charge two times	500
4	Lemongrass Slip 1000pcs	600
5	Labor wages (planting, weeding, 5 Labor @ NRs 200	1,000
6	Irrigation (one time in a year) with 1 labour and 1.5 ltrs fuel	300
7	Harvesting (cutting 2, chopping & drying 3, Packing 1); it can harvest 4 times a year	4,800
8	Miscellaneous (Transportation, snacks for labor and others)	600
	Total	**10,000**

The table highlights that the total cost of production in one *Kattha* is Nepalese Rupees 10,000 per year.
Note: 1 USD = 74 Nepalese Rupees

3.5.2 Total income from Lemongrass (within 1 year)

From one *Kattha* we can get minimum 250 kg dried lemongrass. Its market price is at least NRs. 25 per kg so the price of 250kg. is NRs.6,250. As Lemongrass can be harvested four times a year; the one year total income is NRs.25,000

Now its net profit = Total income - Total Cost of Production
= 25,000- 10,000
= NRs. 15,000

3.5.3 Total cost of production for crops (rice, maize and wheat) (in 1 Kattha land in 1 year)

Table 3: Cultivation exploration of crops

S N	Particulars	Rice	Maize	Wheat	Total
1	Land Rent for one year				1,200
2	Ploughing Charge	300	300	300	900
3	Seed (rice 4kg, maize 1kg, wheat 4kg)	120	50	120	290
4	Fertilizer and irrigation	500	500	500	1,500
5	Labor wages (rice 5, maize 2, wheat 3)	1,000	400	600	2,000
	Total	**1,920**	**1,250**	**1,520**	**5,890**

3.5.4 Total income from traditional crops(within 1 year)

Income from rice

On one *Kattha* we can produce 150kg rice. Its market price is NRs. 16/kg so its income is NRs. 2,400. We get rice straw as well, its price is NRs. 600 making the total income from rice equal to NRs. 3,000

Income from maize

On one *Kattha* we can produce 170kg maize. Its market price is NRs. 24/kg so the income is NRs. 4,080.

Income from wheat

On one *Kattha* we can produce 140 kg wheat. Its market price is NRs.20/ kg so the income is NRs. 2,800.

Total income from all crops = rice + maize + wheat
= 3,000+4,080+2,800
= NRs. 9,880

Now, its net profit = Income - Cost of Production
= 9,880- 5,890
= NRs. 3,990

Thus, thanks to the data, it is clearly show that herbal farming is more profitable than traditional farming.

3.5.5 Herbal tea production

The '*Bhagar Herbal Tea'*, manufactured by the farmers of *Town Bhagar*, contains a mixture of Lemongrass (60%), Mint (25%) and Holy Basil (15%)(*Source: SAHAMATI, 2009*). It is sold on the market and within the local community.

Local communities are already aware of the health benefits from drinking tea. The locally produced tea is cheaper, more tasteful and healthier than other teas available on the market.
Therefore, both local and other consumers drink more and more self-produced tea instead of purchasing other sorts.
Another reason for which people are encouraged to switch to local tea is that it is organically produced, hence produced in a sustainable manner. Reasonable climate, rich soil and the usage of organic fertilizer (compost, green compost etc.) support the production process.

Since 2006, 2,885 packets for total NRs. 43,625 have been sold in the local market. *(Source: SAHAMATI, 2010)* This has been contributing to increase farmers' income level.

After the success of '*Bhagar Herbal Tea'*, the farmers of *Thumsi* also began with the production of herbal tea. Their tea contains a mixture of Lemongrass (50%), Mint (25%), Holy Basil (20%) and Ginger (5%)*(Source: SAHAMATI, 2009)*. It is branded '*Gaindakot Herbal Tea'* and sold in the village, on the local market and abroad (France and Japan). Gradually, the demand for this tea has also been increasing.

3.6 Future plan for organic herbal farming

Table 4: Future plan for organic herbal farming

Opinion	Percentage
Depends on circumstances	13
Extension of other appropriate herbs as per climate and soil condition	17
Garden management	20
No plan	27
Lemongrass, Mint and Holy Basil extension	20
Other herbals extension	10
Lemongrass, Mint and Holy Basil plantation	34
Other herbals plantation	17

We may observe on this table that for example 20% of the farmers would do on their own the garden management as they were trained to organize the herbal farm and are now self-reliable.

3.7 Key Learning

- Local people have learnt about the benefits, uses and importance of different kind of herbal plants.
- After five years of observation, Lemongrass, Mint, Asparagus, Holy Basil and Aloe Vera turned out to be potential plants for farming in the project area.
- A few local people in *Town Bhagar* are now used to drink herbal tea in place of alcohol. The number of people improving their well-being through the native use of herbals is increasing day after day.
- Community Herbal Producers groups from *Town Bhagar* and *Thumsi* have gained more than five hundred fifty thousand Nepalese Rupees from selling their products such as herbal tea, asparagus, lemongrass and others.
- Public land utilization is very effective for the cultivation of herbal plants.
- Good linkage and coordination with stakeholders can easily support implementation processes.
- Water supply is available all the time for irrigation.

3.8 Major challenges

- Chemicals (pesticides, fertilizers, etc.) are accepted by some rural community people in order to increase the quantity instead of focusing on quality.
- The instability of Nepalese politics and government are serious burden for the farmers marketing.
- Lack of education and awareness in communities.
- There are only small lands available, mostly used for crops & vegetables, making it hard for farmers to do herbal farming in large scale.
- Lack of social transformation (Traditional farming >> Organic Herbal farming)

3.9 Conclusion

In Nepal, organic (herbal) farming is in an emerging trend. *Thumsi* and *Town Bhagar* illustrate it in a very proper and clear way. A big contribution can be made for the sustainability of human life, plants and soil. This is specially true in a country like Nepal where lots of wild herbs species, as well as cultivated sorts, are available as organic products.

Organic farming can improve social, economic and environmental profitability for the whole community. The pro-poor people are trying to adopt the way of organic farming even though they do not have a good education and do not get motivation from the governmental level. Some NGOs and local governments work for the rural community revival in general. Making herbal tea, essential oils and some other herbal products (finished or un-finished) from very small lands are examples of the communities' obliged initiation. Even if they plant crops and vegetables to feed themselves in daily-life, they are also willing to do herbal farming in addition. Gradually, they gain awareness of cultivating herbs which can make them socially and economically sound too.

4 RECOMMENDATION

4.1 Small Land Big Utilization (a healthy farm for self-sufficiency and enterprise)

We have different agroclimatic conditions in the country. Depending on the altitude, practically any type of land available can be used to cultivate one or the other medicinal plant. Thus, they jhum fallows, forest lands, river banks, marshy areas, roadsides, farm yards, home gardens are useful for our purpose. The different herbal plants can be combined to achieve multiple plantations.

The below drawing is an example of how different herbal plants can be integrated into crop cultivation. It also shows the herbals' influence as concerns pest management as well as income generation.

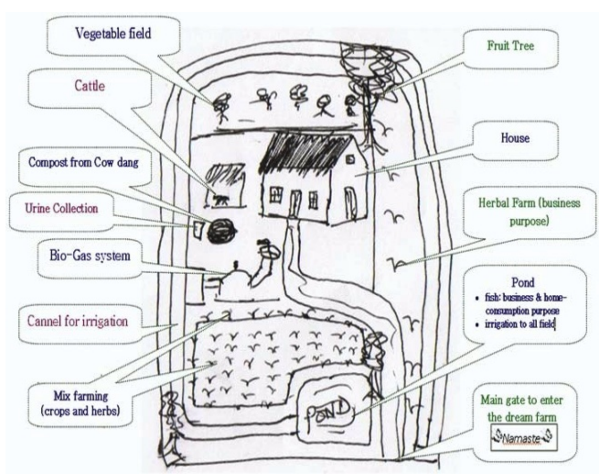


Fig. 4: A dream integrated farming

4.2 Own brand name of organic herbal products

I would like to recommend keeping the brand names of *Thumsi*'s and *Town Bhagar*'s herbal products. Farmers will have good motivation as regards to improvement of the livelihood and the protection of the environment. After experiencing the quality of the herbal products, these brand names will be synonyms of excellence, people from national and international level will reach to become customers.

4.3 Merge the groups into herbal cooperative

I found that the farmers have already established a producers' herbal cooperative in *Gaindakot*. However, all the herbal farming groups are not 100% merged into this cooperative. To create unity, it is very important that all herbal farmers become members/shareholders. They will partly be owner of the cooperative as well as they will have regular profit from it. This will be fruitful for the equity in their brotherhood relationship and to ensure that everyone stands on their own feet.

To have a pictorial look with table and chart, I have designed a sample showing what equitable development means.

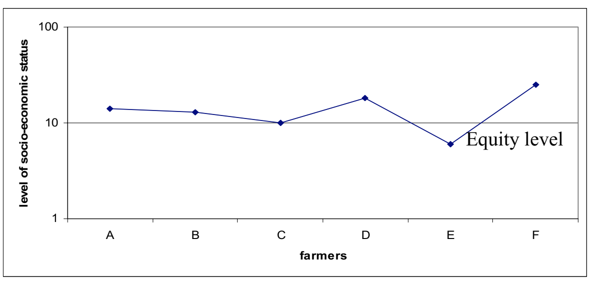


Fig. 5: A sample of equitable development

I have designed the above chat and showed it as equitable. *If we are serious about equitable development we have to provide equal opportunities to the poor through access to (natural, technical and financial) resources*. (Source: NextBillion.net - Development Through Enterprise - Eradicating Poverty through Profit).

Now in this chart, farmer E is most vulnerable and she/he has to overcome with the level of basic fulfillment (level 10). Through the cooperative, each shareholders/member can raise their level at-least up to the level of basic fulfillment. In terms of securing the sustainability of equity, as well as to increase the level of happiness, a development according to this chart is necessary.

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Practical Engineering Education Toward a Sustainable Society: Design and Manufacture of the Taketombo Flying Toy

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Abstract

In order to establish a sustainable society, a fundamental concept of industrial product design is to reduce as far as possible the use of starting resource materials. For education with respect to the design and manufacture of products, it is necessary to consider the environmental impact of materials selection. In the present study, we focus on bamboo as a design material because it has a wide habitat, grows rapidly, is carbon neutral, and can be consecutively deforested. In order to evaluate a practical educational approach, we examined the *taketombo*, which is a popular traditional Japanese flying toy made from bamboo, with respect to basic areas of mechanical engineering. In the present paper, practical design education is described based on the *taketombo*. By adopting this teaching material for design education, students who were not stimulated by traditional educational equipment, such as a Gettingen-type wind tunnel, became interested in our launch pad. Through this product design exercise, which incorporates responsible consideration for the environment in addition to ecological concepts, students were educated through design experience of the *taketombo*.

Keywords:

Bamboo, Taketombo, PBL, carbon-neutral material, Physical computing

1 INTRODUCTION

In industrial commodity design for a sustainable society, it is desirable to achieve the necessary functions using fewer parts and materials. Moreover, reusability and recycling must be taken into consideration.

Numeric simulation is often used in such design in order to reduce the costs associated with prototype manufacture. However, young engineers with little experience will often mistakenly assume that the actual physical prototype will exhibit exactly the same behavior and characteristics as the simulated object. Moreover, when it is necessary to consider a range of different materials, the constitutive equations are often insufficient, and assumptions must be included in the simulations, which do not always conform to actual reality. For this reason, simulations are limited in their ability to completely describe the characteristics of physical objects. Consequently, when training young engineers, problem-based learning (PBL) methods are important for maintaining links between theory, simulations and reality.

Through the concept of the three R's (reduce, reuse, recycle), a young engineer can be made conscious of environmental factors such as choosing materials whose production does not require high energy costs. However, in practical PBL situations, the environmental conformity of materials is often ignored since there are restrictions with regard to safety, cost, and time available. For example, when using an experimental wind tunnel, wing or automobile models fabricated from metal or resin are often provided by the instructor. Therefore, it is rare for a student to consider the environmental suitability of a given material, because of the blind use of the material provided by the teacher. However, when a skillful engineer begins a design, material selection is one of the highest priorities. For this reason, education in materials selection is important in order to provide students with an understanding of sustainability concepts. In addition, if the choice of material is appropriate, prototypes can be easily created and the desired test results achieved.

From the viewpoint of processing and safety, paper and styrene foam are more suitable than metal or resin. However, material strength and rigidity must also be taken into consideration, as should the impact on the environment. One well-known environmentally friendly material is kenaf, which is cultivated in several places around the world, including south-east Asia. In recent years, Hall et al.[1] reported the manufacture of a wheelchair using kenaf, and for educational purposes, Ogawa et al.[2] produced windmill blades from kenaf.

Bamboo is also an ecologically friendly material. It grows over a wide area of Asia, does not have an adverse influence on other plants, does not wither land, and exhibits rapid growth. Moreover, when used as a composite material, bamboo has far greater rigidity than kenaf. Therefore, bamboo is often used as a structural material.

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In the present study, we consider the design of a *taketombo*, which is a traditional Japanese toy. Designing a *taketombo* requires an understanding of basic dynamic effects (centrifugal force, etc.), hydrodynamic effects (drag and lift, etc.), material-mechanics considerations (material modification and destruction, etc.) and the relationship among these factors. Moreover, since the rotational energy generated by the moment of inertia of the *taketombo* at the time of launch is converted into potential energy as the *taketombo* rises, mechanical-dynamics factors must also be considered. In the design and construction of the launch pad for the *taketombo*, a knowledge of control engineering, which is an important aspect of machine education, is also required.

Thus, the *taketombo* incorporates a number of elements that constitute the foundation of mechanical engineering[3]. Moreover, the *taketombo* is easy to manufacture and can be flight tested in a relatively confined area. In addition, its performance characteristics are easily determined. The present paper describes the importance of the choice of material in a realistic engineering design educational program (such as PBL), using *taketombo* design as an example. Environmental issues are also emphasized, with a view towards maintaining a sustainable society.

2 DESIGN EDUCATION

Akioka[4] published the results of a study on the design of a "super-*taketombo*", and Azuma[5], who is famous in the field of flight dynamics in Japan, also carried out research on *taketombo* design. In these studies, the primary goal was to obtain a basic understanding of the phenomenon involved rather than developing practical design techniques. In almost all cases, design techniques based on empirical rules were used. Consequently, *taketombo* makers will generally employ designs based on past precedents rather than giving deep consideration to the design process.

In the design of a *taketombo*, many problems can occur such as reduced flight performance due to poor processing accuracy and frequent breakage upon landing. In designing an efficient *taketombo*, the first goal is to acquire and process the material. For this purpose, bamboo becomes an obvious choice because of its material characteristics and environmental friendliness.

2.1 Characteristics of bamboo

In the present study, bamboo is used as the building material. Bamboo's excellent rigidity makes it a suitable design material as well as a structural material. For example, bamboo is used for fishing rods and umbrellas, and in Japan is sometimes used as a replacement for iron frames in bridges.

2.2 Acquisition of bamboo material

Bamboo may be acquired by recycling moso bamboo discarded at the time of demolition of rafts used in oyster cultivation (Fig. 1). Bamboo that has been soaked in salt water for an extended period is insect resistant, and a smoking process is not necessary as is the case with freshly cut bamboo. After recovery, the bamboo scrap is cut by a rotation saw to form rectangular slices. It can also be cut into strips using a special hatchet for working bamboo.

In the present study, the students learning engineering design based on a *taketombo* used scrap bamboo from rafts, old bamboo rulers which have become deformed and bamboo sold in home centers. In addition, the shaft of the *taketombo* was made from a recycled bamboo skewer that is normally used for cooking.

Fig. 1: Scrap bamboo from rafts used in oyster cultivation

2.3 Design manual

First, the students were told that the *taketombo* should be designed so as to achieve maximum altitude.

2.3.1 Conservation of energy

We provided the following instructions to the students. The driving force of the *taketombo* is an inertial force which depends on the initial rotation velocity. Moreover, if I is the moment of inertia, then prior to launch, the *taketombo* has a rotational energy $E = 1/2I\Omega^2$, where Ω is the angular velocity. Next, the flight of the *taketombo* was explained from the viewpoint of conservation of energy, as follows. The flight of the *taketombo* begins upon its release from the hand. The *taketombo* rises by changing kinetic energy into potential energy, as shown in Fig. 2. The potential energy is a maximum at the maximum altitude. At this time, if $\Omega = 0$, then the rotational energy has completely changed into potential energy, and the student must consider the efficiency of the energy transfer mechanism involved.

Fig. 2: Energy of the *taketombo* during flight

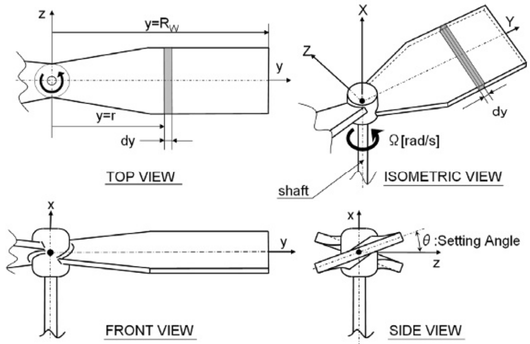


Fig. 3: Coordinate system

Fig. 4: Variation of angle of attack

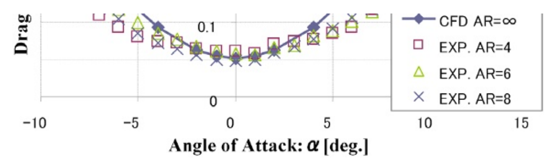
2.3.2 *Aerodynamics*

Since the drag effect for a *taketombo* is small, the inductive energy loss cannot be expressed as a valuation function. For design of a propeller that operated at a low Reynolds number (Re), Harada[6] used the propulsion efficiency as the valuation function. In the present study, we use the energy conversion efficiency, describing the transformation of rotational energy into potential energy, as the valuation function, and simplify it further in order to make it intelligible for educational purposes. The coordinate system used is shown in Fig. 3.

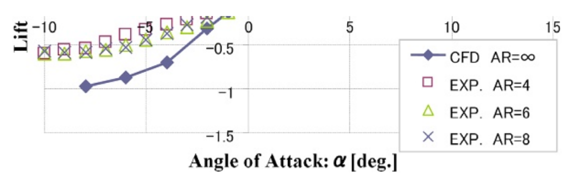
Since the bamboo is in the form of strips, we herein consider a two-blade *taketombo*, which can be easily operated by anybody by simply twisting the handle. For a *taketombo* rotating at an angular velocity Ω [rad/s], the speed v of the air at a distance $y = y_0$ from the x-axis is denoted as $y_0\Omega$.

Since Re can be determined based on the ascending vertical angle α and the wing length L, the lift and drag become roughly computable. When Ω and the rate of climb (vertical velocity) change, the inlet velocity also changes. So, Re and α are continuously changing during flight.

We used a flat plate aerofoil in order to simplify the explanation of the phenomena involved and to make the calculations more easy. As can be seen in Fig. 5, where AR is the aspect ratio of the wing (the ratio of its length to its breadth), the computational fluid dynamics (CFD) results[7] for the drag and lift coefficients with AR=∞ (ideal wings of infinite length), are not easy to obtain experimentally, for example in a wind tunnel[8]. The correctness of the CFD results can be assessed by comparing them to the experimental data, so that the theoretical and experimental approaches compliment each other. In this way, students come to understand that although CFD is useful, it is not perfect.



(a) Drag coefficient



(b) Lift coefficient

Fig. 5: Characteristics of a flat plate aerofoil

2.3.3 *Material mechanics*

Like many industrial devices, aerodynamic and structural characteristics must be taken into consideration when designing the *taketombo*. The physical properties can be easily obtained because bamboo is commonly used as a building material[9]. An example of a design based on these physical properties is shown in Fig. 6. The problem set for the students is a study of the tensile stress resulting from the centrifugal force in a *taketombo*. Using a simplified formula such as that shown in Eq. (1), the student can carry out a desk study on this topic.

$$\delta_{(y=R_0)} = \frac{F}{S} = \int df \Big/ S_0 = \int_{y=R_0}^{y=R_w} y\Omega^2 dm \Big/ S_0 \quad (1)$$

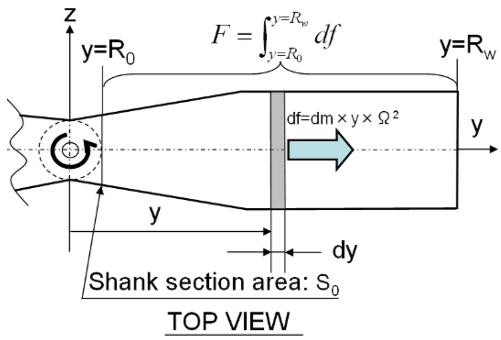


Fig. 6: Schematic diagram of centrifugal stress

Fig. 7: Stress distribution during lift

In addition, the lift computed from Figs. 4 and 5 can be used to conduct a Finite Element Analysis (FEA) of a static *taketombo* with regard to the stress distribution during lift. An example of the results is shown in Fig. 7. Thus, the students are made to study the force which is calculated drag and lift coefficients obtained from hydrodynamics data (Fig. 5). Designing a *taketombo* is therefore considered to be a suitable calculation and design problem.

2.4 Flight quality assessment for a *taketombo*

2.4.1 Tire drive type launcher

In order to efficiently investigate the flight performance of a *taketombo*, a launch device that mimicked the rotation (Fig. 8) of the shaft by hand was manufactured.

The shaft of the *taketombo* is fixed by two (or three) sets of three tires, which apply a driving force to increase the rotational velocity. The moment the velocity reaches a set value, the tires separate from the shaft of the *taketombo*. Fig. 9 shows a photograph of the manufactured launch device. We used gainer-mini, which is a physical computing board commonly used with arduino[10] in Japan, to control the three rotary motors of the launch device. The control program was written in Processing, which is an open source programming language[11]. and the rotation and release time of the *taketombo* were controlled (Fig. 10).

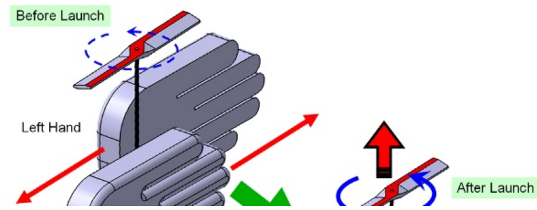


Fig. 8: Rotation of the shaft by hand

Fig. 9: Mechanical launching device

Fig. 10: Control panel

Fig. 11: Simple trigonometric method for determining altitude

2.4.2 Altitude measurement

The altitude achieved by the *taketombo* was determined trigonometrically based on video photography, as shown in Fig. 11. The altitude is determined as follows:

$$h = a + (D - L)\tan\theta_1 - c = b + L\tan\theta_2 - c \qquad (2)$$

$$L = (a - b + D \cdot \tan\theta_1)/(\tan\theta_1 + \tan\theta_2)$$

3 PRACTICAL APPLICATION OF DESIGN EDUCATION

We simplified the mechanical parts design loop for engineering products, and sample results are shown in Fig. 12. The main loop consist of 4 steps: (1) a designer works out a detailed plan for a product; (2) a prototype is created based on the proposed concept; (3) performance tests are carried out on the prototype; (4) If the test results are satisfactory, then the loop is completed. Otherwise, the process returns to step (1). In addition, CAE (Computer Aided Engineering) can be an effective means of reducing the number of prototype trials.

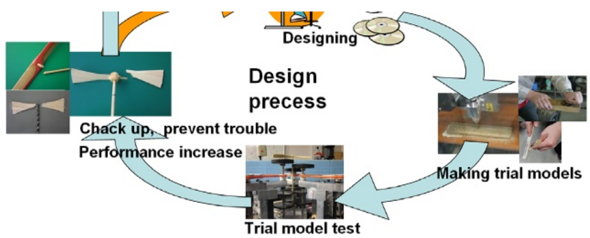


Fig. 12: Design process

(a) Classic *taketombo* (b) Super *taketombo*

Fig. 13: Handmade *taketombo*

3.1 System manufacture

The design plans, such as the use of a flat plate airfoil, were explained to the students. Two types of *taketombo* were considered: a *taketombo* having a wing with a uniform cross section, which has existed for many years as an article of folkcraft (Fig. 13(a)), and the super-*taketombo*, which was proposed by Akioka (Fig. 13(b)).

The purpose of this education is for the students to design a super-*taketombo* using the technical capabilities they have acquired and the imagination to achieve their goal.

The manufacturing process was designed to be completed in five steps based on the progress and degree of comprehension of the students.

STEP 1 (conceptual introduction): The students are asked to use a knife to manually produce a *taketombo* having a wing with a uniform cross section (Fig. 13(a)), without any special knowledge of mechanical engineering.

STEP 2 (basic theoretical introduction): The students attend lectures on mechanical dynamics, material mechanics, and fluid dynamics.

STEP 3 (design case presentation): The students examine the design of a super-*taketombo* (Fig. 13(b)), and then attempt to construct it using a knife.

STEP 4 (tool introduction): In addition to the manual use of a knife in STEP 3, the students can also carry out 3D-CAD and CNC (Computerized Numerical Control) machining. They can also use fundamental CAE methods such as FEM in 3D-CAD.

STEP 5 (application development): The students can use highly advanced FEM and CFD techniques, although specialized knowledge is needed to use CFD and calculation costs are very high.

(a) Filing by hand (b) Finished *taketombo* produced by hand

Fig. 14: Example of STEP 2

3.2 Example of design and manufacture

An example of STEP 2 is shown in Fig. 14. At this stage, many students simply copied the model and learned little. Examples of designs produced in STEP 4 are shown in Fig. 15. In this step, although students who do not make original designs, but instead imitate existing *taketombo*s, do not fail, they also do not gain good experience. On the other hand, students who challenge themselves experience many failures and in this way achieve progress. A design example in which centrifugal force was not taken into consideration, resulting in fracture, is shown in Fig. 16. However, in many cases, the performance was improved through trial-and-error, as indicated in Table 1.

Table 1 Sample altitude record of students' *taketombos*

Year-STEP	Rotation[rpm]	Hight [m]	Duration[s]
'09 STEP4	8093	4.61	3.13
'10 STEP4	9359	6.16	6.22

Fig. 15: Various proposed *taketombo* forms

Fig. 16: Failure example

Fig. 17: Experiment

3.3 Flight experiment

The maximum altitude achieved by each *taketombo* was measured. The launching device shown in Fig. 9 was built and used for altimetry (Fig. 11). Fig. 17 shows the experiment being conducted. Attempts to control the angular velocity to be the same while using the same *taketombo* indicated a reproducibility error of less than 8%. A part of the record of an undergraduate student who progressed to STEP 4 is shown Table 1. Students are often not interested in wind tunnel tests, in which the object of study is fixed. However, the students expressed a great deal of interest in the newly designed *taketombo* launch device.

4 CONCLUSION

In order to achieve a sustainable society, the training of next-generation engineers is extremely important. In the present study, three-dimensional CAD, which enables the use of numerical computation methods such as FEM, including the element of a dynamics system subject, was used. It is necessary for students to understand the differences between reality and simulations, and the design and manufacture of the *taketombo* described in this paper is a useful way to teach this.

The students managed to design lighter and stronger products than conventional ones. Furthermore, students who are not stimulated by conventional CAD lectures or wind tunnel experiments may find such an educational approach interesting.

In particular, when carrying out design education such as PBL, it was shown that a *taketombo* manufacturing theme was an effective means of education for a sustainable society.

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Evaluation of learning environment for ESD (Education for Sustainable Development) using activity index of salivary amylase

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Abstract

Facing a becoming more complex society of the world, next generations should have more tough and multiple talented abilities, which may be fostered by a rather different educational manner as ever carried out in schools. In advanced era of information technology, indirect experience and pseudo-experiences are getting more the cases in school educations, where a shortage of direct experience yields misgivings about even a negative aspect in the growth of children.The Ministry of Education, Culture, Sports, Science & Technology in Japan (MECSST) has reported that the children who have many of experiences with playing in nature and/or works in social situations, acquire a higher sense of justice and morality. MECSST recommends, therefore, more fulfilled practical activities in school, in local regions and home etc. Recently, we have noticed the "Outdoor education" proposed by Szczepanski, et al., Linköping University, Sweden, which is evaluated as a more effective educational manner, developing a tough and multiple abilities with mental health, concentration, scientific literacy and sense of one's able-feeling. Learning process with action and thinking is the substantial factor which may be practiced in forest, schoolyard, park, industry and any other places, i.e. outside of the class room, where a moderate stress can be kept during the learning. In this study, we have tried to define more quantitatively the learning conditions suitable for developing the talent of children, where the well-balanced stress is generated. For that purpose we have used salivary amylase activity monitor (NIPRO) to measure the level of stress. Amylase in the saliva is known as a possible index for quantitative assessment of sympathetic activity and stress level.Typical experimental result indicates that, when the examinee moved to some area differently changed from the former place, larger change in activation of salivary amylase has been measured. Salivary amylase activity is considered, therefore, to be able to estimate learning environment for a well-balanced stress condition, which is suitable for the education for children within the scope of the sustainable development.

Keywords:

Salivary amylase, stress, outdoor education

1 INTRODUCTION

Recent years, our life circumstance becomes more convenient and comfortable due to the rapid economic growth. The "conventional social development" succeeded in providing an affluent production and consumption for us, while the development also caused ecological destruction, enhancing economic gap, abusing human rights and many of other negative aspects. The educational activity called ESD (Education for Sustainable Development) is, therefore, suggested presently as a manner of fostering the people for next generation and our society in the future all over the world being sustainable and reliable. ESD is also educational activities in a local area to cultivate human resources who try to build futuristic sustainable communities or to develop a relationship and communications among the people. The concept of ESD is not just knowledge-oriented learning, but experience-oriented one. The learning approach of ESD is, therefore, the activities taken by means of thinking, discussing and working for solving practical problems. These activities bring to learner to be awared of connection of oneself to social issues, which yields more wills and skills for their activities especially in the younger generation.

Many people already understand the importance of practical experience. However, for the children in the information developed society, the decreasing opportunities of direct experience is getting more concerned. The report of MECSST (Ministry of Education, Culture, Sports, Science and Technology) in

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Japan has indicated that the children who have many of experience with playing in nature and/or works in social situations, acquire a more sense of justice and morality[1]. In addition, National Institution For Youth Education has reported the factors of what kind of experience is necessary for children`s character-building, investigated by analyzing the personal qualities and abilities obtained by various experience in childhood[2].

Recently, we have noticed the “Outdoor education” proposed by Szczepanski, et al., Linköping University, Sweden, which is evaluated as a more effective educational manner, developing a tough and multiple abilities with mental health, concentration, scientific literacy and sense of one’s able-feeling. Learning process with action and thinking is the substantial factor which may be practiced in forest, schoolyard, park, industry and any other places, i.e. outside of the class room, where a moderate stress can be kept during the learning. Both too much or too less stress may be an important factor in planning an educational environment. Therefore Szczepanski,et al. refer to the necessity of keeping moderate stress.[3]

In this study, to find out more effective learning circumstancce including outoside of the classroom and experiencing practical actions, we have tried firstly to define more quantitatively the learning conditions suitable for children, where the well-balanced stress is generated. For that purpose we have used salivary amylase activity as an index for a well-balanced stress, wich can be measured easily even in the outdoors.

2 EXPERIMENTAL

2.1 Instrument

We have used salivary amylase activity monitor (NIPRO CM-2.1) to evaluate the level of stress. Amylase in the saliva is known as a possible index for quantitative assessment of sympathetic activity and stress level[4].

Amylase can be measured simply by collecting saliva by using an absorbing stick just after the each event, then put into the instrument for measurements.

2.2 Measurement

We measured the amylase activity of examinee of university students. Additionally, subjective questionnaires were carried out to understand the amylase activity change under following experimental conditions.

1. Visiting different environments
2. Simple but many arithmetic calculations at each point in different environments.
3. During the assembling jigsaw puzzle (300 pieces) for 90 minutes (measured at every 10 minutes)

3 RESULTS AND DISCUSSIONS

3.1 Changes in amylase activity in visiting different environments

Figure 1 shows changes in amylase activity of examinee, A – E, moved to different environments of university campus as usual circumstance to outside campus as unusual area and back to the campus.

University campus is located in distance from urban area and blessed with a good natural environment. Examinee visited a gathering cafeteria for students on the campus, and walked out to the place, where they do not usually use as their daily route to the campus.

Without strenuous activity, the examinee has remained at each area for 30 minutes. The value of amylase activity measured is plotted as relative change against the value at the initial point in Fig.1.

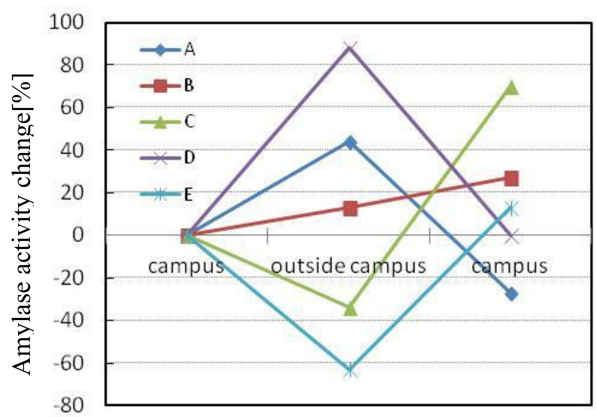

Fig.1: Changes in amylase activity in visiting environment

Variation of amylase activity seems to be 3 patterns as shown in Fig.1. According to the subjective representation, the examinees(C and E) with decreasing activity at the outside of the campus has felt a stable and even no nervous stress, while the examinees(A and D) with increasing activity at outside the campus has felt fatigue and sleepiness. Additionally, the examinee (B) has represented somewhat general situation knows as “stress” by oneself.

Examinee B is considered to have less effect of environmental change, as the examinee has visited that place (outside campus) several times ever before.

3.2 Effect of Concentration and environment change on the activity of amylase

Figure 2 shows concentration as an instant response of corrective answer in percentage and activity of amylase. Examinees made a simple arithmetic calculation (addition) for 5 minutes (3 times). The measurement of amylase activity was conducted beginning and after the calculation. Line-chart is indicating the amylase activity and bar-chart is expressing the percentage of instant response of corrective answer indicating ones concentration. Furthermore, examinees (A, B and C) made calculations at different place at each time and examinees (D, E and F) made calculations at the same place every time.

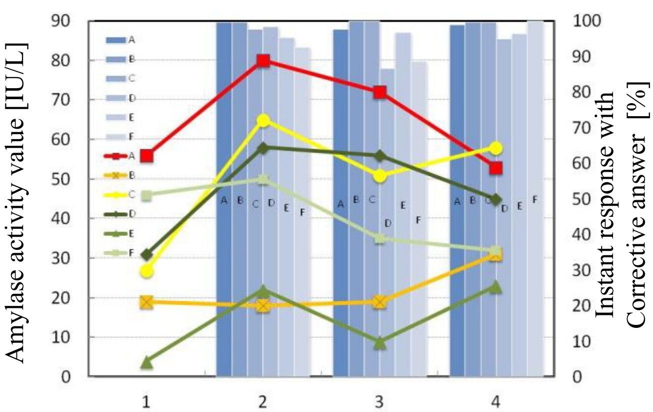

Fig.2: Corrective answer amylase activity with different environment.

Because the calculations were simple, therefore the corrective answer in percentage is more than 80%. But activity of examinee (D, E and F) varies more than that of examinee (A, B and C). Examinee (A, B and C) who moved to different place indicate higher percentage than that of examinee (D, E and F), who made calculations at the same place. The Relationship between percentage of corrective answer and amylase activity seems to be that amylase activity values of examinee (D, E and F) are relatively low, therefore, the examinee may need more stress which may result in higher corrective answers.

Some stress which brings a appropriate stress may give a more effective educational condition, which may be characterized by the activity of amylase. Further discussion on upper and/or lower limit of stress assessed by amylase activity is necessary.

3.3 Changes in amylase activity during the assembly jigsaw puzzle

Figure 3 shows a change of subjective feeling and the amylase activity during the assembling jigsaw puzzle. Examinees assembled jigsaw puzzle (300 pieces) for 90 minutes. Addition to the indicators of amylase activity and subjective feeling by questionnaire, each handling and attitude were recorded by a video camera to understand the subjective feeling more objectively.

Amylase activity has varied greatly by individuals during the assembling for 90 minutes.

In Fig.3, the subjective index summarized into 10 representative indexes is plotted from negative to positive order. Then we can find that an interesting distribution of the change of amylase activity is standing out. Furthermore, other (-) is unified infrequent indexes such as “frustrating”, ”confuse” and ”bored”, other (+) include “doing smoothly” and ”excited”.

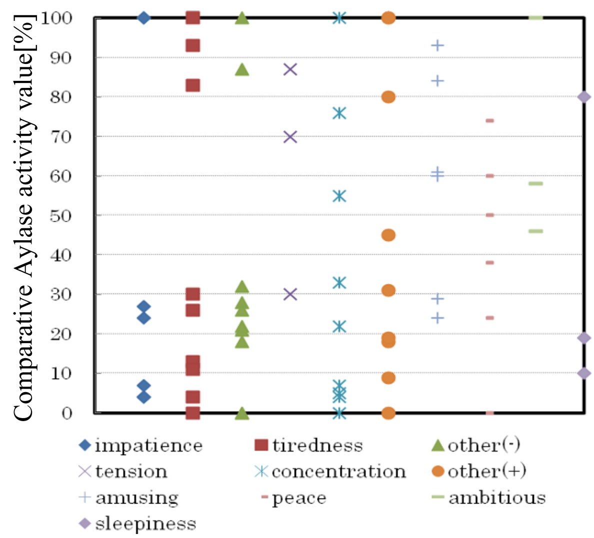

Fig.3: Percent changes of amylase activity during assembling jigsaw puzzle (300 pieces) for 90 minutes with subjective feeling summarized into 10 representative indexes ordering negative to positive feeling.

The change of amylase activity during assembling jigsaw puzzle seems a relationship with subjective feeling from negative to positive situation, which may be related to not only the stress with negative feeling such as “tiredness” and ”impatience”, but also varies subjective feeling, such as “concentrated” and “amusing”.

4 SUMMARY

Measurement of amylase activity has a possibility to determine the stress level easily and responds to one’s subjective feeling change acutely, while amylase activity value is not always corresponding to subjective feeling variations. In addition, Amylase activity value may include individual difference of each subjective situation. Therefore, Amylase activity must be analyzed and considered with subjective information on life style or living circumstance for estimating whether the cause of amylase activity value alteration is depending on the change of learning situation or not.

The relativity of value of amylase activity with various each subjective feeling should be more investigated with more experiment with more samples and considered.

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Municipal Solid Waste Management System-----
A case study in ShangHai

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Keyword： Municipal Solid Waste，Scenario，Weighting，RDF，Bio-Treatment， Incineration， Landfill

ABSTRACT

With the rapid development of economy and population, Municipal Solid Waste in Shanghai was augmenting daily. The reported generation of MSW was 7million tons in 2007. Treatment and Dispose of MSW had became an imperative problem for Shanghai. Currently, there were many problems of MSW Treatment system, 52.5% were treated in sanitary landfill, 16% in incineration, 10% in composting, 19% in unsanitary landfill, and 2.5% recycling with no RDF. The waste were only collected with brief classify and even transported mixed and the major problem was that carbon dioxide were released with a gigantic volume in current system. This paper proposed 4 types scenarios through Waste Management Assessment Model to analyze the combustibles cost, recyclables cost, collection cost, transport cost, and also analyzed environmental impacts, calculated the impact weighting, compared which scenario were most appropriated in ShangHai.

1.Introduction

1.1 The current classification model

The classification of MSW in ShangHai were started at 1995, and adjusted several times, like ”Organic, Inorganic, Hazardous, Nonhazardous”;”Solid, Moist, Hazardous”;”glass, combustible, hazardous” etc.

Since 2007, Shanghai began to implement four classification modes. That Residential area classified "hazardous waste, glass, recyclable materials, and other waste"; In enterprises, established to implement "hazardous waste, recyclable materials, and other waste"; In public they classified with "recyclable Materials, other waste"; addition of food waste, bulky waste, construction Building waste, disposable plastic food containers for divided disposal.

1.2 Coverage

At present, the amount of settlement in Shanghai implemented garbage four categories have reached 3738; 2471 enterprises implemented garbage three categories; implemented garbage two categories of public places are including: Nearly 200 roads, parks and 380 bus stops.

1.3 Current Transportation

Sanitation units according to the actual situation to configure transportation vehicles and set transit point to operate wastes' collection and transportation. There are 79 vehicles and 54 transit points in motion now.

1.4 Current Disposal

As Fig.1 showed, in 2007(waste amount was about 7,020,000t) there were 52.5% amount of waste in ShangHai treated in sanitary landfill, 16% in incineration, 10% in composting, 19% in unsanitary landfill , and2.5% recycling with no RDF.

Because of the great generation of waste was exceeded the landfill capacity, they did Unsanitary landfill in 2007.

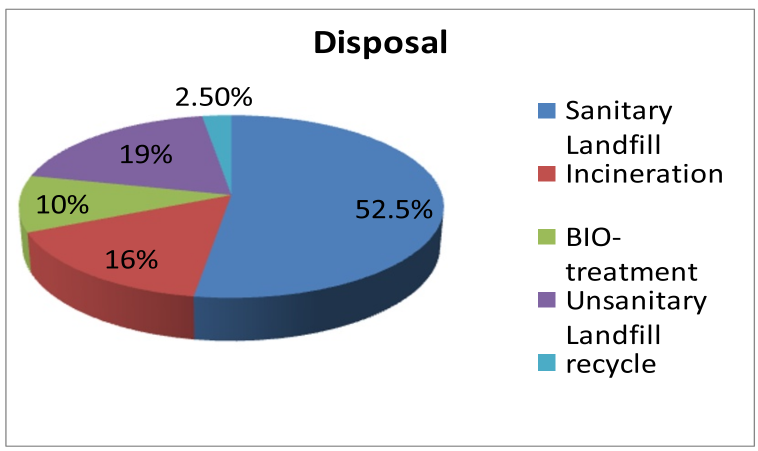

Fig.1 Disposal Percentage of MSW in 2007.

1.5 Object

Shanghai government did a plan that use 3% of GDP and until 2015,CO2 emission should be cut down 25% of current emission, SO2 should be cut down 35%, and the total waste

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generation should decrease 25% and should approach Non-hazardous rate 100%.

In this research we supposed 4types scenarios to approach that object and compared cost and environmental benefits to suggest a appropriated way to deal with waste of Shanghai.

2. Problems

2.1 Capacity of treatment facility

Table.1 showed the amount of current treatment facility, with 3 landfill centre, 2 incineration facilities and only 1 bio-treatment facility. So the capacity of landfill is 2,427,250tons/year, 730,000tons/year for incineration and 365,000tons/year for bio-treatment. Connect to Fig.1, we know many facilities are runned over their capacity.

	Amount	Treatment(tons/day)
landfill	3	10000
incineration	2	3000
Bio-treatment	1	1500

Table.1 Treatment Facility(2007)

2.2 Lacking operability

"Environment protection" is one of China's national policy. So as a part of Environment protection measure, MSW treatment are expressly embodied in many laws such as 《Environmental Protection Law of the People's Republic of China》; 《Solid waste pollution prevention law of People's Republic of China》; 《City appearance and environmental sanitation regulations》.etc.

But whether it is state law or local ordinances, the point is that lacking of detailed regulations about how to classify, how to collect and dispose, the main responsibility for classification is not clear, and local laws and regulations does not rise to the legal level, all of these caused poor operability to protect environment.

3. Method

3.1 Sample

The population in Shanghai at 2007 was 18.58millon, and from Table.2, the waste generation in 2007 was 7.02million tons, including 58.76% of Organic, 12.82% of paper. 13.98% of plastic, 5.36% of glass, 4.41% of textiles, 0.98% of metal,1.49% of other waste.

Year	2003	2004	2005	2006	2007
Waste Generation(million ton/year)	5.85	6.10	6.22	6.58	7.02
Growth rate(%)	–	4.27	1.96	5.78	6.68

Table.2 waste generation from 2003~2007

We surveyed the proportion of waste in 2007 of ShangHai, the most part was combustible waste occupied 45.43% at all, it means 3,189,186 tons combustible waste were generated in 2007. Table.1 showed the incineration capacity was 1,095,000tons/year only, the rest combustible waste was went to Landfill.

1,482,624 tons Organic waste occupied 21.12% of the proportion, but the BIO-treatment capacity was only 547,500 tons/year (Table.1), and in 2007 there was 10% (702,000 tons from Fig.1) waste were treated with BIO way, because beside one Bio-treatment center there were many communities built their own composting point. And in Bio-treatment center, they dealt the Organic waste in two ways: composting and gasification, 3.11% of garden waste were treated with composting way.

Although we knew there were 11.82% of paper, 9.98% of plastic 5.36% of glass, 0.98% of metal, but only little part were recycled by social communities and the rest part were delivered to landfill center or incineration center, because ShangHai government had no Material Recovery Facility in 2007.

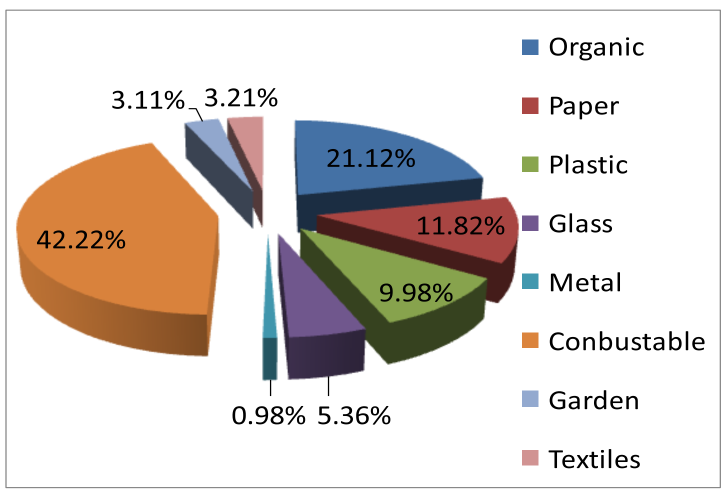

Fig.2 proportion of waste in 2007

3.2 Scenario

This paper proposed 4 types scenarios through Waste Management Assessment Model to analyze the combustibles cost, recyclables cost, collection cost, transport cost, and also analyzed environmental impacts, calculated the impact weighting, compared which scenario were most appropriated in Shanghai.

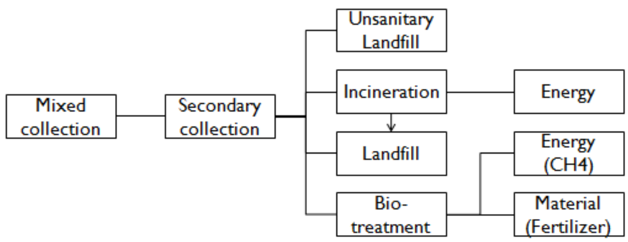

Fig.3 scenario 1

Scenario I is the current disposal and recovery flow, collected with mixed way and need secondary collection, and go to Bio-treatment center Incineration center and landfill center, recovered Energy and fertilizer.

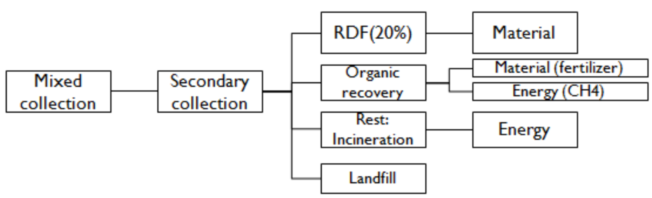

Fig.4 Scenario II

Scenario II suggested current collection (mixed collection) and do secondary collection to separate paper and plastic (20%) to RDF, organics go to Bio-treatment to recover fertilizer and methane, and rest waste go to incineration center and landfill center.

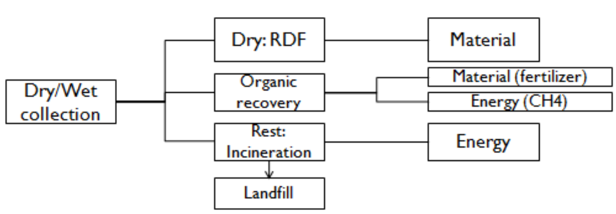

Fig.5 Scenario III

Scenario III used Dry/Wet collection to decrease the collection cost and make higher operability. Dry waste go with Refuse Derived Fuel to get RDF materials and wet waste all goes to Incineration to get energy and the ash goes to landfill.

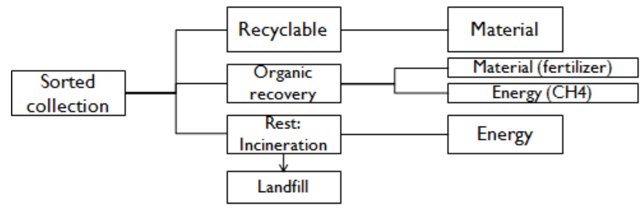

Fig.6 Scenario IV

Scenario IV would cost more, after sorted collection, recyclable waste goes to Material Recovery Facility to get material, Organic waste goes to Bio-treatment facility to get fertilizer and methane, than rest waste goes to Incineration.

4. Future work

After these 4 scenarios, we should use a soft named INTEGRATED WASTE MANAGEMENT MODEL (IWM-2) to calculate collection cost, transport cost, treatment cost, final disposal cost, and get scenario total cost.

In another hand, we also should get the human impact and environmental impact: climate change gas emission, acidification potential, human toxicity, landfill use.

And use all of these dates to calculate and compare the weighing of impact categories of 4 scenarios, and carry out which scenario is most appropriated (compatible environment with cost) in Shanghai.

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A New approach for municipal solid waste governance aiming to become green city bases on a sound material – cycle society initiative in Hanoi, Vietnam

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Abstract

This study aims to analyze the Japanese Sound material-cycle society (SMCS) model in compatible condition with current municipal solid waste (MSW) in Hanoi, Vietnam at the first step: waste classification. About household waste, author co-operated with some workers, officers and experts in Hanoi Urban Environment Company (URENCO) in 3Rs (Reduce-Reuse-Recyle) project in 4 main wards of Hanoi: Phan Chu Trinh, Lang Ha, Nguyen Du and Thanh Cong. This project supplies collection containers for households and public places for separate waste at source with 3 categories: Organic waste, Inorganic waste and Recyclables. In comparison with old state, household waste at these places are classified properly with higher value for recyclable and organic waste. About waste from commercial activities, author conducted a site-study in some big and media size super markets, shopping malls, open markets and restaurants about waste classification at source. Author interviewed collectors and directly classified and measured the composition of waste in 2 weeks with collectors. The author also went to Nam Son sanitary landfill site, the biggest MSW treatment facility of the North in Soc son (Hanoi) to survey the real situation of MSW when it is buried. The capacity and environmental impacts from landfill activities are also quantified. The output of this study is to identify MSW composition and material cycle aim to increase composting and recyclable material amount, quantify the reduction in landfill load and propose some policies to improve local people awareness for better MSW governance. Basing on collected data from these activities, author expects to propose a new scenario for MSW treatment by using Integrated Waste Management Model (IWM-2) to improve the current situation aiming to build a clean-green-beautiful Hanoi as local government target

Keywords:
municipal solid waste (MSW), waste classification, 3R project, Hanoi, IWM-2

1 INTRODUCTION

Hanoi is capital of Vietnam, located in the Northern at Hong River delta. Hanoi was expanded from 1 August 2009 with total area of 3,344.7 km2 (old Hanoi is about 927.39 km2) and consists of 10 urban districts and 18 suburban districts and 1 town. Currently Hanoi's population is about 6,232,940 people excluding thousands of visitors from another provinces living and working temporarily. Population density is approx 3,565 person per square kilometer (Hanoi Statistical Year Book 2010). Recent years, urban districts areas have been experiencing a fast urbanization. According to official statistic, in 2009, Hanoi has 6,500 factories and enterprises, over 90 hospitals and big medical centers, 70 markets and hundreds of restaurants and commercial centers. Current Hanoi with large rural areas, few people have sufficient awareness about waste classification. More and more industrial zones are developing, people life style also change so much, infrastructure, legal framework is not caught up with urbanization speed therefore the amount of waste is increasing and causing many environmental burdens for inhabitants and local government (MSW Management: Annual Report, Hanoi People Committee, 2009)

The problem with lacking of landfill area for municipal solid waste doesn't happen in Hanoi only. Many countries/ areas all over the world have been facing with this situation and most of them, especially in developed countries choose method of improve people awareness about waste classification to reduce landfill area instead of widening it. For example, Germany is leading country in the world for amount of recyclable waste. The issue of waste classification was taken seriously in this country from 1991. They separate waste in different color bins. Yellow bin is for food/ milk container, carton, plastic or metal, navy blue bin for paper, green bin for organic waste and black bin for glass. They also apply many advanced technologies in separating waste at waste treatment facilities to have the highest value of recyclables. Waste classification awareness is also improved and educated for children. Waste from non-value disposal became worthy goods and help improve living conditions (German, 2006)

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In Singapore, an efficient collection mechanism has been applied for several years. Waste collection became an attractive business and is handled for good contractors. One contractor is responsible for collecting waste in one defined area in 7 years. Contractor collects waste door-to-door, then gathers in big collecting site. Waste is treated under "national recyclable program". Environmental Law is considered strictly in Singapore with high level of awareness. Thus, Singapore is always considered as one of the cleanest countries all over the world (Ngo.Thuy Thi Minh et al., 2008)

In developing countries, municipal solid waste collection still has many problems. They are facing with some difficulties such as collection network, weak transportation, inefficient machines and technology etc. that lead to increasing cost but low efficiency. Moreover, private sector participation in this field has many restrictions and residents' awareness is still very weak. Therefore, in comparison with developed countries, waste collection and classification in Vietnam and other developing countries are still at low level.

In Vietnam, household solid waste is the main discharge source of MSW (World Bank et al., 2004). In additional, commercial waste counts a large proportion of recyclable sources (UNEP Training Manual, Vol1) 3Rs project with Japanese initiative about a sound material – cycle society specialized in MSW source separation is a reliable information source to select a suitable technology for waste treatment in the future. The selection of classification MSW at source is the shortest and most efficient way for local government to solve current challenges.

2 METHODOLOGY

2.1 Study Area

Because of complicated changes from old Hanoi to new Hanoi so the fieldwork was just conducted at four core wards in Hanoi (Nguyen Du, Lang Ha, Thanh Cong and Phan Chu Trinh) and some main commercial centers in urban areas. These areas have dense population habitation, traffic system with many small alleys. Waste generation per capital in these areas is also higher than other urban areas (Urenco, 2009). The current eco-social and administrative background of the four pilot wards are shown in Table 1:

Table 1: Background of model wards

No	Items	Phan Chu Trinh	Nguyen Du	Thanh Cong	Lang Ha
1	Location (Dist.)	Hoan Kiem	Hai Ba Trung	Ba Dinh	Dong Da
2	Are (km2)	0,44	0,38	0,96	0,65
3	Population	8,224	11,140	24,872	28,584
4	No. of households	~ 1,900	~ 2,000	~ 7,000	~ 7,300
5	Average waste amount (tons/day)	9	11	20	12

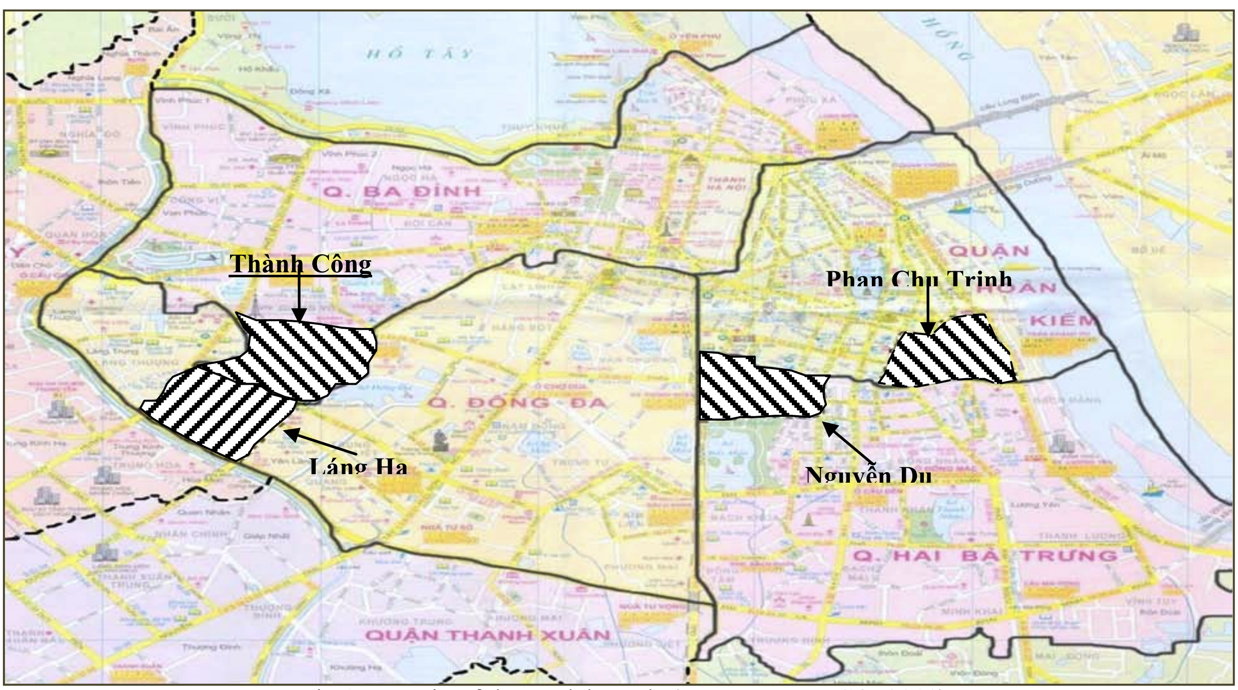

Fig.1: Locatin of the model wards (source: URENCO, 2010)

2.2 Collection and analysis data

In developing country, the reliable information on waste quantity and detailed composition is difficult to achieve on a disaggregated level (Nguyen Phuc Thanh et al., 2010). However, to get the output for IWM-2 model, input data plays an important role. Therefore, the result from 3R project in Hanoi is chosen to become a reliable secondary data source of waste composition for household area. The project for Implementation Support for 3R Initiative in Hanoi has been started for first stage in three years from November 2006. It aims to establish a balanced and unique 3R system centered around the source separation (SS) and recycling of organic waste under 3R initiative and connect this to the formation of a "Sound Material-Cycle Society" in Hanoi (Project Complement Report, JICA, 2010). Applying the development of the Project Design Matrix (PDM) and co-operation among many stakeholders, the project has been deployed in four core model wards. Households and public places in model areas are prepared and distributed waste container with image color and logo for each category of waste.

No	Categories / Item	Organic waste	Inorganic waste	Recyclables
1	Kinds of waste	Flower, Vegetable, Fruit, Leftover Food, Tea leaves, coffee residue, Grass, Leaves…	Bone, Tree Branch, Shell, Pottery, Textile, Briquette, Coal, Diaper	Paper (Magazine, Newspaper, Books, Notebook, Carton), Metal (Iron, Aluminum, Copper, Can), Plastic (bottle, box, nylon bag, shoes)
2	Household container	Green container with liquid strain	Orange container	Each household keep recyclables in nylon bag or outside container
3	Collection container for discharge	Green container – 240 litter	Orange container – 240 litter	Residents can keep to sell to junk buyers/shops or directly give to collection workers at discharge points.
4	Discharge time	6:00 pm – 8:30 pm	6:00 pm – 8:30 pm	
5	Discharge day	Everyday	Everyday	
6	Discharge point	Residents bring household collection containers to these points and discharge waste into the collection containers.		
7	Transfer station	Several points to store 4-10 collection containers.		

3R project helps many households in Hanoi Hanoi to recognize better about waste classification at source. However, this project has not covered waste generation in commercial centers such as super markets, open markets, shopping malls and restaurants. A typical aspect of Hanoi commercial system is the number of open market still higher than super markets. People also keep custom to buy food and others in open market than super market for nearer distance and convenience. Therefore, these places generate a big amount of waste every day. To have composition of waste in these places, author contacted with some big and medium-size super markets, open markets and restaurants. With target to get waste composition at source, author with waste collector in these place weighing and classifying generated waste in three mentioned categories. Almost super markets have own contracted private company that is responsible for collecting, classifying and discharge waste every day. Waste from restaurant is classified with separation food residue and can, bottle, tissue. Open markets generated a large amount of waste everyday and by taking sample to survey waste composition, author also get data for organic, inorganic and recyclables.

2.3 Analytical procedure

After collecting first and secondary data, author worked with some experts in Hanoi Urban Environmental Company to assess the results. In comparison with target, using PDM model, the waste composition in both sectors: household and commercial is defined and it become the reliable information source for calculating effect of project, landfill load reduction as well as input for IWM-2 in next step.

2.4 A life Cycle Inventory Model: IWM-2

The IWM-2 computer model is applied to have a waste management scenario optimization and comparisons (Fobbes Mc Dougal et al., 2nd edition). Input data is actual data getting from results of 3R project and this site-study. Four scenarios with analyzable and comparable environmental burdens and economic costs will give the suitable answer for waste management in Hanoi in near future.

3 RESULTS AND DISCUSSION

3.1 Waste composition in household areas

The existing collection system was changed into a new collection system suitable for source separation which requires residents to keep and discharge waste in new and different ways. Moreover, the new system was designed in consideration of more modern style and conveniences of residents and collection workers. Under this project, waste collection rate in Hanoi urban districts reachs approximately 100%, all kinds of domestic waste are collected, transported and treated daily in order to keep our city always clean and beautiful. Residents have a responsibility to prepare household containers for separated waste for source separation and discharge waste into the regulated separation containers at the designated discharging points and time. In project complement report, with many efforts and co-operation from many stakeholders, the household waste composition was as following chart:

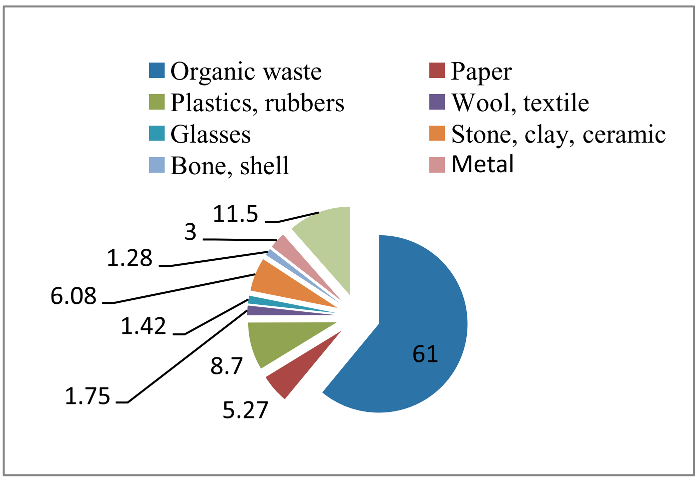

Fig.2: Waste composition at household

Clearly, in comparison with the old system, all kinds of waste are disposal to landfill site, now waste generation is characterized in many categories with the distinguish aspects: organic waste, inorganic waste and recyclables.

3.2 Waste composition in commercial areas.

The classification of waste in super markets is more easier to conduct because the composition of waste is not as complicated as domestic waste. Moreover, the collectors in some big super markets belong to private companies so they classified generated waste quite carefully.

In contrast with waste composition in super market, waste in open market doesn't have so high value because almost amount of waste is organic waste with residue of fruit, vegetable and foods.

Waste classification in restaurant system in Hanoi also had some different results. If some big restaurants have clear regulations for separating waste at source other street side restaurants in small and medium size dispose waste freely on the street without any separation.

Hereinafter are some results that author collected in surveying waste classification in model super markets, open markets and restaurants:

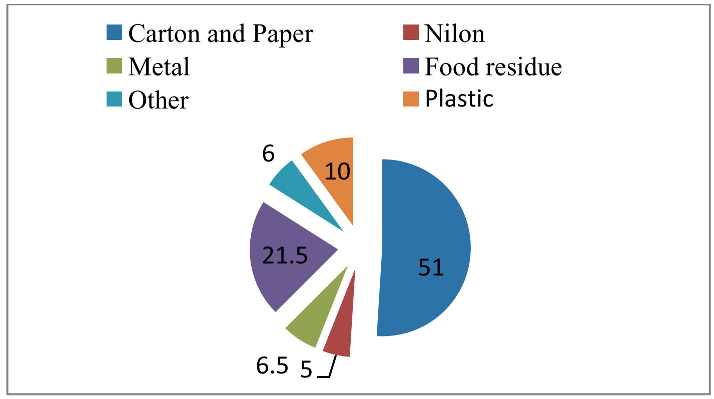

Fig. 3: Waste composition in super markets and shopping malls

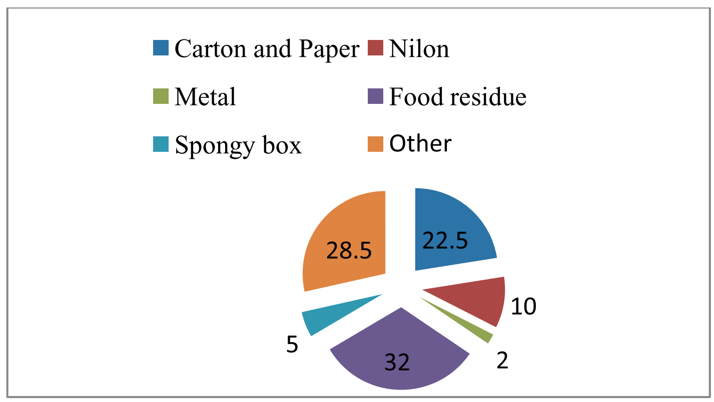

Fig. 4: Waste composition in open market

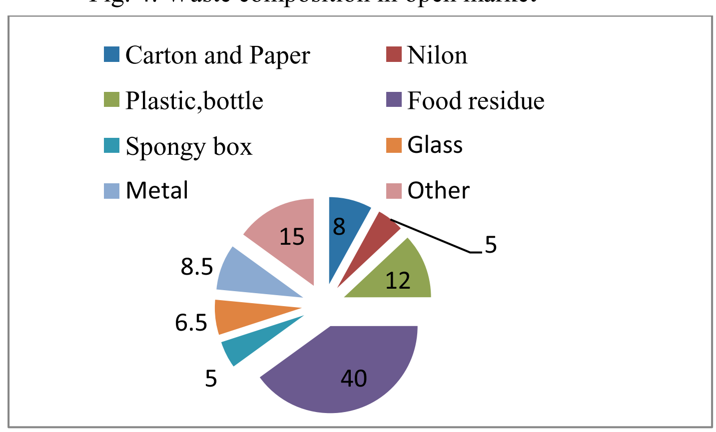

Fig. 5: Waste composition in restaurants

3.3 Potential recycling material

Before having these activities, all kinds of waste were disposed to landfill site. The sanitary landfill site had to bury both organic and inorganic waste. There are some kinds of material take very long time to disintegrate and cause serious impacts on ground and water environment. Only a small amount of can, bottle are collected by junk buyers and recycle activities are not synchronous with waste management system. However, from the collected results, after waste classification activities are deployed, some kinds of material have high potential for recycling. Organic waste counts a large proportion of household, restaurant and open market waste: 61%, 40% and 32%. It is the input for composting as 3R's target. Other materials in commercial activities have high recycle value such as paper and carton from super market and open market waste: 51% and 22.5%. Plastic and metal are also easy to collect and recycle with high rate from restaurants, supermarket and shopping malls: 12% and 10%. Other materials with lower fraction such as metal, glass, spongy especially nylon in above figures are collected and separated properly help reduce the burden for landfill site and significant long term effect of environmental features.

3.4 Some social and environmental outputs getting from the new approach.

Indicator 1: Disposed waste to the landfill site is reduced to 30%.

This result is very satisfactory indicator because the burden with Nam Son waste treatment complex now is too big. The target to reduce the landfill weight is very important factor to assess the efficiency of project and it is also important indicator of this fieldwork. Nam Son waste treatment complex was designed with operation time in 2020. However, waste generation in recent years has been increasing fast (15%/year) while average GDP increase just 12%/ year, so as calculated by some experts this site will be closed in the beginning of 2012. Other waste treatment facilities are built or planned to build in next time (Hanoi People Committee report, 2010) but if people continue to discharge waste without source separation, landfill capacity will be soon overloaded. With results from 3R project and author's survey, a large proportion of organic waste is composted in Cau Dien Composting Company with a capacity of 60,000 m^3/year. Fertilizer from this plant is using for afforestation. Recycling activities basing on these results also get more potential. Amount of recyclables is kept in households has been increase and residents sell them for junk buyers instead of throw them away with other kinds of waste.

Indicator 2: Percentage of residents in pilot project areas who recognize the sanitation condition of the area is improved is more than 50%. Many propaganda activities related to 3R project have been conducted in model areas and citizens eager with new method of waste treatment. "3R Stars Club" or Mottanai campaign attracts many participations (Urenco, 2010)

3.5 Propose new scenarios

Use IMW-2 computer model to select a suitable scenario for waste treatment in Hanoi basing on collected data. Starting from basic scenario: landfill scenario for all kind of waste. The second option is composting priority scenario for organic waste and land fill. The third option is composting for organic waste combining incinerating for some kinds of material and land fill. The last option is composting, incinerating and recycling for recovery energy and value, then land fill. The next step is author will compare four options and assess the environmental and social value. With support from this model, author proposes some ideas to improve waste management situation in Hanoi in near future.

4 SUMMARY

Waste management and environment protection in Hanoi has been the most concerned issue. The government and HPC have been developing a legal and legislation system to construct an appropriate system for waste management. The objectives are reduce amount of disposal solid waste, increasing recycle and reuse amount, open source separation activities for other areas for both inner or outskirts, reduce the negative impacts from waste treatment to human health, environment and urban landscape. Above are some simple results from author's fieldwork. It need more time to have more careful analysis and assessment about other indicators related to waste composition with new approach for sustainable development for Hanoi in near future. In order to increase effectiveness of this new approach, local government should raise environment awareness among people by environmental education, propaganda to make people serving natural resources and reuse, recycling solid waste. At household level, people should have different containers for organic waste and recyclables and discharge separately. In public places, local government should place containers for different kinds of waste. Local government should also encourage different organization, private companies and individuals to deal with MSW problem together with government. It is should be considered applying some economic instruments such as increasing collection fee or polluter-payer… In general, having good awareness about waste management can reduce many environment problems and waste classification at source is the best solution for MSW management in Hanoi from now on.

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Integrated LCA for Municipal Solid Waste Management in Developing Country

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Abstract
Fast growing mega cities in developing Asian countries are faced with problem of municipal solid waste management (MSWM) due to land scarcity, rapid urbanization and population growth. To determine the most sustainable strategy to solve this problem, Life Cycle Assessment (LCA) has been commonly used. This study developed localized weighting approach for integrated LCA by taking Jakarta as a case study. The result of this study hopefully could be reflected and adapted in other highly populated cities in developing Asian countries as a sustainable approach in solving MSWM problem.

Keywords:
Integrated MSWM, Solid Waste Management, LCA, Environmental Load Point

1 INTRODUCTION

Indonesian Municipal Solid Waste (MSW) generation/capita/day is 0.6 to 0.8 Kg [1]. As comparison to other highly populated developing countries in Asia, India generates 0.4 to 0.6 Kg [2] and China about 0.085 to 1.33 Kg waste/capita/day [3][4]. In 2008, Indonesian population of about 24 million was estimated to generate 38.5 million tons of MSW. This amount is increasing by about 2.5% annually [1].

Similar to other developing Asian countries, the composition of Indonesian MSW has higher organic fraction (58%). Detailed composition is shown in figure 1.

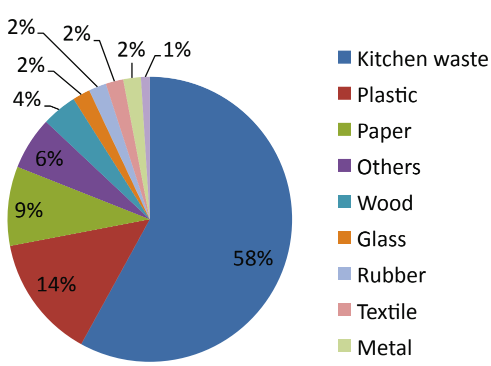

Fig. 1: Indonesian solid waste composition 2008[1]

The percentage of non-organic waste is expected to rise along with industrialization. The change of waste composition and the increasing waste quantity lead to the urgency of major cities in developing countries to adapt more advanced technology to process the waste.

To determine the most feasible technology, LCA is usually applied. This study proposes a way to improve the accuracy of assessment tool by formulating Integrated LCA named Environmental Load Point (ELP) that was developed in Nagata Laboratory at Waseda University. The superiority of this methodology is that it allows personalization of category importance priority by taking survey to local respondents to produce more relevant results. Another advantage is that it has additional category relevant to this study which is "waste disposal" measured in kilogram of solid waste landfilled.

2 METHODOLOGY

2.1 ELP quantification

ELP quantification is the process of discovering the integrated indicator for each of the nine environmental impact categories of ELP (table 2). Values required to calculate this indicator are annual emission or consumption of a certain country and category weighting (from now called as "category importance" to avoid disambiguation). Annual load is the result of multiplication between weight coefficient and annual emission gained from country's statistics offices and the corresponding ministry, while category importance is primary data that could be collected by various methodologies such as taking survey.

This study uses two methodologies to generate reliable and comprehensive results of category importance. The first one is by distributing Analytic Hierarchy Process (AHP) based questionnaires to several groups of people in Indonesia. The second methodology is by text mining from Indonesian online news.

Analytic Hierarchy Process (AHP) Questionnaire

AHP is a mathematic-psychology based structured survey approach commonly used in higher institutes of engineering. Table 2 shows a sample of AHP

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questionnaire used to determine category importance. The blue area was filled-in by respondents and the grey area generate the opposite number of importance automatically. Respondents may choose nine different level of importance.

Table 2: AHP questionnaire sample

ELP 9-category		B: 1.Energy drain	2.Global warming	3.Ozone depletion	4.Acid precipitate	5.Resource consumption	6.Air pollution	7.Ocean & water pollution	8.Problem of waste disposal	9.Ecosystem effect	P of multiplication*1	Category weighting*2	Category weighting %*3
A	1.Energy drain	1	1/3	3	5	3	1/9	1/9	1/3	1/9	0.01	0.575	0.037
	2.Global warming	3	1	5	3	1	1/7	1/7	1/3	1/9	0.03	0.687	0.044
	3.Ozone depletion	1/3	1/5	1	5	3	1/5	1/5	1/3	1/7	0.00	0.499	0.032
	4.Acid precipitate	1/5	1/3	1/5	1	1/7	1/7	1/7	1/3	1/9	0.00	0.224	0.014
	5.Resource consumption	1/3	1	1/3	7	1	1/9	1/9	1/5	1/9	0.00	0.391	0.025
	6.Air pollution	9	7	5	7	9	1	1/5	1/3	1/9	146.71	1.741	0.112
	7.Ocean & water pollution	9	7	5	7	9	5	1	1	1/9	11,014.00	2.813	0.181
	8.Problem of waste disposal	3	3	3	3	5	3	1	1	1/9	135.54	1.725	0.111
	9.Ecosystem effect	9	9	7	9	9	9	9	9	1	33,682,406	6.861	0.442

Definition of importance

9	A is significantly much more important	3	A is a bit more important	1/5	B is more important
7	A is much more important	1	A and B are equally important	1/7	B is much more important
5	A is more important	1/3	B is much more important	1/9	B is significantly much more important

Reference: Nagata Laboratory at Waseda University

*1: Multiplication 9 impact categories

*2: One ninth power of multiplied answer of 9 impact categories

*3: One ninth power of multiplied answer of 9 impact categories is divided by total value of category importance

Survey by text mining from Indonesian online news

The second methodology used to find category of importance in this study was text mining. Text mining was done by using Google web search Engine that was set to show the number of news that contains the word from the nine categories found in Indonesian language online news published in one year. Each of the search result is divided by the total number of result of all category and then multiplied by 100% to show how significant a category as compared to rest of the categories.

Table 3. Text mining result sample

	Resource Consumption	Air Polution	Water and Sea Polution	Waste Disposal Problem	Ecosystem Influence
Tempo Interaktif	9	36	85	54	8
Republika Online	5	26	28	22	8
Metro TV News	6	19	26	21	5
Antara	15	12	47	23	17
Media Indonesia	12	26	60	29	18
KOMPAS.com	24	55	69	74	20
Pikiran Rakyat	0	13	18	26	2
Detikcom	0	35	26	49	8
Other	93	423	391	782	42
Total	164	645	750	1080	128

News published from 1 January 2010 to 31 December 2010

Google search done in 14 September 2011

3 ANALYSIS

3.1 Annual Load

Annual load is the total amount of emission or consumption of a certain country in one year multiplied by the weighting coefficient. The items for weighting coefficient in this study were short-listed from Nagata Lab Waseda University database. Weighting coefficients and the amount of annual emission were taken from Indonesian statistics office, related ministries of Indonesia, and the estimations based from the latest research papers. Even though the possible related emissions and consumption in each category for MSWM are CO_2, CH_4, N_2O, NO_x, NH_3, particulate matters, BOD, COD, SO_2, C_2H_4, and PO_4, all the available data for each category items are summarized in Table 4. Some data were not available and some are not related to MSWM but presented for the purpose of other possible Indonesian LCA studies.

Table 4: Annual load calculation

impact category	item	weighting coefficient C	consumption or emission TQ (Kg)	annual load A = C x TQ
energy drain[1]	oil	1.00E+00	6.46E+10	6.46E+10
	natural gas	1.10E-01	1.30E+13	1.43E+12
	coal	7.70E-01	7.33E+10	5.64E+10
global warming[2]	CO_2	1.48E+01	2.22E+09	3.29E+10
	CH_4	2.45E+01	2.75E+09	6.74E+10
ozone depletion	Data not available			
acid precipitate[3]	NO_x	7.00E-01	1.58E+09	1.11E+09
	SO_2	1.00E+00	1.45E+09	1.45E+09
resource consumption[4]	iron ore (Fe)	1.00E+00	1.65E+09	1.65E+09
	nickel (Ni)	3.50E+00	3.83E+05	1.34E+06
	tin (Sn)	3.85E+00	1.93E+06	7.42E+06
	Bauxite (Al_2O_3)	6.41E-01	3.36E+07	2.15E+07
	Gold (Au)	6.71E+00	3.63E+06	2.43E+07
	Silver (Ag)	8.01E+00	1.20E+07	9.60E+07
air pollution[3]	SO_2	1.40E+00	1.45E+09	2.03E+09
	NO_x	1.00E+00	1.58E+09	1.58E+09
	CO	9.16E-03	5.70E+08	5.22E+06
	$PM_{2.5}$	1.09E+00	6.10E+07	6.65E+07
	PM_{10}	1.09E+00	6.80E+07	7.41E+07
ocean & water pollution	Data not available			
waste disposal[2]	Solid waste	1.00E+00	5.24E+10	5.24E+10
ecosystem influence[5]	Petrol	5.00E+10	4.94E+10	2.47E+21

[1] US Energy Environment Administration 2010
[2] Ministry of Environment, Indonesia 2009, 2008
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3.2 Category Importance

Category importance is the primary data taken to capture and represent the local concern regarding environmental issues of the nine impact categories in ELP. This is to be taken into account as an integrated LCA calculation. The two methodologies to get category importance were mentioned earlier: AHP and text mining. For text mining, google search engine was set to the option of showing only Indonesian news in Indonesian language that were published between 1st of January 2010 to 31st of December 2010. There were about 23 online news resources including major national newspaper such as Republika, Media Indonesia, and Kompas. Other popular news sources such as Metro TV News, Antara, Pikiran Rakyat, and Detikcom were involved. Provincial newspaper such as Surabaya Post and Bisnis Bali were also involved to capture provincial perspectives. Result shows that the first most published news is energy drain. Problem of waste disposal is in the second rank and global warming is in the third position.

For the second methodology, AHP questionnaires were distributed to 170 respondents in which 45 of them were eco-school teachers from three districts in and around Jakarta. The rest of the 125 respondents were university students from Bandung Institute of Technology (ITB). The eco-school teachers were teaching elementary to secondary classes in environmental-oriented school and the ITB university students were majoring in various engineering faculties (physics engineering, electrical engineering, environmental engineering, microbiology, etc.) The results of these primary data collection are shown in fig.3.

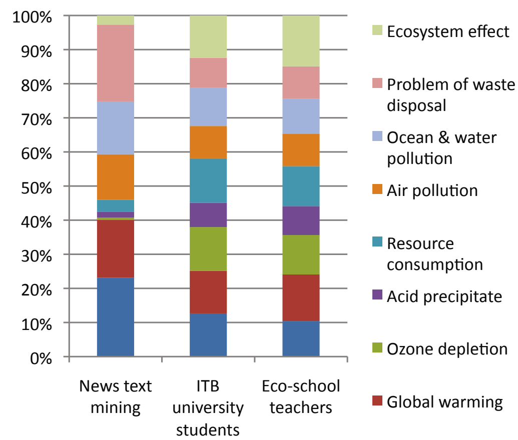

Fig.3 : Text mining and AHP results in Indonesia

ITB university students give higher importance in resource consumption, ozone depletion and energy drain. Eco-school teachers give higher importance to resource consumption, ecosystem effect, and global warming. It is interesting to analyze that despite the significantly higher exposure of news about waste problem in the media, it does not show in the interest of the two groups of respondents as priority.

The reason of clash of interest might be because Eco-school teachers already taken care of their waste at school by waste segregation activity and then collected by scavengers for recycling. The school's organic wastes are made into compost fertilizer as one of the student's activities. Eco-school teachers also observe the ecosystem on a daily basis in their nature-based school so that they could see the changes in the environment first hand. Thus, ecosystem effect is put as the first priority.

ITB university students who put priority on resource consumption and energy drain are mainly coming from physics engineering who are very much into oil and gas related issues. They are very well aware of the threats of resource depletion and the impact on energy scarcity. On the other hand, those who are coming from environmental engineering contribute to the priority concern on ozone depletion in relation to global warming potential.

3.3 Mathematical formula for ELP quantification

After all values are collected, the following three steps mathematical formula for ELP quantification can be applied to get the integrated indicator for LCA process. Step (1) has been done and summarized in table 4, step (2) is shown by table 5, and partial example of step (3) is shown in the case study in table 6 and 7.

$$A_j = \sum_k (C_{j,k} \times TQ_k) \tag{1}$$

$$ELF_k = \sum_j (C_{j,k} \times W_j / A_j) \tag{2}$$

$$ELP_i = \sum_k (ELF_k \times Q_{i,k}) \tag{3}$$

ELP_i: Integrated Indicator
Aj: Annual load in j impact category
$C_{j,k}$: Weight coefficient for k item in j impact category
TQ_k: Annual consumption or emission for k item
ELF_k: Integrated coefficient for k item
W_j: Weight coefficient (category importance) from questionnaire in j impact category
$Q_{i,k}$: Total consumption or emission for k item in I Process

Suffix i: Process or product
Suffix j: Impact category
Suffix k: Item in impact category

3.4 Environmental Load Factor

Environmental Load Factor (ELF) is the emission factor that is required for the final ELP calculation. It is the sum of weighting coefficient multiplied with category importance, divided by aggregated annual load of each category. ELF of each available data for item that is related to waste disposal is summarized in table 5.

Table 5: ELF calculation

impact category	item	ELF (C*W/A*10^16)		
		ITB Students	Eco-school Teachers	Text mining
energy drain	oil	8.14E+02	6.71E+02	1.49E+03
	natural gas	8.96E+01	7.38E+01	1.64E+02
	coal	6.27E+02	5.17E+02	1.15E+03
global warming	CO_2	1.85E+05	2.01E+05	2.50E+05
	CH_4	3.06E+05	3.34E+05	4.14E+05
acid precipitate	NO_x	1.94E+05	2.32E+05	4.86E+04
	SO_2	2.77E+05	3.31E+05	6.94E+04
resource consumption	nickel (Ni)	2.53E+06	2.27E+06	6.73E+05
Acid precipitation	SO_2	3.53E+05	3.55E+05	4.97E+05
	NO_x	2.52E+05	2.54E+05	3.55E+05
air pollution	CO	2.31E+03	2.32E+03	3.25E+03
	PM_{10}	2.75E+05	2.76E+05	3.87E+05
Waste disposal	Solid waste	1.66E+04	1.81E+04	4.30E+04

4 CASE STUDY OF ELP APPLICATION IN JAKARTA INTEGRATED MSWM

4.1 Scenarios and system boundaries

The final disposal site for Jakarta MSW is *Bantar Gebang* sanitary landfill located in Bekasi district initially constructed in 1988 covering area of 110 hectares. Since December 2008 a Public Private Partnership (PPP) runs the management of this landfill. The private sectors, *PT Godang Tua Jaya* and *PT Navigate Organic Energy Indonesia* agreed to manage and improve the site for 15 years. As per 2011, the improved facilities are composting plant and energy recovery from captured landfill gas (LFG). From site observation, it was found out that the composting facility processes 300 TPD organic wastes from the food market to produce 60 TPD compost. Energy recovered from LFG is less than 2 MW using a GE Jenbacher gas engine.

Landfill gas capture is a temporary solution for MSW management. When waste amount increases and waste composition changes due to population growth and industrialization, higher technologies such as anaerobic digestion (AD), Refuse Derived Fuel (RDF) or incineration should be considered. However, for the purpose of showing the application of the developed integrated LCA in simplified manner in this study, municipal waste incineration and landfilling are taken as scenarios for case study. The boundaries are the incineration and the landfilling process only.

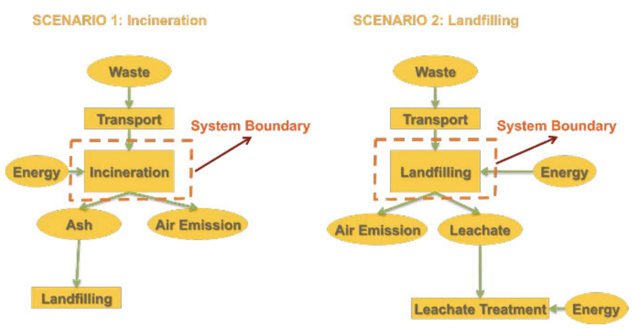

Fig.4 Scenarios and system boundaries

4.2 ELP result comparison of news text mining, ITB university student, and Eco-School Teachers in Indonesia for incineration

The ELF summarized in table 5 has to be integrated with each waste composition inventory data from incineration and from landfilling and then multiplied by the amount of waste input or energy required to come up with the final ELP value. There is currently no incineration plant for municipal waste in Indonesia and inventory data for landfill is not available yet, thus the Japanese one is used for both scenarios. Japanese inventory data was taken from LCA software database developed by JEMAI (Japan Environmental Management Association For Industry).

Incineration

Incineration in developing countries like India with higher organic waste percentage has shown negative performance due to low calorific value and high moisture content. But in the case of China, auxiliary fuels such as coal is added to the incineration plant to increase calorific value. In this constructed scenario, it is assumed that the total of 6000 TPD mixed waste of Jakarta with 55.37% organic waste is incinerated. Table 6 and figure 5 and 6 show the ELP calculation results for this incineration process using three different ELF from ITB students (ELP1), Eco-school teachers (ELP2), and Indonesia news text mining (ELP3).

Table 6: ELP for Incineration

		Incineration		ELP (ELF x Input x Inventory Data)		
impact category	item	Input	Inventory Data	ELP1	ELP2	ELP3
energy drain	oil	6.00E+09	3.89E-04	1.90E+09	1.57E+09	3.48E+09
	natural gas		6.80E-04	3.65E+08	3.01E+08	6.68E+08
	coal		1.46E-03	5.50E+09	4.53E+09	1.01E+10
global warming	CO_2		2.70E+00	3.00E+15	3.27E+15	4.05E+15
	CH_4		1.54E-07	2.82E+08	3.08E+08	3.82E+08
acid precipitate	NO_x		2.94E-06	3.42E+09	4.09E+09	8.58E+08
	SO_2		3.30E-07	5.48E+08	6.55E+08	1.37E+08
resource consumption	nickel (Ni)		2.50E-10	3.79E+06	3.41E+06	1.01E+06
Acid precipitation	SO_2		3.30E-07	6.99E+08	7.03E+08	9.83E+08
	NO_x		8.52E-07	1.29E+09	1.30E+09	1.81E+09
air pollution	CO		1.36E-06	1.89E+07	1.90E+07	2.66E+07
	PM_{10}		6.25E-08	1.03E+08	1.04E+08	1.45E+08
Waste disposal	Solid waste		3.10E-02	3.09E+12	3.36E+12	7.99E+12
			ELP	3.00E+15	3.27E+15	4.06E+15

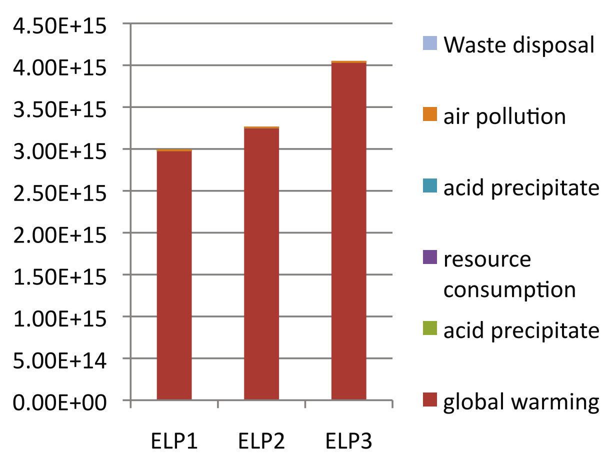

Fig.5 ELP for Incineration

ELP1 from ITB students shows the lowest total value while ELP3 from Indonesian News has the highest total value. This is mainly because the global warming item, CO_2, is highest emitted from the incineration plant and even emphasized by the Indonesian news as the third priority. Global warming was not anywhere in the top three priority according to ITB students thus it appears with the lowest (ELP1).

The importance and emission given to global warming category are significantly higher than the rest of the categories that caused the other items cannot be seen in the same scale in figure 5. For the purpose of revealing the results of other categories, global warming category is eliminated from Figure 6. ELP results for acid precipitation are higher for the ITB students and Eco-school teachers, while the media results in higher energy drain. Interestingly, when global warming category is eliminated, ELP3 is lower than ELP2. This shows further significance of global warming expressed by the media.

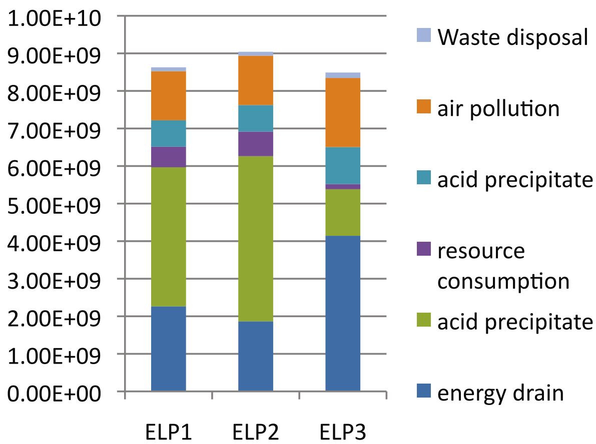

Fig. 6 ELP for Incineration without global warming category

Landfilling

Landfilling in Jakarta is still the main practice of waste management. Compacting and landfill zones retention are required to allow the aerobic processes to take place so that the lifetime of the landfill can be lengthen.

In this scenario, all 6000 TPD mixed waste of Jakarta is to be landfilled. Table 7 and figure 7 show the ELP results for incineration process using three different ELF from ITB students (ELP1), Eco-school teachers (ELP2), and Indonesian news text mining (ELP3).

Table 7: ELP for Landfill

impact category	item	Landfill: Input	Landfill: Inventory Data	ELP (ELF x Input x Inventory Data): ELP1	ELP2	ELP3
energy drain	oil	6.00E+09	8.26E-04	4.03E+09	3.32E+09	7.38E+09
	natural gas		1.75E-04	9.40E+07	7.75E+07	1.72E+08
	coal		1.66E-04	6.24E+08	5.14E+08	1.14E+09
global warming	CO_2		3.44E-03	3.81E+12	4.16E+12	5.16E+12
	CH_4		8.87E-08	1.63E+08	1.78E+08	2.20E+08
acid precipitate	NO_x		1.26E-06	1.46E+09	1.75E+09	3.67E+08
	SO_2		2.91E-07	4.83E+08	5.78E+08	1.21E+08
resource consumption	nickel (Ni)			0.00E+00	0.00E+00	0.00E+00
Acid precipitation	SO_2		2.91E-07	6.17E+08	6.20E+08	8.67E+08
	NO_x		1.26E-06	1.91E+09	1.92E+09	2.68E+09
air pollution	CO			0.00E+00	0.00E+00	0.00E+00
	PM_{10}		1.08E-07	1.78E+08	1.79E+08	2.51E+08
Waste disposal	Solid waste		1.00E+00	9.98E+13	1.08E+14	2.58E+14
			ELP	1.04E+14	1.13E+14	2.63E+14

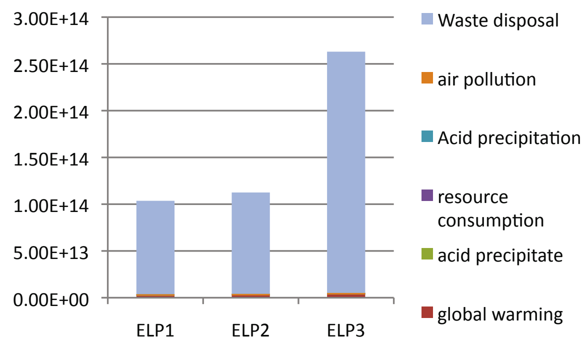

Fig.7 ELP for Landfill

The result of total ELP shows significance of waste disposal category. The Indonesian media has significantly higher result especially for waste disposal, followed by Eco-school teachers and ITB students. Similar rankings were shown when the rest of the categories are revealed for global warming and energy drain.

4.3 ELP result comparison of Incineration and Landfilling

The total average ELP for each scenario are shown by figure 8. It is clear that Landfilling has significantly lower ELP than Incineration. CO2, CH4 gas emissions, and energy consumption are the main factors that contribute to this results, emphasized by the Indonesian people's concern on energy drain and global warming.

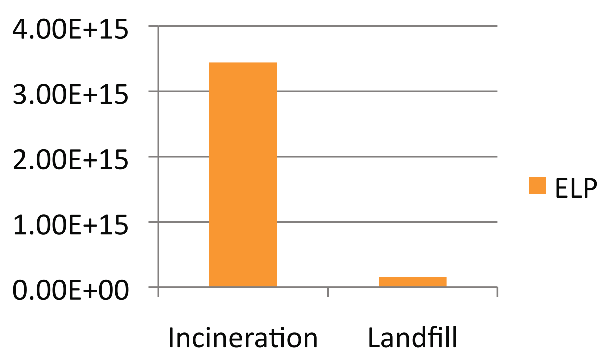

Fig 8. Total Average ELP result comparison

5 CONCLUSION

In developed countries where land is extremely scarce and air pollution control is strict, landfilling is not an option, but in developing countries like Indonesia, the consumption on energy is one of the biggest considerations on decision making because it is directly related to operation and maintenance cost. Although waste disposal is one of the most published topic in the media, people are more concern on global warming because of the daily weather fluctuation, flooding, and other environmental inconveniences influenced by global warming especially that Indonesia is an archipelago country with many smaller islands. The total ELP for MSWM in Indonesia shows that landfill has lower point than incineration. This trend, however, is expected to alter when waste composition and quantity changes with economic growth and industrialization.

6 DISCUSSION

Both primary and secondary data were challenging to collect for this study since waste management related inventory data for Indonesia were not ready yet. On the other hand, national emission and consumption often had to be recalculated and assumptions made by previous scholars had to be used due to the absence of data. For example emission data on green house gases were presented sectoral while emission data on waste were provided provincial. Some pollutant detectors such as NOx were only available in several cities, thus estimation figures had to be used.

Using the Japanese inventory data might not be the best solution due to differences in waste characteristics and climate variations, but the methodologies of AHP and text mining to formulate category importance which were used as an approach to produce Integrated LCA in this study is one step closer to get better understanding to find out MSWM priorities for developing countries.

It is hoped that comprehensive statistics data could be prepared nationally for better emission and consumption inventory data of MSW.

Further possible researches to follow up this study are the application of ELP approach to more complicated MSWM scenarios such as Mechanical Biological Treatment (MBT) that includes recyclables recovery, anaerobic digestion, and refuse derived fuel (RDF), to find more holistic results for Integrated MSWM.

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Guidelines for Siting Community-based Solid Waste Facilities in Beijing, China

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Abstract

Beijing, the capital of China, has a land area of approximately 1368.32km^2 with an urban population of about 19.61 million in 2010. Over the past three decades, MSW generation in Beijing City has increased tremendously from 1.04 million tons in 1978 to 4.134 million tons in 2006. (BMAC2010)The average generation rate of MSW in 2006 was 0.85kg/capita/day. Currently, more than 80% of MSW generated in Beijing is land filled, 10%is incinerated and 10% is composted. (WANG, 2010) If these trends continue the amount of waste will surpass the capacity of transfer stations, treatment plants and final disposal sites. In addition due to environmental and health problems occurring in the vicinity of current waste treatment and final disposal plants, residents show strong rejection to the construction of such facilities. Solid waste management facilities represent long-term commitments of public resources that can dramatically alter the quality of life in a community. In order to address this urgent challenges this research proposes the introduction of an integral waste management system that includes not only technological and logistics aspects associated with waste collection, treatment and disposal but will also incorporate the local community and stakeholder participation, in the process of decision-making. Using integrated evaluation and assessment methodology including Life Cycle Assessment and Life Cycle Costs, as well as social assessment tools, we will introduce guidelines that will help design not only environmentally friendly and economically affordable but also socially acceptable waste management practice.

Keywords:
Beijing, Waste management, LCA, LCI, LCC, community-based

1 INTRODUCTION

Municipal solid waste (MSW) management in China has emerged as a serious issue, which poses a challenge with regard to environmental quality and sustainable development (Zhao et al., 2009) In Beijing the daily generated MSW now exceeds 16,000t, but the daily design capacity of the existing waste treatment and disposal facilities, mainly landfills, is only 10,350t. Therefore, many of the facilities are overloaded, resulting in the expected closure of current landfill sites in the next few years. (Yan et al., 2010) In this situation new facilities construction are serious required. However, because the issue of NIMBY (not in my back yard syndrome), public show strong rejection to the construction of such fertilities, especial for incineration plant. In order to address this challenge, this paper tries to modeling an integrated waste management system which contains recycle actives with public and community participation and the participation during decision-making.

2. OVERVIEW OF THE CURRENT SITUATION

2.1 WSM generation and treatment

The waste management in the city, wich consists of eight urban districts and ten suburb districts is full of complecities. In 2006, sanitary landfill accounted for 80% of MSW disposal. Incineration and composting comprised 10% and 10%. Fig.1 shows the main waste treatment fertilities location. There are 13 landfill sites and four incineration/composting plants in Beijing city, with a total designed capacity of 10350 ton/d. But the waste generation rate in Beijin city is 11326

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ton/d. Obviously almost all the landfill sites and treatment plants are over loaded.

(source: B.B.Xi, et al., 2009)

Fig.1

Fig.2 shows from 2000 to 2009 waste generation and waste treatment situation. With the rapid economic development and urbanization, the municipal solid waste has rapidly increased. Comparing with2000, the waste generation amount was doubled in 2009. Safe treatment amount means the amount of waste which was transported to sanitary landfill plants. At the same time the amount which couldn't be transported to sanitray landfills was open dumping. Now, in Beijing there have become a rubbish dumps ring located in the seventh r ing's of the city.

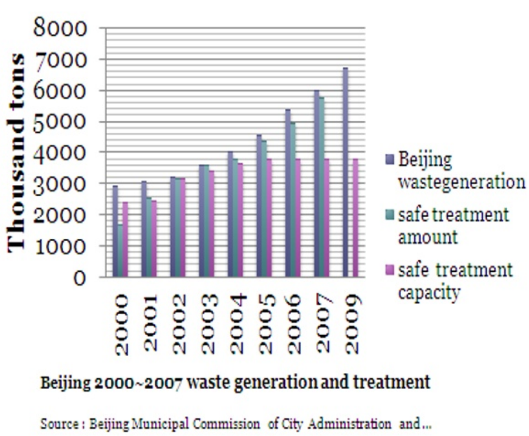

Fig.2

Due to the life style was changed so much, the quality of MSW composation also change so much. The typical characteristics of MSW in Beijing City include biodegradable organic composition in the urban waste reaches more than 60%, waste of paper and other high caloric value about 30%; organic composition in the rural waste is around 35%;(WANG, 2010) Although the combustible waste accounted for 91.51% in 2006, the low calorific value and high moisture content of MSW both indicated that it could not be incinerated effectively, without the addition of fuel or meticulous.

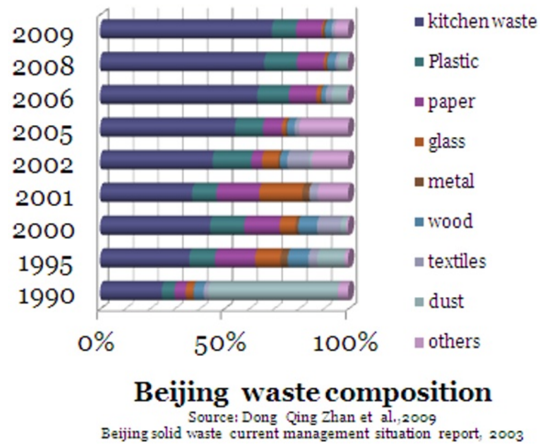

Fig.3

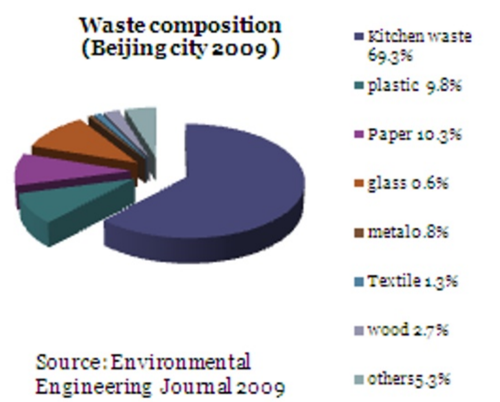

Fig. 4

2.2 MSW transportation and disposal

All the treatment plants in Beijing city are a distance from where the waste is generated. There are 6 transger station with the total capacity of 5500 ton/d. The purpose of these satation is not only to transfer the waste but also to pretreat and separate the waste to ensure efficient transportation for recycling. But there are just 2 separate station and have a limited capacity of 980 ton/d. The general MSW material flow in Beijing is shown in fig.5

Fig.5

In Beijing the main recycle activeities were done by cleaners and collectors. The waste treatment in Beijing is landfill as a dominant means over 85% . It is hard for single waste treatment technology to realize categorized waste treatment, which has influences on effects of waste separate collection and city resident's activity in waste separte collection.(WANG, 2010) Here, increasing community participation in MSW management also show a very important role. In the privious research like in Yala municipality, Thailand, a package of new practieces was introuduced. One of pracite was ("Garbage for eggs"). That practice was tend to encourage people to do recyle. Like this kind of actives also should be considered in beijing city.

3. OBJECTIVE AND METHODOLOGY

While, now we can catch the main trouble in Beijing MSW management that continuously increased generation, insufficient waste treatment capacity and unreasonable waste treatment structures, in addition insufficient participation in community and strong rejection on waste treatment fertilities construction. Therefore, my research will focus on three parts. One is using the life cycle assessment tools for development of integrated waste management in Beijing, another is try to incorporate the local community and stakeholders participation during recycle activities part and decision making part. Furthermore, try to formulate part of guideline for MSW management in Beijing. Do support on the decision making section for the local government and stakeholders.

Life Cycle Assessment (LCA) is a methodology for examining environmental impacts associated with a production, process or service "from cradle to grave"- from production of the raw materials to ultimate disposal of wastes. (Ozeler D et al., 2005) In this research around 7 scenarios will be modeled which will basic on the current government short-time, long-time planning and target. Then use the LCA tools to do assessment on environmental impacts and cost-benefit.

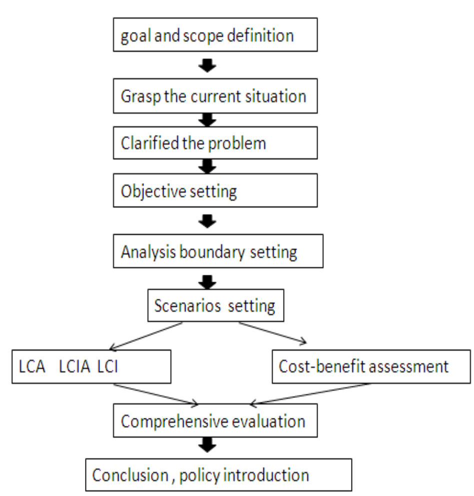

Fig.6 Research flow

4. FUTURE STUDY

In this research LCA –IWM (Life Cycle Assessment- Integrated Waste Management) software will be used for assessment. My future study will contain two parts; one is current policy study and previous research study. The most important key will be data collection, including second hand data and data from government. After that will be scenarios modeling and software practice.

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The contribution of Eco design approach on the urban environmental sustainability: Management of Mixed Solid Waste and Leachate contaminations, the case of Kahrizak leachate treatment Plant in Tehran

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Abstract
The problem of leachate treatment is something critical for the landfill of Tehran (Kahrizak). Natural Leachate treatment is a way to help the environment rehabilitate itself, and lessen the threats of pollution for alive habitats. It produces an appropriate situation for existing plants and animals to keep on living and also it may help other existences to find their new habitat in the site of rehabilitated landfill. One of the biggest problems in Tehran is lack of water. Therefore it can help using recycled water for irrigation and keep microclimate of the region alive. Designing a good region to recycle the leachate naturally and absorb the contaminants of soil and water in the originate site, is a huge responsibility for environmental designers.

Keywords:
ecodesign, solid waste leachate, sustainability

1 INTRODUCTION

Due to the growing population of the cities, especially big ones, the problems of wastes and landfill leachate purification is growing too. The leachate is a liquid that is produced by water penetration to the waste. Leachate is a poisonous and dangerous liquid and should be treated as soon as possible in every landfill. The problem of leachate treatment is something critical for the landfill of Tehran (Kahrizak). As it is known, Kahrizak is the biggest landfill of middle-east. So it is obvious that a huge amount of leachate be produced every day. Regarding the growing population of Tehran, the amount of produced waste is increasing dramatically every day. The waste water from kitchens and toilets is one part of leachate. In a day a human being produces an estimated 1150 grams of urine and 200 grams of faeces [1]. The municipal waste is the other producers of leachate. According to statistics, 7000 tones of waste per day, is transferred to Kahrizak landfill. This amount consists of every possible kind of waste, such as municipal, clinical, industrial and…. Since 70% percent of the waste is leachate, Therefore 6000 tones of leachate are produced in Kahrizak everyday [2]. Since it is very poisonous and the limit of COD and BOD is very high in leachate of Kahrizak, this liquid is not industrial waste water or municipal one. Treatment of such huge amount of water needs time, energy and a considerable budget. Treating such leachates needs using biological and chemical methods together.

2 METHODS

There are numerous methods used to treat the leachate all over the world, but the method of treatment depends on the components of the leachate, its age, types of wastes which produced leachate, the temperature and humidity of the place and …

Almost all of the methods of leachate purification contain chemical treatments. But since the location of treatment is related to the environment, the side effects of such treatments could damage it. Chemical methods are very rapid and functional, but they will damage the animal habitats, plant territories and other existences, Especially in Landfill of Kahrizak, where the recycled leachate is released in the nature. The containing chemical of the water will be absorbed by plants and animals' body and it may enter the food chain of citizens in Tehran and even other cities. For

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these reasons other solutions for leachate treatment should be verified.

The polluted sites that are related closely to the nature and may damage the lives of citizens should be purified naturally in order to save the environment and reduce the risk of threatening citizens' lives. Kahrizak is the exact sample of such sites where faces different kinds of pollution and needs emerge act. The direction of the main wind in Tehran helps the pollutants go through the city and residential areas. But the process used to treat its leachate is to use chemicals. It is not a natural purification yet. The aim of this paper is to introduce a new method of natural leachate treatment and some suggestions to implement it with the existing material of the site (soil, native plants of the region, building wastes…)

3 RESULTS

One of the best environmental methods of leachate treatment that is used currently in Japan is called Fukuoka! In the Fukuoka Method, the leachate collection discharge pipes are important facility for supplying air, removing leachate and maintaining an aerobic environment. The leachate

Discharge pipes must be protected from loads that occur during landfill operation and consideration must be taken concerning the type of waste disposed of to prevent loss or reduction in function during the landfill operation stage and care must be taken to enable maintaining the leachate collection discharge pipe discharge opening open to the atmosphere. This method has 6 phases and the first one is to recycle the leachate through the site and filtering the big components of it. After it the next step is to give oxygen to leachate by gathering it in a pond and move it regularly. After giving oxygen to the leachate it should be passed through sandy land in order to purify it using especial bacteria and plants. Passing this phase leachate should be ceased in a pond, to be filtered again. Until this phase the leachate is treated partially, but the nitrogen and phosphorous of it, are in high level. Plants like bamboos and wetland plants are the one which can absorb these components and make the leachate treated completely. Therefor the solution is to build an artificial wetland in order to let the pollutants in the leachate be absorbed naturally. Although it takes time to purify the leachate without using chemicals, the side effects of such method if less dangerous for the nature. The last phase is to have a sample pond with alive existences such as wetland plants and animals(fishes,…) in order to observe whether or not the clearance of recycled water is enough or not [3]. Since these existences are very sensitive to the limit of water pollutants, they will react if it is not suitable for living. That 's a good method to purify the leachate and verify its quality naturally.

During leachate treatment in Kahrizak, ferric chloride is added to the leachate in order to filter the big components of it. As it is mentioned before, these big components could be filtered by ceasing it in a pond. The stages of such treatment need a suitable design in the area to cycle and purify the leachate. Designing a site should be done regarding the existing materials in the site. As Kahrizak is situated in a desert area, there are no sands in the region to pass the leachate through it. The suggested solution is to use building materials instead of sand. By this method these kinds of waste could be reused and the leachate will also be treated. And for the phases of giving oxygen to the leachate and having artificial wetland, could be implemented using the materials of the same site. To move leachate, the site needs to have a high hill. This hill can be built artificially using solid wastes. They can be gathered as a hill and isolated by covers, in order to have biogas and lead leachate to the gathering pond.

Using the materials of the site, to perform a process is essential in eco-design. By such action, the costs of transferring materials, time and energy consumption are being reduced. Besides, the wastes and the polluted soil can be treated in the same site.

4 CONCLUSION

In order to damage the environment less than ever, it is needed to know the ways through which human beings can behave it. One thing that human being can do is not to damage some parts of the environment to heal other parts of it up. So to purify the polluted soil and water, which the reason is also the human being, people should find natural solutions. Natural Leachate treatment is a way to help the environment rehabilitate itself, and lessen the threats of pollution for alive habitats. It produces an appropriate situation for existing plants and animals to keep on living and also it may help other existences to find their new habitat in the site of rehabilitated landfill. One of the biggest problems in Tehran is lack of water.

Therefore it can help using recycled water for irrigation and keep microclimate of the region alive. Designing a good region to recycle the leachate naturally and absorb the contaminants of soil and water in the originate site, is a huge responsibility for environmental designers

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Energy Consuming Comparison of Wastewater Treatment Technologies through Life Cycle Assessment
A Case Study of Intelligent Controlled Sequencing Batch Biofilm

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Abstract
Energy consumption and energy efficiency issue of wastewater treat plants in China has been attracted by researchers under the power shortage context. In this article, LCA (Life Cycle Assessment) is applied to identify and compare the energy consumption of each stage of different technologies in municipal wastewater treatment from the view of whole process. Intelligent Controlled Sequencing Batch Biofilm Reactor (ICSBBR) is taken as an example and the energy consumption from its raw and processed materials exploitation, construction, treatment and rebuilding and removing is identified and quantified, which is also compared with traditional treatment process of wastewater in China. This study shows that application of the efficiency oriented aeration devices and well-designed intelligent control system is essential paths to improve the energy consumption of ICSBBR during its whole life cycle. Moreover, the wastewater treatment effects could be improved by this system due to the automatic controlling of dissolved oxygen (DO). And LCA is an important foundation of improving products quality and a main measure of sales promotion for manufacturers in recent years.

Keywords:
wastewater treatment, energy consumption, ICSBBR, LCA

1 INTRODUCTION

In the summer of 2010, it is reported that the power shortage of China is about 15% of whole electricity production, and this trend is believed to be more serious in the coming future due to coal supplement shortage and global price growth. In 1996, the centralized processing rate of municipal wastewater in China was only 11.4%, and will reach to 40% in 2010, and over 1,000municipal wastewater treatment plans (MWWTP) will be constructed in future and most of them will be small and mid-scale ones[1]. For a general wastewater treatment plan, energy, usually is electricity, takes 60%-70% of total maintenance cost (Tan, 2011).

From the view of life cycle, from construction stage to the final demolishment stage, the energy consumption is a key factor which could influence the resource, environment, and sometimes it also could lead social impacts. However, the traditional method has been unable to reflect the whole process of energy utilization due to its limited boundary. The traditional method usually is based on the economic and technology aspects, it could provide the view from production stage but not big one.

Life Cycle Analysis (LCA) is a new system of environmental impact assessment techniques and methods, which uses the technology facilities as the main line to collect, identify, quantify, analyze and assess resources consumption and the data and information of environmental impact of products throughout the life cycle, provides an environmental assessment tool of comprehensive, accuracy information.

This paper try to identifies and analyzes quantificational the whole energy consumption process from designation, exploitation and manufacturing of raw material, construction, handling, running, reconstruction and expansion of wastewater plant, abandoning and back out of Life Cycle Assessment (LCA). Meanwhile this study tries to compares this technique to traditional activated sludge process (TASP), which aims to bring out new technical economy and environmental assessment method.

2 OBJECTIVE AND SCOPE

2.1 Intelligent Controlled Sequencing Batch Biofilm Reactor

ICSBBR is a more advanced technology which could reach higher energy utilization rate by the information system. System will adjust aeration time based on the data of oxygen utilization rate collected by sensors

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automatically. Well-designed software will guarantee the dissolved oxygen (DO) maintains in the required level. Therefore, treatment and energy consumption rate could be improved respectively.

According to the previous study, a stable performance of ICSBBR under hydraulic retention time (HRT) of 7 hours, at which point the removal efficiencies of NH3-N, TP and COD reached 99%, 100% and 96%, respectively (Ding 2011). When compared with conventional SBBRs, the SBBR controlled by the ICS reduced the HRT and total aeration time by 56% and 50% (Ding 2010), respectively, and achieved better performance at removing the COD.

When carbon nitrogen (C/N) ratio is 12.5, an experiment scale ICSBBR could reach the best performance and COD, TN, NH3-N removal efficiency is 94.8%, 87.4% and 90.1% respectively (Ding, 2011).

In this study, Sheng Jian wastewater treatment plant is taken as the study object. The capacity of Sheng Jian wastewater treatment plant is 10,000m3/d, a sequencing batch biofilm reactor with intelligent control system (ICSBBR) is adopted. The logical treatment process of this plant is as shown in Figure 1. Main technology parameters of ICSBBR as following: total hydraulic retention time (HRT) is 7 hours. The characteristics of designed raw domestic sewage were (average value): pH (5.9-7.5), COD (200-250mg/L), BOD5 (100-150 mg/L), suspended solids SS (100-150mg/L), NH_3-N (25-35 mg/L), and TP (4-6 mg/L). The reactor was seeded with activated sludge collected from Qing He Municipal Wastewater Treatment Plant, Beijing, China, which had a mixed liquor suspended solids (MLSS) and SS content of 1,638 mg/L and 3,562 mg/L, respectively.

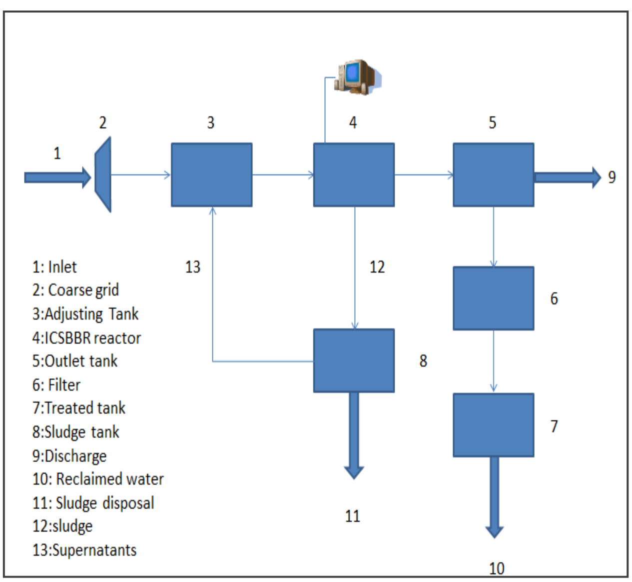

Fig. 1: ICSBBR process flow

2.2. The unit of LCA appraised function

According to the general urban planning, most of the city's wastewater treatment plants need to be rebuilt and updated to some extent with the increase of wastewater quantity and the increase of the discharge standard. For Sheng Jian wastewater treatment plant, the energy consumption problem should be considered in a 20 years' runtime.

It is well known that the consumptions and functions of a wastewater treatment plant's facilities have scale effects. The capacity of Sheng Jian wastewater treatment plant is 10,000m^3/d, which is a typical wastewater treatment plant for small or middle town. This article uses such scale as the function unit for LCA analysis to compute the input and output of the wastewater treatment system. The traditional activated sludge process (TASP), which is used as a contrast, also applies this scale as the function unit, in order to make them comparable.

In this paper, two indicators have been analyzed and compared based on the energy consumption of the wastewater treatment under different technology: (1) The energy consuming of wastewater treatment is converted into electric energy (kWh) or heat energy (kJ), and the consumed energy for treating per unit polluted water capacity(m^3) or energy consumption ratio; (2) The whole energy consuming every year of different wastewater treatment technology has been calculated in terms of the same scale and similar water quality condition.

3 THE DETAILED ANALYSIS LIST OF ENERGY CONSUMPTION

3.1 The input-output of wastewater treatment facility

During the life cycle of wastewater treatment facility, the energy, resource and the processing object input by environment and the contamination output to environment and their influence, are shown in Figure.2

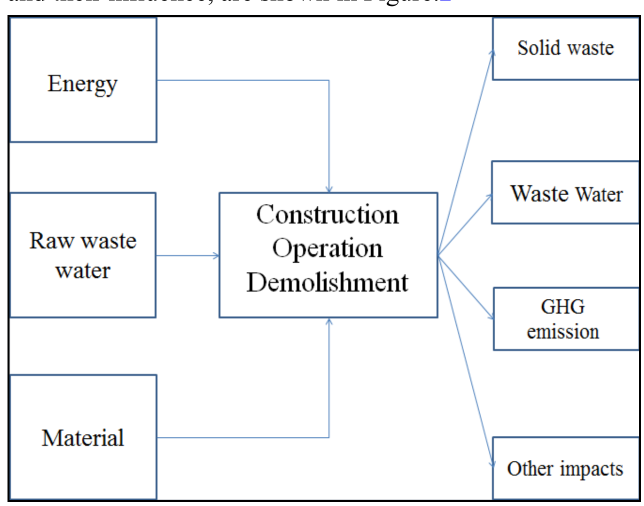

Fig. 2 The input output flow of ICSBBR wastewater treatment

The resources input by the environment include the various raw materials as well as natural resources for material production, such as water, air, natural ore etc; raw wastewater is the research object. The energy sources include coal, petroleum and the electric energy etc., which are converted into Joule conformably. Materials and energy may be used in the whole life cycle is shown in Table 1.

Table 1 Materials and energy consumption in MWWTP

Stage	Raw material	Energy
Construction	Steel, iron, cement, sand, water, PVC, copper, clay, bitumen, epoxide resin etc.	Transportation, construct, mechanical Dissipations
Operation	Medicament etc.	Power consumption, fuel, equipment dissipation
Demolishment	Topsoil, filling material etc.	mechanical dissipations, fuel,etc.

3.2 The energy consumption in the construction phase

The energy consumption during the construction phase includes raw material production, construction and transportation. The total energy of some kind of material is consisted of its natural calorific value and the energy consumption for production. Unified energy unit is adopted to quantify the different energy.

Table 2 material and energy of construction stage

	Intelligent Controlled SBBR 10^6 kWh	Traditional Activated Sludge Process(TASP) 10^6 kWh
Total energy of raw material	1.63	1.74
Total energy of communications and transportation	0.16	0.10
Total energy consumption for construction	0.323	0.51
Total energy consumption	2.113	2.35

According to quantities analysis and concerned standards, the building materials quantity of ICSBBR can be calculated and the production energy consumption can also be quantified based on its material quantity and energy consumption for production. The construction energy consumption can be counted according to the construction area, and the construction energy consumption per unit area; the energy consumption for transportation building material can be counted according to the consumption amount of building material, transportation mileage, and energy consumption for transportation per unit.

3.3 Energy consumption in operation stage

The material consumption during running phase of treatment facilities is much low. The medicament consumption is the main portion. The energy consumption in this phase includes the power for wastewater treatment, the fuel and equipment loss for transportation, etc. Among them, the power consumption for wastewater treatment always occupy the total energy consumption more than 85%; in which, the electricity consumption of aeration systems is over 88.5% (Tan 2011). ICSBBR could reduce 40% electricity consumption rather than the traditional SBBR system due to its energy reduction orientation aeration system (Jin, 2011).

Table 3: The list of main electrical equipment and energy consumption of process

Stage or process	Equipment	Power	Actual power consumption
Primary Treatment			
First Lifting	Lifting pump	1.5 kW	1.5 kW
Grid	Grid machine	1.5 kW	1.5 kW
Second Lifting	Lifting pump	0.75 kW	0.75 kW
Secondary Treatment			
Stir	Stir pump	2.2 kW *4	8.8 kW
Aeration	Ventilators	4 kW * 2	8 kW
Advanced treatment			
Inverse flow	Pump	5 kW * 2	10 kW
Filter	Filter Pump	2.2 kW * 2	4.4 kW
Sludge treatment			
Sludge pumping	Sludge Pump	0.75 kW	0.75 kW
Sludge transportation	Belt dewatering machine	1.1 kW	1.1 kW
Total			36.8 kW

It can be concluded from the Table 4, both of the construction consumption and energy consumption of operation stage are lower than the TASP because of the intrinsic property of ICSBBR. As far as energy consumption, energy utilization and environmental impacts caused by the energy produced process; the environmentalism of ICSBBR is superior clearly to the TASP.

3.4 Energy consumption in demolishment stage

The energy consumption in the demolishment phase is related with the machine equipment for demolishment mostly, normally, which includes two parts: demolishment and transportation. The energy consumption of demolishment is 90% of the energy consumption of construction according to concerned documents (Yang, 2000). The energy consumption of transportation for soil and filling material is calculated by construction area, the average density of soil and filling material (2.0 kg/m^3) and average transportation mileage (20 km).

3.5 Final result

The total energy consumption and material consumption is shown in table 4.

Table 4: total energy consumption and material consumption of ICSBBR and TASP from LCA (10^6 kWh)

Stage		ICSBBR	TASP
Construction	Material consumption	2.31	2.25
	Energy consumption	2.113	2.35
Operation	Material consumption	2.34	4.09
	Energy consumption	5.56	17.11
Demolishment	Material consumption	0.01	0.01
	Energy consumption	0.441	0.46
Total energy consumption		12.653	19.92

It can be concluded from the Table 4, both of the construction consumption and energy consumption of operation stage are lower than the TASP because of the intrinsic property of ICSBBR. As far as energy consumption, energy utilization and environmental impacts caused by the energy produced process; the environmentalism of ICSBBR is superior clearly to the TASP.

4. CONCLUSION

During the life cycle of wastewater treatment plants, energy consumption is a key factor of cost. To reduce or utilize energy efficiently is very important, which could also reduce other environmental impacts. Based on ideas of LCA, from the very beginning of construction stage to the final demolishment stage, several methods are put forward to improve energy efficiency. This paper, applied the thought of LCA, recognizes and quantizes the ICSBBR in Sheng Jian wastewater treatment plant in Yun Nan province, China, from the stage of design, exploitation and machining of raw material to wastewater plant construction, running, reconstruction or extension, and demolishment, which had been compared with the TASP. The results show, the energy consumption of ICSBBR during each stage is lower than ordinary means of active sludge; and with intelligent mode is applied to the operation stage, the energy consumption is much lower than the TASP and even than traditional SBBR (Ding 2011). The results show that the ICSBBR, because of its small land occupation, simple maintenance, little foul smell, and environmentalism, is superior clearly to the TASP.

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A Study on the Pollution Control Policy for Industrial Waste Water in Hanoi City, Vietnam

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Abstract

The development industrial production of Hanoi City has lead to water pollution by discharging untreated waste water. The study focused on the relationship between industrial production and emission of COD and Metals. Based on industrial production data and I-O table of targeted industrial sectors, simulation is used to describe that relationship. Simulation result indicates feasible solutions for reduction of pollutants, increase investment in waste water treatment in Hanoi City.

Keywords:

Industrial waste water, environmental policy, economic-environment trade off.

1 INTRODUCTION

In recent years, the economic development of Hanoi City has achieved many successes in which the contribution of industrial sector can not be denied. Industrial production has continued to grow with the expansion of industrial zones and increase the number of firms. However, during this development, environment protection has not been suitably considered in which waste water is the most severe problem. Estimated, every day, industrial sectors of Hanoi discharges about 100,000m^3 of waste water into water environment in which only 30% is treated meaning that there is a huge amount of untreated waste water flows to rivers and canals of Hanoi. To solve the problem, Vietnam in general and Hanoi in particular issued regulations such as technical regulation on industrial waste water, environmental fee for waste water discharge, regulations on sanction in environmental protection, etc. However, such regulations either do not have effective enough or cause conflicts with economic development.

For this reason, the study focused on industrial waste water problem in Hanoi City with regarding relationship between industrial production and emission of pollutants. The major part of the study is simulation of the relationship between industrial production and emission of COD and Metals.

2 METHODOLOGY

The methodology used for the study is based on mathematical model that defines existing environmental and industrial states in Hanoi City. The model will classify and categorize available data and information in major industrial sectors regarding waste water discharge. For that simulation, data and information on economic indicators industrial output, input/output table, investments, production and flow of goods and services into the market system are needed. Data and information on industrial production are divided into 15 industrial sectors, which is typical in term of waste water discharge and contribution to Gross Regional Product (GRP) of Hanoi.

The method can be separated in two major steps: Describe situation of the pollutants discharged to environment from industrial sectors by using simulation of relevant data in LINGO software; and based on analysis of current regulation system and simulation results, propose solutions to improve industrial waste water situation in Hanoi.

Based on pollutant emission situation (basic case), we run the simulation for several scenarios of reducing pollutant emission and reducing treatment cost for treatment technologies.

3 ESTABLISHMENT OF SIMULATION

3.1 Classification of pollution parameters

In order to determine pollution level of water environment and based on industrial waste water status of Hanoi, we classified pollution parameters as follow:

Table 1: Pollutant index

Index	Parameter
1	COD
2	Metals

BOD, COD, TSS and metals are typical pollutants in water environment in Hanoi City. However, to have clearly assessment to industrial waste water, COD and metals should be concentrated in order to avoid overlapping with cases of BOD and TSS which are also emitted by both industry and domestic activities.

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3.2 Classification of industrial sectors

In order to assess situation of industrial production regarding water pollution, all industrial sectors should be classified into some major sectors. This classification is also based on International Standard Industrial Classification.

Table 2: Pollutant index

Index	Industrial sector
1	Food products and beverages
2	Tobacco products
3	Textiles
4	Wearing apparel
5	Leather products
6	Wood and wooden products
7	Paper and paper products
8	Publishing, printing
9	Chemicals and chemical products
10	Rubber and plastic products
11	Non-metallic mineral products
12	Basic metals
13	Fabricated metal products
14	Furniture
15	Other manufacturing

3.3 Classification of treatment types

There are four types of treatment applied in industrial sectors in Hanoi.

Table 3: Pollutant index

Index	Treatment type
1	No treatment
2	Biological treatment
3	Chemical treatment
4	Biological + Chemical treatment

3.4 Formulas establishment

Total emission of pollutant from industry is calculated by:

$$ZZ_i = \sum_{j=1}^{15} EM\_total_{ij}$$

Where:

ZZ_i: Total emission of pollutant *i* in all industries

EM_total_{ij}: Emission of pollutant *i* in industry *j*

$$EM\_total_{ij} = X_i e_{ij}$$

Where:

Xi: Production of industry *i*

eij: An amount of pollutant *i* emitted by one unit of production of industry *j*

Total emission of pollutant by sector after treatment:

$$EM_j = \sum_{i=1}^{15} \sum_{k=1}^{4} EMY_{kij}$$

In which:

EMj: Total emission of pollutant *j* after treatment

EMYkji: Emission of pollutant *j* by treatment type *k* of industry *i*

Emission of pollutants by sector with treatment type

$$EMY_{kij} = X_j e_{ij}^k r_{ij}^k$$

Where:

e^k_{ij} : An amount of pollutant *i* emitted by one unit of production (1 mil. VND) with treatment type *k* for each industry *j*

Xj: The production of industry *j*

r^k_{ij}: Application rate of treatment type *k* to treat pollutant *i* in industry *j*

The amount of treated pollutants

$$EM\_treated_{ij} = EM\_total_{ij} - \sum_{k=1}^{4} EMY_{kij}$$

Where:

$EM\_treated_{ij}$: Amount of pollutant *i* treated in industry *j*

EM_total_{ij}: Emission of pollutant *i* of industry *j*

EMY_{kji}: Emission of pollutant *i* by treatment type *k* of industry *j*

Investment needed for treatment by treatment type, pollutant and sector

$$Invt\_treated_{kij} = EM\_treated_{ij} Cost_{kij}$$

Where:

$Invt\_treated_{kij}$: Investment needed to treat pollutant *i* by treatment type *k* in industry *j*

$Cost_{kij}$: Investment cost to treat pollutant *i* by treatment type *k* in industry *j*

Total cost for treatment of pollutant

$$TRT\_C = \sum_{i=1}^{2} \sum_{j=1}^{15} \sum_{k=1}^{4} Invt\_treated_{kij}$$

Treatment cost by treatment type and pollutant:

$$TRT\_CY_{ki} = \sum_{j=1}^{15} Invt\_treated_{kij}$$

Industrial production in Hanoi:

In order to evaluate situation of industrial production of Hanoi, we should consider to indicating factors such as

Input/Output table, consumption, final demand, import, export, investment, etc. related to industrial sectors.

Final demand of Hanoi industry is calculated as:

$F_i = C_i + Inv_i + Ex_i$

Where:

F_i: Final demand of industry i

C_i: Consumption of industry i

Inv_i: Investment for industry i

Ex_i: Export of industry i

Production of industrial sector:

$$X_i = \sum_{j=1}^{15} A_{ij} X_j + F_i$$

Where:

A_{ij}: IO table

X_i: Production of industry i in Hanoi

F_i: Final demand of industry i

Objective function:

$$GRP = \sum_{i=1}^{15} X_i - \sum_{i=1}^{15} \sum_{j=1}^{15} A_{ij} X_i - \sum_{i=1}^{2} \sum_{j=1}^{15} \sum_{k=1}^{4} Invt\_treated_{kij}$$

$MAX = GRP$

In which:

A_{ij}: IO table of industries of Hanoi

X_i: Production of industry i

Invt_treatedkij: Investment needed for treatment of pollution emission after treatment by treatment type, by pollutant and by sector.

4 RESULTS

4.1 Emission of pollutants

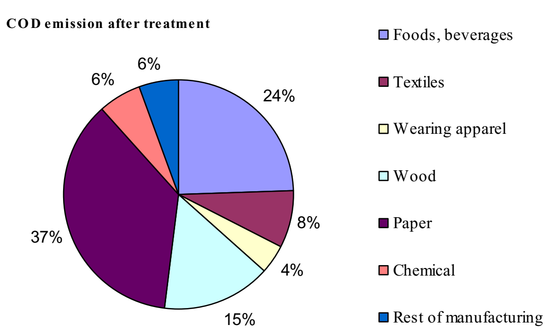

Fig. 1: COD emission after treatment from sectors

The total amount of COD emitted after treatment from all sectors is 141,497 tons/year. In which, paper and paper products are the biggest source with 37% of total amount of COD.

In case of Metals emission after treatment, basic metals production is still the biggest emission. As mentioned before, the firms in this sector discharged a huge amount of metals during their production while they do not invest much in waste water treatment. This result in high metals load in waste water after treatments.

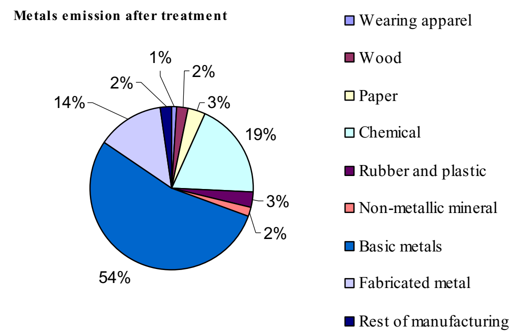

Fig. 2: Metals emission after treatment from sectors

4.2 Scenarios for reduction of pollutants

In order to find the optimal state between treatment cost and pollutant reduction, we ran the model for reduction of COD and Metals with reduction rates of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90%.

The figure below shows the simulation results:

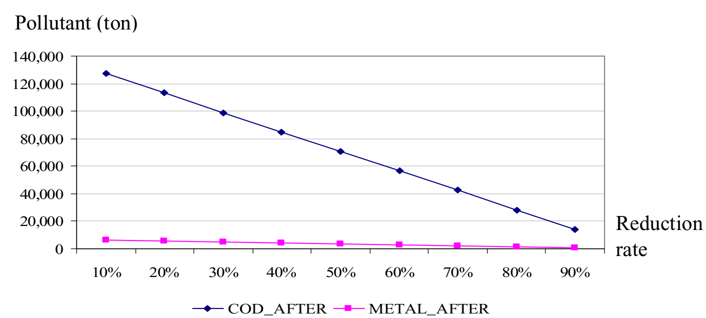

Fig. 3: COD and Metals emission after treatment

Fig. 3 indicates that when we reduce total amount of pollutants, the reduction of COD is much higher than that of Metals. The reason for that trend is because of COD emitted in waste water is the much bigger than that of Metals, the reduced amount of COD is bigger than that of Metals.

As the reduction in pollutants increases, investment for treatment of pollutants also raises meanwhile GRP decreases. So, it is important to figure out the balance among these three factors. In order to express the relationship among GRP, investment for treatment and reduction rates, we put those things into 3D graph as showed in the figure below.

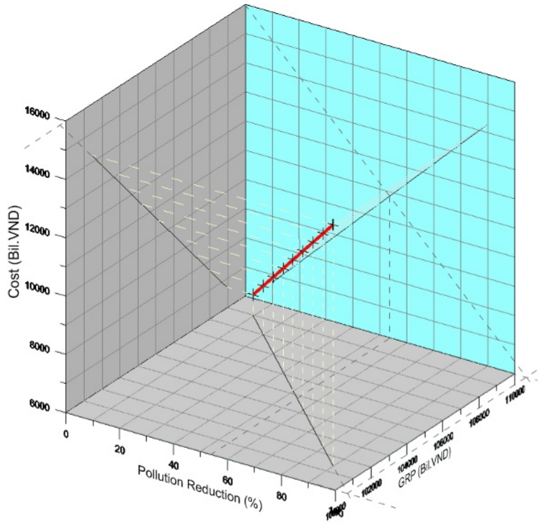

Fig. 4: Optimal investment for treatment

In the model, we assumed that social- economic condition of Hanoi and Vietnam are not changed in simulation cases so that we can easily observe the change of GRP and treatment cost by reduction rates. The figure above indicates that an optimal point can be identified if we could know social marginal benefit ratio of reduction in COD and metals emissions.

Similarly, when we present the relationship among the amount of pollutants after treatment, treatment cost and pollution reduction rates in the 3D graph, we have following figure:

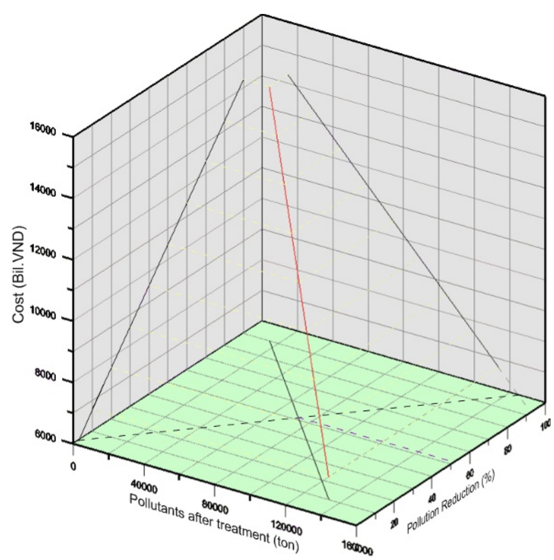

Fig. 5: Relationship among pollutants after treatment, cost and reduction rates

4.3 Scenarios for reduction of pollutants and treatment cost

The optimal point is not a fixed position. It may change as circumstances change. As technology improves over time, the cost of pollution reduction may decrease. The figure below describes the change of optimal point when treatment cost is changed.

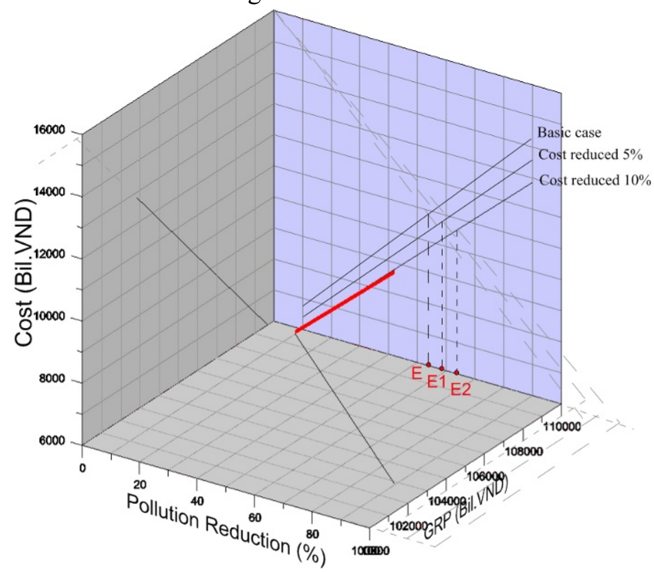

Fig. 6: Optimal point when treatment cost reduced 5% and 10%

We can determine optimal point by intersecting cost curve and pollutants after treatment curve by reduction rates.

Obviously, when treatment cost decreased by 5% and 10%, the optimal point moves from E to E1 and E2 downward respectively. At E1 and E2 in comparison with point E, with lower cost, the amount of pollutants reduced is higher. If the social marginal benefit is increased due to several reasons such as increase in income, the optimal points will move downward, too.

Simulation results indicated that when pollution reduction rate increases, investment needed for three types of treatment also increases, of course. However, combination of biological and chemical treatments tends to be needed more investment than two other types. There are two major reasons for that trend:

- Biological+Chemical treatment type is the most effective type for reduction of pollutants. It means that the more pollutants we want to reduce, the more investment we have to spend for this treatment type;
- Biological+Chemical treatment type has high investment cost leading to investment for this type of treatment much higher than to the other types.

Therefore, in order to reduce pollutants, it is necessary to research on minimization of investment cost for this combined treatment type. However, the results also show the necessity to consider to the two other treatment types: Biological treatment and Chemical treatment as in Hanoi 70% of waste water is not treated. Thus, beside minimization of treatment cost as mentioned before, we need to increase the application rate of the two treatment types.

5 CONCLUSIONS

Simulation cases for different reduction rates of pollutants indicate that investment for treatment in food and beverages, paper products and wood products sectors shall be more effective than that of other sectors in term of COD reduction. In cases of Metals reduction, the most effective investment for treatment shall be achieved in basic metals, chemical and fabricated metals sectors.

Regarding treatment types, as pollution reduction rate increases, investment for more advanced treatment type (treatment type combined of biological treatment and chemical treatment) also raises up. This treatment type has the highest effectiveness in pollutants treatment while it is very costly in comparison with other treatment types. Thus, cost constraint is considered as the biggest difficulty for industrial waste water in Hanoi City.

Therefore, to get acceptable investment for pollutant treatment it is necessary to determine an optimal investment. This study provides a basic information which shows that an optimal investment for waste water treatment can be achieved by knowing social marginal benefit ratio of reduction in waste water emission. At the optimal point, the balance among treatment investment, reduction rate and GRP is obtained. The simulation also indicates that if with lower treatment cost we can achieve more reduced pollution. Treatment cost can be reduced by developing new technology or replacing expensive facilities by the domesticated facilities which are cheaper.

In Hanoi City, the number of firms which are located outside industrial zones in Hanoi is very huge in comparison with the firms inside industrial zones. The outside firms are normally in medium and small scales so they often face to difficulty in investment in waste water treatment plant. Hence, in order to reduce investment cost these firms should be moved into industrial zones which already have centralized waste water treatment plant. In addition, industrial zones should be classified by sectors in order to increase the uniform of waste water characteristics leading to higher efficiency of treatment plant.

The Effect of water rights reallocation system of Yellow River Basin on water productivity, Regional Development and CO_2 emission: a case study of Inner Mongolia, China

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Abstract

The regional development strategy of China was converted from "Coast regional priority development strategy" to "Regional balance development strategy" in 1999. Under this strategy, Northwest China was planned to be the energy production base for local development and supplying power to the Beijing economic bloc. However, the lack of the water resource obstructs the construction of the energy production base. With this background, it is expected to achieve regional development by implementation of "Reallocation of Water Right" policy with reallocation of resources, including electric power. This study reviews existing resource allocation systems, and issue the possibility of reallocation system through calculates the transferable water volume in Inner Mongolia, then analyzes the potential for regional development through the reallocation of water rights. The study also analyzes the impacts of water rights reallocation system on energy use and CO_2 emission.

Keywords:

Water rights, reallocation, regional development, energy use, CO_2 emission, China

1 INTRODUCTION

Since its policies of reform and openness began in 1978, China has continued to enjoy rapid economic growth, although the country's coastal areas have been the main drivers of this growth. Meanwhile, the economic ripple effects reaching inland from coastal areas are minimal, and the regional disparities may become bigger in the future[1]. In recent years, along with rapid population growth and industrial concentration in urban centers, driven by economic growth, power shortages have become a problem particularly in coastal areas, and water shortages have occurred in northern China, particularly in the Yellow River basin. These factors are predicted to become important constraints upon future economic growth in China[2].

In order to address such problems, in 1999 the central government of China announced that Western Development strategy would be a national strategy as a core part of its Tenth Five-Year Plan[3]. This strategy includes as key projects the West-to-East electricity transmission project, to address power shortages in coastal areas, and South-to-North water diversion project to address water shortages in the north China. [4].

The northern route of the West-to-East electricity transmission project is intended to carry electricity to Beijing and Tianjin from areas such as Inner Mongolia and Shanxi Province, in the upper and middle reaches of the Yellow River (the area targeted by the western route of the South-to-North water diversion project). Responding to this plan, the Inner Mongolia Autonomous Region considered establishing a new energy production base using its abundant coal resources. But because the maximum water allocations from the Yellow River based on the Yellow River Water Allocation Scheme (established as a result of flow stoppages on the Yellow River) were already being used, however, the Yellow River Conservancy Commission (YRCC) did not permit new water withdrawals needed for electrical power generation. This situation is a sign of the urgent need to secure water resources in the upper and middle reaches of the Yellow River if the West-to-East Electricity Transmission Project is to succeed. For this purpose, there was a trial run of the Yellow River Water Rights Transfer Management Implementation Regulation in 2004, as a new measure to deal with the above situation. The term "water rights" here refers to the right to withdraw water from the Yellow River, and "water rights transfer" means the transfer of water withdrawal rights from the Yellow River[5]. The power generation sector in Inner Mongolia then sought to obtain water rights from the agricultural sector in an effort to develop the energy sector. The method of transferring water rights here was that the power generation sector invested to promote water conservation projects in the agricultural sector, and the resulting surplus agricultural water was used to generate electricity. This is seen as one effective approach for water

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resource allocation when there are constraints on the water supply.

Many studies have already examined water resource management for the Yellow River[6]. Zhang (2006) [7], meanwhile, evaluated the economic benefits that can be obtained by transferring water rights from the agricultural sector to the industrial sector, in Inner Mongolia and Ninxia Autonomous Region. No research to date, however, appears to have comprehensively examined effective water and energy resource allocation based on water rights transfer systems. Furthermore, water rights transfers in China today are permitted only within a given province, and few studies have discussed any expanded scope or range of water rights transfers. Transfers of water and energy resources are tending to cover an increasingly vast area in China today (through projects such as the North Water Transfer Project and the West-to-East Electricity Transmission Project), so it would also be worthwhile to consider water rights reallocation might be effective to raising water productivity and Regional Development, also might increase CO_2 emission base the China's current technology. It is necessary to consider how to rebuild the water rights reallocation system for co-benefit of raising water productivity and mitigation CO_2 emission.

In this context, the current study focuses on water rights transfers between the power generation sector and the agricultural sector in Inner Mongolia, and aims to assess the potential for regional development by utilizing water rights transfers. The study also analyzes the impacts of water rights reallocation system on regional development and energy use.

2 POTENTIAL FOR REGIONAL DEVELOPMENT THROUGH WATER RIGHTS TRANSFERS

2.1 The potential of transferable water volume

Target region

Fig.1 shows the location of the Inner Mongolia Autonomous Region and the distribution of irrigation districts within the region. Inner Mongolia has about 30 percent of China's entire coal reserves, giving this region great potential for coal-fired power generation.

About half of Inner Mongolia's coal deposits are in Erdos City[10]. Agricultural water accounts for about 90 percent of all water use in Inner Mongolia, so the water-saving potential in the agricultural sector is huge. Thus, Inner Mongolia would appear to have good prospects for effective water rights transfers between the power generation sector and agricultural sector.

Table 1 shows an outline of the major irrigation districts in Inner Mongolia. "Effective irrigation" area here refers to the area of level cultivated land with irrigation facilities and equipment installed, with adequate water resources, and with the potential to conduct normal irrigation during average years[11].

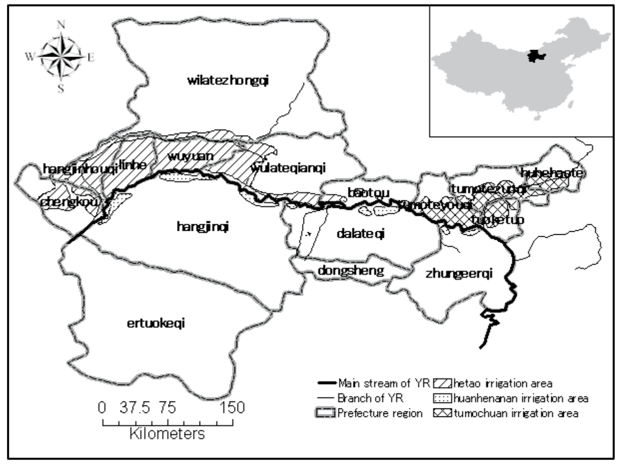

Fig. 1: Location of major irrigation districts in Inner Mongolia

Table 1: Basic data on major irrigation districts in Inner Mongolia

Irrigation District	Cultivated area 10,000 ha	Effective irrigation area 10,000 ha	Cultivated area share of effective irrigation area %
Hetao	51.6	57.64	100%
Yellow River South Bank	3.3	4.62	100%
Tumochuan	27.94	9.47	33.89%

Source: Prepared by authors from references[9]

Annual transferable water volume in the agricultural sector

The current study follows the approach taken by Wang (2006) [12] to define the annual transferable water volume in the agricultural sector (TW) as difference between the original amount of allocated water (AW) and the annual volume of agricultural water after implementing water conservation measures (GIW) (Equation 1). Equation 2 can be deduced from Equation 1, because GIW can be derived from the relationship between the net amount of water required for irrigation (NIW), the irrigation water utilization efficiency ratio (η), and the irrigation shortfall coefficient (β). The ratio η is determined by the efficiency of facilities, and is the product of the canal irrigation water use efficiency ratio and field irrigation water use efficiency ratio. β is the irrigation shortfall coefficient. In areas with tight water supplies, farmers use less than the optimal water required for a given crop. In such cases, the irrigation shortfall coefficient is defined as the ratio of actual irrigation water volume and the optimal water demand volume.

Equations in this study use regular (non-italicized) letters to indicate variables that represent multiple meanings (volume) with multiple letters, and italics to indicate where one letter represents one thing (volume). All of the subscripts have been written without italics.

$$\mathrm{TW} = \mathrm{AW} - \mathrm{GIW} \quad (1)$$

$$TW = AW - \beta \frac{NIW}{\eta} \tag{2}$$

TW: Total transferable water volume, GIW: Gross irrigation demand volume, NIW: Net irrigation demand volume, AW: Water allocated by water rights, η :Irrigation water utilization coefficient, β :Irrigation shortfall coefficient

Derivation of net amount of water required for irrigation

NIW is derived from Equation 3, which was developed by Duan Ai Wang (2002) [13], Fu Guo Bin (2001) [14], and Liu Yu (2005) [15], but this methodology requires detailed soil data.

$$NIW = \sum_{i} \left(ET_i - PE - G_i - ASW_i \right) ISA_i \tag{3}$$

ISAi : Irrigable area for crop I, PE : Effective precipitation volume

ETi : Water demand volume required for evapotranspiration for crop i

Gi: Effective volume of groundwater supplement for crop i

ASWi: Change of effective water storage volume during growing period for crop i

Because we could not obtain adequate soil information for Inner Mongolia, we decided to express this value by the difference between the potential Evapotranspiration (ET) amount of crops that have NIW and effective rainfall volume, based on the approach in CROPWAT by Smith (1992) [16]. As an additional point, in Inner Mongolia it is common practice to irrigate pasture land, and to irrigate during the autumn season [17]. With this in mind, NIW can be derived as shown in Equation 4.

Autumn irrigation is conducted from the end of September through the end of October after crops have been harvested. The moisture from irrigation freezes during the winter along with the soil, and is held there until it melts and is released in the spring during sowing season when water is scarce; this system could be considered to be an irrigation method unique to semi-arid regions.

$$NIW = \sum_{i} \left(ET_i - PE \right) ISA_i + \omega * IA \tag{4}$$

IA: Effective irrigated area

ω : Units for autumn irrigation (m^3/day/ha)

Effective rainfall is the amount of precipitation that falls on cultivated land during the period of irrigation and can be used for crop growing [18]. Effective rainfall is calculated using Equation 5, as defined by the Food and Agriculture Organization (FAO) [16].

$$\begin{aligned} PE &= P(4.17-0.2P)/4.17 \qquad P < 8.3\text{mm/d} \\ PE &= 4.17+0.1P \qquad P \geq 8.3\text{mm/d} \end{aligned} \tag{5}$$

P: Precipitation

Allocated water are based on water rights (AW)

According to YRCC-approved water withdrawals from the main course of the Yellow River for major irrigation districts in Inner Mongolia[19] (Table2) , we calculating the Allocated water base water rights for the three irrigation districts (Hetao Irrigation District, Yellow River South Bank Irrigation District , and Tumochuan Irrigation District) is 4,983 million m^3 (Hetao), 410 million m^3 (Yellow River South Bank), and 690 million m^3 (Tumochuan) respectively.

Irrigable cultivation area, by zone and by crop

The land use classifications for major irrigation districts in Inner Mongolia are shown in Fig.2. Using provincial boundaries we classify the irrigation districts into 15 zones. The cultivated land of Baotou City is separated into the Hetao and the Tumochuan irrigation districts. Next, the irrigated areas are calculated by zone and by crop, as shown in Equation 6.

$$ISA_{mij} = \left(\frac{SA_{ij}}{SA_j} \right) * \left(\frac{ICA_m}{CA_m} \right) * \left(\frac{CA_{mj}}{CA_j} \right) * SA_j \tag{6}$$

ISAmij: Irrigable area, by zone and by crop, SAij: Seeded area of crop i in province j, ICAm: Effective irrigation area of cultivated land in irrigation district m, CAm: Cultivated area in irrigation district m, CAmj: Cultivated area in each zone, CAj: Cultivated area in province j, SAj: Total seeded area in province j

The methodology is explained below in more detail.

Step 1: Calculate cultivated area in each county using the land-use classification map for the year 2000. CAj in the table is the cultivated area in the entire county, and CAmj is the cultivated area associated with each major irrigation district within the cultivated area in each county, in other words, the cultivated area for each zone.

Table 2: Approved water withdrawals from the main course of the Yellow River for major irrigation districts in Inner Mongolia

Associated irrigation district	Water withdrawal permit no.	Approved water withdrawal (10,000 m^3)
Yellow River South Bank Irrigation District	Withdrawal (State, Yellow) [2000] No. 14001	41,000
Hetao Irrigation District	Withdrawal (State, Yellow) [2000] No. 14002	58,340
	Withdrawal (State, Yellow) [2000] No. 14003	440,000
Tumochuan Irrigation District	Withdrawal (State, Yellow) [2000] No. 14007	28,000
	Withdrawal (State, Yellow) [2000] No. 14008	8,000
	Withdrawal (State, Yellow) [2000] No. 14009	8,400

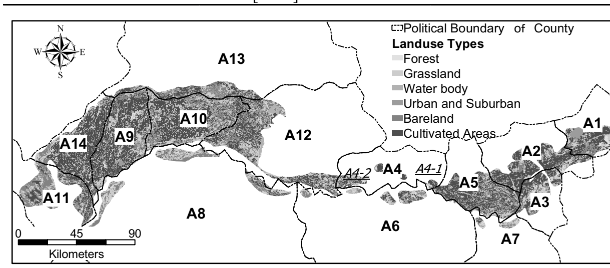

Fig. 2: Land use types and political boundaries or counties of major irrigation districts in Inner Mongolia (2000) Source: Prepared by authors from Supermap[20].

Step 2: Using the results of Step 1 and the total crop area in each county SAj, calculate crop area in each zone (CAmj / CAj) * SAj.

Step 3: To calculate the irrigable area in each zone, multiply the crop area in each zone as calculated in Step 2 by the ratio of effective irrigated area of cultivated land in each irrigation district (ICAm / CAm).

Step 4: Calculate the irrigable area for each zone and each crop ISAmij, from the ratio of crop area for each crop (SAij/ SAj) and the irrigable area in each zone as calculated in Step 2.

Determination of other parameters

For precipitation, we use the average values from seven weather monitoring stations in Inner Mongolia for the years 1971 through 2000.

For water demand by each crop ET_i, because insufficient data was available from weather monitoring stations, we utilize values for each crop in Inner Mongolia, calculated using the Penman-Monteith equation, based on existing literature[21] [22].

We assume no changes in crop-specific ET and precipitation for future planning years.

The irrigation shortfall coefficient is set as 0.8 based on Fu Guo Bin (2003) [23].

The irrigation water utilization ratio for the year 2000 is set as 0.336 for the Hetao Irrigation District[22], and 0.24 for the Yellow River South Bank Irrigation District, based on existing literature.

Because no information was available for the Tumochuan Irrigation District, here we assume the value 0.336, the same as in the Hetao Irrigation District.

For the field irrigation water use efficiency after implementation of water conservation measures, we use the value 0.9, based on Chinese water conservation technology standards [24].

Based on testing in the South Bank Irrigation District in Inner Mongolia, we use 0.7 as the canal irrigation water use efficiency ratio after water conservation measures was implemented.

We assume that future crop patterns will be the same as in the year 2000.

2.2 The model of water rights transfers

The concept of water resource and power allocation

We assume the water rights transfer is not only between the power generation sector and the agricultural sector, but also amony the other industry, tertiary industry etc. Fig.3 show the concepts of water resource and energy allocation. Water resouse saving from irrigation district will satisfy the human water demand firstly. Then allocation to the other sectors inclued tertiary industry, thermal-electric power and the other industry.

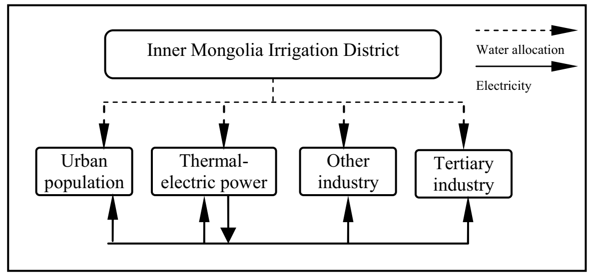

Fig. 3: Allocation system within Inner Mongolia

The model of water and power re-allocation

In this study, we apply the Leontief production function to represent the relationships among industry k (excludes electricity generation industry), electricity generation industry e, and service industry s, and increased value added ΔV for each industry, as well as labor ΔL, water resources ΔW, and electricity inputs ΔE. We use the upper limits of increases of labor, water resources, and electricity generation as constraining factors (Equations 7 to 12). The increase in electricity generation is determined endogenously from the relationship with water resource allocation to the electricity generation industry, as shown in Equation 13.

$$\Delta V_{\mathrm{k}} = \min\left\{\frac{\Delta L_{\mathrm{k}}}{l_{\mathrm{k}}}, \frac{\Delta W_{\mathrm{k}}}{w_{\mathrm{k}}}, \frac{\Delta E_{\mathrm{k}}}{e_{\mathrm{k}}}\right\} \tag{7}$$

$$\Delta V_{\mathrm{e}} = \min\left\{\frac{\Delta L_{\mathrm{e}}}{l_{\mathrm{e}}}, \frac{\Delta W_{\mathrm{e}}}{w_{\mathrm{e}}}, \frac{\Delta E_{\mathrm{e}}}{e_{\mathrm{e}}}\right\} \tag{8}$$

$$\Delta V_{\mathrm{s}} = \min\left\{\frac{\Delta L_{\mathrm{s}}}{l_{\mathrm{s}}}, \frac{\Delta W_{\mathrm{s}}}{w_{\mathrm{s}}}, \frac{\Delta E_{\mathrm{s}}}{e_{\mathrm{s}}}\right\} \tag{9}$$

Constraining factors

$$\Delta L_{\mathrm{k}} + \Delta L_{\mathrm{e}} + \Delta L_{\mathrm{s}} = \Delta L_{\mathrm{total}} \tag{10}$$

$$\Delta W_{\mathrm{k}} + \Delta W_{\mathrm{e}} + \Delta W_{\mathrm{s}} + \Delta L * p = \Delta W_{\mathrm{total}} \tag{11}$$

$$\Delta E_{\mathrm{k}} + \Delta E_{\mathrm{e}} + \Delta E_{\mathrm{s}} + \Delta L * q = \Delta E_{\mathrm{total}} \tag{12}$$

$$\Delta E_{\mathrm{total}} = \frac{\Delta W_{\mathrm{e}}}{\alpha}(1 - \delta) \tag{13}$$

ΔV: Increased value added, ΔL: Increased labor inputs, ΔW: Increased water inputs, ΔE: electricity inputs, ΔWtotal: Potential increase in water resources, ΔEtotal: Potential increase in electricity, ΔLotal: Potential increase in labor, l : Labor input per unit of value added, w: Water input per unit of value added, e: Electricity input per unit of value added, p: Water use per capita, q: Electricity use per capita, α : Water demand per unit of electricity generation, δ : Power transmission loss ratio, k: Industry (excluding electricity generation), e: Electricity generation industry s: Service industry

The increase in labor is determined endogenously based on the existing urban plans of region [25]. The upper limits of future population increases for Inner Mongolia are calculated (at 13.6 million) from the differences between the respective urban populations in the year 2000 and the upper limits for Inner Mongolia according to their urban

Table 3: Basic units for analysis (2000)

Annual domestic electricity use per capita (urban)	kWh/person	155.20
Annual domestic water consumption per capita (urban)	m^3/person	37.08
Industrial water demand (excluding power gen. industry) per unit of value	m^3/10,000 yuan	153.58
Industrial electricity use (excluding power gen. industry) per unit of value	kWh/10,000 yuan	3672.58
Industrial workers (excluding power gen. industry) per unit of value added	persons/10,000 yuan	0.17
Service industry water demand per unit of value added	m^3/10,000 yuan	2.06
Service industry electricity use per unit of value added	kWh/10,000 yuan	445.00
Service industry workers per unit of value added	persons/10,000 yuan	0.65
Electricity generation industry water demand per unit of value added	m^3/10,000 yuan	139.36
Electricity generation electricity use per unit of value added	kWh/10,000 yuan	3538.70
Electricity generation workers per unit of value added	persons/10,000 yuan	0.07
Water demand per unit of power production	m^3/10,000 kWh	28.80
Power transmission loss ratio	%	5.56
CO_2 emissions per kWh from electricity and heat generation using coal/peat	kg/ kWh	0.911

The increase in water resources (in other words, the transferable water volume), is, as previously calculated, 2,571 m^3 million for Inner Mongolia. Data for the year 2000 are used for resource inputs per unit of value added, and for average resource consumption per capita [26-31] (Table 3).

3 RESULTS AND DISCUSSION

Estimates of annual transferable water volume in the agricultural sector

Table 4 shows the calculation results of the annual transferable water volume of the agricultural sector. The table shows that water conservation measures, if implemented, would results in a transferable water volume of 2,571 million m^3 per year in the target region.

Table 4: Transferable water volume (100 million m^3)

Irrigation district	Water rights (volume)	Water demand (2000)	Future planned annual water demand	Transferable water volume
Tumochuan	6.90	7.76	4.51	2.39
Yellow River South Bank	4.10	4.07	1.94	2.16
Hetao	49.83	49.26	28.67	21.16
Total	60.83	61.08	35.12	25.71

Economy and environmental impact of water re-allocation

Water and power re-allocation in Inner Mongolia is shown in Fig. 3 and the economic and environment impacts of water rights transfer are shown in Table 5. Most of water and power are allocated to industries that not included power generation, and contribute to the output increasing. The total value added might increase about 178.2 billion yuan through allocation of water and electricity power**.** On the other hand, the increasing of power production might results CO_2 emission because the coal is used in the power generation in Inner Mongolia. The results shown 54 million ton CO_2 might emitted through allocation of water and electricity power. Improvement of generating efficiency and development of clean energy is important task in China.

Table 5: the effect of water tranfer in Inner Mongolia

water conservation (million m^3)	CO_2 emillion (milllion ton)	value added (million yuan)
2571	54	178253

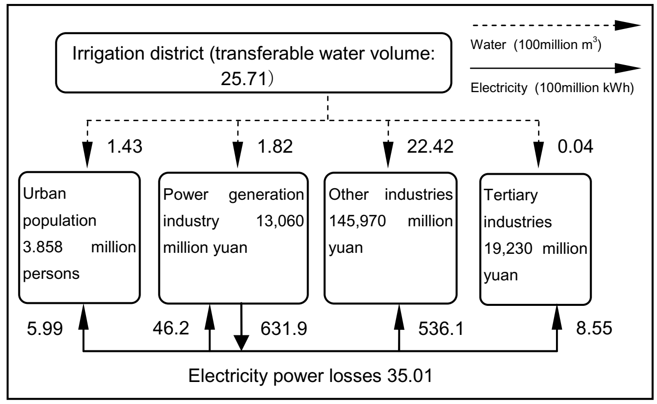

Fig. 3: water and electricity power allocation in Inner Mongolia

4 SUMMARY

This study focuses on water rights transfers between the power generation sector and the agricultural sector in the Inner Mongolia Autonomous Region. We estimated annual transferable water volume in the agricultural sector in Inner Mongolia firstly, and then we assume the saving water cans re-allocation among within each sectors, estimated the Economy and environmental impact of water re-allocation. We can find some conclusions as follow.

- Agricultural water accounts for about 90 percent of all water use in Inner Mongolia, so the water-saving potential in the agricultural sector is huge. A lager of water can save by improvement of irrigation facility.
- By re-allocation the saving water, the water demand of power production and industry can be satisfied. And, the economic development will be results by the water and power allocation,
- On the other hand, the increasing of power production might results CO_2 emission because the coal is used in the power generation in Inner Mongolia. Improvement of generating efficiency and development of clean energy is important task for China.

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Concept of Optimal Replacement System for Urban Infrastructures Considering Breakage Risk and Social Cost: a Case Study of Sewer Pipes

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Abstract

Infrastructure stock that was acquired rapidly during Japan's period of high economic growth presents challenges for management to avoid negative impacts from facility aging, such as sewer pipe breakage, under conditions of tightening public works budgets. The authors present a conceptual framework for managing the maintenance and replacement of infrastructure, using combined sewers as a reference. A risk evaluation is used to obtain an annual cost of not replacing the infrastructure; this cost is then combined with the societal cost (internal cost of construction or maintenance work plus economic externalities derived from environmental and social impacts) of performing routine maintenance or replacement based on different replacement periods from 5 to 90 years. We show that given such a full consideration of costs, replacement periods for sewers in densely populated areas may be closer to 30 years than the general assumption of 50 years.

Keywords:

infrastructure, life-cycle-assessment, facility management, pricing externalities

1 INTRODUCTION

Much of Japan's infrastructure stock was constructed during the period of high economic growth in the 1960s, and there is concern that in the future high costs will be faced when major maintenance or replacement programs are needed. The potential for loss of function or serious accidents from deterioration of these structures is real. However, with tightening public works budgets and long-term population decline, maintenance and replacement programs need to be rational. Works planning must also consider not only the direct cost but also social and environmental impacts. We set out to develop an improved method for the management of infrastructure maintenance programs that selects the optimal timing for updating infrastructure by taking into account the risk of damage in combination with the direct construction costs (internal costs) and external costs. External costs were estimated by converting negative influences (external diseconomies) into a monetary value. The sum of internal and external costs is referred to as societal cost. We selected combined sewers as the target infrastructure for developing this method.

2 STUDY METHOD

The approach we adopted in this research was to determine the optimal period for replacing ferroconcrete pipes of combined sewers by integrating a price for the risk associated with aging with the full societal cost of construction and routine maintenance. In civil engineering, pipes and drains are generally assumed to have a design life of 50 years. However, for the most efficient replacement policy under tight financial conditions, the areas to be replaced need to be prioritized by taking into account the degree of loss and social disruption that could occur from the failure of aging pipe. Our general approach here was to calculate the cost of (1) original construction (2) routine maintenance, and (3) the risk of potential sewer failure (damages that would arise multiplied by the probability of occurrence) for each year after sewer construction. These costs were added for each year, and then the year at which the minimum cost occurred was identified. Moreover, we calculated the contribution of external costs (external diseconomy) and added these to the internal (direct) cost of sewer replacement to obtain the total costs.

We divided the country into densely populated, suburban, and non-urban areas on the assumption that the various diseconomies and construction costs associated with pipe failure would differ with population density. We then performed the analysis as a case study, and we assumed a specific set of construction conditions (open-cut excavation, confluence-type sewage collection, 450-mm ferroconcrete pipes on a sand base, 45-m replacement section, average soil thickness of 1.28 m, and 16.2-day construction period). The densely populated, suburban, and non-urban areas, respectively, had the following characteristics: population: 7.8 million, 3.8 million, and 38.2 million; area: 11692, 2899, and 82337 km^2;

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population density: 6.7, 1.3, and 0.5 people/km^2; and percentage of the entire sewer system held: 60%, 12%, and 4%.

3 CALCULATION OF INTERNAL COSTS

Published unit costs were used for the construction cost of laying new ferroconcrete pipe by using the open cut method [2] and for routine sewer maintenance [3]. The assumed work frequency was once every 3 years for the first 31 years and once every 2 years for the next 60 years.

For each 45-m unit section of sewer, the calculated cost of construction was 2,894,641 yen in densely populated areas, 2,858,673 yen in suburban areas, and 2,813,349 yen in non-urban areas, the only difference between them being the cost of procuring pipe. Routine maintenance costs (mainly pipe cleaning and inspection) were the same in all three areas, 75,166 yen.

4 CALCULATION OF EXTERNAL COSTS

4.1 Contributing factors

In calculating external costs we took into account air pollution (NO_X emissions from construction machinery and construction-related traffic congestion), global warming (CO_2 emissions from construction machinery and construction-related traffic congestion), vibration from excavation work, noise from excavation work, construction waste (disposal of asphalt, macadam, and soil), temporary loss of pedestrian space, and loss of time owing to traffic control. We used monetary conversion coefficients from past research [4] for noise, vibration, construction waste, loss of pedestrian space, and loss of time. The costs of NO_X and CO_2 emissions were calculated from published unit rates.

4.2 Air pollution and global warming

The amounts of NO_X and CO_2 emissions needed to calculate the associated external cost were calculated as follows. The external costs of air pollution and global warming from NO_X and CO_2 emissions, respectively, were obtained from life cycle inventory analysis of emissions due to material consumption, construction work (original construction, routine maintenance, and pipe replacement) and traffic congestion caused by traffic control during construction. First, emissions from the manufacture and transport of materials, use of construction machinery, and consumption and disposal of construction by-products and waste were obtained from published sources used for calculating the internal (direct) costs of construction (construction, routine maintenance, and sewerage pipe replacement) [1,2]. The cost of emissions from fuel consumption was calculated from tables published for 2006 by the Association of Japanese Construction Machinery Manufacturers [5]. The unit emissions from different activities were multiplied by the amount of each activity and a unit price conversion factor.

The life cycle NO_X and CO_2 emissions were calculated from data published by the Architectural Institute of Japan [6] and the Japan Environmental Management Association for Industry [7,8].

All traffic was assumed to be light passenger vehicles with traffic congestion caused by the regulation of traffic for construction or maintenance works. The amounts of CO_2 and NO_X emission were calculated from the fuel consumed during idling when vehicles were stopped and the fuel consumed when vehicles had to accelerate upon restarting. The assumptions used for the calculations were as follows: fuel consumption during idling was considered to be 0.013 L/minute (idling time was obtained from the lost time calculations in section 4.6); fuel needed when starting (0.026 L/vehicle stoppage) was multiplied by the number of stoppages (red signals per 500 vehicles (286) × stoppage time (40 s)/signal cycle length (70 s); two traffic directions were used; and the emission rates were 0.006 kg-NO_2/L and kg-CO_2/L of fuel consumed.

On the basis of past research, the conversion factor for the monetary cost of NO_X emissions was 2,920 yen/kg for densely populated areas, 580 yen/kg for suburban areas, and 200 yen/kg for non-urban areas [9]. The cost of air pollution depends on the size of the exposed population. For this reason, the conversion factors were determined from scaling, in which suburban areas were set at a value of one, densely populated areas 5.043, and non-urban areas 0.013. The external cost of CO_2 emissions was uniformly set as 2,300 yen/ton – c(8.43 yen/kg [9], and unit costs were set from past research for NO_X.

4.3 Noise and vibration

To calculate the external cost of noise and vibration, we considered only the excavation and construction work of sewerage pipe installation and replacement. We considered that the contribution from routine maintenance, such as inspection and cleaning, was minor; we therefore did not include it in the calculations. We used the unit cost of noise and vibration reduction during construction [4], and we multiplied this by the required amount of reduction. The unit cost of reduction was 12 yen/dB/person/day for noise and 9 yen/dB(A)/person/day for vibration. To obtain these numbers we took the environmental standards for excavation work in Tokyo (85 dB for noise and 75 dB(A) for vibration), and determined the difference between these and the level at which a person first begins to feel discomfort (55 dB for noise and 65 dB(A) for vibration). The population affected was calculated by considering a range of influence of 20 m on either side of the shoulder level (i.e., 40 m total) and multiplying this by the population density of the area that faced the construction site. The construction period was assumed to be 16.2 days, as per the specified construction conditions.

4.4 Construction waste

We calculated the external costs of construction waste disposal from unit rates determined from the marginal reductions in land values and the costs of CO_2 emission related to maintenance of the final disposal site [11].

These unit rates are 1,631 yen/t for asphalt, 386 yen/t for concrete, 853 yen/t for soil, and 547 yen/t for mixed waste and waste wood. Total external costs were calculated by multiplying the amount of waste sent for final disposal by the unit rates. We assumed that 41.9% of generated waste was sent for final disposal [12].

In pipeline installation and replacement, re-usable and waste amounts of excavated soil, asphalt, and macadam were obtained from unit rates used in calculating the internal (direct) cost of construction [2]. For routine maintenance, we assumed that 20% of the removed soil from each cleaning event was disposed of as industrial waste [3].

4.5 Reduced pedestrian space

The external cost of the reduction in pedestrian space during work periods was calculated for both routine maintenance and construction from the amount of space taken up and the number of pedestrians. We used unit rates [4] for pedestrian space improvement during construction and calculated the total value from unit cost conversion coefficients from the following general expression.

External cost = volume of pedestrian flow × number of days of restriction/30 × unit cost of providing pavement width [yen/m/person/30] × amount of pavement width lost ＋(unit requirement for changed road surface condition – unit requirement for road surface condition under normal conditions [yen/person/30])

The equations to determine the unit cost of providing pedestrian space and the cost of providing this space with specific types of pavement materials are as follows. In these equations, Y is the unit cost of providing pedestrian space or the cost of a given material (yen/person and 30) and x is the length of the zone over which pedestrian space is provided (m):

Pavement width:	$Y = 0.1590x + 17.852$
Road surface, gravel:	$Y = 0.0787x + 32.803$
Road surface, iron plate:	$Y = 0.0787x + 37.803$
Road surface, asphalt	$Y = 0.1770x + 78.557$

The general pavement conditions adopted were as follows [12]. In all areas the length of the construction zone was 45 m. The pavement width was 3.5 m in densely populated areas, 3.0 m in suburban areas, and 2.0 m in non-urban areas. The pavement width was assumed to be halved during construction. The road surface was assumed to be converted from asphalt to iron plate in all areas. The number of pedestrians was 700/day in densely populated areas, 600/day in suburban areas, and 400/day in non-urban areas. The work period was assumed to be 10 days for construction and 0.23 days for routine maintenance.

4.6 Loss of time because of disrupted traffic

We assumed that during original construction work, routine maintenance, and sewerage pipe replacement traffic in both directions would be restricted to the use of a single lane, and the delay time was calculated from expression (1).

$$TD = \frac{sqR^2}{2(s-q)} \quad \cdots\cdots\cdots\cdots \quad (1)$$

Where TD = stoppage time in one direction per cycle (seconds), s = saturation traffic flow (stand/second), q = traffic demand (stand/second), and R = stoppage time (seconds).

All vehicles were passenger cars, and the unit cost of stoppage time was set at 40.1 yen/minute on the basis of past research [13], as were other calculation parameters as follows: traffic demand (stand/second) was 0.116 in densely populated areas, 0.069 in suburban areas, and 0.035 in non-urban areas; in all areas the distance between stops was 50 m, the saturation traffic flow was 0.42 stand/second, the duration of the red signal was 5 s, the duration of the green signal was 30 s, the cycle length was 70 s, the work period was 16.2 days for construction and 0.37 days for routine maintenance, and the daily period of traffic control was 0800 h to 1730 h.

4.7 Calculation results

The external costs of construction for a standard 45-m length of sewer are shown in Fig. 1; the external costs for routine maintenance are shown in Fig. 2.

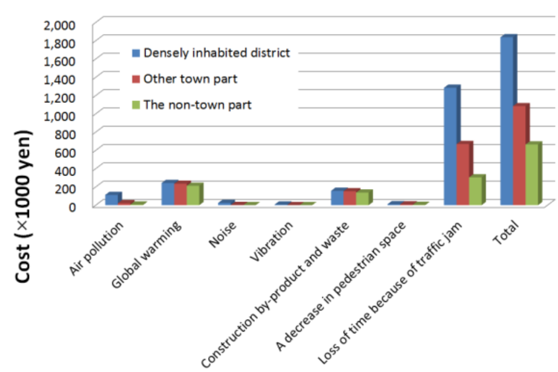

Fig. 1: Calculated external costs of construction

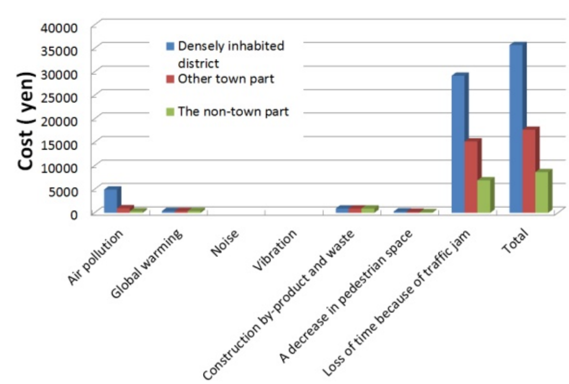

Fig. 2: Calculated external costs of routine maintenance

5 COSTS OF RISK OF SEWER DAMAGE

5.1 Calculation results

The presence of combined sewers contributes to sanitation and comfort in our living environment. Damaged sewerage pipes have a large negative impact on people's lives and social activities, because replacement facilities take time to install. In addition, subsidence of roads because of sewer collapse can cause traffic accidents and disrupt traffic. Flood risk is also increased by the loss of drainage function. We estimated the cost of the risk of sewerage pipe damage by quantifying the cost (external cost + internal cost) of damage and multiplying it by the annual probability of occurrence [14]. Similarly, the annual amount of damage was calculated from the amount of damage by flood when a sewer is damaged, multiplied by the flood probability plus the sewer restoration construction cost.

The amount of flood damage was calculated from the amount of damage to buildings and property on the basis of the characteristics of different areas and flood damage studies [15]. The amount of damage caused by a given flood was multiplied by the probability [17] of a flood of that magnitude occurring. The cost of construction work to replace pipes by the open-cut construction method was added to the damages cost. The probability of road subsidence from sewerage pipe collapse was calculated from studies in Osaka [14] (Fig. 3).

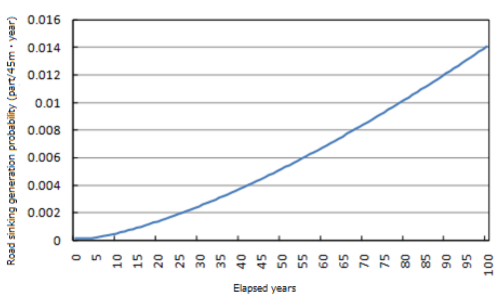

Fig. 3: Probability of road subsidence occurring with years since construction

5.2 Calculation results

The probability of damage occurring (Fig. 3) was multiplied by the cost of the damage to determine the cost of risk in any given year. The internal cost of sewerage pipe damage and replacement per 45-m section of pipeline, comprising the direct influence on houses, offices, and office facilities, plus the cost of pipe maintenance and repair, was 28.8 million yen in densely populated areas, 12.9 million yen in suburban areas, and 12.2 million yen in non-urban areas. When both internal and external costs were considered, the corresponding costs were 29.6 million yen, 13.5 million yen, and 12.6 million yen.

6 OPTIMAL REPLACEMENT TIME

6.1 Calculation of societal cost

We calculated the cost of construction for a standard 45-m section of pipe by each type of area (Fig. 4). The internal cost of construction makes up the major component of the cost and was relatively uniform for the three types of area. External costs were more dependent on population density. From the breakdown of external costs (Figs. 1 and 2), by far the biggest contributor was the time lost because of the need for traffic control, in both construction and routine maintenance.

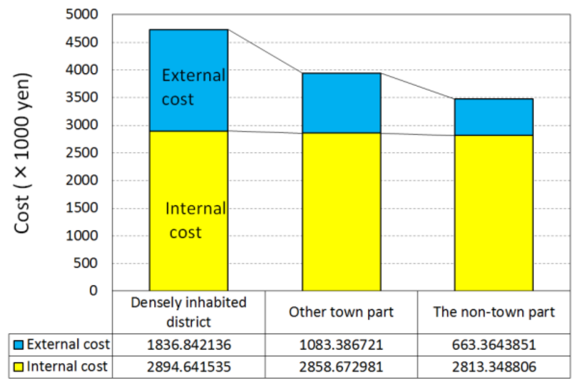

Fig. 4: Full social cost and contributions of internal and external costs by each type of area

6.2 Calculation of optimal time to replace sewers

We summed the annual amounts of each cost (risk cost, cost of construction, and routine maintenance) for each year after installation of a new sewer and identified the year when the cost of replacement was minimized (Table 1). Curves showing the trend in costs with time for each cost component are shown in Fig. 5 (internal cost only) and Fig. 6 (societal cost) for densely populated areas. The optimal replacement time varied from 29 years in densely populated areas when only internal costs were considered to 41 years in suburban and non-urban areas when both internal and external costs were considered (Table 1). Adding in external costs such as environmental impacts and lost construction time had the effect of increasing the optimal time of replacement, but the effect was more pronounced in the densely populated areas than in the other two areas (Table 1).

Table 1: Optimal time for sewer replacement (years)

	Densely populated areas	Suburban areas	Non-urban areas
Internal cost only	29	39	39
Societal cost basis	33	41	41

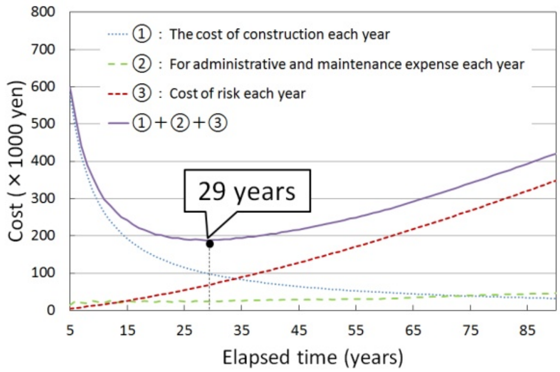

Fig. 5: Best time to replace sewers in densely populated areas (for internal cost only)

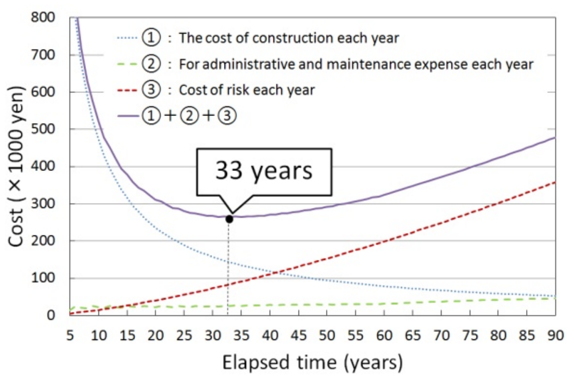

Fig. 6: Best time to replace sewers in densely populated areas (for full societal cost)

7 CONCLUSIONS AND FUTURE

This paper presented a case-study approach using sewer pipelines to illustrate a conceptual method for identifying the optimal replacement period for infrastructure stock. This method incorporated prices for externalities associated with construction and routine maintenance, as well as the risk of damage from sewer failure over time. Adding in external costs increased the optimal replacement period, chiefly in densely populated areas, where the costs of externalities such as lost time and exposure to air pollution were high. Similarly, the potential for damage from road subsidence or inconvenience to the population if sewers collapsed meant that the replacement time was considerably shorter in densely populated areas than in suburban and non-urban areas—that is, the risk cost is higher.

We recognize that the calculation of societal cost may involve different challenges when applied to different types of infrastructure. On the basis of our experiences with the current study, some targets for future development of the method are:

- More accurate discrimination between internal costs and external costs. Accounting for costs associated with extensions to the construction period incurred by the road administrator and other costs to minimize complaints during construction could help in this regard.
- Better definition of the range of influence (system boundary) in the calculation of external costs.
- Improved general applicability of the case study by analyzing the sensitivity of the outcomes to major variables such as soil thickness, road subsidence probability, and flood probability.
- Improved accuracy of the monetary conversion factors for the external cost estimates.

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