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University Campus Solid Waste Management

Combining Life Cycle Assessment and Analytical Hierarchy Process

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Preface

Millions of tons of solid waste are generated every year. To achieve environmental sustainability, extensive and comprehensive solid waste management programs incorporating integrated solid waste management approaches are needed. Along with issues of sustainability, cost escalation and environmental impacts are factors that must be addressed. These issues can be addressed through different methods such as the Life Cycle Assessment (LCA) and the Analytical Hierarchy Process (AHP) in the field of solid waste management. While environmental and economic solid waste management improvements are necessary, the improved sustainability of the entire system is the highest priority. The goal of this book is to estimate the recyclable material generation and composition of solid waste to define hot spots in solid waste generation in pilot areas and to assess solid waste management systems. Targets of interest are based on environmental and economic analyses using the cluster analysis, a method which combines the LCA and AHP approaches. To achieve these objectives, all waste generation sources from the pilot areas were divided into six sources. Observations on the domestic waste composition and the source collected recyclable materials were performed to facilitate the characterization process. LCA and AHP were used to establish the most favorable economic scenarios. Results from these two approaches were combined using the cluster analysis method to achieve the optimal solution yielding lower environmental impact and higher economic benefit. Conclusions show that combined LCA-AHP is capable of a 75 % reduction in harmful environmental impact points and a 40 % increase in economic production per month. The proposed approach could serve as a basis for the formulation of general solid waste management guidelines toward a sustainable environment.

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Chapter 1
Introduction

1.1 Challenges of Solid Waste Management

Solid waste management is a complex issue with a wide range of consequences for the different organizations. For an instant, a matter with high environmental impact due to existence more than 13,000 universities worldwide (Hazelkorn 2013), around 4333 of which are located in Europe having more than 18 million student population generating environmental effects as direct activities such as using classrooms, laboratories, offices, and catering (commuting and eating of drink and food at universities by students), and indirect activities like waste treatment facilities (Adelman 2009; Lukman et al. 2009).

Comprehensive understanding of the solid waste stream and actions specification is necessary to reach to an effective solid waste management at resource (Franklin 2002). Combination of solid waste data is essential in the systems evaluation, management plans, and programs. Consequently, before addressing solid waste matter, a number of sources and investigation on solid waste composition should be performed (Zhao et al. 2014). In fact, solid waste composition has some fundamental importance in solid waste management, particularly in reaching to a sustainable institute, regardless of the definite of considered solid waste management methods and techniques for implementation. First step of stabilization of a solid waste management organization is an enhanced understanding of the stream of the institutional solid waste (Saeed et al. 2009). Increased knowledge may help to attain higher degrees of solid waste deviation in an attempt for facing to challenges that have been seen while implementing sustainable solid waste management programs.

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1.2 Solid Waste Generation

Institutions like universities are similar to low populations due to their size, population, and multi-compilation sources existing on their campuses (Alshuwaikhat and Abubakar 2008). Not only they need to protect proper infrastructure, but also they need services as small towns, such as housing, transportation, retailing, leisuring, and solid waste management. Such institutions are solution cases for triennial learning and studies, foremost employers, economic performers, and cultural and recreational providers as well as infrastructure resources (Lambert 2003). These components potentially are substantial for accelerating public shifting to sustainability (Stephens et al. 2008). Particular challenge of HEIs' sustainable developments is the conducting integrated solid waste management system (Armijodevega et al. 2008; Zhang et al. 2011).

Generating rate of the solid waste by the pilot area has been recently estimated to be approximately 8 tons per day (Tiew et al. 2011). On the national level, dictatorial approaches intended to maintain an effective SWM by adoption. Current changes and modifications on the original operation have been presented to make available solutions for solid waste management. The components which share to the solid waste management issues are: (1) insufficient resource compilation, (2) overdependence on equipment which are imported, (3) improper finance methods, (4) improper technology application, (5) inequality in service stipulation, and (6) technical expertise deficiency (Basri 2001; Zhao et al. 2014). Therefore, knowledge-based solutions required. In fact, existing gaps in the recent development of correspondence issues have been added to the elaborated problems' solutions of solid waste management.

The rate of paper recycling collection was 50% at pilot area. This issue is caused by lack of responsibility on the coordinators side and also ignoring a recycling system (Tiew et al. 2010). Hence, the management needs to conduct different solid waste generation sources to improve solid waste management, which starts with enforcing a green regulation for the employees to increase recycling rate while simultaneously reducing the disposal of solid waste. Furthermore, increased knowledge on managing solid waste may well help senior education institutions to reach higher diversion rates of solid waste and gives them some enforcement to apply sustainable management of solid waste programs on campus.

In addition, examining solid waste by source generation is principally essential, as the composition and specification of solid waste show a discrepancy based on the source (Hilkiah et al. 2008). Thus, this procedure helps the areas to become green, reducing costs of solid waste disposal and reduction of landfill space (Noeke 2000). Many campuses perform recycling the solid waste as a starting of sustainability plans of the solid waste management, (Abadie et al. 2010; Moore 2010; Zhang et al. 2011). HEIs logically save money by recycling that are often observable and in general noncontentious (Sterling and Thomas 2006). Therefore, one key aspect of solid waste management scheduling is to guarantee the detection of areas where particular procedures should be implemented to diminish the environmental effects of solid waste management.

In order to find out the hot spots with potential of environmental impacts related to consider solid waste management methods, life cycle assessment approach is introduced as an essential part to achieve the complete picture of the campus' environmental consequences. It can assist quantification of the energy and materials consumed as well as the discharge and solid waste generated in the life cycle of university solid waste production sources except hazardous waste. Life Cycle Assessment (LCA) was used widely in products and analyzing process in this field, and its utilize in evaluating environmental efficiency in the service area, particularly higher education, is almost new (Lukman et al. 2009). Environmental LCA is a tool for analyzing system which has developed since the 1990s and achieved a confident stage of standardization and harmonization (Obersteiner et al. 2007). In addition, this method of impact assessment is being used recently in quite a lot of countries to assess treatment options for detailed solid waste fractions (Finnveden 1999; Buttol et al. 2007; Denboer et al. 2007; Winkler and Bilitewski 2007; Kindermann et al. 2008; Banar et al. 2009; Delborghi et al. 2009). In this investigation, a combination of LCA method with AHP by Cluster Analysis is employed to solve the solid waste management problem of the campus.

The AHP axiomatic basis does not propose rationality, but proposes that attentive individuals having proof for their attitude to provide certainty that the model contains adequate ideas (Khan and Faisal 2008). Additionally, most important phases hereby are the choice of criteria determination and relative criteria importance. They should be carried out carefully, with the hope that some days they are built on a theoretically sound basis. The results obtained through the AHP method in the investigation are comfortable with the experts' view and all official works in the SWM (in the area of economic and environment related to solid waste management at campus). However, solid waste management engineers and planners require tools that produce effective results are easy to use, are comprehensive, and require a moderate duration to arrive upon results.

1.3 Approach of the Book

In this book, an attempt has been made to address the following challenges:

1. Solve the problem of selecting the optimal solid waste–management scenarios for solid waste generated on a campus. This issue is solved through the combination of LCA with AHP with cluster analyses. AHP enables one to break down the problem in a systematic and logical way, which helps to handle the complexity.
2. To introduce a comprehensive methodology that incorporates diverse issues involved in prioritizing the solid waste–management method.

The goals of the book are as follows:

1. Estimate the daily solid-waste generation and composition, which consists of domestic waste, garden waste, electronic waste, and construction waste, as well as the amount of recyclable materials from different sources at the campus.

2. Assess the environmental-impact potential of solid waste–management systems by comparing different scenarios at campus using life-cycle assessment.
3. Compare different solid waste–management scenarios from environmental and economic points of view using an analytical hierarchy process.
4. Propose the most appropriate solid waste–management system for the campus by combining environmental and economic criteria using a cluster analysis method.

To determine the potential for environmental impacts, different solid waste–management options for plastics and paper—including recycling, incineration, and landfill—are compared. LCA was employed to measure the environmental-impact potential of the defined solid waste–management systems. Conducting an investigation on solid waste–composition analyses, while considering different solid waste–generation sources and applying LCA, can be considered as another important factor of this book. However, to determine expert opinion as a basis for environment and economic decision making for municipal solid waste management, analytical hierarchy process (AHP) is applied in an attempt to complete the data requirements of environmental and economic aspects of comprehensive decision-making. In addition, a combination of LCA and AHP with cluster analyses was used to reveal an appropriate scenario of solid-waste management. Therefore, a comprehensive framework is introduced to improve solid-waste management. It is worthy of note that different campuses that have been trying to obtain sustainability and improvement of solid-waste management regarding their solid-waste composition can apply the introduced procedure presented herein. Consideration of the domestic-waste generation at different sources of the campus was performed to determine the environmental and economic hot spots and help decision-makers to focus before attempting to control the solid-waste generation. This considerations included the following points:

- Performing a life-cycle assessment of solid-waste management.
- Combining an environmental impact assessment method (LCA) with AHP to cover conditions for which there was employment of a vital decision-making procedure to solve the complex challenges of solid-waste management.
- Introducing a procedure to select the most appropriate solid waste–management system so that decision-makers could determine a preferable system.
- Combining LCA and AHP by applying cluster analysis method in solid-waste management

Chapter 2
Overview of Solid-Waste Management

2.1 Pilot Campus

Universities are considered to be similar to small towns because of their large size, large population, and various complex activities taking place on campuses (Alshuwaikhat and Abubakar 2008). As such, they not only need to maintain an appropriate physical infrastructure, but they also require services similar to those in small towns including accommodation, transport, retail, leisure, and, of course, solid-waste management.

Higher-education institutions (HEIs) are key sites of tertiary learning and research, major employers, economic actors and providers of cultural, and recreational and infrastructure resources (Lambert et al. 2007), and they have substantial potential to catalyze and accelerate societal transition toward sustainability (Stephens et al. 2008). Integrated solid waste–management systems in particular are one of the greatest challenges for HEIs' sustainable development (Armijodevega et al. 2008). HEIs generate thousands of tons of solid waste; this waste is classified as domestic waste. The dramatic expansion of the Malaysian higher-education (HE) sector in scale and scope has placed even greater pressure to formally integrate sustainable development into policy and practice. The subsequent parts of this chapter focus on the trends of solid-waste generation, sustainability issues at different HEIs, and a combination of methods to control the escalating costs and environmental impacts of solid-waste management.

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2.2 The Consequences of Population Expansion and Solid Waste–Generation Trends

Expansion of the world's population has resulted in innovations and improvements in technology to allow the increased production and services to cope with the ever-increasing demands of humans species (Coglianese and Nash 2001; Odum 2006; Lee and Tuljapurkar 2008). As a consequence, a prosperous economy offers a higher standard of living to the community, which is indicated by the rapid growth of the world economy. The annual output of the world economy grew to $60.69 trillion in 2008 from $6.2 trillion in 1950 (Encyclopedia Wikipedia 2010), signifying an 879 % increase in just 58 years, or slightly more than 15 % per decade. As a result, the world's energy consumption is projected to grow 2 % annually until 2020. Expansion of the economy attracts urban migration, which without proper management can result in environmental degradation and more pollution. The degradation of environmental quality has been addressed over the years by scholars and scientists and was proven by various research findings (Agamuthu et al. 2004; Haberl et al. 2006; Odum 2006).

While the overall world economy improves, more than 80 countries have a per-capita income lower than the past decade with less than $1.00 needed to acquire essential needs such as clean water and food. This includes approximately 20 % of the world's poorest population who consume only 11 % of global consumption resources, whereas 20 % of the world population in a higher income group constitutes more than 76.6 % of the global consumption (McMichael 2011). The more natural resources are consumed, the more waste and pollution are produced. The acceleration of solid-waste generation due to the world's population increasing (at 1.3 % per annum) - from 5.9 billion in 1998 to more than 6.4 billion in 2006 (Bureau 2011) is a critical issue. It translated into a higher level of environmental pollution with risk and health hazards to the human species (Nadal et al. 2009).

2.2.1 Global Trends of Solid-Waste Generation

Environmental degradation is closely related to resource consumption and solid-waste generation. Solid-waste generation has increased at a tremendous rate over the years particularly in developed and industrialized countries. Municipal Solid Waste (MSW) can be defined as domestic wastes, which include commercial waste and institutional waste generated according to living standards, cultural habits, and other factors (Fauziah and Agamuthu 2001).

Population expansion is among the factors affecting greater waste production where cities, i.e., 2 % of the world's land surface, use 75 % of the world's resources. The rapid increase of MSW generation is also closely related to the economic growth and increase in GDP (Agamuthu et al. 2004; Odum 2006; Shekdar 2009), although some researcher have found that GDP is unsuitable as an indicator of

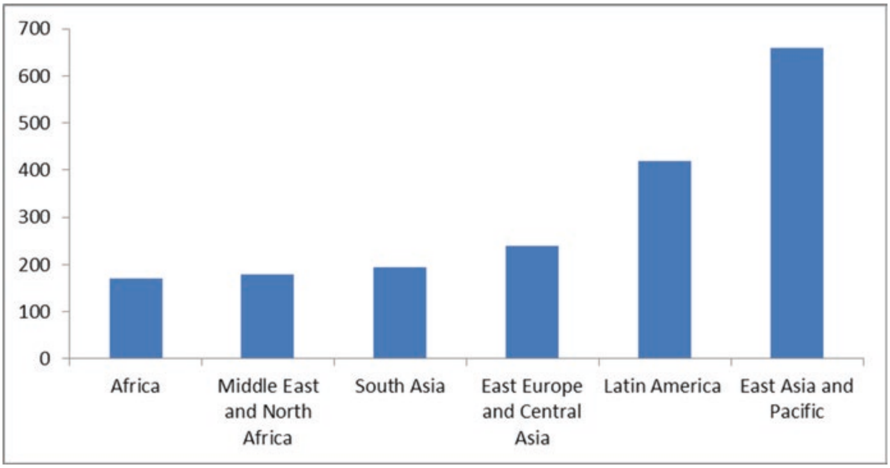

Fig. 2.1 Global solid-waste generation of 1000 tons/day (World Bank 2011)

growth in civilization because it does not address all appropriate issues (Global Recycling Network 2011) including ecological impacts to the environment. Global MSW generation surpassed 1.84 billion tons in 2004 and is estimated to have grown by 31.1 % in 2008 (Demand 2011), whereas cities in China alone generate more than 140 million tons. Figure 2.1 shows the global solid-waste generation.

Some 1.3 billion tons of Municipal Solid Waste (MSW) are generated globally each year, a volume that is increasing rapidly as urbanization, mass consumption, and throw-away lifestyles become more prevalent worldwide. The volume of MSW generated globally is projected to double by 2025 and continue to increase particularly in developing countries. The trend poses serious environmental and health challenges to cities worldwide. To the extent that MSW is not treated as a resource, in most countries it is not an indicator of economic unsustainability (World Bank 2011). Trends in solid-waste generation depend mainly on the living standard of the society, i.e., MSW issues are associated with difficulties and are “policy resistant” compared with other environmental issues. Research findings have proven that a higher living standard allows greater human consumption resulting in greater solid waste–generation capability (Odum 2006). Decreasing the amount of solid waste to be disposed into landfills or incinerated not only is a sound practice, it also decreases the incidence of occupational health problems (Nadal et al. 2009).

Solid waste–generation rates in developed countries were reported to be much higher than those of developing and underdeveloped countries. The generation of MSW in developing nations ranged from 0.25 to 1.97 kg capital per day (Bolaane 2006). However, in more developed nations, the per-capita generation of MSW ranged from 1.1 to 5.07 kg. The average per-capita generation at the global scale is 1.5 kg, and the total generation has increased with population expansion. This calculated to a total global solid-waste generation of 10.2 billion tons per day given a global population of 6.8 billion. In 2001, the average solid-waste generation in Gaborone, Botswana, was 0.33 kg per capita per day, whereas in 1990, each American had already produced approximately 1.97 kg per capita per day (Bolaane 2006). Four hundred eight million tons of MSW generated in industrialized countries in 1990 were contributed by North America (48 %), Europe (37 %) and the Pacific (15 %). MSW increased at an alarming rate in all areas within the period 1975 to 1990.

2.2.2 Malaysian National Trends of Solid-Waste Generation

The Malaysian per-capita average of solid-waste generation increased from 0.5 kg in the late 1980s to more than 1.3 kg in 2009 (Fauziah and Agamuthu 2009). In certain cities, such as Kuala Lumpur and Petaling Jaya, the per-capita generation had increased to 1.5 to 2.5 kg (Delarosa et al. 2006). To date, Malaysians generate approximately 30,000 tons of solid waste every day. The solid waste is mainly composed of putrescible waste (37 %), paper (27 %), and plastic (16.5 %) (Fauziah and Agamuthu 2003). The smaller portion of the solid waste contained wood, rubber, metal, glass, textile, and miscellaneous with contributions of 7 %, 2 %, 4 %, 3 %, 3 %, and 0.5 %, respectively (Hamid 2007).

At the later stage, in early 1980s, the management of municipal and industrial wastes was instigated at the national level by the government. The event led to the implementation of solid waste–disposal regulations, i.e., refuse collection and disposal, and the launch of a hazardous waste–management center (Fauziah and Agamuthu 2004). With increased awareness on environmental issues among the authorities in 1990s, the appropriate management of municipal and industrial solid waste took a high precedence that prompted greater financial provision. Various campaigns were launched to create awareness especially in promoting recycling activities (Saeed et al. 2009). The operation cost of MSW management had increasingly absorbed more and more of the total municipal budget over the years. The cost of collection and transfer of solid waste for disposal alone reached up to 60 %. To date, some municipalities' MSW management cost consumes more than 70 % of their income (Agamuthu et al. 2004). Figure 2.2 shows the solid-waste generation in Malaysia from 1985 to 2010.

Current solid-waste management in Malaysia highly depends on landfills. One hundred sixty-five operational landfills across Malaysia account for 95 % of Malaysian solid waste. The National Solid Waste Management Department of Ministry of Housing and Local Government (MHLG) reported that approximately 25,000 tons of solid waste are generated per day in Peninsular Malaysia (2012 projections) and that a great amount of food waste accounts for the municipal solid waste. However, industry value was estimated 476 million RM in 2005 and more than 600 million RM in 2011. There is already an established informal recycling network that covers every part of the SWM value chain from storage to disposal. However, collectors and middleman traders will "hoard" recyclables until the sell-

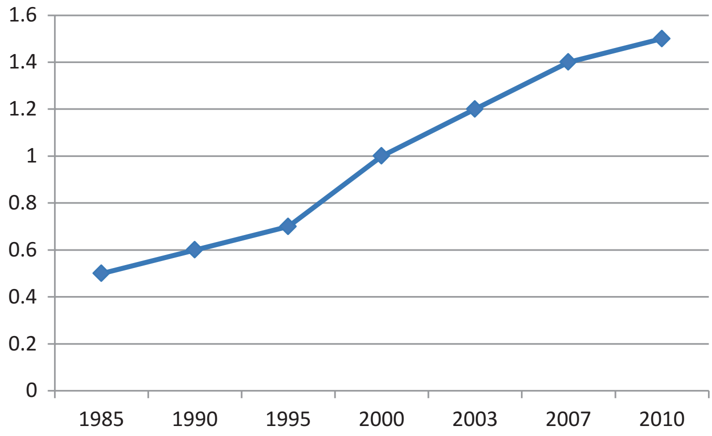

Fig. 2.2 Solid-waste generation kg/cap/day in Malaysia (Periathamby et al. 2009)

Table 2.1 Recyclable materials of Malaysian solid waste (Ministry of Housing and Local Government 2012)

Composition	Percentage (%)	Amount (ton/year)	Market price (RM/Kg)	Values (million RM)
Paper	17.1	1,026,000	0.20	205.2
Plastic	9.1	546.000	0.30	163.8
Glass	3.7	222.000	0.05	11.1
Aluminum	0.4	24,000	2.0	48.0
Scrap metal	1.6	96,000	0.50	48.0
Other nonrecyclable	68.1	4,086,000	–	–
Total	100.0	6,000,000	–	476.1

ing price is right, thus leading to feedstock issue for recyclers. The current recycling rate of 5 % is underestimated because recycling activities are still not regulated (thus, no proper data are collected). However, the recycling rate by market players is estimated to be greater then than 15 %. Table 2.1 shows the recyclable data and their market price obtained by Ministry of Housing and Local Government (Ministry of Housing and Local Government 2012).

The current landscape of MSW management in Malaysia is the privatization of collection of domestic and similar solid-waste and public cleansing with long-term concession (NF Sdn Bhd for central and eastern region). Figure 2.3 shows the solid waste–management hierarchy that begins with Reduces, Reuse, and Recycle and the collection of solid waste followed by pretreatments before disposal and, material recovery, recycling, composting, anaerobic digestion, incineration, gasification, ending with landfilling.

The possibility of solid waste undergoing the top options, as shown in Fig. 2.3, will prevent loss of resources by way of reuse, recycle and composting options.

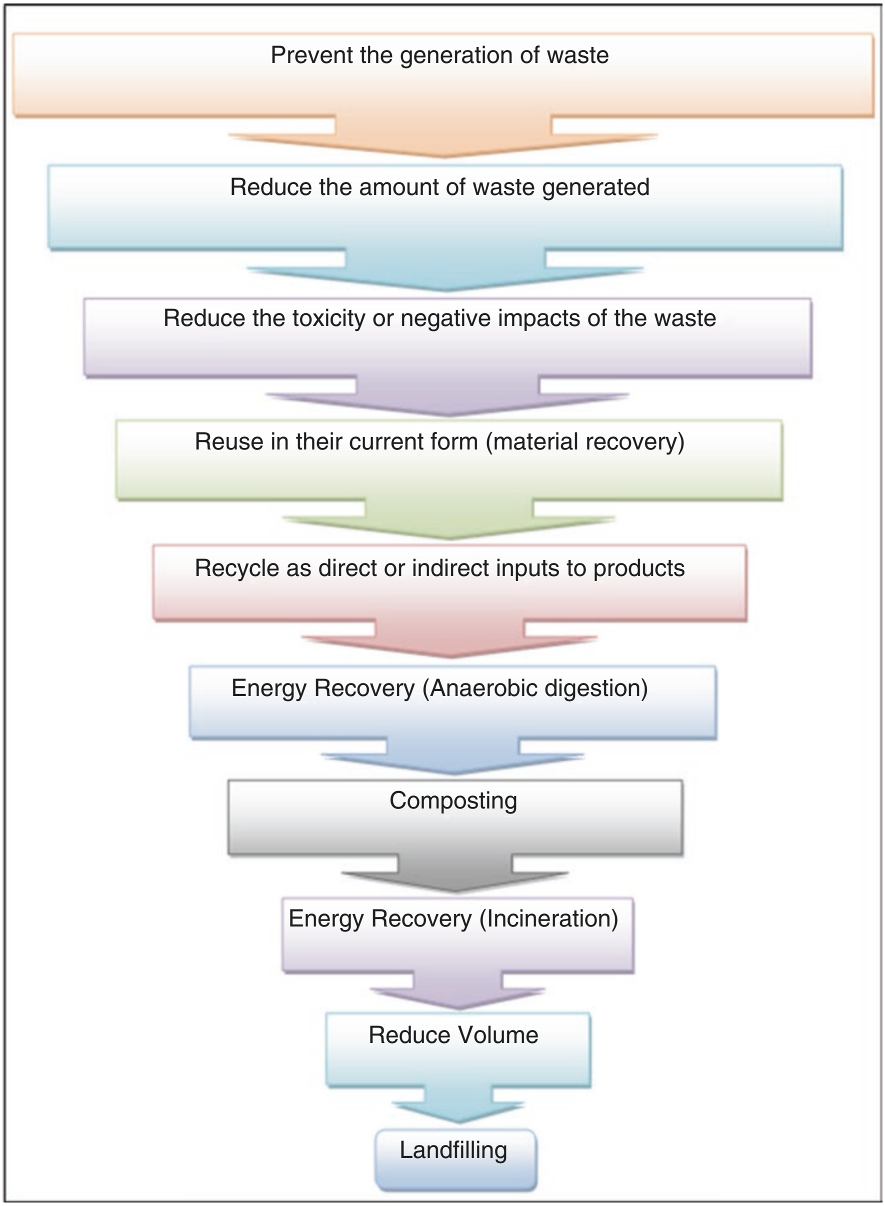

Fig. 2.3 Solid waste management hierarchy (Al-Salem 2009)

2.3 Sustainable Concept at Higher Education Institutes (HEIs)

One of the universities' biggest challenges is sustainable development in the twenty-first century. Due to different specification and expression of the existing model, universities strategies to attempt in sustainability illustrate several differences. Several universities are practicing to reach sustainable development (Alshuwaikhat and Abubakar 2008; James and Card 2012). The conception of HE (Higher Education) sustainability begun by Stockholm Declaration. It was the earliest statement of distinguishing of the humanity interrelationship with the environment (Reinalda and Kulesza-Mietkowski 2005). In recent years, Vare and Scott stated the decade of 2005–2014 as education decade of sustainable development, evidently identifying the vital requirement for integrating sustainable development concerns and platform interested in learning and education (Vare and Scott 2007).

A strategic assessment of HEs' sustainable development in England was published by Higher Education Funding Council for England (HEFCE) in 2008. It was declared that by the 10 years, HE sectors in England will be the most important associations of the social activities in sustainability achievement due to application of the graduated experts, research, share of business knowledge, and dealing with social and public roles. Sustainable development mentions that the significant tricks of HEIs are likely to be ecological, economical, and social viable. It was found that they will maintain to reach these specifications so also for upcoming generations (Armijodevega et al. 2008; Zhang et al. 2011).

Alshuwaikhat and Abubakar (2008) declared that HEIs should neither educate nor express environmental basis by recognizing and diminishing effects of the activities consequence. Their tasks in developing sustainability are verified in several features. Initially, distinct of institutions with a considerable area, HEIs regularly have a wide residence expertise with the extensive variety of topics. These topics are desirable for sustainability. Besides, local and international knowledge can be combined to generate synergies through the prospective of improving new solutions (Forrant and Pyle 2011; Zhang et al. 2011).

Next, the HE division is a fundamental generator of the next generation of leaders, researchers, and innovators. It performs a key task of spreading and instilling the practices and sustainability value by training future experts that will predict, support, and apply sustainability (Thompson 2005). Last, HEIs affect the other public parts by attractive outreach, commitment, and cooperation (Stephens et al. 2008). Although, the obstacles to reach HE sustainability are similar to other public sectors, as well as a non-sufficient projects budget, commitment, and time (Pittman 2004; Velazquez et al. 2006; Evangelinos and Jones 2009; Zhang et al. 2011).

Campuses converse with the challenge of sustainable development in several aspects. Therefore, variety of approaches as environmental-friendly functions are used for formulating principles, pointing declarations, establishing new institutions, and concentrating on the management and university mission in sustainable development. Another approach was employed by the University of Hertfordshire. Hertfordshire University recognized the tasks for a sustainable development by developing Sustainable Development Policy. Such a policy remarks environmental concerns in the category of most excellent value for money, health, safety, and equal opportunities (Summers et al. 2005; James and Card 2012).

Finally, it purposes to advance best practice corresponding with sustainable development within the local community and a number of universities, however, come out to conduct further activities, ethics, assertions, and environmental management system. As an instance, a vision of Sustainability in the University of Waterloo Canada declares that as a result of comprising a set of eligible specifications, greater sustainable community can be achieved (James and Card 2012). This vision of sustainability contains five fundamental keys as "Awareness, efficiency, equality, cooperation, and natural systems. The vision of sustainability encompasses social, economic, ecological and political issues as all equally important as they are inextricably linked in our everyday lives" (Ross and Wall 2004).

Eco-purchase scheme development raises sustainable producing procedures by leading all business in university through an environmentally in charge companies act a considerable task in conducting sustainable activities into the society. An organization of facility auditing has been executed and university parts will be persuaded to improve perceptions of sustainable development (James and Card 2012).

For example, University Technology Malaysia (UTM) as one of the biggest university campuses in Malaysia wants to express the platform of a sustainable community within its own capacity (Sopian et al. 2005) as below:

- Extracting infrastructure design and green building through a sustainable development agenda to attain cost-efficiency
- Optimizing university property and sustainable business opportunities to promote economic feasibility
- Raising sustainable available resources consumption, i.e., energy and water
- Minimizing pollution and waste through efficient solid waste management
- Presenting more local fauna and flora to enrich and protect biodiversity
- Healthy balancing between green areas and developed to achieve ecosystem vitality of the campus
- Enhancing low-carbon activities among the campus community
- Eliminating beverage, packaging, and nonbiodegradable food
- Enhancing quality of life and community spirit, reactive to global and local context in a conducive and harmonious campus environment
- Instilling reliability and principled ethics through voluntary services and permanent assurance at all community levels

- Encouraging services that understand the existing natural environment
- Enhancing a healthy and active existence within a protected environment

Integrated solid waste management systems are one of the greatest challenges to achieving sustainable developed campus. Conducting a solid waste characterization investigation is an important initial task of a successful SWM development and proceeding the HEI sustainability. In order to enhance behaviors of campus community in solid waste minimization, determining the quantity and mixture of solid waste generated in after campus operations are necessary. In addition, valuable SWM needs a comprehensive consideration of the solid waste composition as well as the sources that specify its genesis in the first step. Examining solid waste by creation source is principally essential; as the composition and characteristics of solid waste diverge refer its source (Tchobanoglous and Kreith 2002). Accordingly, SWM plans that are created on the existence of the producing resource are quiet more reliable than imitate programs that have been performed somewhere else (Armijodevega et al. 2008; Smyth et al. 2010).

Numerous solid waste characterization investigations have been conducted in household or municipal sections (Parizeau et al. 2006; Hristovski et al. 2007; Gomez et al. 2008; Chowdhury 2009; Philippe and Culot 2009; Zeng et al. 2010) while a few investigation performed for the institutional section, specifically in health care aspects (McCartney 2003; Mohee 2005) and even smaller number of investigations have assessed the solid waste composition within HE institutions (Mason and Goulden 2004; Felder et al. 2001; Armijodevega et al. 2008). Correspondingly, investigations of solid waste composition present a comprehensive understanding of a waste stream to local decision-makers that customized solid waste management programs locally (Davila et al. 2005; Smyth et al. 2010), solid waste composition investigations at universities and colleges recognize campus characteristics and locally appropriate opportunities for solid waste recycling and decline, demonstrating a vital step toward campus greening (Kim and Creighton 2000).

When suspiciously designed, investigations of campus solid waste composition are fairly economical and can make administrative support, collaboration between students, staff, and faculty and motivate further contribution in campus sustainability subjects (Castka et al. 2004; Beringer et al. 2008). As well as the general ambition to reach green campus, increasing solid waste disposal expenses and reduction of landfill area frequently require approaches of waste minimization at HEIs (Spellerberg et al. 2004; Smyth et al. 2010). A lot of HEIs utilize solid waste management actions, particularly recycling, as an initial step for sustainability scheme (Mason et al. 2003; Malkow 2004). Such a recycling activities definitely reduce the environmental protection expense for HEIs (Zhang et al. 2011). Table 2.5 summarizes continuing campus recycling tricks and programs in some HE regions. It should be considered that setting up environmental scheme such as recycling programs is a complicated activity (Richardson and Danehy 2007; Kaplowitz et al. 2009; Skouloudis et al. 2009).

2.4 Solid Waste Minimization and Recycling Experiences at Universities Campus

Solid waste management is a remarkable feature to address within the higher education perspective. Selecting appropriate strategy of solid waste management and planning of solid waste management systems should be conversant by the conception of the solid waste hierarchy (Wiedmann and Minx 2007). The emphasis of solid waste management practices on universities campus is regularly on recycling dynamism, whereas opportunities for source decreasing may be ignored. In a university situation, students and staff obey a rule to cooperate in source decreasing to avoid solid waste inflowing the waste flow, and their behavior is essential to the accomplishment of any plan which tracks to minimize waste (Tudor et al. 2008; Mihai and Apostol 2012). Research showed that solid waste minimization performance is impressed by environmental and social interests. Minimization of solid waste is likely to be intercepted by conception of inconvenience and time lacking, and considerably is associated with superficial control, conditional parameters, and motivation (Barr et al. 2004; Tonglet et al. 2004; Harris and Probert 2009).

Comparison of paper recycling economic aspect and wood as raw material (Pati et al. 2008) indicated that paper recycling is more economic than wood. Schmidt examined the solid waste hierarchy in Denmark comparing present state with scenarios of more recycled solid waste, consigned to landfill or incinerated (Schmidt and Haucke 2007; Amutenya et al. 2009).

Total recorded recycling rate from April 2009 to February 2010 was 23,427 kg in Malaysia showed that the recycling intensity was not high at National University of Malaysia (UKM). Results showed that controller neglected the beneficial paper recycling system (AlamFlora 2010; Elfithri et al. 2012). Regarding the importance of recycling, recycling target rate of campus was exceeded by 20% in 2010. The efficiency of recycling management in company with association of the universities society would have valuable effects on the university community's welfare. The initial objective is to achieve the goal of zero waste to realize a sustainable campus model. An investigation on paper recycling activities at the campus showed that the highest collection was in December 2010 which is 4886 kg while total collection was dropped to 331 kg in January 2010 due to the gap of communication between coordinators and collector (AlamFlora 2010; Elfithri et al. 2012). Figure 2.4 shows the rate of the paper collection by NF Sdn Bhd from April to February 2009.

The participating rate in collecting paper for recycling is still as low as below 50%. Such a low participation is due to the lack of coordination between participants leading to ignore the recycling activities. Consequently, the management is supposed to enforce community green rules to enhance recycling rate sequent with reducing disposal of solid waste. Results show that some of the offices can contribute more to the system of paper recycling (Elfithri et al. 2012; Eagan et al. 2008).

In order to have an effective municipal solid waste management in a campus, designing an appropriate system is necessary. According to Fig. 2.5, in order to design an appropriate solid waste management system in the campus:

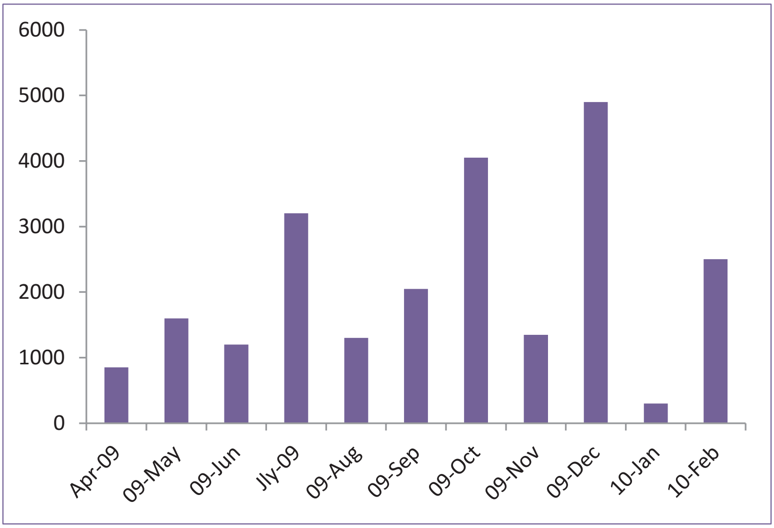

Fig. 2.4 Paper collection rate by NF (kg/month) (AlamFlora 2010)

A. Strive to consider environment and economic to decrease the environmental effects and economic cost
B. Knowing the composition and source of the solid waste generation to reduce it at source. Then, considering recycling, organic waste treatment methods, and energy recovery to treat the solid waste.
C. Defining the clear objectives, design the proper system and apply it in solid waste management.

Commonly, following ingredients are solution of successful environmental plans at HEIs:

- Finding how HEIs work, in particular how inter-decisions are taken
- Obligation and verified support for environmental tasks
- Adequate financial support
- An overall university management
- Sufficient knowledge and infrastructures
- Well-designed communications
- Consistent contractors

Previous researches illustrated a knowledge gap of recycling along with the University society on recycling materials, recycling location, and recycling method (Kelly et al. 2006; McDonald and Oates 2006; Kaplowitz et al. 2009). Availability of key information in different departments depends on the population of involved people in a HEI. To specify this key information and its availability, Thompson (2005) recommended defining a stable and small group of participants in all departments to the enterprise its effectiveness in relation. Increasing and supporting the

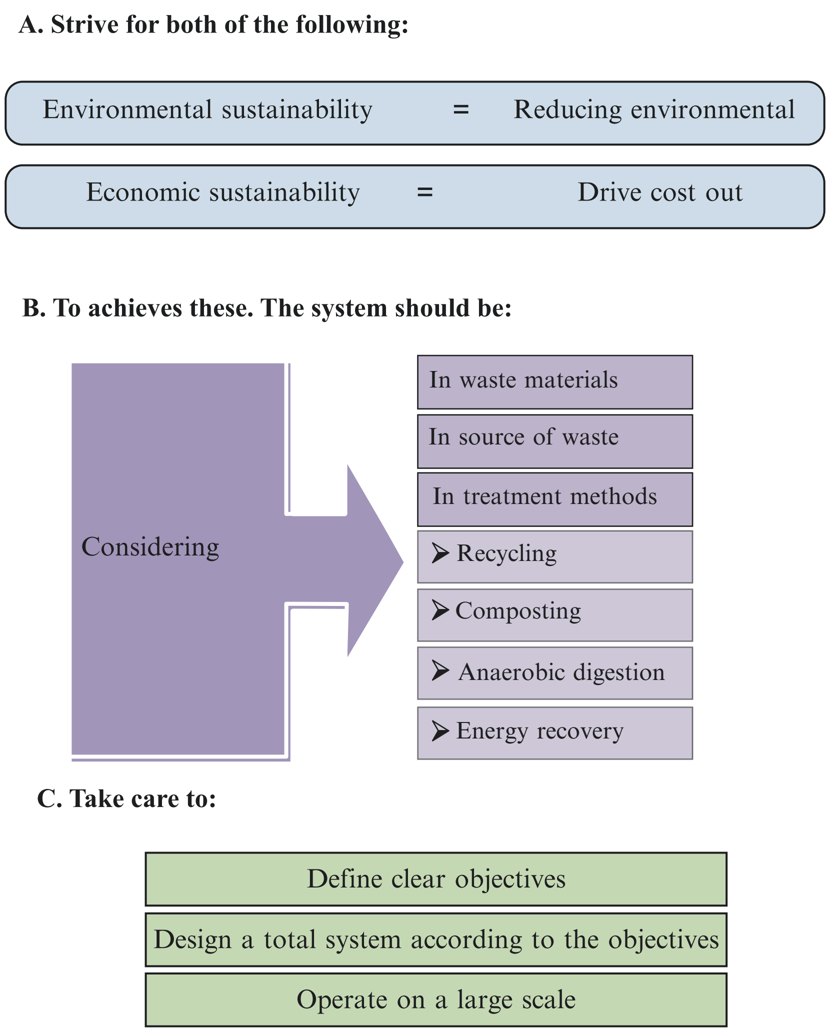

Fig. 2.5 The factors involved in designing an effective SWM system (Huang and Chang 2003)

contribution of an overall University community is essential in succession of recycling program in any campus (Kaplowitz et al. 2009). Accordingly, it is crucial to execute strategies that diminish barriers in recycling. Preceding investigations proposed a suitable infrastructure as well as playing a fundamental role (Youcai et al. 2004; Kelly et al. 2006; Zhang et al. 2011). Conversely, most investigations have focused on recycling activities (Williams and Gunton 2007; Amutenya et al. 2009).

Chapter 3
Solid Waste – Management Models

3.1 Municipal Solid Waste Management Models

Various models were introduced in solid waste management system with the capability to analyze or evaluate or predict future outcomes. LCA is necessary as a tool in evaluating environmental load generated from an activity or a product by means of identification and quantification of energy and material utilized, generation of solid waste emitted to the environment and the impacts.

Besides LCA, geographic information system is also applied in solid waste management in order to determine the most appropriate location for solid waste treatment technology (Skordilis 2004; Ghose et al. 2006; Shmelev and Powell 2006). Risk modeling is applied to access risks on municipal landfills. A simulation of a scenario with the implementation of taxes on virgin resources can also be derived from global model. Bruvoll reported its positive outcome which would offer potential improvements to the current solid waste management systems (Bruvoll 1998). Other techniques of evaluating solid waste management alternatives include the utilization of a variety of weighing application or percentage weight on relevant criteria. Therefore, it is essential that all factors are considered that an appropriate solid waste management system may be established to improve the current system or to replace faulty one. This will ensure the effectiveness of the selected solid waste management system that benefits the solid waste managers and other relevant stakeholder economically and environmentally.

The initial management models of solid waste were optimization models. Those models dealt with special features of the problem, like transfer station site, or vehicle routing (Tanskanen 2000). However, at those primary models a number of short comings were observed like setting only one period, recyclables rarely being considered, considering only one procedure choice for each recyclable type, or having

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a one generating source. Such margins lead them to an inappropriate long-term development (Morrissey and Browne 2004). Developed models since 1980s expanded the boundaries of the former models by adding a level to the solid waste management system. Improved models considered relationships of parameters in the system of solid waste management, instead of noting to each one in isolation. During 1990s, recycling and further methods of solid waste management were added to developed version of models to make a plan on municipal solid waste management (MSWM), like the models that were developed by Chang-Shya (2000) and also Banar et al. (2009). Other existing models also elaborate policy change in the sections that solid waste planning is being pressed by landfill reliance, unto more extensive techniques of solid waste management according to the bases of Integrated Solid Waste Management (ISWM) (Clift et al. 2000; Sabbas et al. 2003; Morrissey and Browne 2004).

ISWM pays attention to the complete variety of waste streams to apply reliable solid waste management options from a list of available practices to decide on the ideal practice based on environmental and economic characteristics of site (Marshall and Farahbakhsh 2013). Smith (2005) research also demonstrated that by the 1990s, few literatures were available in detail of costing information of integrated solid waste management systems. Formerly, it was explained that although the majority of solid waste management models include environmental and economic attitudes, the minorities of SWM reflect on public aspects. Sustainable system of solid waste management should have environmentally beneficial, economical, and socially adequate, as McDougall stated that an effective system of a solid waste management should be popular accepted system (McDougall et al. 2001; Morrissey and Browne 2004).

This capability was emphasized by Petts (2000) who claims that the most effective management of MSW should communicate with environmental, economic, and public priorities. This should pass the traditional consultative solutions by adding an expert to draft the primary solution of public association to make a more efficient solution by public participation prior to key choosing. However, a review of existing solid waste management systems revealed that the majority are classified as cost beneficial-based analysis group, life cycle-based assessment, or multicriteria-applied technique group such as AHP (Morrissey and Browne 2004). Following paragraphs describe summary of life cycle assessment literature as one of the most practical categories of MSW modeling categories.

3.1.1 Life Cycle Assessment

Recent regulatory options cannot exclusively diminish the effects of solid waste management practices. Existing reports indicate that life cycle is a successful solution to solve such a problem (Rebitzer et al. 2004; Niederl and Narodoslawsky 2008; Othman et al. 2013).

Various LCA researches (computer models of life cycle management and deterministic LCA) have been performed in an attempt to analyze and examine the management of solid waste systems and to find the most effective, appropriate, and sustainable choice from the evaluated set of disposal options (Lundie and Peters 2005; Rigamonti et al. 2010). The most significant concerns of these researches and surveys are the solid waste management problems related to safety and sustainability issues as well as the public health (Niederl and Narodoslawsky 2008).

If solid waste management wishes to reach this objective, it has to decrease the overall amount of resources it consumes as well as the environmental difficulties. For this purpose, usually a solid waste hierarchy is proposed and employed for modifying the policies of solid waste management. Different types of modifications for solid waste hierarchies are available (Björklund and Finnveden 2005). An area of waste hierarchy to which special attention has to be paid is the identification of issues for which particular measures have to be taken. In order to show how the alternative managements perform in the process of making a decision, the economic, environmental, and technical aspects have to be critically assessed (Björklund and Finnveden 2005; Banar et al. 2009). This makes LCA a beneficial and useful instrument in the systems of solid waste management. It particularly is employed in identifying the significant areas and issues in hierarchy waste management as well as the overall environmental effects. Based on ISO 14020 standards, LCA hase four main stages which are: describing and defining the goals and scope; the inventory of life cycle; evaluating and interpreting the effects; and additionally assessing and providing opportunities for the improvement of the environment (Finnveden et al. 2005). Currently, many nations are investigating and employing the concepts of life cycle assessment in assessment of modification choices in particular solid waste fractions (Liamsanguan and Gheewala 2008a, b; Al-Salem 2009; Banar et al. 2009). Therefore, life cycle assessment is a holistic evaluation methodology and a useful instrument in the documentation of environmental consideration that has to be included in the decisions made about moving toward sustainability (Liamsanguan and Gheewala 2008a, b).

When the effects of systems, processes, services, and products on the environment are being determined, their impacts in relation to other issues such as the consumption of material, the usage of energy and the environmental emission on the ecosystem and humans during each factor's life cycle is also determined. Through LCA, the effects of the examined systems, processes, and products during their life cycle is being determined. This investigation is explored the researches about systems of solid waste management which were conducted in various countries, namely, a number of Asian countries, underlining some frameworks which could be employed as indicators pointing toward options that lead toward sustainable MSW management in the future. This survey also tries to identify areas of municipal solid waste management that require consideration, improvement, and advancement since LCA had previously been employed for investigating and utilizing benefits and advantages that consist of renewable energies obtained from solid waste (Khoo 2009; Čuček et al. 2012).

The majority of data employed in the inventory of life cycle has been gathered from the available researches on the solid waste. The outcomes of these researches present some opportunities for the assessment of solid waste systems from a life cycle view point. However, a number of shortcomings and limitations have been indicated by authors who have advised to be cautious with the employment of this framework for reaching decisions in the issues of management of solid waste. From these limitations, underlines the investment costs and some other social indicators as huge disadvantages in the employment of this framework for making important decisions. An appropriate LCA needs data that is comprehensive as well as high levels of professionalism (Čuček et al. 2012). Thus, the goal and scope of life cycle assessment has to be properly explained and has to be realistic, and the LCA project itself has to be justifiable. System limitations should be taken into account and the process of collecting data has to be made simpler in a way that will not damage its level of standard. This includes suppositions and beliefs that might be subjective and therefore limit the absolute validity in the verification of the assertions. According to Arena`s report, if we want to use the outcomes of LCA in the process of making a decision, the analysis must be done on data with high degrees of quality and the analysis process itself must be firm and comprehensive (Arena et al. 2003).

Life cycle assessment is the new method most researchers employ to display the solid waste management attributes including the safe disposal of the SW or treatment, recovery, collection, minimization, or reduction (Banar et al. 2009). The latest models of LCA employ International Organization Standardization (ISO) series of 14044, 14041, and 14040 for the assessment of LCA course of action like the LCI (Life Cycle Inventory) along with the assessment of systems and products LCI (or LCIA; that is, Life Cycle Inventory Assessment) (Niederl and Narodoslawsky 2008; Khoo 2009; Shekdar 2009). LCA has essentially been based on four steps: defining the scope as well as objectives, LCI, LCI assessment and interpreting outcomes within the fixed goals of the evaluation (Finnveden et al. 2005). This is helpful for the planning along with optimizing the choices of the management from the available options (Liamsanguan and Gheewala 2008a, b).

LCA can successfully be employed in the systems of solid waste management for the identification of the general environmental problems while providing a framework that is helpful for comparing the varied technologies, methods, and strategies available for the Integrated Waste Management (IWM). Regarding the definition of sustainable development recognizes social as well as economic, resource, and environmental dimensions; these features are common to most attempts to capture the concept of sustainable development. However, decisions which involve life cycles associated with a specific installation either selecting a technology for a pre-identified site or in the most difficult case, containing both technologies and site among several options require compound life cycle assessment tools such as Environmental Impact Assessment. Under ISO 14042, the life cycle impact assessment standard, three general categories of impact including the commonly used resource, the consequences of human health and ecological consequences should be considered when the scope of an LCA investigation is defined. Impact categories are made of stratospheric ozone depletion, acidification, noise, water use, climate change, and eutrophication.

3.1.2 *Using Life Cycle Assessment Models*

Computer patterns have come to be favored devices to help LCA professionals gathering, arranging, and analyzing data. Many LCA investigations use computerized patterns which have been reviewed in order to make model of the systems of waste management beside the prediction of effects and emissions pertaining to environment. Sometimes the writers of the studied LCAs either took part in the development of the patterns or connected to institutions that they were developed by. Investigations which clearly give reasons for choosing specific model of LCA are those by Aye and Widjaya (2006), Buttol et al. (2007). Nowadays, regarding the LCA the newest version of Sima Pro is used, because it has a full library to help for analyzing and it's a new contribution to use this software for municipal solid waste management potential impacts.

Satisfying the requirements of ISO 14044 together with principles for LCA would make the published LCA readers more aware about the restriction of system, methodologies, and hypothesis of investigations and facilitate the interpretation of results on the basis of comparing different LCAs. Nevertheless, different options selected by practitioners of LCA do not seem to affect the arrangement of the favored choices for MSW treatment significantly. Figure 3.1 shows the reviewed

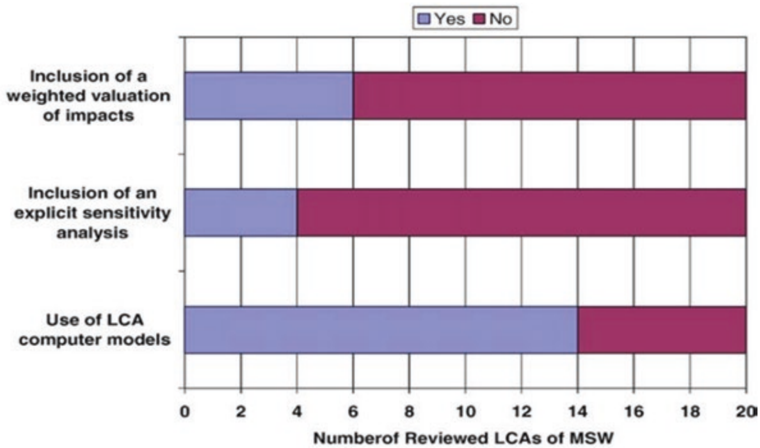

Fig. 3.1 The reviewed LCAs of MSW-management systems including weighted valuation of impacts, sensitivity analysis, and LCA computer models (Cleary 2009)

Table 3.1 Solid waste management methods (used in Thailand-Phuket)

Functional unit	Scenarios	Results
Treated MSW (1 ton)	S1: 71% burned, 26% fill in, 3% recycled	Landfill contributes the majority to global warming effects
	S2: 30% (garden and food waste) separation at origin and recycling, 70% combustible particles, remaining particles landfill disposed	
	S3: 30% (garden and food waste) separation at origin with anaerobic digestion, 70% combustible particles and remaining particles disposed	S4 is the top SWM choice for this area
	S4: separating at origin, 30% recycled, 30% of garden and food waste anaerobic digestion, 70% combustible particles and remaining particles disposed	

LCAs of solid waste management systems including weighted valuation of impacts, sensitivity analysis, and LCA computer models.

Different methodologies of European investigations as a literature are available to compare different aspects. Therefore, different LCA analyzes in some Asian countries are added to the literature. Tables 3.1, 3.2, 3.3, and 3.4 illustrate summary of solid waste management methods in some case investigations (Othman et al. 2013).

The junior levels of utilize of toxicological effect categories are perhaps not surprising while the uncertainties related to them are large relative to the more popular classes such as global warming potential. System boundaries, assumptions, and LCA software could lead one to look forward to no consensus involving to the environmental efficiency of solid waste treatments in combined waste systems. However, the weighted outcome of the reviewed LCAs leans to verify the validity of the "hierarchy of waste." Correspondingly, the outcomes of the statistical analysis of eutrophication and global warming potential indicate better environmental efficiency of thermal treatment scenarios than landfilling, while the outcomes of the more loosely defined combined treatment scenarios indicate a smaller amount of clarity. The global warming potential demonstrates the negligible variation in the comparative inconsistency between the three scenarios (Cleary 2009).

The eutrophication potential outcomes from landfilling scenarios also demonstrate lower variability than the results of the other scenarios. The deviation in the solid waste treatment mixture of the combined treatment scenarios is considerable in the results. In contrast, the more homogeneous combination of thermal treatment and landfilling scenarios generally consequence less statistical deviation. A method with substantial variations in utilization of LCA provides more reliable results compared to the thermal treatment and landfilling scenarios (Cleary 2009). The sequence of paragraphs will describe Analytical Hierarchy Process as another method which is used in this investigation.

Table 3.2 Solid waste management methods (used in China-Tianjin)

Functional unit	Scenarios	Results
The MSW disposal collected at central zone (Tianjin, 2006)	S0: as principle existing treatment, 98.9% for generation at power plant, 49.5% of in monitored LF are disposed with no LFG operation, and the remaining solid waste was open discarded. Current system did not include source separation.	S6 combines all GHG decreasing alternatives indicates the best solid waste management alternatives as GHG emissions are decreased about 40% in comparison to S0
	S1: LFG operation; LFG plant is prepared through LFG collection, promotion, and conversion method. LFG is supposed to generate electricity	
	S2: burning with no energy recovery; all the MSW for generation at power plant	
	S3: materials recycling 8.67% paper, 0.42% metals, 1.3% glass are supposed to be treated in MRF generating subsidiary materials (30% supposed combined waste), and 48.9% for generation at power plant and the rest to dispose with no LFG usage	
	S4: centralizing composting; including 50% kitchen waste for separation at origin and collecting for composing, digested material utilized as fertilizer, 48.9% for delivering for generation at power plant and the rest to dispose with no LFG usage	
	S5: anaerobic digestion; including 50% kitchen waste for treating in an AD plant, generated biogas is applied for power generation and the digested materials is applied as fertilizer. The remaining waste is disposed with no LFG usage	
	S6: integrated system is used to diminish GHG emissions through ISWMS. Thirty Percent of glass, metals, paper, and plastics are recycled. Fifty percent of kitchen waste is separated at origin for treating through AD. 48.9% of MSW is applied for power generation and the rest waste is disposed among LFG usage	

Table 3.3 Solid waste management methods (used in Turkey-Eskisehir)

Functional unit	Scenarios	Results
1 ton of MSW	S0: Recent solid WMS; including recycled materials (0.71% glass, 2.04% paper/cardboard, and 0.25% aluminum) were separated using scavengers and deliver straight to the reoperation facility. The rest, 97%, was collected taken to an unregulated deposition area	Composting scenario demonstrated more environmentally desirable
	S1: The basis of S1 is recent SWM method; integrating some enhancement by material recovery facility (MRF) and adding landfill to the method. The recycling and landfilling percentages are equal to the recent SWM method. Three percent of recyclable material was collected through scavengers to deliver to the MRF, at the landfill area. 4.30% of recyclables were separated in the MRF. These two fractions were processed individually due to differences in their qualities. Subsequent to separation, particles are delivered to the recycling facilities at other cities. Recycling usefulness for these materials are 80% and 70% for the particles brought through scavengers and those separated in the MRF, correspondingly. The remaining, after the recycling procedure, were landfilled in the city of the recycling area. The rest of waste (92.70%) was landfilled in Eskisehir	Methane (CH_4) releases mostly from landfill to photochemical ozone depletion. However, the global warming impact generally consequences from carbon dioxide (CO_2)
	S2: An origin separation method with efficiency of 50% was added as a development to Scenario 1. The recyclables got from origin separation (9.72%) were delivered to the MRF, and following processing they were transported to the recycling facilities in other cities, at an efficiency of 92%. The recyclables mixed with organic waste were also delivered to the recycling facility with an efficiency of 70%. Next to the recycling procedure, residuals were delivered to the landfills	
	S3: This scenario considered the recovery of the biological degradable portion. The flow of the method is the same as Scenario 2 for recyclable particles, whereas organic fraction (77%) from the MRF is delivered to the composting facility. The residue (8.24%) from the MRF is delivered to the landfill	
	S4: An incineration procedure was added to the method as a substitute of a composting facility where the wastes and all organic wastes from the separated recyclables are delivered to the incinerator (85%)	
	S5: all MSW is delivered to the incineration facility (100%)	

Table 3.4 Solid waste management methods (used in Kuwait)

Functional unit	Scenarios	Results
The quantity of MSW produced in the Kuwait state	S1: Includes three main procedures: collection, delivery, and landfilling of solid waste	Biological treatment was the best alternative with the least environmental effects (minimum global warming and acidification potential) due to the reduction of greenhouse gas releases with energy generation as a consequence of anaerobic digestion and landfilling step has more environmental load
	S2: Adding to the existing scenario (1) as thermal treatment process (incineration with direct energy recovery) was carried out after the material recovery procedure. The thermal unit is set with 30% electrical recovery performance and 5% presort residue	
	S3: Utilizes anaerobic digestion prior to landfilling	

3.2 Application of Analytical Hierarchy Process in Municipal Solid Waste Management

Solid waste disposal is a complicated and multidisciplinary issue from social, environmental, technical, and economic aspects. MCDM is a division of general category of systems that enhance the decision-making by utilizing several criteria (Kahraman 2008). Analytical Hierarchy Process (AHP) is a commonly used method to resolve solid waste management problems. The characteristic of AHP is that it facilitates choosing the best alternative among several alternatives by assessing numerous criteria. Many approaches are available for solving environmental problem with multiple criteria, including the AHP method (Geldermann et al. 2000; Chiou and Tzeng 2002; Kahraman 2008). AHP as a multicriteria technique is based on the aggregation procedure and hierarchical formation (Saaty and Vargas 2008). Different evaluation scales are the basis of AHP that verify the significance of options on the subject of each criteria and their fraction. All the weights are calculated in a pairwise comparison according to a one to nine scale for quantifying verbal expressions (Contreras et al. 2008).

Multicriteria approach helps decision-makers to find the problem and choose appropriate alternative practices of some options. The regular approach is used to recognize evaluated options (like various solid waste management scenarios) in terms of important criteria of the developed situations within the result of the alternative ranking. The goal of the model leads the management to select criteria type. Consequently, selected criteria consist of environmental effect or risk assessment (Aguaron et al. 2003; Escobar and Moreno-jiménez 2007; Dağdeviren 2008; Morrissey and Browne 2004).

Based on recent investigations, AH is seldom applied in regard to linguistic variable weight, namely, linguistic hedges. The potentials of the AHP method is considered in evaluating the properties by means of systematic and simple manner as well as the ability of dealing with range of input data (i.e., quantitative, crisp, and qualitative) in the decision procedure (Tarmudi et al. 2010).

Analysis of multicriteria solid waste management systems proofed that AHP is the most regularly applied method for solid waste management solutions (e.g., Kajanus et al. 2004; Morrissey and Browne 2004). Furthermore, the AHP method is applied in some other utilizations (e.g., Li and Li 2009; Morrissey and Browne 2004; Hung et al. 2007) while Sadok et al. (2009) identified other methods that could be used in solid waste management models.

Reversing the rank in comparative measurements raised in practice because of the quality and number of the other options. Therefore, relevant options are not capable to be integrated in the multicriteria situation as they would compose with a dependent option to the other (Saaty and Peniwati 2010). Although AHP is one of the favorite approaches in multicriteria system (e.g., expert choice), little purpose is known to SWM solutions. Fourth priorities was found by utilizing AHP for conserved land by preparing crisp outcomes, in consists of significance properties and qualities (Aull-Hyde et al. 2006; Contreras et al. 2008). The established performance of the AHP software is named Expert Choice, while the AHP technique is extensively utilized in SWM issues. Expert choice is software that calculates the weight of criteria, sub-criteria, and alternatives according to questionnaire as input (Perera and Costa 2008). However, other researchers showed that the AHP technique has been effectively applied to make a decision in solid waste management. In the following paragraph, Cluster Analysis method is described which is done to combine AHP and LCA in this investigation (Renou et al. 2008; Morrissey and Browne 2004).

3.3 Cluster Analysis for Solid Waste Management Methods

Cluster analysis which is the process of selecting of objects is named clustering, in summary. In clustering, located objects in a group are more similar (in some sense or other) to each other than the other groups. It is a key task of tentative data removal, and a regular practice to analysis data, statistically (Eldridge et al. 2006).

Cluster analysis is the main practice to classify a "mountain" of information into controllable meaningful piles. In addition, it is a tool to decrease data by creating subgroups to manage data more conveniently than individual data. Similar to factor analysis, it tries to find any interrelationships between variables (Kaufman and Rousseeuw 2009).

Cluster Analysis technique is a multivariate method which initially intends to set a group of objects based on their characteristics (Hair 2009). Cluster Analysis classifies groups of similar objects in the same Cluster Analysis, based on some prearranged selection criteria. The outcoming Cluster Analysis of objects is supposed to exhibit high internal (within-Cluster Analysis) homogeneity within high external (between-Cluster Analysis) heterogeneity. Therefore, successful classification, will illustrate the objects within-Cluster Analysis together in a geometrically plot, and different Cluster Analysis are showed far apart. The variable of the Cluster Analysis establishes the "character" of the objects since it comprises just the variables applied in objects comparing (Cen et al. 2013).

After evaluation Cluster Analysis the results can be arranged into some groups, appropriately. Next, the view of groups can be explained, as a substitute of individuals. It also could synthesize the outcomes by ranking those groups individually (Huang and Ma 2004). As it concentrates on the improvement of the integration system, the case analysis proposes some suppositions of database usage, which is a type of most important limitation. Establishing local database helps to reach more practical outcomes (Chen et al. 2013).

Cluster Analysis technology as a multivariate data analysis approach combines quantitative and qualitative method, AHP and LCA, respectively, to assess the environmental impacts.

3.4 Requirements of Solid-Waste Management

Sustainable development is the biggest challenge for campuses in the twenty-first century. Higher education institutes (HEIs) should not only educate but also demonstrate environmental principles and stewardship by taking action to understand and reduce impacts that result from their activities. Integrated solid waste–management programs are one of the greatest challenges to achieving campus sustainability. When carefully planned, campus solid waste–composition investigations are relatively inexpensive and can generate administrative support, cooperation among students, faculty, and staff, and inspire further involvement in campus sustainability issues.

Feasibility analysis should be conducted by solid-waste managers to predict the future revenue and cost to be faced. In addition, different methods regarding solid waste–management hierarchy in the university campus should be considered to determine the optimum method of solid-waste management. Concerning the environmental sustainability of MSW-management systems, energy and resource conservation and reduced environmental impacts are desirable. To evaluate the performance of MSW-management systems as well as suggest applicable options for industries and institutes, a combination of economic analysis with modeling of different solid waste–management methods using LCA is a useful tool.

AHP is one of the preferred methods for multi-criteria assessment (e.g., expert choice), but little application is known about solid waste–management problems. The application of AHP as a tool to bring forth preferences toward preserved land provides crisp results on the relative importance of the attributes and qualities. AHP is based on different evaluation scales to determine the importance of alternatives regarding each criteria as well as criteria weights. All of the weights are calculated through pairwise comparison based on a scale of 1 to 9 for quantifying verbal expressions. Environmental and economic criteria are chosen as the main criteria in this investigation, and cluster-analysis method, which is done to combine AHP and LCA in this investigation, is described.

Chapter 4
Solid Waste–Management Design

4.1 Overview of a Solid Waste–Management Plan

Institutional waste was investigated at the pilot campus in the first step of the design. In the next steps, a life-cycle assessment (LCA) and analytical hierarchy process (AHP) were carried out to assess the potential of environmental impacts and to consider the economic aspects of solid-waste management.

Then cluster-analysis method was applied to combine the results of the environmental and economic analysis. LCA and AHP were combined by the cluster-analye method to generate a reasonable assessment of solid-waste management at the campus from the in points of view of the environment and the economy simultaneously.

This chapter illustrates the following details:

- Solid-waste sampling
- Determination of domestic-waste composition
- Recyclable materials collected at the source
- Description of garden-waste generation
- Data collection and estimation of construction- and electronic-waste generation at the campus (in 2011)

4.2 Current Solid-Waste Management

Approximately 7 to 8 tons solid waste is generated at the campus per day. There is a unit called "Landscape" under the Department of Development and Maintenance (DDM), which is responsible for solid-waste management at the campus.

A private company has been contracted to collect and transport domestic waste for disposal. Three motorcycles and one compactor truck owned by the contractor

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are responsible for solid-waste collection at the campus. This domestic waste is transferred to a refuse-derived fuel (RDF) facility for disposal (DDM 2011). Furthermore, six contractors under the Landscape Unit are responsible for collecting the garden waste generated at the campus. Garden waste generated during gardening and grass cutting are put in the bags and left beside the road by cleaners and workers. These bags are collected by the contractor's truck one or two times a day and then transferred to the disposal area at the back of the Faculty of Education of the campus.

Construction waste generated at the campus is managed by the DDM. Based on the number of buildings under construction, several contractors are responsible for collecting and transporting the construction waste for disposal. Collected construction waste is disposed of in an open landfill located 12 km from the campus.

Electronic waste generated at the campus has been managed by a unit called the "Assets Unit." Electronic waste generated by different solid waste–generation sources at the campus is collected by this department. According to the value of electronic waste, two committees under the Assets Unit make decisions about the sale or disposal of electronic waste during the year.

4.3 Improving Solid-Waste Management

To improve the solid-waste management by the campus and achieve the goals of the investigation, five steps were defined as a methodology, which is explained in following paragraphs. In addition, Fig. 4.1 shows the structure of the methodology, which is applied in five steps of the investigation. More details to explain the framework of the proposed design are available at Sects. 4.5–4.9.

Step 1: Primary and secondary data are used in this investigation (Fig. 3.1). Primary data were obtained from three separate investigations in 2011 to attain solid-waste composition at the campus, which is described below.

- Results of the investigation on "domestic waste composition of the campus" 2011. In this investigation, solid waste generated—such as papers, plastics, organic wastes, metals, and others from faculties, dormitories, cafeterias, administrations, services, and residential areas of the campus—were weighted and separated between 14 and 25 April 2011.
- Results of the investigation on "recyclable materials collected at the source" in 2011. Recyclable materials—such as paper, plastic, and metals--collected from different solid waste–generation sources at the campus were measured between 14 and 25 April 2011.
- Results of the investigation on "Garden-waste generation at the campus" in 2011. Garden wastes—such as grass, branches, and fruit generated from gardening activity of the campus—were weighed between 14 and 25 May 2011.

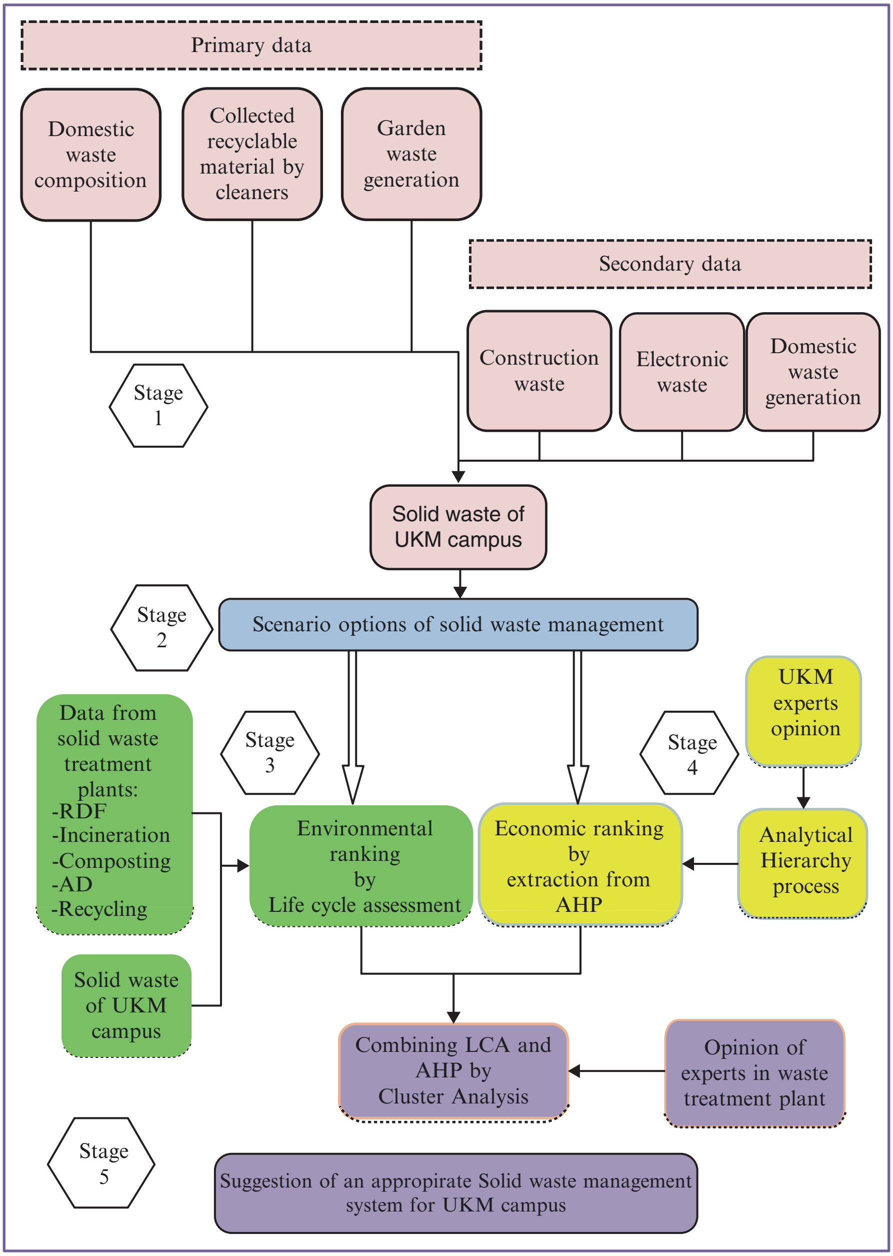


Fig. 4.1 Structure of the planning process

Secondary data in this investigation included data collected from records and documents of the contractor (Natural Florae, NF) and the DDM, which are described below.

– Data on construction waste (e.g., solid waste generated at campus construction buildings) were collected from existing records from 2011 in the DDM as well as from previous investigations.
– Data on electronic waste and electronic-waste records (e.g., printers, monitors, keyboards, mice, and CPUs) were obtained from the Assets Unit during 2011. The Assets Unit is the department responsible for electronic-waste management at the campus.
– Data on domestic waste–generation data, regarding daily domestic waste generated by the campus, was obtained from documents and records of the DDM and NF for 2011.

Step 2: According to solid-waste composition, scenario options are defined for the solid-waste management of the campus. They are compared with each other in economic and environmental points of view using LCA and AHP methods.

Step 3: To assess the potential environmental impacts of these scenarios, an LCA is applied. In this investigation, the solid-waste composition of the campus as well as the environmental inputs and outputs of solid waste–treatment technologies (RDF, incineration, composting, anaerobic digestion plant, and recycling facility) were input in to SimaPro 7.3 software to perform an LCA.

Step 4: Expert opinion is considered using the AHP method to rank the solid waste–management scenarios. Scenarios are compared in terms of economics and environment al impact. Extracted economic results from the AHP are applied in the next step.

Step 5: Environmental results from LCA and extracted economic results from AHP are combined using the cluster-analysis method. Finally, the most appropriate scenario is suggested for solid-waste management at the campus according to the results of the cluster-analysis method.

As Fig. 4.1 illustrates, step 1 is indicated by pink boxes; step 2, by blue boxes; step 3, by green boxes; step 4, by yellow boxes; and step 5, by purple boxes.

Figure 4.2 summarizes and introduces the relationship of each method with the defined goals. Therefore, the results of goal 1 are applied to perform LCA to achieve goal 2. Then expert opinion is considered in the AHP analysis to achieve goal 3. Finally, results of goals 2 and 3 are combined to accomplish the final objective.

4.4 Data Resources of the Investigation

In this investigation, different types of data collection were collected to achieve the objectives. These include primary data, secondary data, data for LCA, and data for AHP. Figure 4.3 shows a general overview of these objectives, methods, and data.

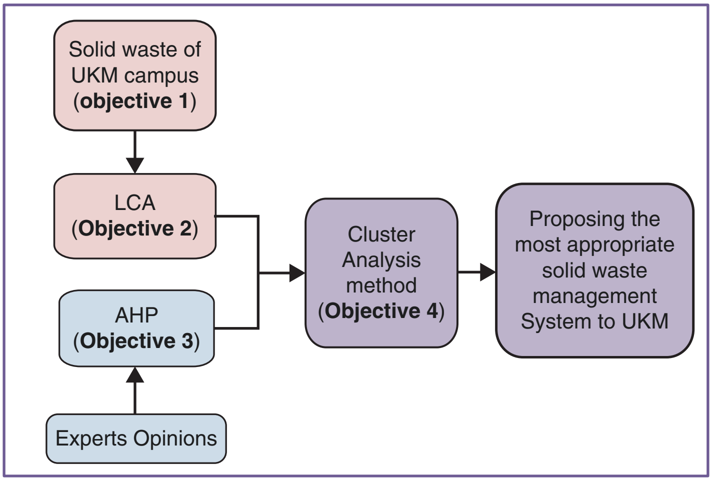


Fig. 4.2 Relations between goals and methods

Figure 4.3 shows the primary data of the investigation, which includes data from three investigations of solid-waste composition to achieve goal 1.

The secondary data includes gathered data from documents reviewed at the DDM, NF, and environmental input and output records of solid waste–treatment facilities. The different stages to achieve the goals of the investigation are explained in following paragraphs.

4.5 Solid-Waste Generation and Composition of the Campus

According to the structure of the methodology (Fig. 4.1), three different investigations—of the domestic waste, the garden waste, and the recyclable materials—was performed in 2015 to determine the solid-waste composition at the campus. Details of those investigations are explained in following paragraphs.

4.5.1 Domestic Waste

To determine the domestic-waste composition at the campus, all solid waste–generation sources are categorized in six different sources. These sources include faculties, dormitories, administrations, cafeterias, services, and residential areas. Then 20 % of each category is selected as sampling points. A procedure of the

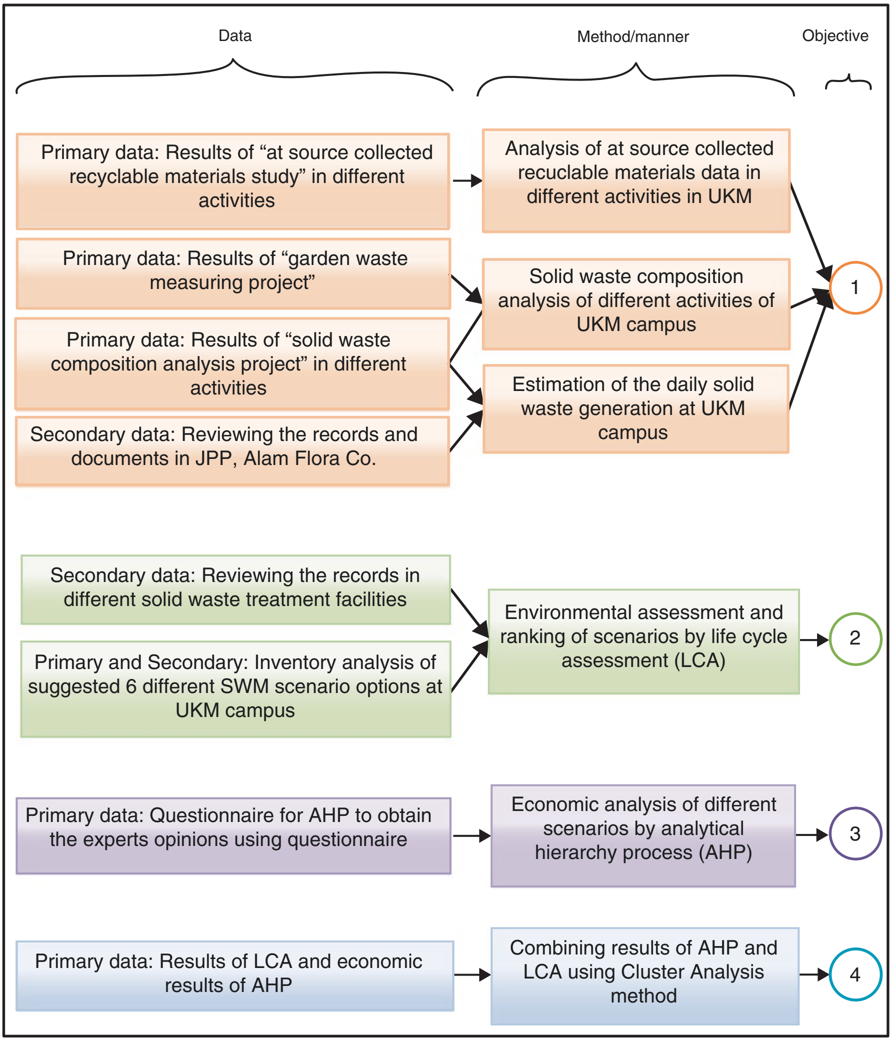


Fig. 4.3 A general overview among the objectives, methods, and data

domestic waste separation is prepared and a suitable location inside the campus is allocated to do domestic waste separation. Figure 4.4 shows the structure of the four functions for the domestic waste–composition investigation at the campus.

4.5.1.1 Categorizing of Solid Waste–Generation Sources

To obtain a reasonable result of domestic-waste composition in different solid waste–generation sources of the campus, the solid waste–generation sources are divided into six categories. The sources are defined according to faculties, dormitories,

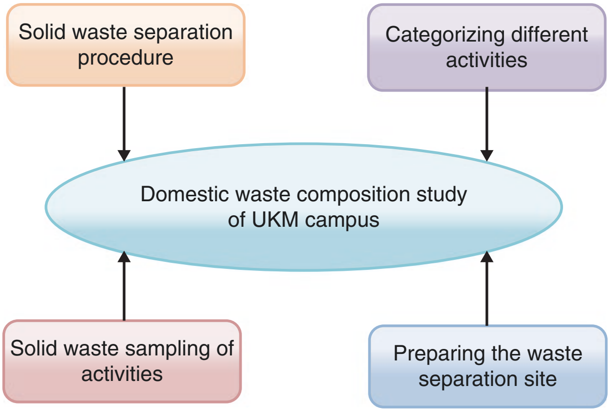


Fig. 4.4 Structure of domestic waste–composition investigation at the campus

cafeterias, administrations, services, and residential areas. Approximately 20 % of each category was selected as sampling points.

To select the most representative sample, waste was chosen according to points. These collections of solid waste form a single activity. These collections are not mixed with waste from other sources. At some waste-collection points, domestic waste from several buildings or sources is collected in the same location and mixed together; therefore, they are not a suitable sample of a single collection activity.

After visiting and investigating the waste-collection points at the campus, three sampling points for cafeterias, with two sampling points for faculties, dormitories, administrations, and services, were chosen for this investigation.

To choose the date of sampling for the domestic waste–composition investigation, the records of domestic-waste generation at the campus (report of weighing the compactor lorry of NF before reloading the waste) were reviewed.

The records showed that the amount of domestic waste in a year fluctuates. The campus generates the lowest amount of domestic waste during the semester break and the highest amount of domestic waste during the semester session. Therefore, according to ideas of the experts in domestic waste–composition sampling, the worst condition regarding the amount of solid-waste generation should be considered as the sampling date. Because the peak solid-waste generation at the campus occurs during the semester session, this date was selected as the sampling duration in this investigation.

4.5.1.2 Domestic-Waste Sampling

According to the locations, situations, and the number of sources, two or three sampling points were chosen to cover all solid waste–generation sources except hazardous waste at the campus (20 % of all numbers for each activity). Domestic-waste samples were separated, and the data were registered and recorded during the sampling period.

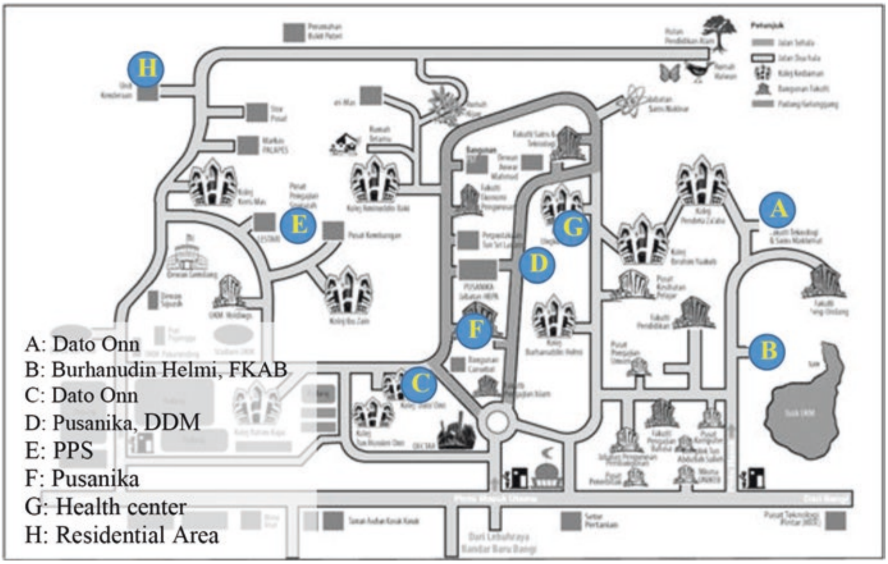


Fig. 4.5 Sampling points of the campus

Faculty

There are nine faculties inside the campus. Figure 4.5 illustrates the selected faculties as sampling points (FKAB and FTSM). Both locations were selected as sampling points for this activity because they are totally isolated (i.e., solid waste from only one activity) from the other sources.

Dormitory

There are 10 dormitories inside the campus housing 9315 students (Fig. 4.5). The domestic waste in waste collection points comes especially for dormitories and waste and is not mixed with waste from other sources. For example, in Zaàba Dormitory, the present waste in the waste-collection points originates from dormitories, cafeterias, and administrations. Therefore, it would not be a suitable sample point.

Cafeteria

There are 18 cafeterias inside the campus (Fig. 4.5). Three cafeterias were selected as sampling points.

Administration

There are several administrations and offices in the campus. Figure 4.5 shows the administrators and the number of staff at the campus.

Services

The campus services include faculties, dormitories, cafeterias, health center, main hall, student center, library, banking, security, post office, shopping, and other sources. Domestic waste from faculties, cafeterias, and dormitories is categorized and considered as three independent sources (Fig. 4.5; Pusanika Building and health center building).

Domestic waste from the health center falls under the category of "services." All services, such as student center, library, banking, post office, and shopping, are located in Pusanika Building and categorized under services.

The main hall and the stadium do not generate domestic waste continuously during the year because they were inactive during the waste-composition investigation, and some other services are categorized under administrative activity.

Staff Residential Area

There are 102 houses in the campus, called "security houses," with a population of 410 people. To estimate the amount and composition of domestic waste in this area, data from the domestic-waste separation of the residential area in the local domestic waste–composition investigation were used in this planning (Kohei 2011) (Fig 4.5; residential area).

According to the schedule of the domestic waste–composition investigation, all samples were collected from sampling points and transferred to the separation activity area by three tricycles and one four-wheel drive car. Figure 4.6 shows the labeling of sample bags (a) and the sample-collector vehicle (b).

Samples were weighed and recorded in the data sheet and prepared to perform the composition analysis (Fig. 4.7a–c).

4.5.1.3 Location of Domestic Waste–Separation Activity

To perform the domestic waste–composition investigation, a specific area was selected inside the campus, which is located at the back of the Engineering Faculty and next to the concrete laboratory.

The areas covered by two canopies, and the floor is covered with plastic washable covers. Thirty mobile garbage bin (MGB) containers and several boxes were allocated to collect the separated recyclable materials and placed under the canopies.

Fig. 4.6 Labeling of sample bags (**a**) and the samples-collector vehicle (**b**)

Fig. 4.7 Collected samples (**a**), weighing (**b**), and organization of waste separation (**c**)

MGB containers and boxes were labelled according to type of separated materials. At the end of each day of the study, separated recyclable materials were transferred to the recycling center, and waste at other domestic-waste areas was collected by NF compactor trucks to take for disposal.

Figure 4.8 shows the location of domestic waste–composition investigation. Figure 4.9 shows the labeled MGBs and boxes to collect the separated recyclable materials.

Fig. 4.8 Location of domestic waste–composition investigation

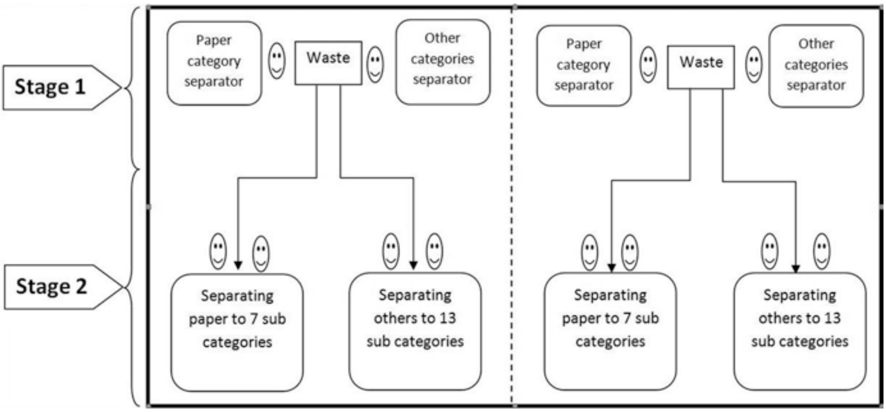


Fig. 4.9 Procedure of domestic waste–composition investigation

4.5.1.4 Procedure of Domestic Waste-Composition Investigation

To achieve successful sampling, sorting, weighing, and results, it was necessary to prepare a procedure and define the project managers, supervisors, and solid waste–separation handlers (Aringa 2010). This process is explained in the following paragraphs.

Project managers are the persons who make the decisions about the number of samples, sampling points, and separation location of the samples. Project supervisors are the persons who have trained the waste-separation handlers and manage the domestic waste–separation activity. They also weigh the samples and separated materials and record the data. Domestic waste–separation handlers include 14 persons who perform domestic-waste separation according to established procedures. For the domestic waste–separation procedure, all handlers are divided into two groups. There are two stages in this procedure that should be done by each group: stage 1, which has three steps, and stage 2, which has two steps. Detailed activities and responsibilities in each stage are described in following paragraphs.

Step 1: After opening the plastic waste bags, two persons are responsible for performing the first stage of domestic-waste separation.
Step 2: Four people are responsible for performing the second stage of solid-waste separation. Figure 4.16 shows the steps of the procedure and the responsibility of handlers during the domestic-waste separation.

To cover all of the domestic-waste components at the campus, domestic wastes are categorized into eight main categories paper, plastic, metal, organic waste, glass, textile, E-waste, and miscellaneous. From the eight main categories, there are an additional 23 subcategories. Table 4.1 shows the categories and subcategories of domestic waste items in this investigation.

Table 4.1 Solid waste–separation categories and subcategories

Categories	Subcategories	Description and example
Paper	Printed paper	Office Paper, Brown Paper Bags, books, notebooks, flyers
	Newspaper and magazine	Newspapers and magazine
	Tissue	Used or unused tissues
	Sanitary tools and diapers	Used or unused diapers and sanitary tools
	Cardboard	Cartoons, food containers, shoe box, food and beverage cartons, cereal boxes, frozen food boxes, toilet paper rolls, egg cartons
	Nonrecyclable paper	Waxed paper, very dirty paper, greasy paper, wallpaper, photography paper
Plastics	Bottle	Bottled mineral water, juice, some detergents…
	Plastic bag	Plastic bags
	Polystyrene	Melamine, some plastic items
	Others	Plastic toys, plastic dishes, shoes, and many plastic items
Metals	Aluminum can	Aluminum food or beverage cans and other cans
	Other metal Can	Tin or other metal cans
	Other Aluminum material	Other aluminum materials
	Ferrous material	Ferrous materials
	Copper	Copper
	Other metals	Zinc, Lead
Organic waste	Kitchen waste	Food wastes that come from the kitchen
	Garden waste	Grass, flower, and tree cuttings
Categories	Subcategories	Description and example
Glass	Recyclable glass	Glass Bottles and Jars
		All colors of Glass accepted: Clear, Blue, Green and Brown
	Nonrecyclable glass	Window glass, mirrors, light bulbs
Textile	Textile	Textiles
E-waste	E-waste	E-waste such as computer tools
Miscellaneous	Others	Other waste such as stone, soil, concrete, leather

4.5.2 At Source–Collected Recyclable Materials

Several private companies act as contractors under DDM that provide workers and cleaners to provide services such as cleaning the buildings, cleaning the campus area, cutting the grass, gardening, and other services.

Every building at the campus has two to four cleaners, according to the size of building, to keep it clean. They are also responsible for gathering the garbage and throwing it into the solid waste–collection points (DDM 2011). Some amounts of recyclable materials are collected by these cleaners from solid waste of the buildings before deposal. Therefore, the real weights of recyclable materials generated are not measured with the disposal domestic waste. To obtain the real amount of recyclable materials generated at the campus, an investigation was conducted to measure the amount of collected recyclable material by cleaners (at source–collected recyclable materials investigation).

At source–collected recyclable materials were measured in 2-week periods according to the schedule in Table 4.2 at the same location of the domestic waste–composition investigation. Data were recorded and prepared for further calculation. Table 4.2 shows the date and time of collecting recyclable materials in this investigation.

4.5.3 Garden Waste–Generation Investigation

Several contractors at the campus collect and dispose of garden waste under the Landscape Unit of the DDM. To estimate the amount of garden waste generated at the campus, a separate investigation was conducted during a 2-week period.

The campus garden waste was disposed of in the area in the back of the Faculty of Education (Fig. 4.10) by the landscape contractor's trucks. Garden waste was measured at the disposal area after reloading from the trucks. Then the weights were recorded in three categories of garden waste including leaves, branches, and miscellaneous. Data were summarized and prepared for analysis and are presented in the next chapter.

4.5.4 Estimation of Electronic-Waste Generation

Electronic waste generated from faculties, dormitories, services, and administrators of the campus were collected, stored, and managed under the Assets Unit. This was based on a specific procedure, which is shown in Fig. 4.11. Data on disposable electronic waste in 2011—such as number of computers, printers, monitors, and other peripherals—were used in this investigation.

Table 4.2 Sampling locations and schedule of the collected recyclable materials at the source

Sampling location	Date	Time
Faculty of engineering (FKAB) and cafeteria	5/3/2012	10:00 AM
	7/3/2012	10:00 AM
	9/3/2012	9:00 AM
Data on dormitory and cafeteria	5/3/2012	11:00 AM
	7/3/2012	11:00 AM
	9/3/2012	12:15 PM
Department of Development and Maintenance (DDM)	5/3/2012	12:00 PM
	7/3/2012	12:00 PM
	9/3/2012	10:00 AM
Health center	5/3/2012	12:30 PM
	7/3/2012	12:30 PM
	9/3/2012	10:30 AM
Pusanika Building and cafeteria	6/3/2012	10:00 AM
	8/3/2012	10:00 AM
	9/3/2012	11:30 AM
Burhanudin Dormitory	6/3/2012	11:00 AM
	8/3/2012	11:00 AM
	9/3/2012	11:00 AM
Centre for Graduate Management (PPS)	6/3/2012	12:00 PM
	8/3/2012	12:00 PM
	9/3/2012	1:00 PM
Faculty of technology and science (FTSM)	6/3/2012	1 PM
	8/3/2012	1 PM
	9/3/2012	9:30 AM

Fig. 4.10 At source–collected recyclable (**a**) materials and (**b**) weighting

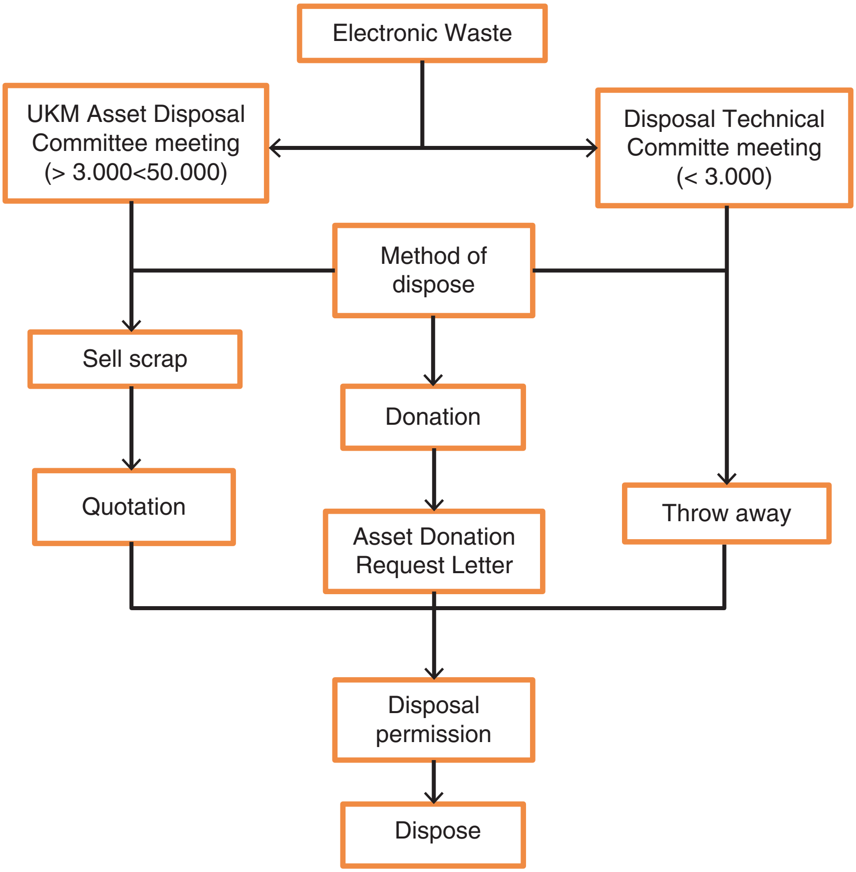


Fig. 4.11 Electronic-waste management

4.5.5 Estimation of Construction-Waste Generation

To estimate the generation and composition of construction waste at the campus, lists of buildings under construction during 2011 were provided from the DDM. Table 4.3 shows the number of buildings under construction at the campus in 2015 (DDM 2015).

4.5.6 Estimation of Solid Waste Generated Daily

Solid-waste generation at the campus is seasonal with peak generation during the semester academic session. There is minimum generation during the semester breaks. The worst condition of solid-waste generated has been considered,

Table 4.3 Buildings under construction (DDM 2015)

No	Name of building	Number of floors	Area (m^2)
1	Faculty of Law	2	1800
2	Faculty of Engineering	5	10,788
3	Graduate School of Business	7	3090
4	PPS	5	5407
5	Gifted Children School	2	3783

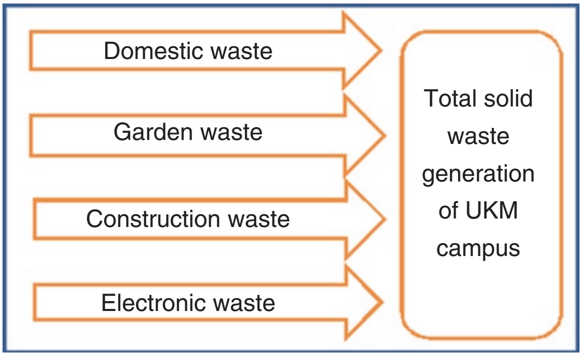


Fig. 4.12 Structure of total solid waste–generated estimation

i.e., estimation of solid-waste generation and composition during the semester. Figure 4.12 shows the structure of total solid waste–generated estimation.

To estimate the total solid-waste generation at the campus, four types of solid waste were considered in 2015: domestic waste, garden waste, construction waste, and electronic waste.

To determine the actual amount of domestic-waste generation in 2015, weight records of the collector's solid-waste trucks before reloading were reviewed. The results of the total solid-waste generation of the campus are explained in Chap. 5.

4.6 Solid Waste–Management Scenarios

To define the scenarios for solid-waste management, existing common solid waste–treatment technologies should be considered (Hong et al. 2010; Othman et al. 2013). Common treatment methods in Malaysia—such as incineration, RDF, composting, anaerobic digestion, and recycling (NSWMD 2011)—were considered in defining the solid waste–management scenarios.

Based on the determination solid-waste composition at the campus, which comes from stage two of the investigation, six scenarios were introduced to the campus for consideration as appropriate solid waste–management systems.

In this investigation, the landfilling method was ignored to treat the mixed waste because of (1) the target of zero waste disposal to landfills by 2020 (NSWMD 2011), (2) the limitation of land space in the campus, and (3) the assumption of a closed system for the campus to treat its solid waste as a move toward a green campus. Then, according to the percentage solid-waste composition at the campus, a specific percentage was allocated to each scenario (Lukman et al. 2009). After determination of the scenarios, LCA, AHP, and cluster-analysis methods were applied. Therefore, three following stages are applied:

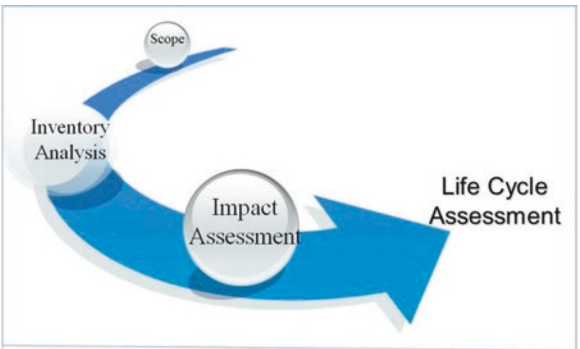
- Defined scenarios were compared with each other in terms of the environment by LCA method.
- Economic comparison of scenarios was performed according to AHP method.
- LCA and AHP results were combined by cluster-analysis method to determine the most suitable method by environmental and economic considerations.

4.7 Environmental Assessment of Scenarios According to Life-Cycle Assessment

LCA is a well-established scientific technique. This investigation conformed to the international standards for LCA: ISO14040 and ISO 14044. These standards stipulate a range of actions that must be followed to conduct an acceptable LCA investigation. Schematic steps of life-cycle assessment are shown in Fig. 4.13.

In this investigation, LCA was applied to assess the environmental impacts of the scenarios as compared with each other using SimaPro 7.3 software. The LCA technique has several distinct steps including scope, inventory analysis, and impact assessment (Rebitzer et al. 2004). Scope of the LCA, inventory analysis, and impact assessment for the campus is described in the following text.

Fig. 4.13 Steps of life-cycle assessment



4.7.1 Scope of the Life Cycle–Assessment Investigation

The scope of life-cycle assessment in this investigation includes domestic waste, garden waste, electronic waste, and construction waste generated inside the campus. The main campus consists of: 9 faculties, 10 dormitories, 18 cafeterias, and 1 residential area. This includes a population of 30,000 people comprising lecturers, staff, and students generating an estimated 8 tons per day of solid waste at the campus (Tiew et al. 2010). The scope of the investigation is shown in Fig. 4.14.

To perform life-cycle assessment, a system boundary is defined as the solid waste generated from faculties, dormitories, administrations, cafeterias, residential area, and services. Figure 4.15 shows the scope of the life-cycle assessment of solid-waste management at the campus.

According to Fig. 4.15, the scope of the LCA is solid waste generated from faculties, dormitories, cafeterias, administrations, and services as well as the impacts of applying solid waste–treatment methods.

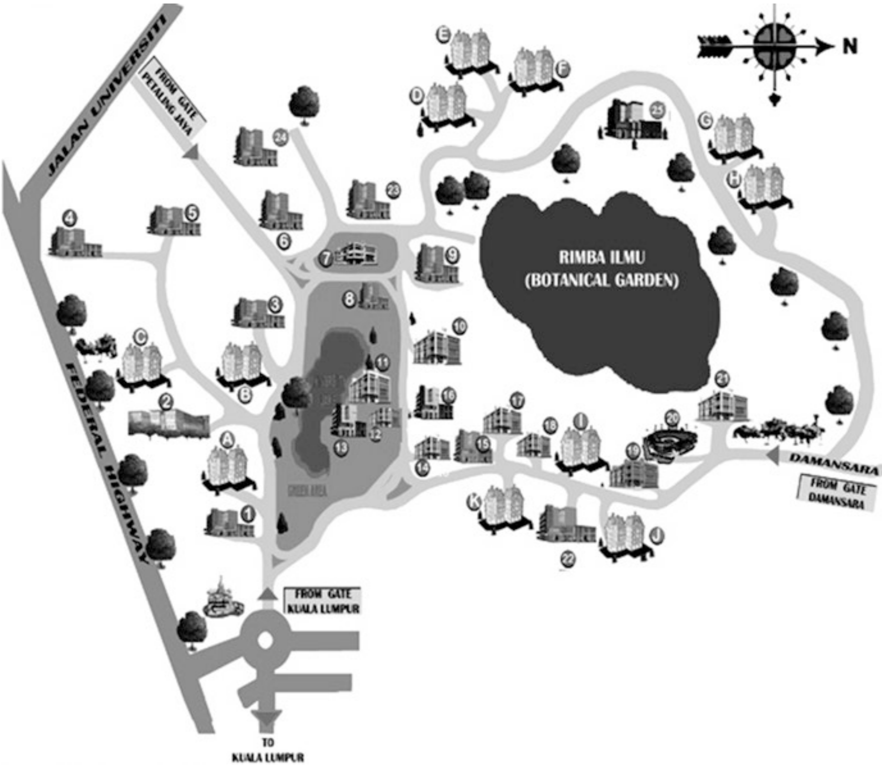


Fig. 4.14 Scope of the investigation

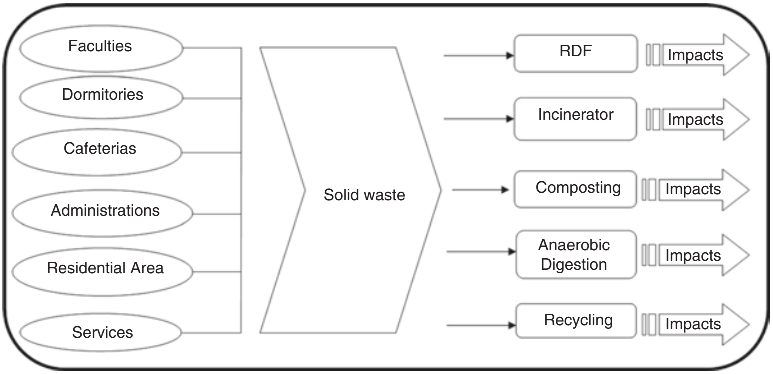


Fig. 4.15 Scope of the life-cycle assessment

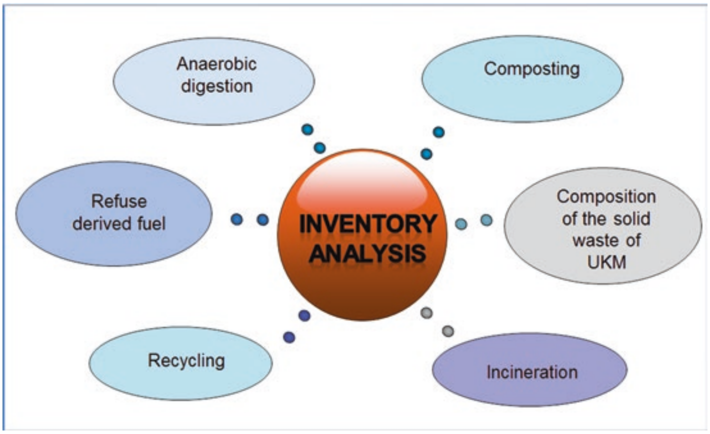


Fig. 4.16 Inventory analysis of life-cycle assessment of solid-waste management

4.7.2 Inventory Analysis of Solid Waste–Management Options

The next phase in life-cycle assessment is to identify and quantify the materials and emissions. The inputs (energy, fuel, and materials) and outputs (emissions to air, water, and soil) are termed "environmental burdens" or "environmental interventions," respectively. Figure 4.16 shows the inventory analysis of life-cycle assessment for solid-waste management at the campus.

To perform an inventory analysis of life-cycle assessment, inventory data of treatment methods (RDF, incineration, composting, anaerobic digestion, recycling) are provided by interviewing experts of related treatment methods, site visits, and review of their documents. Once completed, the results applying these as inputs to SimaPro 7.3, accompanied by the results of solid-waste composition. Outputs of SimaPro, are explained in the next chapter.

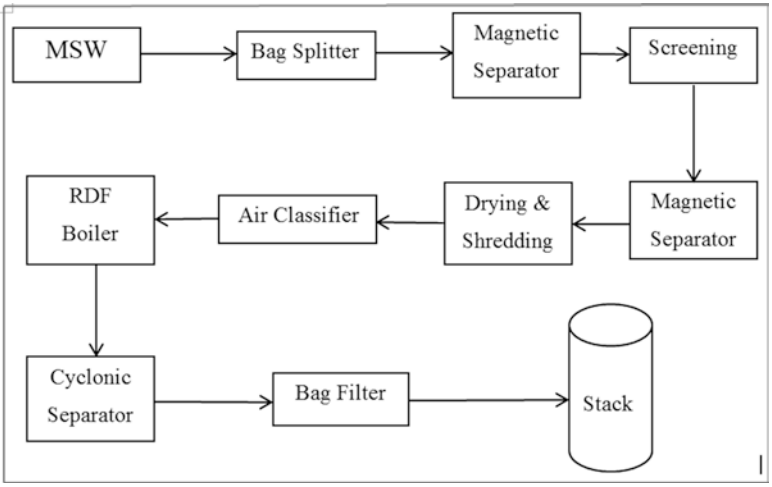


Fig. 4.17 Refused-derived fuel process

4.7.2.1 Inventory Analysis of Refuse-Derived Fuel

There is a 5-acre refuse-derived fuel facility where the built-up area for the plant has been placed. This includes an RDF plant, a power plant, treatment plants, and other covered buildings. The surrounding land area carries agricultural status. The site has been earmarked by a local municipality. The local municipal council has given permission to use the land for an RDF facility. Figure 4.17 shows the flow process of the RDF plant to convert MSW into energy for electricity generation.

Environmental inputs and outputs of refuse-derived fuel facility are shown in Table 4.4. The capacity of the RDF plant is 700 tons of solid waste per day, and Table 4.5 shows the input and outputs of materials and energy as well as the emissions of the facility.

4.7.2.2 Inventory Analysis of Anaerobic Digestion

To prepare inventory data of an anaerobic digestion system, an anaerobic digestion plant was considered. The design capacity is 2 tons organic waste per day, but the current capacity is 600 kg per day. Figure 4.18 shows the process of an anaerobic digestion facility. Environmental inputs and outputs of the anaerobic digestion facility is shown in Table 4.5.

The process is a closed system, and no leachates, air emissions, organic fertilizers, or electricity are produced as products of this system. Electricity is consumed by the company, and the fertilizers are sold to other companies.

Table 4.4 Inputs and outputs of RDF facility

	Item		Amount	Unit/day
Inputs	Water		1020	m^2
	Anti-odor (liquid ozone)		60	kg
	Lime		3800	kg
	Activated carbon		90	kg
	Natural gas		10	m^3
	Lubricant		35	L
	Ferric chloride		140	kg
Outputs	Emission to air	CO_2	104,160	kg
		SO_2	217.3	kg
		CO	60.5	kg
		NOx	217.3	kg
		PM10	8.7	kg
		HCL	112	kg
	Emission to water	BOD_5	729.5	g
		COD	2461.4	g
		Ammonia	770	g
		Nitrate	978.5	g
		Nitrite	17.6	g
		Sulfate	3872	g
		Phosphate	Ng	g
		S particulate	176	g
		PO_4	112	g
		DOC	572	g
	Electricity generation		5.5	MWh
	Sludge		190	kg
	Fly ash		2.1	ton
	Bottom ash		36.4	ton

4.7.2.3 Inventory Analysis of a Composting Plant

To prepare inventory data of the composting system, a composting plant was considered. Table 4.6 shows the inputs and outputs of a composting facility.

The capacity of the composting facility is five tons of organic waste per day, which is spread across a 2-acre area. The composting technology applied in this facility is a simple windrow, and its input is organic waste from the market.

4.7.2.4 Inventory Analysis of an Incineration Plant

Incineration technology has been implemented on three tourist national islands. Six mini-incinerators each have a capacity of 3 to 20 tons.

Table 4.5 Inputs and outputs of anaerobic-digestion facility

	Item		Amount	Unit/day
Inputs	Water		50	L
	Anti-odor (liquid ozone)		0	–
	Natural gas		0	–
	Lubricant		250	g
	Ferric chloride		0	–
Outputs	Emission to air	CO_2	0	–
		SO_2	0	–
		CO	0	–
		NOx	0	–
	Emission to water	BOD_5	0	–
		COD	0	–
		Ammoniacal Nitrogen	0	–
	Electricity generation		120	kWh
	Fertilizer		120	kg

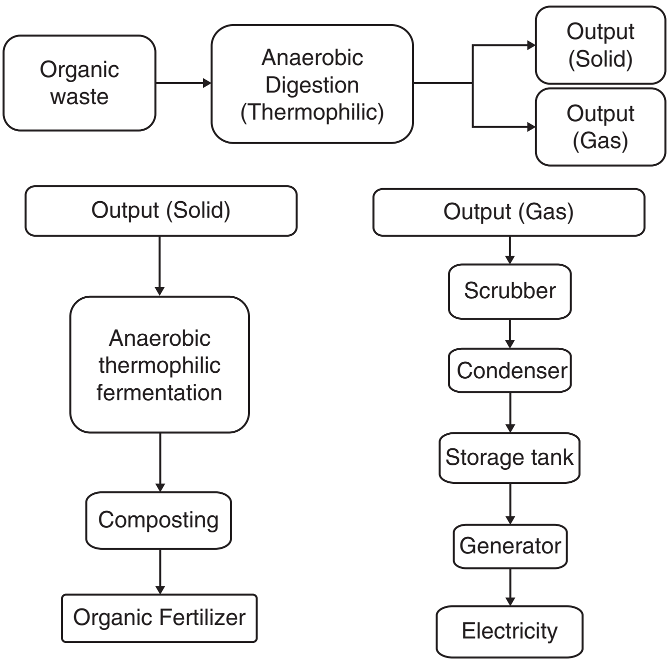


Fig. 4.18 Process of anaerobic-digestion facility

Table 4.6 Inputs and outputs of composting facility

	Item		Amount	Unit/day
Inputs	Water consumption		0.65	m^3
	Anti-odor (ozone, liquid)		20	L
	Lubricant		0.5	L
	Electricity consumption		110	kWh
	Diesel		9	L
Outputs	Emission to air	CO_2	430	kg/ton
		CO	0.6	kg/ton
		CH_4	14.5	kg/ton
		N_2O	0.1	kg/ton
		NH_3	10	kg/ton
		VOC	36.5	kg/ton
	Emission to water	BOD_5	1964.00	g
		COD	6392.00	g
		Phenol	0.60	g
		Free chlorine	0.1	g
		Sulphide	3.90	g
		Ammonia	2934.00	g
		Phosphate	19.40	g
		Total nitrogen	3452.00	g
	Compost		0.73	ton
	Electricity generation		0	–

Another 10 ton–capacity incinerator is used occasionally to burn some government-classified documents. Four incinerators are no longer functioning. As a whole, the incinerators are mostly inactive due to the design of the incinerator, and they serve as a non-localized system for climate and high moisture of inputs (Agamuthu and Nagendran 2010). Therefore, to perform an inventory of an active and proper incineration system, an incineration plant in Thailand was considered due of the similarity of composition of solid-waste and climate condition of these two countries.

The capacity of the composting facility is 5 tons of organic waste per day, which is spread across a 2-acre area. The composting technology applied in this facility is a simple windrow, and its input is organic waste from the market. Table 4.7 shows the environmental inputs and outputs of the incineration facility. The incineration process considered here has a burning capacity of 250 tons per day and is assumed to be the main process used to treat solid waste; it also generates electricity (Liamsanguan and Gheewala 2008a, b).

Table 4.7 Inputs and outputs of the incineration facility (Liamsanguan and Gheewala 2009)

	Item		Amount	Unit/day
Inputs	Water consumption		2796	L
	Activated carbon		30.3	kg/day
	Lubricants		10	L
	Ferric chloride		200	kg/day
Outputs	Electricity generation		34,389	kWh
	Emission to air	CO_2	14,084.95	kg
		CO	11.366	kg
		SO_2	8.742	kg
		CH_4	0.201	kg
		N_2O	0.001	kg
		NO_2	46.662	kg
		Total NMVOC	0.298	kg
	Emission to water	BOD_5	980	g
		COD	2464	g
		TOC	574	g
		Ammonia	279.6	g
		Nitrate-N	326.2	g
		Nitrite-N	5.8	g
		SO4	Ng	g
		S Particulate	175	g
		Phosphate	112	g
	Electricity generation		34,389	kWh
	Sludge		42	kg
	Bottom ash		4.2	ton
	Fly ash		5	ton

4.7.2.5 Inventory Data of Recycling

Products recovered with recycling processes can replace products manufactured from virgin resources, thus avoiding the environmental impacts of virgin-manufacturing processes. The emissions avoided from virgin-manufacturing are included in the system under investigation by subtracting these emissions from the emissions in the recycling system.

Because of the lack of complete data of inputs and outputs for manufacturing the different recyclable materials, data from the database of SimaPro 7.3 (ecoinvent 3.0) was applied to perform an inventory analysis for recycling in this investigation. The ecoinvent database center is a center of expertise and a supplier of consistent and transparent life-cycle inventory data.

The ecoinvent database contains international industrial life-cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste-management services, and transport services. It is widely used as a source for data used for LCA (ecoinvent 2011).

Consideration within this investigation included avoided emissions, material, and energy consumption for manufacturing of any recyclable materials in the ecoinvent database according to the solid-waste composition.

4.7.3 Impact Assessment of Solid-Waste Management

According to the ISO standard, the life cycle–impact assessment (LCIA) is a phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of the system. In this investigation, the main life cycle–impact assessment method, called the "eco-indicator'" method, is used. After completion of the impact-assessment analysis, the LCA results are shown by ranking all scenario options according to environmental points.

4.8 Economic Analysis of the Scenarios by Analytical Hierarchy Process

The fourth part of this investigation is aimed at utilizing analytic hierarchy process (AHP) in measuring experts' opinion in terms of environmental and economic value of solid waste–management scenarios at the campus. To perform AHP, a questionnaire was developed with six scenarios as alternatives.

Questions about the environmental criteria—including three subcriteria (global warming, ozone depletion, and eutrophication) and economic criteria including three subcriteria (investment cost, operation cost and marketability of a product)—were asked of experts on exactly the same points (Appendix E).

The purpose of the AHP is to assist decision-makers in organizing their thoughts and judgments to make more effective decisions in selecting the best solid waste–management system for the campus. Multi-criteria decision analysis (MCDA) models, such as AHP, were applied for solid waste–management options.

The domain experts were chosen from well-recognized individuals who possess active practical experience and are currently applying their expertise, knowledge, and experience. Their good time-management and communication skills were also considered factors. In addition the human-experts interview, knowledge is also acquired from site observations to obtain more information on recycling, RDF, composting, and incineration practices. To perform an AHP analysis, defining an AHP structure model is fundamental. Afterward, pairwise comparison matrix and AHP scoring should be performed to rank the alternatives as suggested by Saaty and Vargas (2008).

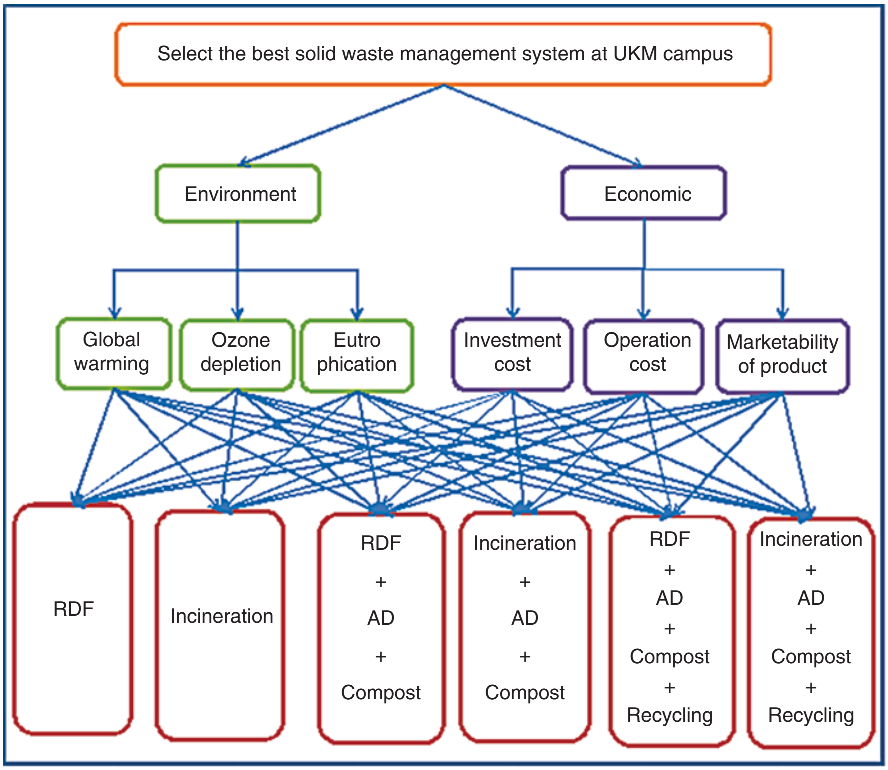


Fig. 4.19 Hierarchy structure model of solid-waste management

4.8.1 Analytical Hierarchy–Process Structure Model of Solid-Waste Management

The AHP technique in this investigation was performed with the goal of selecting an appropriate solid waste–treatment management system at the campus. There are two main types of criteria in the hierarchy structure: environmental and economic.

The hierarchy structure model for solid-waste management at the campus is illustrated in Fig. 4.19.

According to environmental impacts and the potential priority of the solid-waste scenarios, three subcriteria were selected as those to support the main criteria. These included global warming, ozone depletion, and eutrophication.

Emissions from the system were studied, classified, and characterized into three impacts using methodology from LCA (Carlsson 2002; ISO 2006). Furthermore, three subcategories, including investment cost, operation cost, and marketability of the product (Pires et al. 2011), were selected for supporting the economic criteria.

4.8.2 Pairwise Comparison Matrix of the Analytical Hierarchy Process

In this case, after identifying the goal along with the criteria, subcriteria, and alternatives, the respective levels can be run through the pairwise comparison matrix to obtain the weight for each of the comparisons. This is performed until all of the most effective solid waste–management options are precisely identified. Table 4.8 shows the process for the pairwise comparison.

The matrix values for the pairwise comparison for economic and environmental criteria, according to allocated score by experts, is shown. The matrix value for pairwise comparison of environmental and economic subcriteria, according to questionnaire results, was made with pairwise comparisons of all economic and environment subcriteria arranged in different matrices. Table 4.9 shows the matrix value of pairwise comparison of subcriteria.

Table 4.10 shows the matrix value for global warming, ozone depletion, and eutrophication pairwise comparisons according to allocated score by experts. Then, all scores of the subcriteria were normalized to define the weight of each subcriterion (A1, B1, and C1).

After that, all scores of the matrices were normalized. The weight of each criteria and subcriteria were calculated according to (4.1) where X_i is the data point, and "*i*" and "*n*" are the weights of the data points:

Table 4.8 Value matrix for pairwise comparison of main criteria

Goal	Environmental	Economic
Environment	1	X
Economic	1/X	1

Table 4.9 Value matrix for pairwise environmental subcriteria

Environmental criteria	Global warming	Ozone depletion	Eutrophication	Weight
Global warming	1	X	X	A1
Ozone depletion	1/X	1	X	B1
Eutrophication	1/X	1/X	1	C1

Table 4.10 Value matrix for pairwise comparison of environmental subcriteria

Economic criteria	Operation cost	Capital cost	Marketability of product	Weight
Operation cost	1	X	X	D1
Capital cost	1/X	1	X	E1
Marketability of product	1/X	1/X	1	F1

Table 4.11 Value matrix for pairwise comparison of defining scenarios

Subcriteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	X	X	X	X	X	A2
Scenario 2	1/X	1	X	X	X	X	B2
Scenario 3	1/X	1/X	1	X	X	X	C2
Scenario 4	1/X	1/X	1/X	1	X	X	D2
Scenario 5	1/X	1/X	1/X	1/X	1	X	E2
Scenario 6	1/X	1/X	1/X	1/X	1/X	1	F2

$$W_i = \sum \left(\frac{x_i}{\sum_n^i x} \right) \tag{4.1}$$

After calculating the weights of all criteria and subcriteria, the value matrix for pairwise comparison of scenarios were defined for solid-waste management and should have been provided for each subcriteria. Table 4.11 shows the matrix value for pairwise comparison of the scenarios.

According to the matrices values of each subcriterion, the weights of all scenarios were calculated using Eq. (4.1). After considering the weights of subcriteria in each scenario, the weight of each scenario was calculated, and, finally, all scenarios were ranked.

4.8.3 Analytical Hierarchy–Process Scores and Ranking of Scenarios

The final AHP scores were calculated by summing the multiplication of the weight of specific scenarios in related subcriteria-weighting scores, which would be the final results of the AHP investigation. According to (4.2), the AHP score was calculated as follows:

$$AHP_w = \sum_i^1 W_{su\,i} \times W_{sc} \tag{4.2}$$

where "$W_{su\,i}$" is the final weight of the subcriteria, and "i" and "W_{sc}" is the weight of scenario "*n*," comes from the previous step.

After calculation of the AHP scores, all scenarios were ranked, respectively, with the related scores. The results of ranking of scenarios by AHP method is shown in the following chapter.

4.9 Combining LCA and AHP Using Cluster-Analysis Method

In this book, the AHP scores and LCA points describe equally the character of scenarios. The between-groups linkage method, which is a form of cluster analysis, has been applied to cluster the results generated from AHP and LCA.

The cluster variable determines the "character" of the objects because it includes only the variables needed to compare objects. The steps of applying this method are standardization of LCA points, standardization of AHP scores, and combination of the results of the two-step results (Huang and Ma 2004).

4.9.1 Standardization for LCA Points of Scenarios

To achieve standardization of the LCA points of the solid waste–management scenarios, all points were listed according to the results of total LCA considering global warming, ozone depletion, and eutrophication. Then all data were standardized utilizing the following equation:

$$S_l = -\left[\frac{P_i - M_p}{M_p}\right] \tag{4.3}$$

where "S_l" is the standardized LCA point; "P" is the LCA point of a scenario "i"; and "M_p" is the mean of all LCA points. The aim of standardization is taking normal data and preparing it for weighting.

4.9.2 Scoring of Extracted Economic Result of AHP

For the scoring of the AHP results of scenarios, the allocated weights of scenarios were extracted from the AHP analysis. Scores from 1 to 10 were allocated to each scenario in every economic subcategory according to Table 4.12 (Huang and Ma 2004).

Formerly, the weights of economic subcriteria (investment cost, operation cost, and marketability of a product) were extracted from the main AHP calculation because environmental assessment is combined with economic analysis in this stage. To give scores to economic subcriteria, the economic results of AHP are given a score of 1-10 as shown in Table 4.13.

To calculate the total economic score of the defined scenarios, Eq. (4.4) was applied for the matrix of Table 4.13.

Table 4.12 Scoring the economic subcriteria in cluster analysis

Range of weights in AHP	Score	Definition
0–0.099	1	Very bad
0.099–0.199	2	
0.199–0.299	3	
0.299–0.399	4	
0.399–0.499	5	
0.499–0.599	6	
0.599–0.699	7	
0.699–0.799	8	
0.799–0.899	9	
0.899–0.999	10	Very good

Table 4.13 Weighting of economic AHP scores for scenarios

Economic subcriteria	Weight of subcriteria in AHP	Allocated score in cluster analysis					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Capital cost	X1	A1	B1	C1	D1	E1	F1
Operation cost	X2	A2	B2	C2	D2	E2	F2
Marketability	X3	A3	B3	C3	D3	E3	F3

$$T_i = \sum_{6}^{6} E_{ij} W_j \tag{4.4}$$

where "E" is the given score (1–10) for the "i" scenario associated with the "j" evaluation factor, and "W_j" is the weight of the "j" evaluation factor by AHP (Huang and Ma 2004).

4.9.3 Standardization of AHP Scores for Solid Waste–Management Scenarios

To make comparable qualitative data (AHP) to the actual data of LCA (quantitative), economic AHP scores were weighted in the previous steps and standardized according to Eq. (4.5):

$$S_a = \frac{S_i - M_s}{M_s} \tag{4.5}$$

where "S_a" is the standardized AHP score; "S" is the AHP score of the scenario "i"; and "M_s" is the mean of all AHP scores of all scenarios.

4.9.4 Plotting the Standardized Results of AHP and LCA

In addition to the standardized economic AHP scores, the standardized LCA points of scenarios, were listed as a coordinating address for scenarios. Then they were converted to six different points, which are representative of the scenarios in the axis and the distance between the two clusters. These were determined by averaging the distances between all subjects in two clusters. The measured distance is the squared Euclidean distance as given by (4.6):

$$D_{ab} = \sum_{i}^{p} \left(a_j - b_j\right)2 \tag{4.6}$$

Points "a_j" and "b_j" are the coordinates of A and B, with reference to "j" being the axis representing "p" as the dimension. To properly interpret them, the results should consider the nearest scenario to the top and right as the best scenario. The scenario nearest to the bottom and the left is the worst scenario in terms of environmental and economic impacts.

Chapter 5
Waste-Composition Investigation

5.1 Overview of Waste-Composition Investigation

Results of the domestic waste–composition investigation for different categories of the campus are explained in this chapter. This includes faculties, dormitories, administrations, cafeterias, services, and residential buildings along with solid-waste generation by different types of electronic waste, construction waste, and garden waste.

According to the total solid-waste composition, six solid waste–management scenarios are introduced to the campus. Life-cycle assessment was performed to assess the potential environmental impacts of defined scenarios. Results of environmental and economic analyse using the analytical hierarchy process (AHP) are shown here.

In addition, cluster analysis is applied to combine the LCA results and extracted economic results from AHP in the subsequent stage to consider different municipal solid waste–management scenarios. This is done for both environmental and economic criteria to propose an appropriate Municipal Solid Waste (MSW) management system for the campus.

Finally, the results of different investigations are compared and interpreted.

5.2 Stage 1: Solid-Waste Generation and Composition

To be come aware of the solid-waste generation and composition at the campus, domestic-waste composition, at-source recyclable materials, and garden-waste composition were surveyed for a period of 2 weeks. Electronic and construction waste of the campus were also calculated.

P.T. Ghazvinei et al., *University Campus Solid Waste Management*,
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5.2.1 Domestic Waste–Composition Analysis

Table 5.1 shows the daily amount of disposed domestic waste, including recyclable and nonrecyclable materials, from different solid waste–generation sources at the campus (Appendix A).The results show that the largest amount of domestic waste is generated in dormitories and faculties, respectively. Approximately 240.9 g of domestic waste is generated per person per day in dormitories. The amount in faculties is 20 g, with administration offices at 95 g, and in residential areas at approximately 490 g per person per day in residential areas. Furthermore, the largest amounts of paper, plastic, and organic waste are generated in dormitories.

Results show that the highest percentage of domestic composition is related to uncooked waste (32.8 %) and cooked waste (20.8 %), which means that approximately half of the total domestic-waste is generated by dormitory and cafeteria sources (Appendix A). Different campus sources are compared in Fig. 5.1.

Dormitories and cafeterias are the two most important sources to generate domestic waste. Therefore, on one hand, management and control of domestic-waste generation at dormitories and cafeterias on the campus has a significant effect in reducing organic waste. In by contrast, with by controlling and managing the organic waste generated at those two sources as hot spots, approximately half of the total domestic waste generated at the campus could be reduced. Table 5.2 shows the composition of disposable domestic waste at the campus.

5.2.2 Comparing the Investigation with Other Solid Waste–Composition Investigations

A detailed investigation was performed to achieve proper decision-making ability for solid-waste management at the campus. In the current investigation, not only domestic waste considered; electronic waste, construction waste, and garden waste were also evaluated. Figure 5.2 shows the comparative results of the investigation in 2009 and those of current investigations.

Comparison shows that recyclable materials, such as paper and plastics, increased by approximately 8 %. Also aluminum, glass, and electronic waste show an increasing trend from 2009 to 2015, which could be due to the increase in the on-campus population of the campus and an increase in recyclable materials usage. Likewise, organic-waste composition has been reduced by approximately 8 % because of recommendations provided to the cafeterias to better manage their organic waste.

Table 5.1 Domestic-waste composition and generation from different sources

Category	Papers	Plastics	Metals	Organic	Glass	Textile	E-waste	Miscellaneous	Total (kg/day)
Dormitories	352.9	482.9	26.8	1238.7	24.4	69.6	13.4	26.5	2235.2
Faculties	169.8	209.3	10.4	372.7	8.1	23.5	1.7	13.6	808.6
Administrations	95.5	36.8	6.2	67.3	0	0	0	3.6	209
Cafeterias	216.5	212.8	52	1211	89.8	27.8	2.5	18.3	2245
Services	27.3	26.6	0.7	55.8	1.4	1.5	0.2	2.1	115.6
Residential area	26.2	31.3	3.8	90.3	4.4	1.7	5.9	17.4	184.7
Total	1088.2	1099.7	120	3106.2	133	142	23.7	81.5	5798.1
Percentage	18.8	19	2.1	53.5	2.3	2.5	0.4	1.4	100

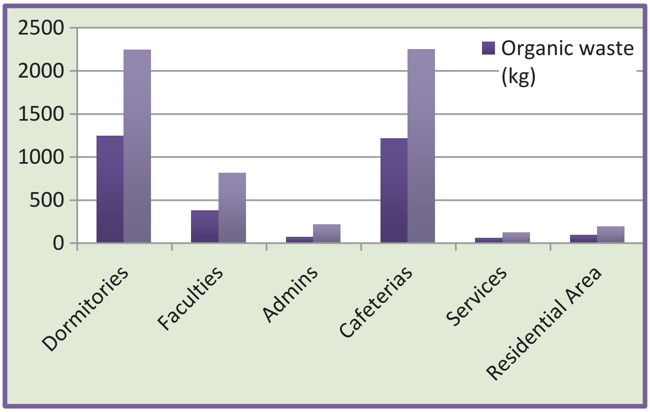

Fig. 5.1 Comparison of organic-waste and total-waste generation of different sources

Table 5.2 Composition and amount of disposable domestic waste

Composition of disposed domestic waste	kg/day	%
Recyclable colored paper	349.1	6
Recyclable black-&-white paper	157.5	2.7
Nonrecyclable paper	581.6	10
Recyclable plastic	233.1	4
Nonrecyclable plastic	866.6	15
Recyclable aluminum	23.7	0.4
Recyclable scrap	91.4	1.6
Nonrecyclable metals	4.8	0.1
Cooked kitchen waste	1901	32.8
Uncooked kitchen waste	1205.2	20.8
Glass	133.1	2.3
Textile	142.1	2.4
E-waste	23.7	0.4
Miscellaneous	81.5	1.4
Total	5798.1	100

5.2.3 Analysis of Recyclable Materials Collected at the Source

After sampling and measurement of recyclable materials collected at the source, the data were summarized and prepared for further analysis (Table 5.3). The results showed that the largest amounts of recyclable materials are collected from dormitories and faculties.

The most valuable recyclable material is aluminum, and cafeterias are the most important producer of this kind of recyclable material, especially aluminum cans. In

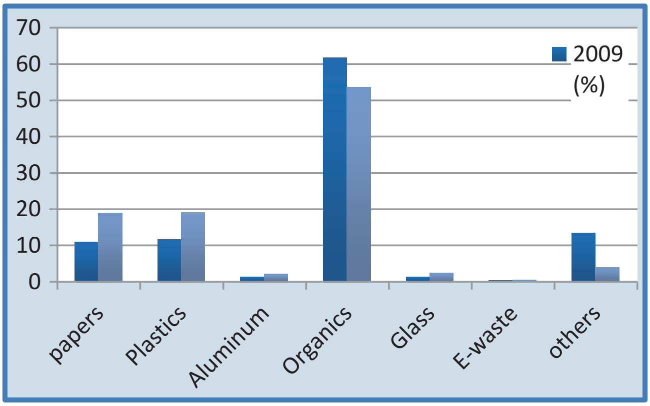

Fig. 5.2 Comparison of the results of the current and previous investigations

Table 5.3 At source–collected recyclable materials investigation at different sources

No.	Sources	Colored papers	Black-and-white papers	Plastics	Aluminums	Scraps	Total (kg/day)
1	Dormitories	56.4	34.7	58.7	12.2	1	163
2	Faculties	27.6	45.7	22.1	14.1	3.2	112.7
3	Cafeterias	64.3	11.1	49.6	48.2	25.9	199.1
4	Administrations	4.5	46.2	1.8	1.8	1.6	55.9
5	Residential area	0	0	0	0	0	0
6	Services	11.4	2.3	13.1	1.63	1.04	29.5
	Total	164.2	140	145.3	77.93	32.74	560.2

addition to cafeterias, the next most important producers are dormitories because of the high population of students (Table 5.4).

A comparison of recyclable materials collected at the source with recyclable materials collected from disposal waste showed that the largest amounts of these materials are transferred for disposal. This means that the most recyclable materials could not be collected at the source. The results show that only 25 % of recyclable materials are collected at the source, and the rest of them are disposed of (Fig. 5.3). Dormitories generate approximately 40 % of recyclable materials, followed by a 27 % generation of recyclable materials from faculties. Therefore, dormitories and faculties are the hot spots and should be a priority in recyclable-materials reduction at the campus.

Garden waste includes leaves, branches, and miscellaneous such as fruits, grass, and others (Table 5.5).Results of the investigation illustrate that the campus produces 1658 kg of garden waste per day. This amount of garden waste could be treated by a composting method to produce compost that is described in stage 2.

Table 5.4 Comparison of disposed recyclable materials collected by cleaners

No	Sources	At source collected recyclable materials (kg/day)	Recyclable materials in disposal waste (kg/day)
1	Dormitories	163	882.4
2	Faculties	112.7	587.5
3	Cafeterias	199.1	220
4	Administrations	55.9	285.6
5	Residential areas	0	36.4
6	Services	29.5	25.7
	Total	560.2	2037.6

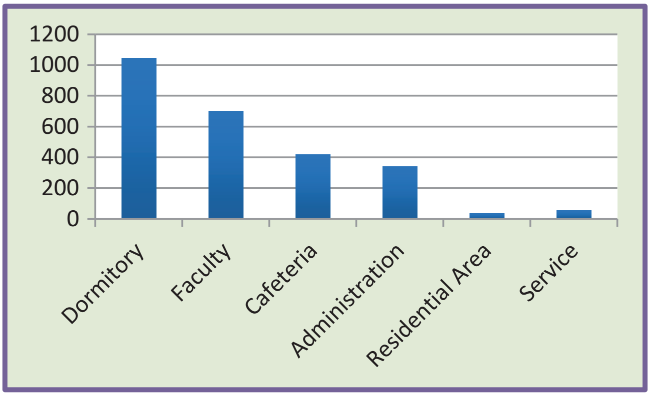

Fig. 5.3 Comparison of recyclable-materials generation in different sources

Table 5.5 Garden waste–generation investigation at the campus

Type of garden waste	Fist week (kg/day)	Second week (kg/day)	Total (kg/day)
Leaves	7074	8975	16,049
Branches	823	3719	4542
Miscellaneous	1189	1431	2620
Total	9086	14,125	23,211

5.2.4 Electronic-Waste Generation

Results show that a total of 96 CPUs, 143 monitors, 14 speakers, 47 mice, 52 keyboards, 11 scanners, and 15 printers were collected from different sources of the campus for disposal in 2015. This equates to approximately 8.6 kg/day.

5.2.5 Construction-Waste Generation

Construction waste generated is calculated according to the square-meter area of campus buildings that are under construction (Table 5.6). Construction of each 100-m^2 building generates 5.3 tons of construction waste, and 33.7 % of the wastes generated by conventional construction are reusable and recyclable. The net profit from on-site reuse and recycling of waste for conventional construction is estimated to be 0.87 % of the total construction cost (Satari 2011). Table 5.7 shows the calculation of construction waste generated at the campus in 2015.

5.2.6 Daily Domestic-Waste Generation

Domestic waste was after collecting by lorry after during February - May 2015. The average daily domestic-waste generation during the semester was approximately 5.9 tons/day in 2015. This data are related to domestic waste from all sources of campus. In next steps results of solid-waste generation, different sources are analyzed in defining scenarios.

Table 5.6 Construction waste

No	Name of building	Number of floors	Area (m^2)
1	Faculty of Law (Moot Court)	2	1800
2	Faculty of Engineering	5	10,788
3	Graduate School Business	7	3090
4	PPS	5	5407
5	Gifted Children School	2	3783

Table 5.7 Construction-waste generation

No	Name of building	Area (m^2)	Waste generation (per 100 m^2)	Waste of each building (ton)	Construction waste (tons/year)
1	Faculty of Law	1800	5.3	95.4	95.4
2	Faculty of Engineering	10,788	5.3	571.8	381.2
3	Graduate School Business	3090	5.3	163.8	81.9
4	Center for Post-Graduation Students	5407	5.3	286.6	143.3
5	Gifted Children School	3783	5.3	200.5	133.6
Total		835.4 tons/year			

5.2.7 *Total Solid-Waste Generation*

Table 5.8 shows total recyclable materials, compostable materials, and energy-recovery feed. The results show that approximately 40 % of solid waste is compostable; 20 % can be used in anaerobic digestion; 20 % can be recycled; and the rest could be mixed waste that can be treated by incineration or RDF methods.

5.3 Stage 2: Introducing Scenarios for Solid-Waste Management

To define the solid waste–management scenarios (Table 5.9), solid waste of the campus is categorized into three types: mixed waste, organic waste, and recyclable materials. Refuse-derived fuel and incineration methods are applied to treat mixed waste; anaerobic digestion and composting methods are applied to treat organic waste; and recycling method applied for recyclable materials.

In the first and second scenarios, RDF and incineration are used to treat the 100 % of solid waste at the campus. In third and fourth scenarios, RDF and incineration are used to treat of 50 % of solid waste, and composting and anaerobic digestion method are used to treat the rest. In the fifth and sixth scenarios, recycling method is added to the previous scenarios' options.

Table 5.8 Solid-waste composition

Type of waste	Compostable (kg/day)	For AD (kg/day)	Recyclable (kg/day)	Generated (kg/day)
Domestic solid waste	1205	1901	878.5	5800
Garden waste	2400	0	0	2400
Electronic waste	0	0	8.6	8.6
Construction waste	0	0	771	771
Total	3605	1901	1858.1	8919.6

Table 5.9 Defined scenarios for solid-waste management

Scenario	RDF (%)	Incineration (%)	Composting (%)	Anaerobic digestion (%)	Recycling (%)
Scenario 1	100	0	0	0	0
Scenario 2	0	100	0	0	0
Scenario 3	50	0	20	30	0
Scenario 4	0	50	20	30	0
Scenario 5	30	0	20	30	20
Scenario 6	0	30	20	30	20

5.4 Stage 3: Life-Cycle Assessment of Different Solid Waste–Management Scenarios

SimaPro 7.3 software was applied to calculate the environmental impact assessment. Previous results are related to the total points of each treatment technology when it treats the functional unit (1 ton of solid waste of the campus). Results show the environmental impact points for global warming, ozone depletion, and eutrophication (Table 5.10).

Comparison of five solid waste–treatment technologies (Fig. 5.4) shows that recycling has the lowest and incineration has the highest environmental impact. It should be noted that the recent comparison is an environmental assessment of treatment technologies when they were applied to treat 100 % of solid waste. In the next step, environmental impact points of each scenario were calculated according to allocated treatment technologies. Table 5.11 shows the calculated environmental impact points of global warming (GW), ozone depletion (OZD), and eutrophication (EUT) for scenarios by LCA.

Table 5.11 shows the calculation of global warming, ozone depletion, and eutrophication environmental impact points and the total points of the scenarios.

Table 5.10 Treatment methods and related environmental impact points

Impact category	RDF	Incineration	Composting	Anaerobic digestion	Recycling
Global warming	0.021	0.280	0.005	−0.026	−0.046
Ozone depletion	−0.0005	−0.024	0.145	−0.006	−0.119
Eutrophication	0.032	1.077	0.044	−0.0429	−0.353

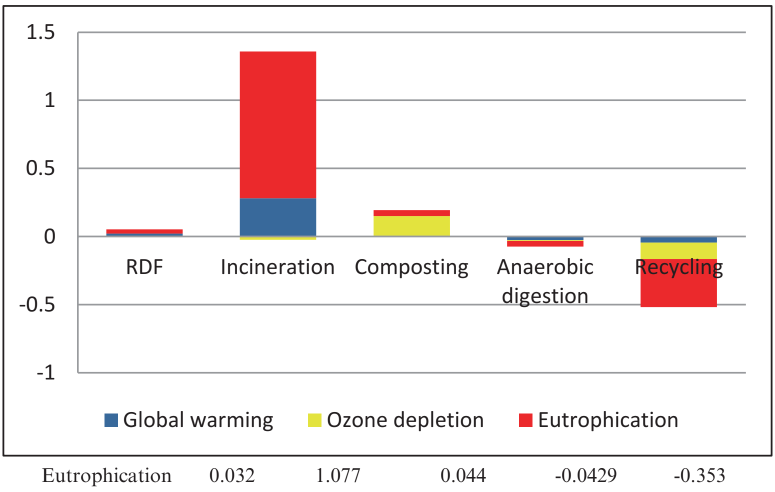

Fig. 5.4 Comparison of treatment technologies regarding potential environmental impacts

Table 5.11 Impact points of defined scenarios

Scenario	Impacts	RDF	Incineration	Composting	Anaerobic digestion	Recycling	Total
Scenario 1	GW	0.021	0	0	0	0	0.021
	OZD	−0.0005	0	0	0	0	−0.0005
	EUT	0.032	0	0	0	0	0.032
	Total						0.052
Scenario 2	GW	0	0.28	0	0	0	0.280
	OZD	0	−0.024	0	0	0	−0.024
	EUT	0	1.077	0	0	0	1.077
	Total						1.33
Scenario 3	GW	0.008	0	0.002	−0.005	0	0.005
	OZD	−0.0002	0	0.058	−0.001	0	0.056
	EUT	0.005	0	0.018	−0.009	0	0.014
	Total						0.070
Scenario 4	GW	0	0.112	0.002	−0.005	0	0.109
	OZD	0	−0.009	0.058	−0.001	0	0.047
	EUT	0	0.431	0.018	−0.0085	0	0.44
	Total						0.596
Scenario 5	GW	0.004	0	0.002	−0.005	−0.0093	−0.0081
	OZD	−0.00001	0	0.058	−0.001	−0.024	0.0327
	EUT	0.002	0	0.018	−0.008	−0.070	−0.059
	Total						−0.034
Scenario 6	GW	0	0.056	0.002	−0.005	−0.009	0.043
	OZD	0	−0.005	0.058	−0.001	−0.024	0.028
	EUT	0	0.215	0.0178	−0.008	−0.070	−0.03
	Total						0041

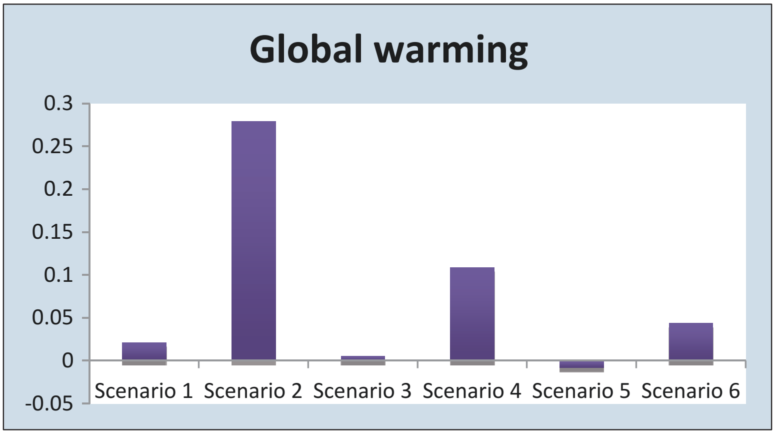

Fig. 5.5 Comparison of the scenarios regarding potential global-warming impact

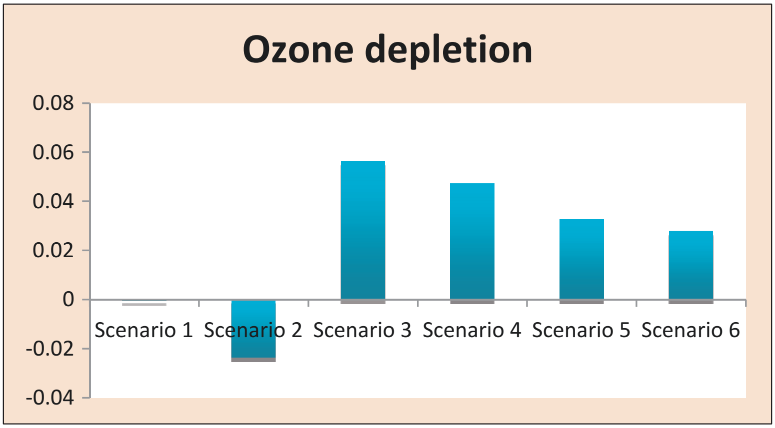

Fig. 5.6 Comparison of the scenarios regarding potential ozone-depletion impact

Scenarios are compared together regarding the impact points. According to the LCA results, scenarios 5 and 3 are the best scenarios from point of view of the environment, respectively, because of having the lowest environmental impacts points. Scenarios 2 and 4 are the worst scenarios because they show the highest potential of impact (Fig. 5.5).

Scenarios 5 and 3 are the best scenarios in terms of global-warming potential of the solid waste–management system, and scenario 2 is the worst one, which means that integration of RDF, composting, anaerobic digestion, and recycling is the best-integrated solid waste–management system to control global warming potential (Fig. 5.6). Regarding the ozone-depletion impact, the results show that scenario 2 is the best to protect the ozone layer among the solid waste–management concepts. Scenario 2 applies the incineration method to treat the solid waste.

Considering the eutrophication impact, scenarios 5 and 6 are the best scenarios, respectively. In these scenarios, recycling, composting, and anaerobic digestion are the same methods to treat the organic waste and recycling materials. According to Fig. 5.7, a combination of recycling, composting, anaerobic digestion, and recycling is the best scenario to save the aquatic environment at the campus. To have a reasonable decision-making ability regarding a solid waste–management system, all important environmental impacts should be considered together rather than focusing on one impact. Figure 5.8 shows the results of the comparison by LCA of

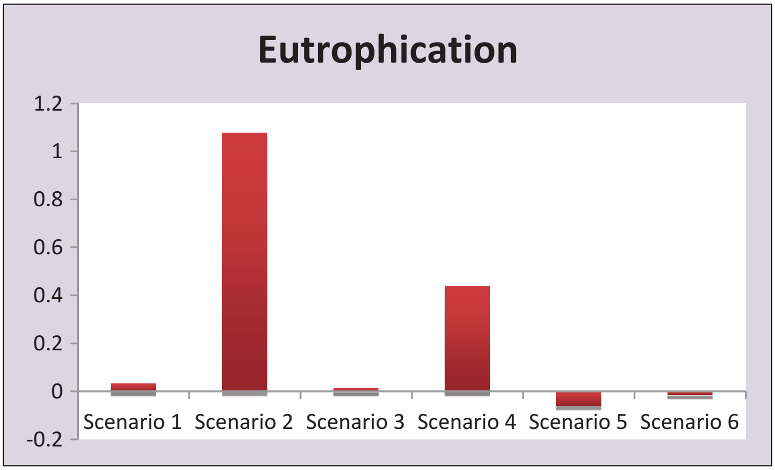

Fig. 5.7 Comparison of the scenarios regarding potential eutrophication impact

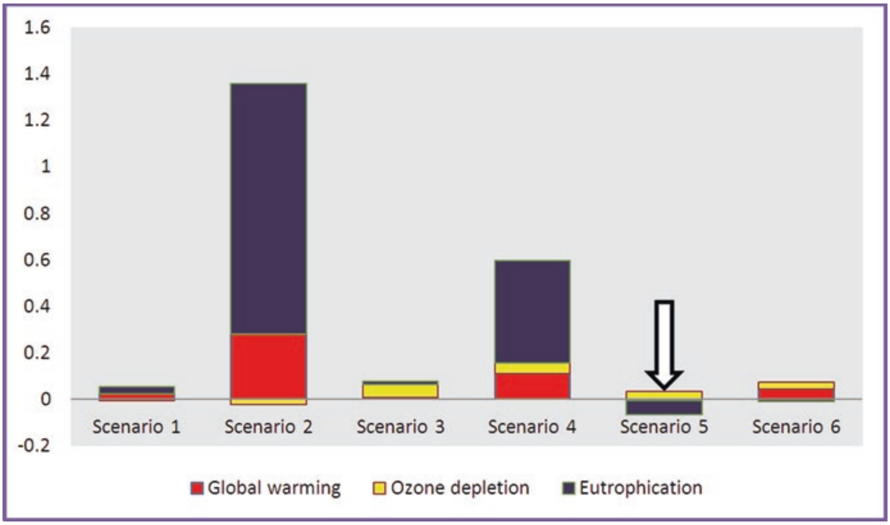

Fig. 5.8 Comparison of scenarios considering all environmental impacts

solid waste–management scenarios at the campus from point of view of the total environmental impacts.

The environmental point of scenario 5 is as low as −0.034 points, which means that not only does it lack environmental impacts, it also can reduce the impact points of the other sources such as power plant, compost, and fertilizer producer facilities. Therefore, scenario 5 is the most appropriate scenario for solid-waste management of the campus from the point of view of the environment, whereas scenario 2 is the worst scenario, which applies only the incineration method to treat the solid waste of the campus. Scenarios 1, 3, 6, 4, and 2 are the most acceptable scenarios after scenario 5, respectively.

5.5 Stage 4: Analytical Hierarchy Process of Solid Waste–Management Scenarios

According to the analytical hierarchy–process method, criteria and sub-criteria would be pairwise compared and scenarios should be compared with each other in points of each subcriterion. Then the subcriteria should be weighted and applied in the ranking of scenarios.

5.5.1 Pairwise Comparison Results

Criteria and subcriteria were compared with each other using pairwise comparison step. Scenarios were compared in each subcriterion. Results of pairwise comparisons, weighting, and ranking of scenarios are explained in the following paragraph.

5.5.1.1 Pairwise Comparison of Economic and Environmental Criteria

In the first level of comparison, according to expert opinion, Table 5.12 shows the result of pairwise comparison of economic and environmental criteria.

Results of pairwise comparison of the main criteria show that the weights of economic and environmental criteria are 0.5, which means in expert opinion that saving the environment and the cost of improving the solid waste–management system of the campus reflect similar values.

Table 5.12 Pairwise comparison of environmental and economic criteria

Main criteria	Environment	Economic	Weight
Environmental	1	1	0.50
Economic	1	1	0.50

Table 5.13 Pairwise comparison of economic subcriteria

Economic subcriterion	Investment cost	Operation cost	Marketability of product	Weight
Investment cost	1	2	3	0.528
Operation cost	1/2	1	3	0.333
Marketability of product	1/3	1/3	1	0.140

Table 5.14 Pairwise comparison of environmental subcriteria

Environmental subcriterion	Global warming	Ozone depletion	Eutrophication	Weight
Global warming	1	2	2	0.493
Ozone depletion	1/2	1	2	0.311
Eutrophication	1/2	1/2	1	0.196

5.5.1.2 Pairwise Comparison of Economic and Environmental Subcriteria

To allocate the proper weight to each economic and environment subcriterion, subcriteria are compared with each other using pairwise comparison (Table 5.13).

Results show that the weight of investment cost is 0.53, operation cost is 0.33, and marketability of products is 0.14, which means, in expert opinion, that (1) the investment cost of a solid waste–management system is three times more important than operation cost and two times more important than marketability of the product and (2) the importance of operation cost is approximately two times that of marketability of the product at the campus.

The result of pairwise comparison of global warming, ozone depletion, and eutrophication (Table 5.14) illustrates that the weight of global warming is approximately 0.49, ozone depletion is 0.31, and eutrophication is approximately 0.19, which means that in a solid waste–management system, global warming impact is more important than ozone depletion and eutrophication impacts, whereas ozone depletion and eutrophication reflect similar values.

5.5.1.3 Pairwise Comparison of Defined Scenarios

Results of comparing the scenarios in terms of investment cost (Table 5.15) show that scenario 6 has the highest weight and scenario 1 has the lowest weight. Therefore, scenario 6 is the best scenario, whereas scenario 1 is the worst scenario in the solid-waste management of the campus. Table 5.16 shows the comparison of scenarios from the point of view of operation cost.

In terms of operation cost subcriteria, scenario 6 has the highest weight and scenario 2 has the lowest weight. Regarding expert opinion, integrated RDF, composting, anaerobic digestion, and recycling technologies in the solid-waste management

Table 5.15 Comparison of the scenarios regarding investment cost subcriterion

Investment cost	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	1/3	1/4	1/4	1/5	1/3	0.045
Scenario 2	3	1	1/2	1/4	1/6	1/4	0.067
Scenario 3	4	2	1	3	1/3	1/2	0.171
Scenario 4	4	4	3	1	1/2	1/4	0.131
Scenario 5	5	6	3	2	1	1	0.303
Scenario 6	3	4	2	4	1	1	0.283

Table 5.16 Comparison of the scenarios in regarding operation cost

Operation cost	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	6	1/2	1/2	1/3	1/4	0.101
Scenario 2	1/6	1	1/5	1/3	1/4	1/4	0.041
Scenario 3	2	5	1	3	1/3	1	0.200
Scenario 4	2	3	1/3	1	1/2	1/3	0.111
Scenario 5	3	4	3	2	1	1/2	0.257
Scenario 6	4	4	1	3	2	1	0.290

Table 5.17 Comparison of the scenarios regarding marketability of product

Marketability of product	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	1	1/2	1/3	1/4	1/4	0.060
Scenario 2	1	1	1/3	1/4	1/5	1/6	0.048
Scenario 3	2	3	1	1	1/3	1/4	0.113
Scenario 4	3	4	1	1	1/2	1/4	0.137
Scenario 5	4	5	3	2	1	1/2	0.250
Scenario 6	4	6	4	4	2	1	0.392

of the campus has the lowest operation cost, and applying RDF technology alone to treat the solid waste of the campus has the highest operation cost.

According to Table 5.17, in expert opinion, scenario 6 has the best marketable product because it has the highest weight in the mentioned subcriteria, and scenario 2 is the worst scenario of product marketability compared with other scenarios. Table 5.18 shows the result of comparing the scenarios from the point of view of global warming.

Comparison of the scenarios in terms global warming subcriteria (Table 5.19) shows that scenario 5 has the highest weight and scenario 1 has the lowest weight in terms of expert opinion. Therefore, applying the integration of RDF, composting, anaerobic digestion, and recycling is the most suitable solid waste–management system to protect the environment in terms of global warming. The greatest amount of greenhouse emissions is produced when the management applies only incineration technology to treat the solid waste of the campus.

Table 5.18 Comparison of scenarios regarding global warming

Global warming	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	1/2	1/3	1/4	1/2	1/3	0.066
Scenario 2	2	1	1/2	1/4	1/3	1/2	0.083
Scenario 3	3	2	1	1/2	1/3	1/2	0.123
Scenario 4	4	4	2	1	1/3	1/2	0.194
Scenario 5	2	3	3	3	1	2	0.321
Scenario 6	3	2	2	2	1/2	1	0.212

Table 5.19 Comparison of scenarios regarding ozone depletion

Ozone depletion	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	1/2	1/5	1/3	1/6	1/5	0.039
Scenario 2	2	1	1/3	1/6	1/7	1/6	0.046
Scenario 3	5	3	1	2	1/2	1/2	0.164
Scenario 4	3	6	1 /2	1	1/5	1/3	0.119
Scenario 5	6	7	2	5	1	1/2	0.304
Scenario 6	5	6	2	3	2	1	0.327

Table 5.20 Comparison of scenarios regarding eutrophication

Eutrophication	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Weight
Scenario 1	1	1/3	1/4	1/3	1/5	1/5	0.043
Scenario 2	3	1	1/2	1/3	1/5	1/3	0.073
Scenario 3	4	2	1	1 /2	1/4	1/2	0.113
Scenario 4	3	3	2	1	1/4	2	0.192
Scenario 5	5	5	4	4	1	2	0.401
Scenario 6	5	3	2	1/2	1/2	1	0.178

Table 5.20 shows that, according to expert opinion, scenario 6 is the most suitable solid waste–management scenario when only ozone depletion protection is considered because this scenario reflects an integrated incineration system using composting, anaerobic digestion, and recycling to treat the solid waste. Scenario 1 is the worst scenario because it has the lowest weight in the environmental subcriteria. Table 5.20 shows the result of comparing the scenarios regarding eutrophication.

According to the comparison of different scenarios in eutrophication subcriteria, expert opinion is that scenario 5 is the best scenario to reduce eutrophication impact. Scenarios 1 and 2 are the worst scenarios in terms of those subcriteria. This means that applying a single method, such as RDF or incinerator to treat the solid waste of the campus, confers high environmental burdens in terms of eutrophication.

Table 5.21 Weighting of environmental criteria, economic criteria, and subcriteria

Main criteria	Subcriteria	Weights of main criteria	Weights of subcriteria in each main criteria	Total weights of each subcriterion
Environmental	Global warming	0.5	0.493	0.246
	Ozone depletion	0.5	0.311	0.155
	Eutrophication	0.5	0.196	0.098
Economic	Investment cost	0.5	0.528	0.264
	Operation cost	0.5	0.333	0.166
	Marketability of product	0.5	0.140	0.07

5.5.2 *Criteria and Subcriteria Weighting*

After pairwise comparison of criteria, subcriteria, and scenarios with each other, their weights are considered to calculate the final weight of scenarios. This step shows the result of the final weighting of scenarios before ranking (Table 5.21).

To calculate the final weight of each subcriteria area, the weight of the main criteria (environmental and economic) is multiplied by the weight of each subcriterion area under the main criteria. As Table 5.21 shows, investment cost has the highest weight because it is the most important option to design a proper solid waste–management system, and marketability of product has the lowest weight.

5.5.3 *AHP Score and Ranking of Scenarios*

Final AHP scores for each scenario was calculated by summing the multiplication weight of each scenario in related subcriteria weight.

Figure 5.9 shows that scenario 5 has the highest score and is thus the most suitable scenario in terms of AHP with environmental and economic criteria. According to expert opinion, the integration of RDF, composting, anaerobic digestion, and recycling pose the lowest environmental burden and also the lowest cost to treat the solid waste of the campus. In the next stage, the result of life-cycle assessment are combined with economic data that were extracted from AHP to select the most appropriate solid waste–management system.

5.6 Stage 5: Combination of LCA and AHP

To combine the life-cycle assessment result (environment) with the extracted economic results of AHP, LCA results are standardized in the first step. Then economic data are weighted by cluster analysis. Finally, the economic data are standardized and plotted with LCA data to rank the scenarios.

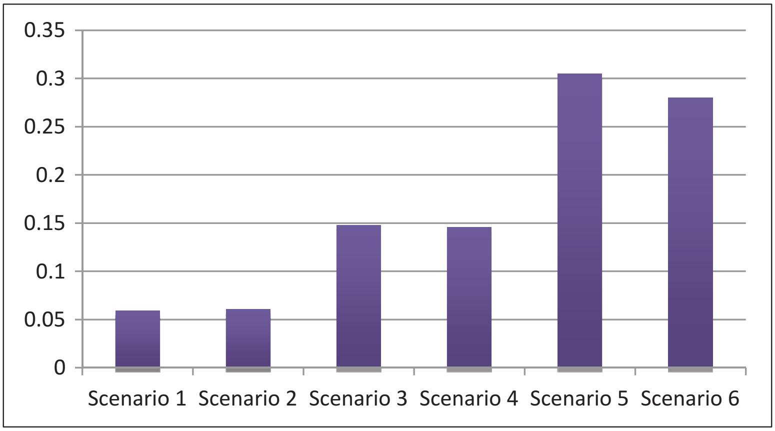

Fig. 5.9 Ranking of scenarios by AHP

Table 5.22 Standardization of environmental points for the scenarios

Scenario	LCA points	Standardized environmental points
Scenario 1	0.052	0.82
Scenario 2	1.077	−2.7
Scenario 3	0.076	0.74
Scenario 4	0.596	−1.05
Scenario 5	−0.034	1.12
Scenario 6	−0.022	1.07
Average	0.290	

5.6.1 Standardization of Environmental Points

Referring to the equation of standardization, the average of the LCA points is calculated. Then the LCA points of each scenario are subtracted from the average. The results are divided by the average LCA point of each scenario. Finally, the results are multiplied by (−1) due to conversion of the results to positive points as shown in Table 5.22.

5.6.2 Scoring of Extracted Economic Result of AHP

To define the weight of the scenarios in each economic subcriterion area, a score between 1 and 10 is allocated to each scenario according to the weight of scenarios in each economic subcriterion area (Table 5.23).

Table 5.23 Scoring of scenarios in cluster-analysis method

	Investment		Operation		Product	
Scenario	Cost	Score	Cost	Score	Marketability	Score
Scenario 1	0.045	1	0.101	2	0.060	1
Scenario 2	0.067	1	0.041	1	0.048	1
Scenario 3	0.171	2	0.200	3	0.113	2
Scenario 4	0.131	2	0.111	2	0.137	2
Scenario 5	0.303	4	0.257	3	0.250	3
Scenario 6	0.283	3	0.290	3	0.392	4

Table 5.24 Economic score and standardization of economic AHP scores

Scenarios	Economic AHP score	Standardized economic weight
Scenario 1	1.334	−0.4
Scenario 2	1.001	−0.55
Scenario 3	2.335	0.47
Scenario 4	2.002	−0.01
Scenario 5	3.531	0.58
Scenario 6	3.143	0.41
Average	2.224	

According to the scoring table of the cluster analysis method, higher scores are allocated to better scenarios in each subcriterion area. Therefore, lower scores are related to the scenarios with high investment cost, high operating cost, and production the worst marketable product, whereas a higher score is related to the scenarios with lower investment cost, lower operating cost, and better marketable product.

5.6.3 Standardization of AHP Scores of Scenarios

To reach comparable economic results, the economic AHP scores of scenarios were standardized according to the standardization equation, which is described in Chap. 3 (Table 5.24). After the standardization of economic AHP scores, data are prepared for plotting with standardized LCA points in the next step.

5.6.4 Plotting the Standardized Results of AHP and LCA

After standardization of the economic score that comes from AHP and standardization of the environmental points from LCA, the results are plotted to determine the distance of scenario points from the optimum point. The *x*-axis represents the

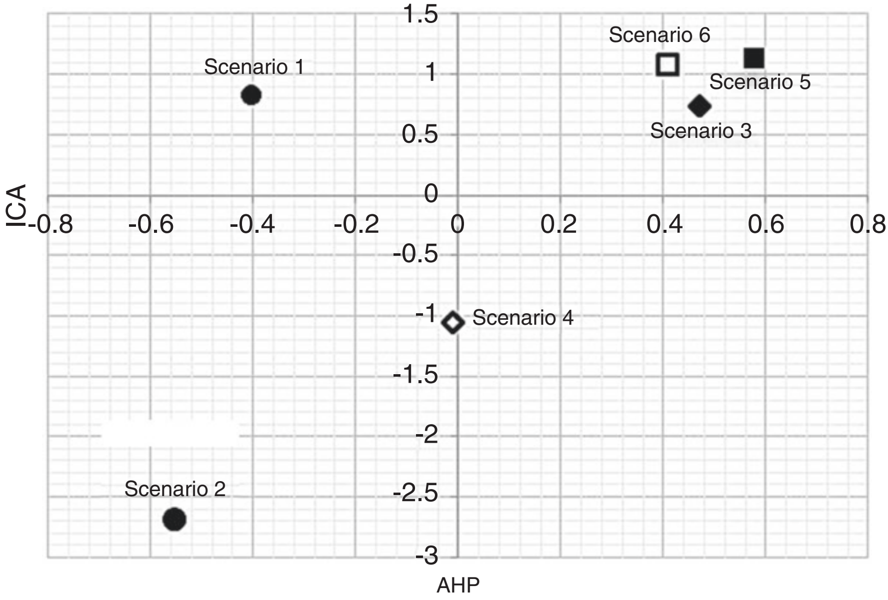

Fig. 5.10 Plotting the environmental and economic combination

standardized AHP score, and the *y*-axis represents the standardized LCA point. The optimum point is the point with highest environmental point in the *y*-axis (LCA results were multiplied by −1 in the standardization) and highest economic score in the *X*-axis (because the high score was allocated to low cost).

Figure 5.10 shows the result of cluster-analysis method by combination of LCA and AHP. According to the cluster-analysis results, scenarios 5, 6 and 3 are in +*X* and +*Y* area, which means that they have a positive AHP score and positive LCA point.

Results show that scenario 5 is the most suitable scenario because of its proximity to the optimum point. In this method, the optimum point is a point with highest positive *X* and highest positive *Y*. Therefore, applying the combination of RDF technology with composting, anaerobic digestion, and recycling is the most suitable solid waste–management system. In addition, scenario 2, 1, and 4 are the worst scenarios, respectively, because of their score and location on the axes.

Chapter 6
Solid Waste–Management Framework

6.1 Structure of the Proposed Solid Waste–Management Framework

Whole solid wastes of the campus are divided into three categories: 60 % organic waste, 20 % recyclable materials, and 20 % other waste. Of organic wastes, 20 % is compostable waste, which could be treated by a composting method in gardening and landscaping. Other organic wastes Refuse Derived Fuel (40 %) are treated by an anaerobic digestion method. The produced fertilizer could be applied in gardening and landscaping on the campus. Other solid wastes are treated using the RDF method. Electricity generated from RDF and anaerobic digestion could be consumed inside the campus. Nonrecyclable, noncompostable, and noncombustible wastes (< 1 %) are taken outside of the campus for landfilling. Recyclable materials (20 %) would be sold to recycling centers to generate revenue.

Different methods were applied to introduce an appropriate system to decision-makers in higher education to have a systematic procedure to manage their generated solid waste. Regarding the suggested solid waste–management system, universities are not only able to minimize the cost and obtain revenue; they can also protect the environment and move toward being a green university. Figure 6.1 shows the proposed solid waste–management framework.

6.2 Comparison of the Results Between the Analytical Hierarchy Process and Cluster-Analysis Methods

Regarding previous steps and considering expert comments to select an appropriate solid waste–management system, analytical hierarchy process (AHP) economic and environmental criteria were analyzed without considering a life-cycle analysis (LCA). Applying the cluster-analysis method helps to combine AHP and LCA

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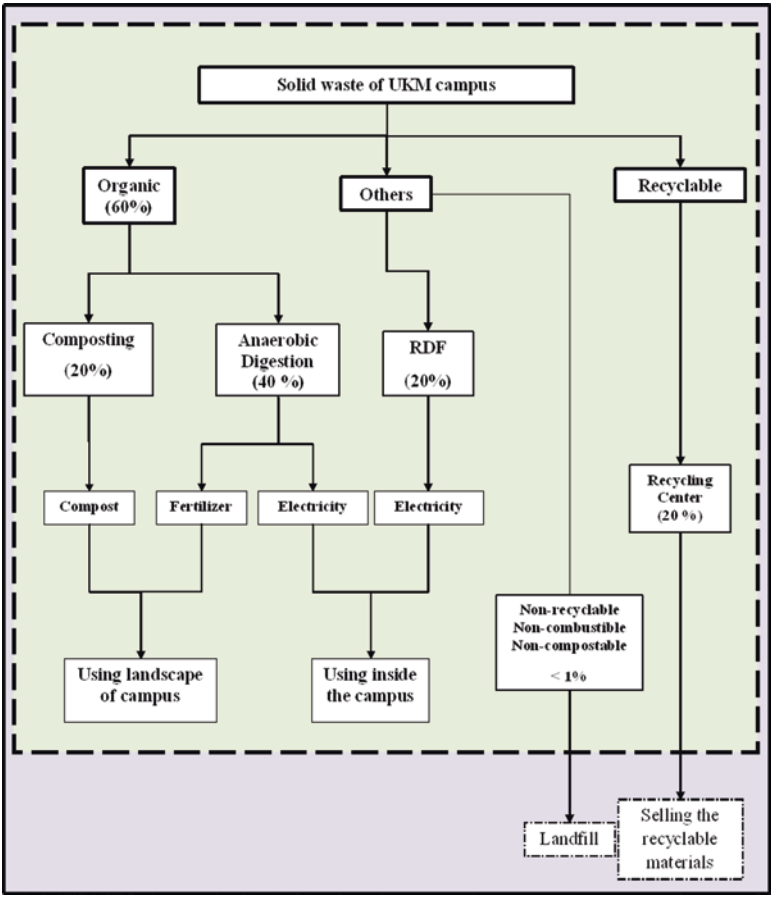

Fig. 6.1 Proposed solid waste–management framework

Table 6.1 Comparison of AHP and cluster results

Scenario	Ranking by AHP (economic & environmental)	Ranking by cluster analysis (LCA & economic AHP)
Scenario 1	6	4
Scenario 2	5	6
Scenario 3	3	3
Scenario 4	4	5
Scenario 5	1	1
Scenario 6	2	2

results to produce a single ranking of scenarios. The results of the AHP and cluster method are compared in this step (Table 6.1).

Comparing these methods illustrates that the results expert-opinion analysis are similar to the cluster-analysis result in terms of selecting the most appropriate solid waste–management system, whereas there is no similarity in defining the worst scenario. Both AHP and cluster analysis of the proposed scenarios found that scenarios 5 and 6, respectively, were the best options. Scenario 5 integrates RDF technology with composting, anaerobic digestion, and recycling, and in view of that it is proposed as the most suitable solid waste–management system because of the validation and selection of the same scenarios by both methods.

Because the environmental impacts of the solid waste–management scenarios have been assessed more accrue than expert's opinion; the result of cluster analysis method is considered more reliable and scientific than AHP.

6.3 Combination of LCA and Environmental Results of AHP

To perform a combination of LCA and environmental results of AHP, LCA points and AHP scores should be standardized (Tables 6.2 and 6.3). The results of this combination could be applied when the environmental impacts of solid waste–management system are considered and their economic aspects ignored.

After calculation of the standardized LCA and environmental results of AHP, plotting was applied to indicate and rank the scenarios. Figure 6.2 shows the plotting of the standardized results of LCA and environmental results of AHP. The results show that scenario 5 is the best solid waste–management system in terms of environment impacts regarding both expert opinion and LCA method because it is closest to the optimum point (the point with the highest

Table 6.2 Standardized environmental scores of AHP

	Weight of AHP	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Global warming	0.493	1	1	2	2	4	3
Ozone depletion	0.311	1	1	2	2	4	4
Eutrophication	0.196	1	1	2	2	5	2
Standardized scores		1	1	2	2	4.196	3.115

Table 6.3 Standardized AHP scores and LCA points

	Environmental AHP scores	LCA points	Standardization of AHP score	Standardization of LCA points
Scenario 1	1	0.052	−0.55	0.82
Scenario 2	1	1.077	−0.55	−2.7
Scenario 3	2	0.076	−0.01	0.74
Scenario 4	2	0.596	−0.01	−1.05
Scenario 5	4.196	−0.034	0.89	1.12
Scenario 6	3.115	-0.022	0.40	1.07

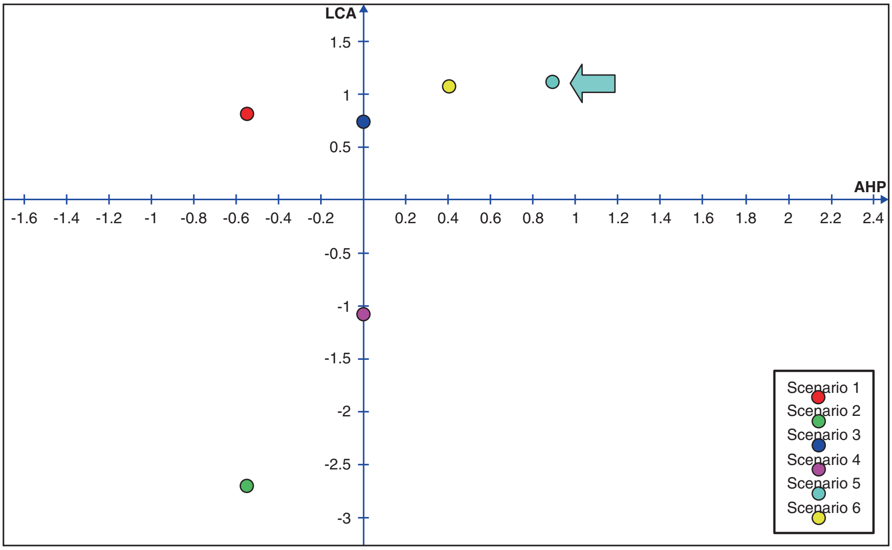

Fig. 6.2 Standardized results of LCA and environmental results of AHP

AHP score and LCA point). Scenario 2 is the worst solid waste–management options.

Comparison of the ranking of scenarios by LCA and cluster-analysis method in terms of environment illustrate that in both these methods, scenario 5—which has integrated RDF, composting, anaerobic digestion, and recycling—has the least environmental impacts. However, to indicate the next appropriate scenario, LCA shows that scenario 1 is the best scenario after scenario 5, whereas cluster-analysis method shows that scenario 2 in the best scenario after scenario 1. Furthermore, to indicate the worst scenarios, LCA and cluster-analysis method show the similar solid waste–management system, i.e., the one with the highest impact point in terms of the environment.

6.4 Advantages of the Proposed Solid Waste–Management System

Regarding the current condition of solid-waste management, domestic waste is taken into the RDF plant and other waste—such as garden waste, disposable electronic waste, and construction waste—is disposed of in an open dump. After selection of the most appropriate integrated solid-management system at the campus, the advantages of applying this system are compared with the current solid waste–management system regarding two points of view: environmental and economic.

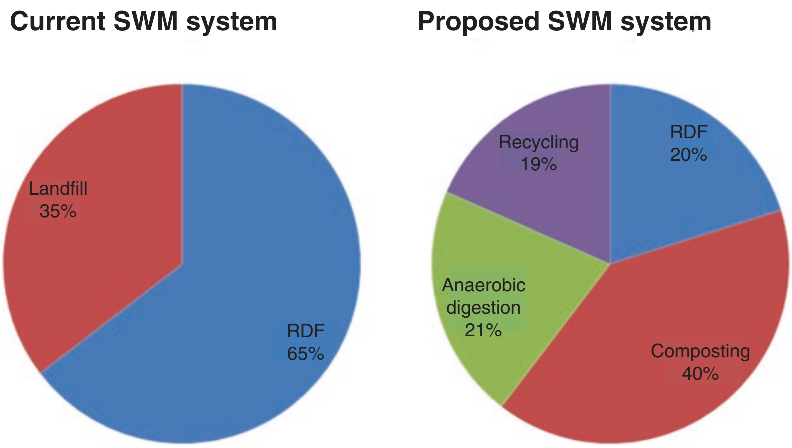

Fig. 6.3 Comparison of the current SWM system with the proposed SWM system

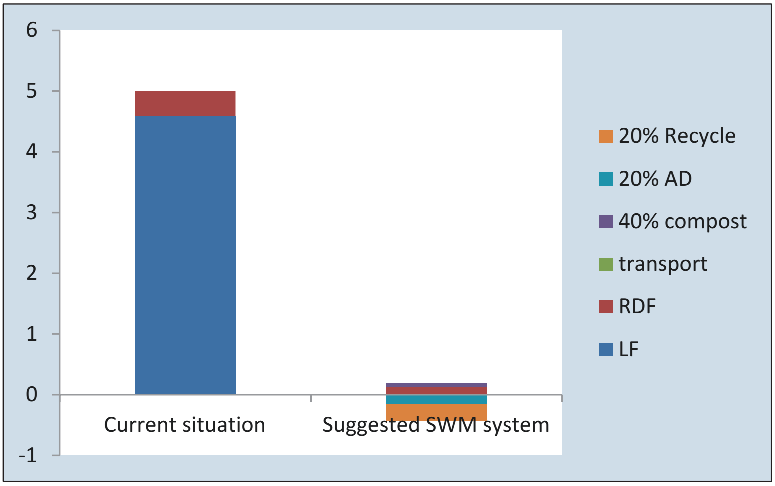

Fig. 6.4 Comparison of the current condition with the proposed SWM system regarding global-warming impact

Figure 6.3 shows the comparison of current solid-waste management with the proposed solid waste–management system.

Approximately 5.8 tons of campus domestic waste per day was taken to the RDF plant for disposal (65 %), and the rest of them (35 %), which is approximately 3.18 tons per day—including garden waste and construction waste—goes to the landfill. However, as Fig. 6.4 shows, different technologies are applied to treat the campus solid waste in the proposed system.

6.5 Environmental Advantages of the Proposed Solid Waste–Management System

To compare the environmental impacts of the current condition with the proposed solid waste–management system, the impacts of global warming, ozone depletion, and eutrophication of the current system are compared with those of the proposed system. Figure 6.5 shows a comparison of current solid-waste management and the proposed system regarding global warming impact.

Comparing the current condition of solid-waste management with that of the proposed system illustrates that the campus produces approximately 5 points of global-warming potential per month; however, by applying the suggested scenario, this is decreased to −0.24 points of global-warming impact per month. This occurs due to the production of compost, fertilizer, and electricity at the campus and reducing the necessity of production of these products in other factories. Therefore, it reduces the total environmental impacts of these factories to produce compost, fertilizer, and electricity. According to the huge amount of these products produced, the number of environmental points could be negative. This investigation shows that the campus can improve the environmental condition in terms of global warming approximately 20 times better than the current solid-waste management by applying the proposed system. Figure 6.5 shows a comparison of current solid-waste management and the proposed system regarding ozone-depletion impact.

Although, in the current condition of solid-waste management at campus, ozone depletion potential is almost zero, composting technology produces approximately 0.173 ozone depletion points per month when the proposed solid waste–management system is applied at campus. Since, ozone depletion point in recycling is

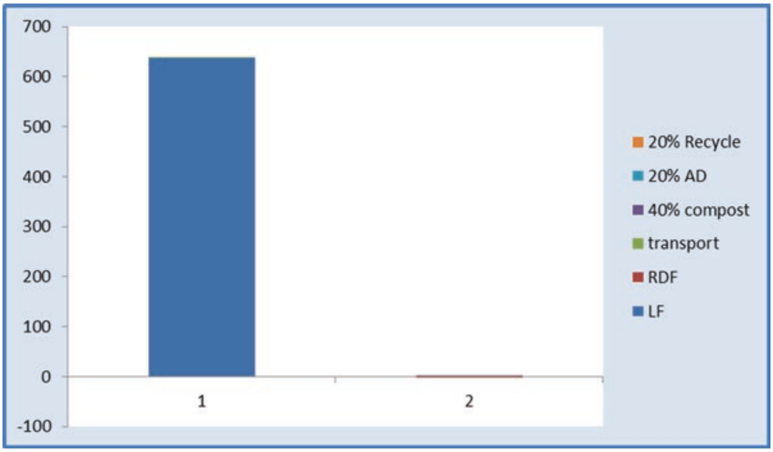

Fig. 6.5 Comparison of the current condition with the proposed SWM system regarding ozone depletion

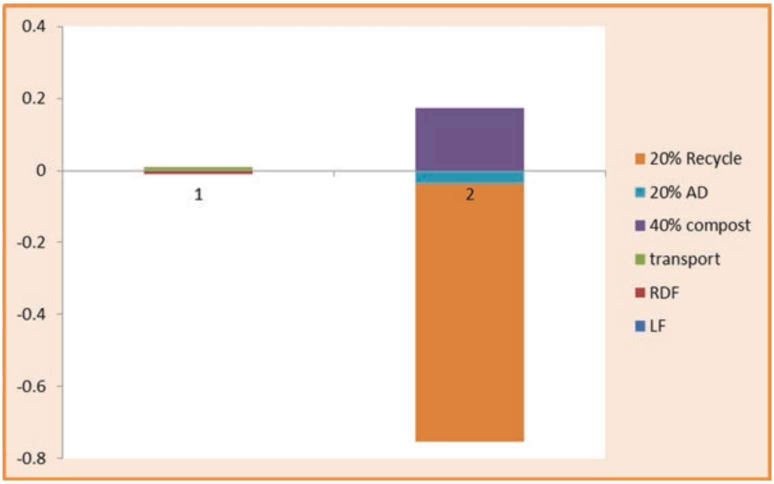

Fig. 6.6 Comparison of the current condition with the proposed SWM system regarding eutrophication

approximately −0.717 points per month and in anaerobic digestion is approximately −0.036 points per month. Figure 6.6 shows a comparison of current solid-waste management and the proposed system regarding eutrophication impact.

Figure 6.7 shows that, managing can improve the environmental condition in terms of eutrophication approximately 600 points better than the current condition by applying the proposed solid waste–management system in this investigation.

Figure 6.7 shows that managing can improve the environmental condition and reduce the environmental impacts in terms of the solid-waste management at the campus by applying the proposed solid waste–management system. With the current condition, the environmental impacts of solid-waste management are approximately 600 points per month regarding global warming, ozone depletion, and eutrophication, whereas with the proposed solid waste–management system, it is approximately −150 points per month. This means that the environmental condition of the proposed system is 5 times better than the current solid waste–management system. With the current solid waste–management system and the proposed solid-waste management, investment and operation costs are considered to make economic comparisons. Marketability of product is an alternative to know the preference of experts, and it is not directly related to the cost of technology such as operation and investment costs, whereas the revenue of product already considered in the operation cost (Fig. 6.8).

The results shows that the current solid waste–management system at the campus does not have any investment cost for management. Management pays approximately USD 6000 monthly for contractors' fees to collect and dispose of the solid waste. Because the life span of solid-waste technologies are 25 years, management should pay USD 611,000 for the treatment of solid waste, whereas management

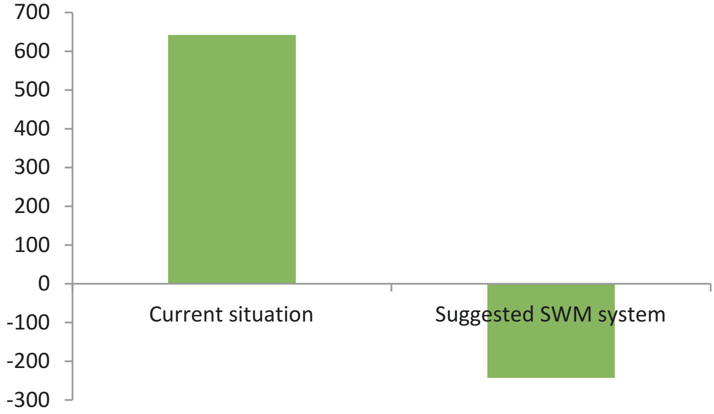

Fig. 6.7 Comparison of the current condition with the proposed SWM system regarding total environment impacts

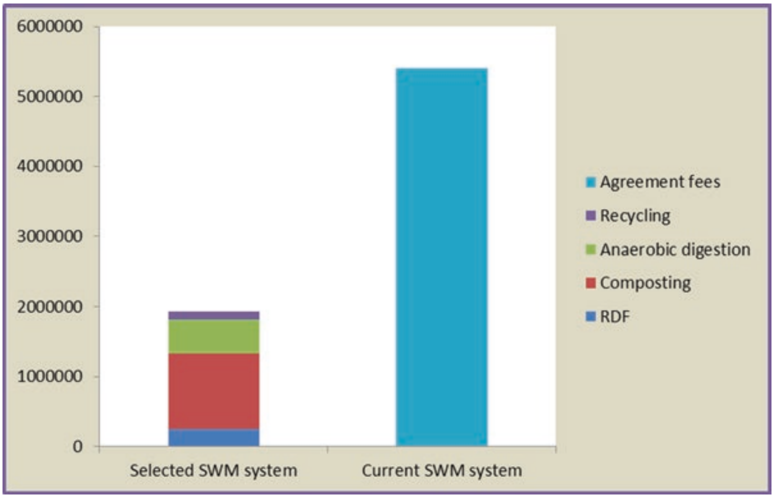

Fig. 6.8 Comparison of investment cost of the proposed SW management system with that of the current SW management system

currently pays approximately USD 1,740,000 to contractors for collection and disposal of the solid waste during this time. Therefore, USD 1,103,000 could be saved by applying the proposed solid waste–management system (Fig. 6.9).

According to the comparison of the two systems, the current solid waste–management system produces no revenue, whereas the proposed system generates approximately USD 10,000.00 in revenue per month. This money comes from selling the recyclable materials, electricity, and fertilizer production from anaerobic digestion and compost production.

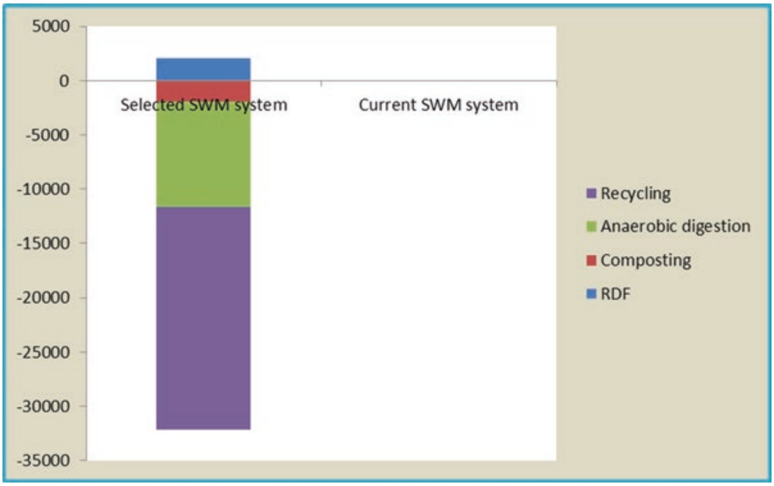

Fig. 6.9 Comparison of the operation cost of the proposed SW management with that of the current SW management system

6.6 Comparison of Current Investigation with Relevant Investigations

Regarding different investigations based on the appropriate solid waste method, other investigations are considered and compared with the current investigation. Considering LCA investigation, an LCA investigation of University of Maribor, Slovenia is described here (Lukman et al. 2009). As a part of the required data was not available, only the engineering departments were investigated by LCA. According to Benítez and Lozano (2008), university contains different areas of activity: education, operation, assessment, and outreach and reporting. But, in this investigation all solid waste generation sources except hazardous waste that are considered for the campus are dormitories, cafeteria, faculties, administration, residential area, and services. Therefore, a wide variety of sources are considered versus the University of Maribor. The first practice of the LCA investigation concentrates mostly on procedures including environmental effects of the structuring and maintenance of classes, heating, lighting, and other consumption of electricity, also water consumption. The second practice includes usual variety of consumption, consisting of printing paper and plastics as PET bottles. Various end-of-life solid waste management decisions for the paper and plastic waste are also proposed, as well as recycling, incineration (Lukman et al. 2009). But, in this investigation it was done on comprehensive end-of-life waste management decisions that are regularly based on the solid waste composition at the campus. Therefore, the investigation focused on solid waste treatment technologies like RDF, composting, anaerobic digestion, and recycling because of different conditions between composition of solid waste at European and Asian University.

The University of Northern British Columbia (UNBC) investigated on solid waste system at the campus of Prince George (Smyth et al. 2010). Sampling and characterization of solid waste was done based on a defined procedure, respectively (Smyth 2008; Batool and Chuadhry 2009). It was found that the campus of Prince George had generated 1.2–2.2 metric tons of solid waste weekly in the 2007–2008 academic year. More than 70% of produced waste could have been delivered for solid waste reduction, composting and recycling activities. Meanwhile, during the solid waste composition analyses in 2015, the campus produced about 5.9 tone domestic wastes, 2.4 tone garden wastes, and 2.3 tone construction wastes per day (Smyth et al. 2010).

In British Columbia, compostable organic material, plastic, paper, nonrefundable drink containers indicated the most considerable material types to target waste diminution and recycling activities. In the campus, about half of the domestic waste is organic waste and 37% is paper and plastic; in addition, 2.3 tons of total solid waste of the campus is garden waste that could be converted into compost. The University of British Columbia is similar to the pilot campus regarding organic wastes. The majority part of the budget was cost for the heaviest part of the waste stream according to its characteristics; however organic wastes produce the highest greenhouse gases, once buried in a landfill (Bogner et al. 2008).

A research of Royal Roads University, in British Columbia, determined that compostable organics stand for 60% of the waste stream of the campus (Smyth et al. 2010), that is more than twice the quantity at the campus of UNBC. Correspondingly, making compost from institutional organic waste outside the university or in the campus grounds was a common practice, by HE sectors (Armijodevega et al. 2008) which is the problem at the pilot campus. For instance, Ohio University obligated to compost food waste with the income of the in-vessel method of composting with the capability of composting of organic waste up to 25 metric tons (Tandy et al. 2010). The Research Group of Prince George Public Interest has conducted a compost program; voluntarily the compost program includes gardening on the UNBC, Prince George Campus to divert 13,000 kg per year of organic material (Smyth et al. 2010).

In an investigation on performance of zero waste program at the campus site of Massey University in New Zealand (Kelly et al. 2006), environmental management structure was used in view of recycling activities during the organic residuals investigation concerned personal conversation and staff training. It was approved that practices resulted well, with constant supervision of the supervisory staff. The succeeding environmental management procedures included steady formation of working relationship with the staff of the facilities management to launch a transition practice of the research/development tasks and the implementation of superior environmental process on a constant basis (Mason et al. 2003).

Scenario 1 and 2 contains energy recovery treatment methods and suggested the appropriate methods regarding AHP, LCA, and cluster analysis. In addition, results of comparing six scenarios which are defined based on the existing municipal solid waste management methods in order to select the most appropriate integrated solid waste management methodology shows that the proposed scenario for the campus with least potential of environmental impact is 1 and 2 scenario. Anaerobic digestion is considered as one of the main treatment methods for organic waste which is appropriate to integrate with other methods at the campus as one of the important energy recovery methods. However, high percentage of organic waste which is around 53% offers a possibility of bioconversion into value-added products.

Therefore, this investigation proved that the assessment of multicriteria analysis becomes easier through various tools such as LCA and AHP. Based on the results, the most favorable solution for a campus is the combination of material recovery beside RDF facility with the use of organic fraction (anaerobic digestion and composting) which can be attained by the financial and environmental parameters.

Chapter 7
Summary of Design Recommendations

7.1 Design of Solid-Waste Management

Domestic waste–composition investigation into different solid waste–generation sources shows that the largest amount of domestic waste is generated at dormitories and faculties. Managing and controlling domestic-waste generation at dormitories and cafeterias has a significant effect of reducing organic waste and could reduce half of the total domestic waste. According to the comparison of recyclable materials generated from different sources, the results show that the most important sources of recyclable materials generation are dormitories because they generate 40 % of these materials follows by faculties, with 27 % generation. Therefore, dormitories and faculties are two hot spots in terms of recyclable-materials generation that should be considered. Comparing recyclable materials collected at the source and those existing in disposable waste shows that the greatest part of recyclable materials generated are transferred for disposal and more than 25 % could not be collected more than 25 % at the source. Furthermore, 3.6 tons of compostable waste, 1.6 tons of recyclable materials, and 1.9 tons of usable waste for the anaerobic-digestion method are generated per day. According to the solid-waste composition, some solid waste–management scenarios were suggested, and they were compared using LCA and AHP. Combining of the life-cycle analysis (LCA) and analytical hierarchy process (AHP) results in the cluster-analysis method illustrates that scenario 5—by integration of 20 % RDF, 40 % composting, 20 % anaerobic digestion, and 20 % recycling—is the most appropriate solid waste–management system.

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7.2 Conclusion of the Solid Waste–Management Plan

Considering the management of this amount of waste, life-cycle assessment and analytical hierarchy process, respectively, were applied to analyze the environmental and economic aspects of solid-waste management. The main focus of the investigation was on selecting the best solid waste–treatment technology and integrated solid waste–management system using AHP, LCA, and cluster-analysis methods.

The selection of an appropriate solid waste–treatment system is evaluated by a decision-maker to achieve defined goals by AHP and LCA methods. AHP was applied here to assign priorities to the alternatives based on the model hierarchy structure for solid-waste treatment, which is described in following paragraphs.

1. Solid waste from the campus shows a great potential for reutilization. Results show that the composition of waste are 20 % compostable, 20 % recyclable, 40 % usable for anaerobic digestion, and 20 % mixed waste. Six different solid waste–management scenarios were compared in terms of environmental and economic impacts.
2. The LCA investigation was conducted to determine the environmental-impacts potential of solid waste–management scenarios. It was found that the integrated-treatment technologies of refuse-derived fuel, composting, anaerobic digestion, and recycling (i.e., scenario 5) has the least potential environmental impact in terms of global warming, ozone depletion, and eutrophication.
3. The economic results of AHP in terms of investment cost, operation cost, and marketability of products showed that the integrated-treatment technologies of incineration, composting, anaerobic digestion, following by recycling (i.e., scenario 6) has the most advantages.
4. According to the combination of LCA and AHP results, cluster-analysis method illustrates that the integrated treatment technologies of RDF, composting, anaerobic digestion, and recycling (i.e., scenario 5) is the most appropriate solid waste–management method with the least potential environmental impacts and the most benefit.

7.3 Contributions of the Investigation

1. The proposed design will serve as basis for environmental-impact assessment of solid-waste management as a move toward sustainable campus using life-cycle assessment.
2. The proposed integrated LCA–AHP using cluster-analysis method is the first of its kind in solving complex solid waste–management problems and decisions applicable to other countries.
3. The proposed design provides a solid waste–management framework to the campus in general. The above contributions are also applicable to other campuses with similar wastes composition.

4. The proposed design provides sets of procedures for the best solid waste–management system with respect to the magnitude of environmental and economic impacts to decision makers.

7.4 Recommendation of the Book

There are great possibilities to achieve higher rates of waste diversion in campus waste management by the following:

1. Waste-reduction guidelines designed specifically for the faculties, dormitories, administrations, cafeterias, and services should be designed to educate students and staff on reduce, reuse, and recycling alternatives.
2. New technologies should be explored, such as vending machines, which can greatly eliminate the need for several recycling receptacles and also reduce labor-collection costs, as well as charity boxes to collect the recyclable material as donations.
3. Introduce a recycling curriculum including basic ways to reduce waste (smart purchasing, reusing or fixing old goods, etc.). On-campus NGOs could help elevate awareness of the use of recyclable materials instead of degradable materials.
4. Compost and fertilizer could be in surplus than the required usage in the campus. There can be recommendations on the use of compost and fertilizer, which can serve as a means for income generation.

7.5 Limitations of the Investigation

Some limitations to be overcome include an incomplete database and the lack of historical information on past experiences of different campuses. Hence, to ensure the effectiveness of relevant policies, a sound database on waste policies for different campuses and higher-education institutions are pertinent to establish a more complete assessment model.

In AHP method, data are gathered from several experts from a set of standard questionnaires. Some inconsistencies and inaccuracies in the responses may arise from the censor-based study, which is not unusual but is greatly acknowledged.

Appendix A: Result of Fault Diagnosis for the 22- and 32-Bus Test Systems

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Table A.1 Fault Diagnosis Results of the 22-bus test system

		Identify fault location				Isolation				Restoration	
		RBFNN 1, 3, 5, 7			RBFNN 2, 4, 6, 8	RBFNN 3, 6, 9, 12				Temporary	
Sample	Fault type	Distance from main source (km)	Distance from DG1 (km)	Distance from DG2 (km)	Faulty line no.	CB1	CB2	CB3	CB4	Recloser '1'	Close '1'
950 m of line 1	1 Ph-G	0.960	2.060	7.055	0.98	0	0	0	0	CB1	CB2-CB3-CB4
	2 Ph	0.960	2.061	7.059	0.91	0	0	0	0	CB1	CB2-CB3-CB4
	2 Ph-G	0.950	2.053	7.060	1.02	0	0	0	0	CB1	CB2-CB3-CB4
	3 Ph	0.961	2.057	7.057	1.07	0	0	0	0	CB1	CB2-CB3-CB4
	Actual	0.950	2.050	7.050	1	0	0	0	0		
200 m of line 2	1 Ph-G	1.195	1.794	7.197	1.98	0	0	0	0	CB1	CB2-CB3-CB4
	2 Ph	1.189	1.803	7.189	2.03	0	0	0	0	CB1	CB2-CB3-CB4
	2 Ph-G	1.211	1.802	7.193	2.01	0	0	0	0	CB1	CB2-CB3-CB4
	3 Ph	1.195	1.811	7.190	2.02	0	0	0	0	CB1	CB2-CB3-CB4
	Actual	1.200	1.800	7.200	2	0	0	0	0		
350 m of line 3	1 Ph-G	2.347	0.643	8.351	3.03	1	0	1	0	CB2	DG1-CB4
	2 Ph	2.352	0.657	8.344	3.01	1	0	1	0	CB2	DG1-CB4
	2 Ph-G	2.361	0.656	8.346	3.09	1	0	1	0	CB2	DG1-CB4
	3 Ph	2.355	0.647	8.351	3.05	1	0	1	0	CB2	DG1-CB4
	Actual	2.350	0.650	8.350	3	1	0	1	0		

450 m of line 4	1 Ph-G	3.450	0.453	9.442	4.01	1	1	1	0	CB4	CB4
	2 Ph	3.449	0.458	9.449	3.98	1	1	1	0	CB4	CB4
	2 Ph-G	3.450	0.452	9.448	4.00	1	1	1	0	CB4	CB4
	3 Ph	3.451	0.456	9.447	4.02	1	1	1	0	CB4	CB4
	Actual	3.450	0.450	9.450	4	1	1	1	0		
560 m of line 5	1 Ph-G	4.560	1.562	10.554	4.96	1	1	1	0	CB4	CB4
	2 Ph	4.559	1.555	10.553	4.92	1	1	1	0	CB4	CB4
	2 Ph-G	4.560	1.559	10.561	5.02	1	1	1	0	CB4	CB4
	3 Ph	4.558	1.556	10.556	5.08	1	1	1	0	CB4	CB4
	Actual	4.560	1.560	10.560	5	1	1	1	0		

Appendix B: MATLAB Code

```
clear all;
clc;
% determine network
% DataNetwork_1;
% DataNetwork_2;
DataNetwork_3;
% define faulted line
Nline_fault = 2;
```


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