Energy Science, Engineering and Technology

SIGRID REITER
EDITOR

Energy Consumption

Impacts of Human Activity, Current and Future Challenges, Environmental and Socio-Economic Effects

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ENERGY CONSUMPTION

IMPACTS OF HUMAN ACTIVITY, CURRENT AND FUTURE CHALLENGES, ENVIRONMENTAL AND SOCIO-ECONOMIC EFFECTS

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PREFACE

Energy is central to sustainable development : it has huge environmental, social, and economic impacts amongst which its influence on climate change, poverty reduction efforts, industrial and agricultural productivity and environmental and human health. Developing strategies of a sustainable energy transition is one of the most important worlds' challenges of the twenty-first century. The choices that we will make in the coming years about energy will determine what world future generations will inherit.

Sustainable energy is the sustainable production and use of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Slowing the growth in energy demand while improving the energy efficiency of services and systems and increasing the share of renewable energies is essential. Improving energy accessibility in developing countries and changing the end-users' behaviours and lifestyles towards less energy consumer ones in developed countries while maintaining their high levels of life are also important energy challenges. This will require the active engagement of all sectors of ou societies, including energy production, transportation, buildings, industry and agriculture, as well as all actors involved in energy including the governments, the scientific community, the local communities and the individual consumers.

The book *Energy Consumption : Impacts of Human Activity, Current and Future Challenges, Environmental and Socio-economic Effects*, gives an overview of the key issues, strategies, operational guidelines and policy implications of current research on transition to more sustainable energy consumption. It investigates the important issue of the relations between human activities, energy systems and energy use. It addresses the environmental, social and economic impacts of energy consumption and their interrelationships. Its aim is to guide the reader to more efficient policies and to actions that really will improve the future. Written by academic and research experts in the field of energy, this book develops solutions and opportunities for energy demand reduction, energy efficiency improvement, increase in the share of renewable energy sources, technological progress and behavioural change in the field of energy. The book sets out various alternative pathways that are open to our societies. All those who are interested in the energy challenges will find in this book practical knowledge and operational solutions, providing a solid foundation to help make well-informed choices, as individuals and as societies.

The sixth first chapters address strategies towards sustainable energy transition of the main energy-intensive sectors : energy production, transportation, buildings, agriculture, industry and domestic appliances. The first chapter focus on the electricity generation sector and the transportation sector, mainly by studying the influence of combinations of vehicle technologies improvements and alternative fuels. It quantifies the absolute abatement potential in terms of greenhouse gas emissions and identifies potential barriers to each. The second chapter investigates parameters influencing energy consumption of the built environment, dealing with the building and the transportation sectors, including location, urban form, density, mix use, mobility patterns, buildings insulation, energy mix and inhabitants' behaviours. The third chapter looks at the influencing factors of the energy performances of buildings, especially the role of the end-user, and analyses the differences between some energy assessment methods applied to buildings. The fourth chapter concerns energy use in agriculture showing energy-saving strategies. It discusses also the issues related to land-use change and deforestation. The differences in energy-use intensity and energy-use efficiency of developing and developed countries are highlighted. The fifth chapter studies the energy efficiency of industrial and domestic appliances through the concrete example of energy consumption estimation during food oven cooking. Methods of energy consumption assessment and modeling approaches are discussed. The sixth chapter contributes to the important area of understanding barriers to teenage energy conservation and teenage motivation to adopt changes in energy behaviours, as teenagers are the adults of tomorrow.

Improvements in energy efficicency and decreases in GHG emissions need specific policies and operational actions that will involve investments in research and technology transfer. The four last chapters open further the debate on this question and on the socio-economic impacts of energy consumption. Chapter seven analyses the influences of independant research and development and technology transfer on energy consumption. This chapter shows also the role that adequate energy policies can play on these activities. Chapter eight addresses issues related to the regulation framework as well as specificities of the developing countries as far as energy consumption is concerned. It discusses progress in sustainable energy in the Colombian context from the triple point of view of the access to energy and the energy coverage in rural sectors, the improvements in energy efficiency and the development of renewable energies. Chapter nine discusses the relation between energy consumption and social inequality, concentrating more specifically on the issue of fuel poverty. Possible policies for tackling fuel poverty are being presented in this chapter. The last chapter presents a monitoring of the impacts of renovation investments in buildings on Energy, Economy, Environment and Employment systems. This chapter highlights the tade-offs between the investors' point of view and the global economic performance of the measures tackled.

The main findings presented in this book could have huge positive impacts and lead to a significant reduction in energy consumption, namely if adapted policies and operational strategies are adopted at the right scale. I hope that this book will trigger debate, public awareness, further research, concrete actions and new policies to assist the transition to more sustainable energy futures.

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Chapter 1

GREENHOUSE GAS EMISSION CONTROL OPTIONS: ASSESSING TRANSPORTATION AND ELECTRICITY GENERATION TECHNOLOGIES AND POLICIES TO STABILIZE CLIMATE CHANGE

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ABSTRACT

Prioritizing the numerous technology and policy options is an important step in formulating a cohesive strategy to abate U.S. greenhouse gas (GHG) emissions. This chapter compares various options across two key sectors of the U.S. economy, electricity generation and transportation. The analysis presented in this chapter includes quantification of the abatement potential and discussion of potential barriers to a range of GHG control options. Diminishing coal's use and associated GHG releases is the primary route to reducing electricity generation impacts. The current grid mix with carbon capture and sequestration in all coal plants could yield a 22-percent savings in U.S. GHG emissions, while shifting to a mix that is 50-percent renewables would yield a 9-percent reduction. In the transportation sector, improving the efficiency of passenger vehicles is imperative, with this sector's long-term potential greatly enhanced by fleet electrification. In the short term, deploying all efficiency-improving technologies available for conventional vehicles could cut U.S. GHG emissions by 10 percent while bringing the

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average fuel economy of new vehicles above the Corporate Average Fuel Economy's year-2020 target (which is just 35 mpg). In the longer term, plug-in hybrids running on greener electricity and cellulosic ethanol are predicted to provide a 25 percent reduction in current U.S. emissions. Travel mode shifts, while an immediately viable option, are not estimated to provide savings near the levels of emerging electricity generation and vehicular technologies.

Keywords: Greenhouse gases, transportation energy, electric power generation, energy policy, fuel economy

INTRODUCTION AND SCOPE

Climate change presents a challenge of unparalleled magnitude and urgency. Climate change is projected to introduce severe disruptions in global economic activity. A 5 to 6°C rise in global average temperature – anticipated by the end of the century, based on the current rate of emissions – is forecast to inflict a 20% loss in global GDP (Stern 2006), an economic shrinkage matched only by the Great Depression. Attention at all levels of policy making should turn to stabilizing climate change. Accounting for degradation in the Earth's absorptive capacity, current estimates find that 450 ppm atmospheric CO2e is needed to avoid dangerous consequences; and, after accounting for projected global economic growth, this target will require the U.S. to cut year-2000 emissions by 80% by the year 2050 (Luers et al., 2007).

Reductions of this scale will require strategies that address the economy's many sectors. Numerous technologies and logistics strategies exist or are near technical maturity; however, no single strategy can achieve needed reductions in isolation, and all face obstacles to mass acceptance. Certainly carbon pricing, either through taxation or cap-and-trade schemes, will help to overcome a glaring market externality in which economic actors do not perceive the true costs of their GHG-producing actions; however, carbon pricing is a supportive policy, and will not in and of itself reduce GHG emissions.

The urgency of climate change in the face of multiple barriers (including up-front costs, imperfect information, risk, market distortions, and organizational and attitudinal inertia) requires thoughtful policy to accelerate market adjustments. To that end, the objective of this chapter is to quantify the potential of a wide range of technologies and behaviors to reduce U.S. GHG emissions and examine the barriers these will face. While cost is an important consideration, steep GHG targets have been set. Costs are notoriously difficult to estimate in light of new technologies, and most shifts are likely to yield cost savings. Thus, our focus lies in absolute reduction potential and non-cost barriers. To facilitate comparison, reductions (in million metric tons of carbon equivalents [MMTCE]) from the adoption of options to 1% of the total potential market are used here. These estimates can then be scaled to reflect various levels of adoption.

Figure 1 illustrates the various sources of GHG emissions in the U.S. economy. This paper emphasizes emissions from electricity generation and transportation for four reasons: First, over 60 percent of U.S. GHG emissions happen when fossil fuels are combusted at power plants or in vehicles (EIA 2008). While electricity generation emissions can be reduced through greater efficiency downstream, especially in the residential and commercial sectors, emissions from these sectors remain largely constrained by the fundamental carbon intensity of fossil fuel-fired power plants. Second, the transportation and electric power sectors are comprised of supply-side entities that are relatively consolidated, have a history of being regulated (in terms of product efficiency and emissions), and whose emissions emerge from relatively homogeneous processes. Third, emissions from these sectors are rapidly growing, a scenario quite different from the industrial sector where emissions are declining as the economy transforms. Finally, as this chapter will reveal, electricity generation and transportation ought to be considered side-by-side, due to opportunities for synergistic interaction between the two which could yield even greater reductions in GHG emissions.

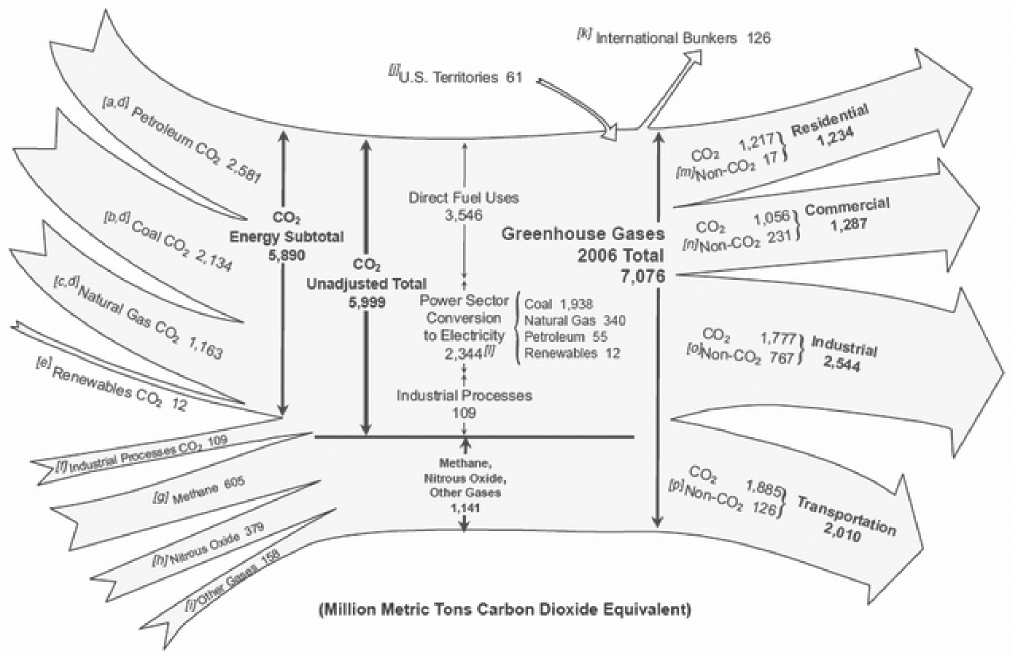

Figure 1. GHG Emissions in the U.S. Economy in 2006 (Source: EIA 2007, Diagram 1).

ELECTRICITY GENERATION

Electricity generation is responsible for 33% of U.S. GHG emissions (EIA 2008). These arise predominantly due to CO2 emissions when fossil fuel feedstocks are converted to electric power.

There are several paths to reducing such CO2 emissions. As described below, grid dispatch can be managed to minimize utilization of carbon intensive power plants. Retrofitting existing fossil fuel power plants and introducing new fossil fuel technologies can improve conversion efficiency or enable the capture and sequestration of CO2 emissions. Finally, future capacity additions can be shifted toward less-carbon intensive sources (including renewables). The array of options must be considered in light of several factors, including current consumption patterns and grid composition, expected increase in demand for electricity, and available supplies of fossil fuels.

Table 1. Potential GHG Reduction from Shifts in Electricity Generating Feedstocks and Technologies

<table>
<tr><th rowspan="2">Plant Technology</th><th rowspan="2">Wholesale Cost (cents/kWh)</th><th rowspan="2">Current Share of Capacity (%)</th><th rowspan="2">Current Share of Generation (%)</th><th rowspan="2">Plant Carbon Intensity (lb CO_2/kWh-Generated)</th><th rowspan="2">1 Percent of U.S. Total GHG Emissions (MMTC)</th><th colspan="2">Vs. Coal-Fired Plants</th><th colspan="2">Vs. Grid Average</th></tr>
<tr><th>Annual GHG Savings (MMTC)</th><th>Percent of U.S. GHG Emissions</th><th>Annual GHG Savings (MMTC)</th><th>Percent of U.S. GHG Emissions</th></tr>
<tr><td>Coal</td><td>4.2</td><td>31.97</td><td>49.97</td><td>2.109</td><td>10.17</td><td colspan="2">--</td><td>(3.858)</td><td>(0.200)</td></tr>
<tr><td>Natural Gas (NG)</td><td>3.2-5.6</td><td>39.06</td><td>20.31</td><td>1.182</td><td>5.70</td><td>4.467</td><td>0.231</td><td>0.608</td><td>0.032</td></tr>
<tr><td>Petroleum</td><td>Not Easily Obtained</td><td>5.870</td><td>1.534</td><td>1.749</td><td>8.43</td><td>1.733</td><td>0.090</td><td>(2.125)</td><td>(0.110)</td></tr>
<tr><td>Geothermal</td><td>4.0-6.0 (Hydrothermal)
8.0-28.0 (EGS)</td><td>0.237</td><td>0.37</td><td>0.007</td><td>0.03</td><td>10.131</td><td>0.525</td><td>6.273</td><td>0.325</td></tr>
<tr><td>Nuclear</td><td>6.7</td><td>10.38</td><td>20.13</td><td rowspan="6">0.000</td><td rowspan="6">0.00</td><td rowspan="6">10.166</td><td rowspan="6">0.527</td><td rowspan="6">6.308</td><td rowspan="6">0.327</td></tr>
<tr><td>Wind</td><td>2.0-9.5</td><td>1.611</td><td>0.802</td></tr>
<tr><td>Solar (CSP)</td><td>12-14</td><td rowspan="2">0.051</td><td rowspan="2">0.015</td></tr>
<tr><td>Solar (PV)</td><td>13-22</td></tr>
<tr><td>Biomass</td><td>Not Easily Obtained</td><td>1.064</td><td>0.624</td></tr>
<tr><td>Hydroelectric</td><td>Not Easily Obtained</td><td>7.969</td><td>6.139</td></tr>
<tr><td>Coal w/ ICGG</td><td>4.6-5.3</td><td>Negligible</td><td>Negligible</td><td>1.294</td><td>6.24</td><td>3.926</td><td>0.203</td><td>0.068</td><td>0.004</td></tr>
<tr><td>Coal w/ CCS</td><td>5.2-9.2 (New)
6.2-11.2 (Retrofit)</td><td>N/A</td><td>N/A</td><td>0.316</td><td>1.52</td><td>8.641</td><td>0.448</td><td>4.783</td><td>0.248</td></tr>
<tr><td colspan="4">Grid Average</td><td>1.308</td><td>6.31</td><td>3.858</td><td>0.200</td><td colspan="2">--</td></tr>
<tr><td colspan="4">Expanded Nuclear and Renewable Sectors (35% Coal, 15% NG, 50% Nuclear & Renewable)</td><td>0.915</td><td>4.41</td><td>5.753</td><td>0.298</td><td>1.895</td><td>0.098</td></tr>
<tr><td colspan="4">Grid Average with CCS in Coal</td><td>0.412</td><td>1.99</td><td>8.178</td><td>0.424</td><td>4.320</td><td>0.224</td></tr>
<tr><td colspan="4">Expanded Nuclear & Renewable Sectors, CCS in Coal</td><td>0.288</td><td>1.39</td><td>8.777</td><td>0.455</td><td>4.919</td><td>0.255</td></tr>
</table>

Notes: Summer capacity and amount generated values come from EIA's (2008a) Tables 8.2 and 8.11; prices are from MIT (2003), Holt (2005), IPCC (2005), Geisbrecht (2008), and the NREL Energy Analysis Office (2005). The wholesale price of petroleum, hydroelectric and biomass electricity could not be easily obtained. CCS assumed present in coal plants in relevant cases at 90% CO2 removal efficiency (IPCC 2005). Feedstock carbon intensities and plant heat rates from Aabaken (2006). Annual U.S. electricity generation and GHG emissions from EIA (2008a). IGCC efficiency improvement midpoint of estimates from Tennant (2005). More details can be found in Kockelman et al. (2008).

In 2006, Americans consumed 3.8 million GWh of electricity[1], producing 2.7 billion tons of CO2 (EIA 2008). Table 1 summarizes the U.S. grid's composition in 2006.

Annual U.S. demand for electricity is projected to increase 29 percent by 2030, to 4.7 million GWh, driven primarily by increased growth in residential and commercial consumption. The EIA (EIA 2008) estimates that capacity additions of 263 GW will be needed to meet the added demand. Moreover, coal power is projected to represent a greater share of the grid by 2030 (roughly 54 percent [EIA 2008]) than it does today, thanks to its relatively low cost. Natural gas's share is expected to fall to just 14 percent, due to rising price volatility. Nuclear's share is not expected to grow significantly, due to its uncompetitively high fixed costs.[2] Renewables are projected to reach 13 percent of total electricity supply by 2030, primarily due to growth in wind and geothermal power (EIA 2008).

Management of Grid Dispatch

Grid capacity and demand for electricity are variable quantities. Grid capacity at a given time is determined by the combination of power available from base-load, intermediate, and variable sources. Base-load sources generate a constant output and cannot be quickly activated or deactivated; these include nuclear, hydroelectric, and some coal plants. Intermediate and variable sources either are easily activated or deactivated or have intermittent generating capacity; these include solar, wind, oil, natural gas, and some coal plants. Demand for electricity peaks both diurnally and seasonally, and peaks can be acute: a daytime peak can be twice as much as a nighttime trough, and in warm climates a summer peak can be nearly twice a spring peak (Denholm 2008). Minimum base-load capacity is largely controlled by daily peaks, and nighttime demand typically lies well below base-load capacity, leaving utility companies with much excess generating capacity.

Improved management of grid dispatch could be achieved by shifting existing demand to existing excess capacity, using "smart" dispatch systems, and developing energy storage technologies. Dynamic pricing of electricity could be used to incentivize shifting demand for electricity to times when there is unused capacity, reducing overall base-load capacity needed and capturing peaks of some intermittent renewables (notably wind (Denholm 2008)). A "smart" network could use real-time data and automated controllers to level power dispatch to where needs are highest and mitigate concerns about relying upon intermittent renewables for baseload generation. Storage technologies could make renewables with unstable capacities more reasonable investments, by enabling these to be used as base-load sources (collected when capacity is high and dispatched as needed). Energy storage could be implemented either at a decentralized level (batteries used by individuals or companies owning plug-in hybrid electric vehicles, for example) or as bulk storage used by utility companies.

[1] Electricity consumed is lower than electric produced due to 7.5 percent transmission and distribution losses, which are assumed throughout this chapter (U.S. Climate Change Tech. Prog 2005).

[2] The outlook for both natural gas and nuclear is unclear. Natural gas production has rebounded from years of decline behind the emergence of shale gas, but price volatility and the extent of domestic reserves remain concerns. Nuclear faces persistent concerns of safety, national security, and lack of a waste disposal plan, but enjoys growing advocacy due to its carbon neutrality and could become cost-effective under scenarios of carbon pricing. (A$100 per ton of GHG price may be needed for competition with natural gas and coal [MIT 2003].)

Improving Fossil Fuel Efficiency

Given the nation's continuing reliance on fossil fuel plants for power provision, power-plant efficiency must be addressed. Coal is in a position to remain a part of the U.S. energy equation for generations to come. Absent taxes, subsidies, and technological advances in other generation types, coal will remain, on average, the cheapest and most reliable type of electricity, thanks to its low fixed costs and well distributed reserves (which minimize variable and transmission costs). Estimates of natural gas supplies had been trending down, from a 2001 projection of 35 trillion cubic feet (TCf) supplied in 2020, to a 2008 projection of less than 23 TCF by 2030 (Shuster 2008). While the success of shale gas has driven recent natural gas production increases, concerns about supply shortages and price volatility as well as use as a transportation fuel will likely diminish its role in the U.S. grid mix. Thus, addressing coal emissionsis key to reducing carbon emissions from power generation. Routes to reduce coal-based CO2 emissions include improving combustion efficiency and carbon capture and storage (CCS).

The U.S. electric grid contains a substantial number of older, pulverized-fuel (PF) coal-fired power plants[3]. The efficiency of PF coal plants can be improved by employing higher temperature and pressure steam conditions to more thoroughly combust fuel inputs. This shift can improve efficiency from 30-35% to 46-48% net efficiency; boiler and turbine technology currently in development could increase this efficiency to 50-55% (DTI 2006). Super-critical boilers can be employed as retrofits and are cost-effective as new investments, as compared to sub-critical boilers (DTI 2006). Integrated Gasification Combined Cycle (IGCC) technology has been suggested as the next generation of power plant technology which could be widely used for coal. IGCC power plants convert carbon in solid fuel feedstocks into a synthetic gas which is then combusted. The gasification reaction and intermediate conversion steps can be used to yield H2 and separate out CO2 (to facilitate CCS) and other impurities. IGCC plants can achieve efficiencies around 40%, and these may reach 50 to 60% by 2020 (Tennant 2005). Several IGCC plants exist around the world (including three in the U.S.), but cost of electricity from an IGCC is 11-27% higher than from a PF plant, representing a significant near-term barrier (Holt 2005).

In the longer term, carbon capture and storage (CCS) is an option for reducing carbon emissions from power generation. CCS is the process of separating and compressing CO2 from industrial or energy sources for long-term storage or use as an input in other industrial processes. CCS is widely used in some industries but application in energy generation will require new methods suited to combustion reactions. A report by the Intergovernmental Panel on Climate Change (IPCC 2005) found that CCS has the potential to reduce CO2 emissions per kWh by 80 to 90%. While CCS is possible for all types of power plants, some will require more power than others to operate (notably IGCC will require the least power due to more concentrated CO2 in combustion gases[4]).

Increased demand for power to operate CCS systems and transport and store CO2, along with higher upfront plant construction costs, will make CCS significantly costlier. The IPCC (2005) estimates that the incremental cost of CCS could be $0.02-0.05 per kWh for a PF plant

[3] 68 percent of coal capacity is from plants that went online in 1978 or earlier and thus employ older, lower efficiency technology (EIA 2006b).

[4] PF power plants with CCS systems would require 24-40% more power, while IGCC power plants would require only 14-25% more power (IPCC 2005).

and \$0.01-0.03 per kWh for an IGCC plant. The most likely scenario in which CCS will become cost effective thus involves carbon pricing. IPCC (2005) estimates abatement costs using geological storage to be \$30-70 per ton CO2 for a PF plant and \$20-70 per ton CO2 for an IGCC plant. A recent MIT study (MIT 2007a) concludes that CO2 prices greater than \$30 per ton are needed to make CCS cost effective. CCS systems could also include retrofits of existing power plants, and Geisbrecht (2008) estimates that retrofitting a typical PF power plant could increase the cost of energy \$0.02-0.07 per kWh and \$0.01-0.03 per kWh at 90% and 30% removal efficiencies, respectively (though abatement cost declines with increasing removal efficiency). Widespread application of CCS will necessitate mature methods of sequestering CO2. Modes of storage proposed include geological storage, oceanic storage, and storage in mineral carbonates, but more research is needed in this area (IPCC 2005). Geological storage seems to have garnered the most attention. While geological storage has been successfully demonstrated in select cases (naturally occurring formations, as well as enhanced oil recovery), no large-scale cases have been proven and blowouts pose a major risk (to safety and the GHG reduction success).

Potential for Renewables

Renewable energy sources cause no direct GHG emissions and do not give rise to concerns of safety, national security, byproduct waste management or long-term supply shortages. The U.S. energy resource base is vast (50,000 times current annual energy usage) and the overwhelming majority is renewable: fossil fuels represent only 6.5%, while wind, photoconversion, and geothermal resources represent 27%, 27%, and 39%, respectively (DOE 1989). Further, many renewables can be installed at a decentralized level by individuals and businesses, thereby eliminating transmission and distribution losses and simplifying grid administration while yielding energy cost savings.

Hydroelectric power is currently the largest source of renewable electricity in the U.S. While there is estimated to be a potential 30,000 MW of additional capacity[5], this source is not expected to grow much in the future due to complex environmental issues and regulations (EIA 2008).

Wind power is rapidly expanding in the U.S. In 2007, wind power experienced a boom year as capacity grew by 46% and represented 35% of new capacity additions (Wiser and Bollinger 2008). Wind power prices are currently \$0.04 per kWh on average, competitive with overall wholesale power prices, though wind power is more economical in regions with higher quality wind resources (in the West and Great Plains) and tax credits and subsidies have caused wind to be more cost-effective overall in many places (Wiser and Bollinger 2008). Wind power faces significant barriers in terms of transmission infrastructure to connect disparate resources and load centers and low capacity factors (due to variable wind speeds, which diminish transmission investment cost-effectiveness). Improved grid management and battery-based storage could moderate this hurdle. Scale could also make intermittence less of an issue, as more "noise" could mean a more predictable level of generation. One forecast projects wind to be producing 20% of America's on-grid electricity by 2030, nearly 30 times its current production (Milligan 2007). Notably, wind power is also

[5] Total U.S. capacity presently is 1 million MW. (EIA 2008)

a potential power source at a distributed level, and in 2007 the 4.7 MW of off-grid capacity additions nearly matched the 5.7 MW of on-grid additions (Wiser and Bollinger 2008).

Geothermal power plants harness subterranean heat reserves stored in rock and water strata to generate electricity while yielding near negligible GHG emissions (0.6 lbs CO_2e per kWh. The U.S. enjoys a vast geothermal resource, capable of supporting U.S. consumption for 10,000 years (MIT 2007b). With current technology it is only economical to access hydrothermal systems (characterized by high porosity and water contents) at shallow depths (3 km or less), but these represent only 0.1% of U.S. geothermal resources. Accessing further reserves is technically possible, but further development in the areas of drilling, stimulation techniques, exploration, and conversion efficiency is needed for cost-effectiveness. MIT forecasts that a 100,000 MW geothermal capacity is possible within 50 years with modest technology investments (MIT 2007b). Geothermal resources offer the advantage of being a potential baseload source, but those suitable for electricity generation are largely concentrated in the West and away from major population centers. Unlike wind power, though, geothermal power has a high capacity factor, so investment in transmission infrastructure is more cost-effective.

Like wind, U.S. solar power experienced great recent expansion. U.S. solar resources are substantial enough that less than 2% of the land devoted to agricultural grazing could meet U.S. energy needs (Denholm and Margolis 2007). The most prominent solar power technologies are Photovoltaic (PV) and Concentrating Solar Power (CSP). PV systems use semiconductor materials to directly generate electricity from sunlight, are deployable anywhere, and are considered a possible distributed source that could "backfeed" excess power to the grid. According to EERE (2008), PV generated power must fall 50-70% in price to achieve grid parity. This is expected to happen between 2010 and 2015, but could happen even sooner in regions with good solar resources and/or high electricity prices (Margolis 2008). The U.S. Department of Energy estimates that rooftop PV systems with a 30-year useful life have an energy payback period of just one to four years, depending on subsidies granted and energy prices. Solar resources are intermittent, but the overlap between peak demand and solar availability gives solar a relatively high capacity factor. The most prominent barrier to high penetration of PVs is the difficulty in using a distributed source to generate grid electricity; the U.S. grid was not designed to communicate with small downstream sources, so inverters and grid management systems to enable this must be developed and deployed. CSP systems capture solar heat to power generators and require direct sunlight but can generate significant volumes of power and are a potential centralized source. Renewed interest resulted in 65 MW of capacity going online in 2007, with another 3,600 MW planned (EERE 2008). CSPs can be located near existing transmission lines due to the flexibility of solar resources; nevertheless, the need for direct sunlight primarily limits CSP to the Southwest.

Biomass power can be generated from a variety of biomass feedstocks including lumber and mill waste (wood residue), municipal solid waste (MSW), landfill gas, and agricultural waste. Biomass feedstocks sequester carbon prior to being used as a feedstock, thereby offsetting emissions from their combustion. Currently, many industries generate their own electricity from biomass, accounting for 58 percent of the 54 million MW generated in the U.S.; electric utilities contribute the balance, primarily through co-firing with coal to help meet emission regulations (EIA 2008b). Perlack et al. (2005) estimate that the U.S. forestry and agricultural industries are capable of supplying 1.3 billion tons of biomass annually.

Using Mann and Spath's (1997) energy efficiency expectations and assuming an energy content of 15 GJ per ton biomass[6], a 1.3 billion ton supply could yield 2 million GWh of electricity, or about half of 2006's generation. The use of some agricultural wastes could have the added benefit of reducing emissions from the release of high GWP gases. Nevertheless, expansions of biomass power will likely face competition for biomass inputs from the biofuels and bioproducts sectors. Encouragingly, research to integrate these production processes in a single refinery is ongoing.

Table 1 shows potential GHG reductions from shifts in power generating feedstocks and technologies, both from older generation coal-fired plants and an average grid mix. The grid shows reductions in CO_2 however these are nearly identical to reductions in GHG (grid average is 1.34 lb CO_2e/kWh, for instance). The most significant reductions come from moving away from older generation coal. Notably, IGCC coal plants are competitive with natural gas in the GHG reductions offered, but offer less than half of the savings of a plant equipped with CCS. Shifting the entirety of the U.S. grid to a 50 percent nuclear/renewable mix could reduce U.S. GHG emissions by 10 percent, while introducing CCS in all coal plants could abate 22 percent of U.S. GHG emissions. Assuming current energy demands, this shift would hit the nation's likely year-2020 targeted reduction of 20 percent; but it remains far the year 2050 target of 80 percent (Luers et al., 2007 and Stern 2006), particularly in the face of rising population and economic activity. Transport is another key opportunity, as discussed below.

TRANSPORTATION

The transportation sector accounts for 28% of U.S. GHG emissions and is responsible for 46% of the nation's energy-related GHG emissions growth since 1990, due to increasing vehicle-miles traveled (VMT) and stagnant vehicle fuel economy (EIA 2008). A variety of modes contribute to U.S. transportation emissions, including light-duty vehicles, heavy-duty trucks, air, shipping, and rail, which contribute 62%, 19%, 9%, 3%, and 2%, respectively (EPA 2006b). Transportation GHG reduction paths include lower carbon intensity vehicle fuels, improved fuel economy, and travel demand management to reduce travel and shift travel to more efficient modes.

Vehicle Fuels

Vehicle fuels are responsible for GHG emissions through the energy consumed to recover, process, and transport them (well-to-pump [WTP] emissions) as well as through combustion of the fuels themselves (pump-to-wheel [PTW] emissions). PTW emissions depend on the efficiency of the vehicle itself; for a given fuel, these are largely fixed by the stoichiometry of the fuel combustion reaction (on a per unit energy basis). WTP emissions, in contrast, can vary significantly, depending on efficiencies of the various fuel-pathways. PTW emissions are typically the majority of WTW emissions, though Wang (Wang 2003) notes that declining tailpipe emissions will make WTP more significant on a per-mile basis. Thus,

[6] The 15 GJ value is a weighted average of mid-point heat contents for wood and agricultural residues.

accurate assessment of vehicle and fuel technologies should consider well-to-wheel (WTW) emissions, as done here.

The high energy content of fossil fuels makes them ubiquitous vehicle fuels in spite of their high carbon content. Gasoline and diesel account for 72% and 24%, respectively, of domestic surface transportation motor fuel consumption. Petroleum-based diesel fuel enjoys higher energy content than gasoline and is refined and combusted at a higher efficiency, resulting in a slightly lower GHG emission rate than gasoline per unit of energy. However, diesel fuels have posed air quality problems. The EPA recently implemented new emission standards for lower sulfur fuels and stricter NOx and PM standards on diesel vehicles, to be fully phased in by 2010, and emission control systems to comply with these are currently in development. While petroleum fuels made from crude oils are relatively uniform in their GHG emission rates, oil shales, oil sands, and heavy crudes could significantly increase emissions from oil and diesel (Wang 2006). Thus, as global demand for petroleum increases and high-grade crudes become harder to obtain, gasoline and diesel could become even less desirable from a GHG emissions standpoint.

Excessive reliance upon petroleum based fuels was estimated to cost the U.S. $150 to $250 billion in 2005 (or 1% of GDP), when oil was $40 per barrel. This figure includes wealth transfer, economic retardation from oil scarcity, and macroeconomic readjustments (Green and Ahmad 2005), but does not include underwriting of military operations or environmental impacts. Notably, the U.S. demand for petroleum is actually being driven increasingly not by motor gasoline (which only accounts for about half of the products refined from crude oil), but by diesel (which accounts for about a quarter) and other petroleum products. Between now and 2015, demand for diesel is projected to grow about 4 times faster than demand for gasoline; by 2030, the demand for diesel is forecast to grow 14 times as fast (EIA 2008). Addressing issues of GHG emissions and economic costs from petroleum based fuels require considering the whole range of products coming from each barrel of crude oil. Diesel fuels can also be made from other feedstocks, including coal, natural gas, and low-value refinery products via Fischer-Tropsch Synthesis; but the more complicated refining processes to produce these result in slightly higher emission rates (EPA 2002).

Natural gas can be used in various forms for motorized transport, with GHG reductions on the order of 20 to 30% per BTU (EPA 2007a), and CNG and LNG combined already meet 15.6% of U.S. bus fuel demands (APTA 2008). Natural gas has received much attention as a potential light-duty vehicle fuel because prices are, on average, lower than recent years' petroleum prices, and distribution may be achievable via existing pipe networks to homes (and businesses). Nevertheless, domestic supply uncertainties could make natural gas-based fuels problematic in the long run.

A wide range of renewable biofuels made from plant matter, including sugars, starches, and cellulose, also have been proposed as petroleum alternatives. U.S. corn-based ethanol has expanded significantly, from 1,741 million gallons consumed in 2001 to 6,846 million gallons in 2007 (EIA 2007) over 5 percent of gasoline sales. The WTW GHG emissions of ethanol fuels depend significantly on feedstock type, nitrogen fertilizer production, farming processes used, energy use in the biofuel plant, and possible co-production of other goods (Wang 2008). Corn-based ethanol currently averages a GHG content about 20% lower than gasoline, but this can fall to 55% lower than gasoline if the production plant is fueled by biomass or, alternatively, can end up exceeding gasoline carbon intensity if coal-fired power is used in production (EPA 2007b).

Table 2. Potential GHG Reductions from Shift in Vehicle Fuels

Fuel	WTW Emissions (lb CO_2e/Mbtu)	HHV Energy Content (Btu/gal fuel)	WTW Emissions (lb CO_2e/gal fuel)	Energy Content Ratio (gal fuel/gal fuel replaced)	1 Percent GHG Emissions (MMTCE)	Annual GHG Savings (MMTCE)	Percent of U.S. GHG Emissions
Gasoline (weighted mix)	219	124,000	27.16	1.00	4.70	Vs. Gasoline	
Corn ethanol neat fuel	171	83,333	14.28	1.49	3.68	1.02	0.014
Corn ethanol (biomass fuel produced) neat fuel	101	83,333	8.38	1.49	2.16	2.54	0.036
Cellulosic ethanol neat fuel	20	83,333	1.66	1.49	0.43	4.27	0.060
E85 (Corn-based) blend	179	94,190	16.82	1.32	3.83	0.87	0.012
E85 (Cellulosic) blend	50	94,190	4.69	1.32	1.07	3.63	0.051
L S Diesel	213	138,700	29.57	1.00	1.72	Vs. Diesel	
Biodiesel neat fuel	69	126,222	8.70	1.10	0.51	1.21	0.017
B20 blend	184	136,444	25.16	1.02	1.46	0.26	0.004

Notes: Ethanols substitute for gasoline (3,300 mbd [EIA 2008a]) and biodiesels substitute for diesel (1,100 mbd [EIA 2008a]). WTW emissions from EPA (2007b). "Fuel replaced" refers to gasoline for ethanols and ethanol blends and diesel for biodiesel and biodiesel blends; energy content ratio reflects the fact that more of alternative fuel must be combusted to liberate an equivalent amount of energy due to lower energy contents in alternative fuels.

Encouragingly, key emissions factors are nitrogen fertilizer demands and plant efficiency, which are improving, leading to a 50% reduction in ethanol plant energy use over the past 20 years (Wang 2008).

Cellulosic ethanol made from feedstocks including switchgrass, corn stover, crop residues, and farmed trees has been proposed as a less carbon intensive fuel that solves many issues related to corn-based ethanol. Some newer proposed cellulosic feedstocks (in particular fast growing trees) could result in a net GHG reduction via the amount of carbon sequestered to soil by the plants (Wang 2006).

Biodiesels can be made from oils, recycled oils and animal fats yielding a fuel that can substitute for petroleum based diesels. Biodiesel is currently consumed at a rate of 260 million gallons annually, having grown dramatically from 18 million gallons in 2003 (EIA 2007). Average U.S. biodiesel carbon intensity is 68% lower than petroleum diesel (EPA 2007b), and can vary greatly depending on co-products (Huo et al., 2008). The potential replacement capacity of biodiesel is estimated to be only a small fraction of U.S. diesel consumption, and fuel quality is often an issue.

Table 2 illustrates properties and potential reductions from shifting 1% of gasoline and diesel consumption to alternative fuels (both neat fuels and blends, on an energy basis). These shifts would be possible with no improvement in engine or driveline efficiency. Shifting all U.S. gasoline consumption to a cellulosic E85 blend could reduce GHG emissions by 5%. Despite their GHG reduction potential, concerns about biofuels persist. The dedication of land to farming could impact GHG emissions in the larger scale via land use changes (including induced changes domestically and abroad, due to the profitability of ethanol) and biofuel production could threaten water supplies in regions where heavy irrigation is needed (Wang 2008). These issues are generally a larger concern for corn-based ethanol than for cellulosic ethanol. Biodiesels could push cities into non-compliance with air quality regulations due to higher NOx emissions. Perhaps the largest barrier will be equipping the vehicle fleet and fuel distribution system to handle biofuels. The different fluid properties of biofuels will, in many instances, require new distribution piping and currently only 290,000 vehicles in the light-duty U.S. fleet (0.01%) are capable of running on biofuels, with refilling stations are largely concentrated in the Midwest (EIA 2008b).

Electricity and hydrogen are also potential substitutes for liquid fuels in future generations of vehicles. Unlike biofuels (which tend to be less carbon-intensive than motor gasoline on an energy-basis), electricity and hydrogen are actually more carbon-intensive than gasoline on an energy-basis. However, both fuels emit zero PTW emissions and can be used at a far greater efficiency than motor gasoline is burned, thus yielding significant gains on a WTW basis. For both hydrogen and electricity reductions in WTP emissions are a central challenge Electricity in the U.S., as noted above, largely comes from fossil-fuel intensive production methods while hydrogen currently requires energy inputs far in excess of its usable energy.

Non-liquid fuels also require a distribution network and a vehicle fleet that can store the fuel. Electric vehicles appear to lead here: battery technology is progressing rapidly and electric vehicles can largely be charged from the existing electric grid (as discussed below). Safe on-board storage of hydrogen is a problem that still lacks a solution.

Light-Duty-Vehicle Efficiency

On a per-mile basis, PTW emissions vary greatly depending on engine efficiency, transmission efficiency, vehicle design, vehicle operating conditions, and emission treatment systems. The wide suite of options to improve passenger vehicle efficiency includes conventional improvements, many of which are currently cost-effective and are expected to be widely present in vehicles within a 15-year span, as well as advanced powertrain technologies. The latter are more costly and will likely be slower to penetrate the vehicle market (absent policy intervention), but offer greater potential for long-term fuel economy improvements.

Vehicles powered by spark-ignition (SI) engines and running on gasoline constitute the great majority of the U.S. passenger vehicle fleet. These operate in an efficiency range of only 10-20%. Most of the energy in the tank is expended in thermal, frictional, and standby losses in the engine and driveline, while only a fraction of the fuel's energy powers useful accessories or makes it to the wheels (NRC 2006). SI engine vehicles are candidates for conventional improvements, which increase fuel economy by reducing vehicle loads and improving engine and transmission efficiency. Table 3 presents Jones et al.'s (2008) estimates of GHG savings from conventional improvements. Many of these technologies already exist in several makes and models currently on the market and others are poised to enter the market, if proper demand for fuel economy exists. Vehicle mass reductions are one crucial design aspect that has been resisted by vehicle manufacturers on the grounds that it could compromise occupant safety but now regarded by many experts (e.g., Wenzell and Ross 2006) as an option for improving fuel economy, both because it can potentially be achieved without compromising vehicle size (a more important design parameter from a safety standpoint) and because more massive vehicles actually reduce overall fleet safety by posing threats to other vehicles. Cumulatively, the technologies in Table 3 could offer a new vehicle fuel economy of 31 mpg to 42 mpg, a 17 to 57 percent improvement over an average new U.S. vehicle. The technologies are, however, applicable to different degrees in different vehicles, so midpoints of the potential improvement ranges are used in Table 3.

Compression ignition (CI) engine vehicles running on diesel enjoy great standing in the European passenger vehicle market and will likely be a U.S. option, pending improved emission control system technology. Diesels combust fuel more thoroughly than SI gasoline engines for an overall fuel economy improvement of 20 to 40 percent (Jones 2008). The associated GHG savings are less; however, since diesel fuel is more carbon intensive. Diesel engines can be combined with conventional improvements to transmissions and vehicle design, but the fundamentally different engine type precludes conventional engine technologies. Table 3 shows GHG reductions from a conversion to diesels (without and with conventional transmission and vehicle design improvements). Diesel engines with the relevant conventional improvements do not offer significant savings over an SI engine vehicle including all conventional improvements; both could reduce U.S. GHG emissions by 5 percent compared to baseline 2007 vehicle technology if adopted in all passenger vehicles.

Hybrid electric vehicles (HEVs) have penetrated the U.S. market in recent years. In 2007, about 3% of new vehicle sales were hybrid models, up from 0.5% in 2004. Hybrids supplement SI engines with electric motors and battery packs. Fuel economy improvements are realized due to engine downsizing and more efficient engine operating points enabled by the second onboard power source, fuel cutoff during deceleration and idling, and regenerative braking. The U.S. EPA (EPA 2008) reported fuel economies of four of the most popular hybrid vehicles: the Toyota Prius, Honda Civic Hybrid, Nissan Altima Hybrid, and Ford Escape Hybrid are 46, 42, 34, and 32 mpg. However, these vehicles employ many conventional modifications, so fuel economy improvements are not exclusively attributable to hybridization. Table 3 shows potential GHG emission savings from conversions of the passenger fleet to a hybrid (without and with all conventional transmission and vehicle design improvements). While some hybrids readily pay for themselves in lifetime fuel savings, consumers often demand a shorter payback period of three to five years, which hybrids cannot always deliver. Emerging Li-ion batteries which scale to high production volumes, rely on cheaper commodity inputs, and can offer more power for less metal material (compared to current NiMH batteries) should lower this barrier by decreasing the cost of one of the priciest components (Kromer and Heywood 2007).

Plug-in electric vehicles (PEVs) could shift vehicle fuels from liquid fuels to electricity. Both Nissan and GM have released such vehicles in the U.S. market: the 73-mile all-electric (EPA-rated) battery electric vehicle (BEV) Leaf and the 35-mile all-electric (with extended range) Chevrolet Volt plug-in hybrid EV (PHEV). Toyota will release its PHEV Prius model very soon. In general, a PHEV runs on an initial grid charge for a specified range at which point it switches to, essentially, normal hybrid operation. The GHG emission reduction potential of PHEVs depends on a variety of factors. The type of electricity generation used where the vehicle is charged influences WTW vehicle emissions, and vehicle range determines the fraction of a driver’s VMT that will be electrified (Khan and Kockelman 2012). Analysis of daily mileage distributions suggests that vehicles with ranges of 20 and 40 miles could capture 50 and 75 percent of an average drivers’ daily driving (EPRI 2001), assuming the vehicles are charged nightly. Table 3 shows potential GHG emissions reductions from a PHEV 40 and PHEV 60 running off of various electricity scenarios. Notably, the impact of adding additional range to the vehicles is relatively small compared to electricity generation feedstock. At grid average electricity, PHEV 40s and 60s could eliminate 13 and 14 percent of U.S. GHG emissions if employed in the entire passenger vehicle fleet. If charged with coal, HEVs outperform PHEVs, while in the scenario of expanded renewables and CCS the reductions climb to 16 and 18 percent for a full PHEV fleet. In the short term, carbon intensity of electricity will depend on the type of electricity generation used in the local utility company’s intermediate capacity range which varies greatly by region; in the long-term as PHEVs penetrate the market the GHG reductions from the energy pathway will tend towards the average grid mix (Kromer and Heywood 2007).

Electrifying the vehicle fleet would be a fundamental shift in the nation’s energy use patterns and as such numerous policy issues arise. Benefits could accrue from centralizing combustive processes from numerous disparate tailpipes to a small number of power plants. This centralization facilitates carbon capture and sequestration (CCS) along with improvements in regional air quality and public health, as emissions shift away from population centers (Pratt et al., 2007). Accommodating substantial growth in electricity demand could present a barrier, though if grid dispatch is properly managed, favorable interaction with the utility industry could be obtained. Pratt et al. (2007) estimate that up to 43 percent of the LDV fleet could be charged overnight with available generation and 73 percent using available daytime and overnight generation (Table 1 illustrates the types of power generation technologies with available capacity). In the long-term overnight charging could represent an overnight base-load that could increase demand for base-load generators and make investments in cleaner base-load generators more cost-effective. In some scenarios, increased demand for currently underutilized overnight generating capacity could even drive down electricity prices (Pratt et al., 2007). Synergy between overnight peak wind power capacity and expected overnight PHEV charging also has been suggested as a possibility (Short and Denholm 2006). Dynamic electricity pricing has been proposed as a policy mechanism to induce owners to charge their vehicles overnight.

The biggest hurdle for PHEV technology will be cost. As a benchmark, currently, there are several after-market kits that enable conversion of a Toyota Prius into a limited-range PHEV; these retail for $10,000 to $12,000 (Shelby and Bui 2006).The biggest factor in PHEVs high cost is the battery price, but as battery technology improves cost should drop. In the longer term (2030 horizon), Kromer and Heywood (2007) project incremental costs of $3000 to $6000 for vehicles of 10 to 60 miles of range, a high enough incremental price that most consumers will not perceive PHEVs as cost effective within a reasonable payback period. BEVs face much less of a cost hurdle, thanks to the simpler, all-electric drivetrain design (though range limitations impede user flexibility). Tuttle and Kockelman's (2012) discounted cost comparisons of the Leaf, Volt, and Prius PHEV suggest that these new vehicles are pretty cost competitive, especially for longer driving distances and higher gasoline prices. Uncertainties about production levels are limiting adoption. In the future, uncertainty about battery replacement costs (and range limitations for BEVs, but not PHEVs) may limit adoption. Paul et al.'s (2011) simulated adoption and use of PEVs across the U.S. suggest sales may remain low, without significant shifts in U.S. energy prices, buyer preferences, and/or government policies.

Expanded options in terms of vehicle ranges could increase the market for PEVs by better matching vehicle range to individual daily commuting patterns, thereby increasing the vehicle's cost effectiveness. Vyas et al. (2002) examine national daily commuting patterns and conclude that if vehicles of 10 mi, 20 mi, 40 mi, and 60 mi ranges were available, 59% of national VMT could be electrified, assuming a person will only buy a PHEV if its range exceeds their daily average driving (so they enjoy the full benefits of its electric abilities). Khan and Kockelman. (2012) studied the day-to-day driving pattern of GPS-instrumented vehicles in Seattle and found that many (to most) households could swap out a vehicle for a BEV or PHEV, depending on the all-electric range attribute.

Efficient vehicular operation can reduce fuel consumption immediately, regardless of vehicle type. Vigilant tire pressure maintenance can improve fuel economy and is an opportunity for 36-40 percent of drivers (NHTSA 2004). Consumers can select low rolling resistance tires when they replace tires (every 3 to 5 years, on average), a choice that could impact 80 percent of tires currently on the road and is estimated to pay for itself in fuel savings within the life of the tire (NRC 2006). Peak vehicle efficiency is found at speeds between 30 and 55 mph (West et al., 1997) when vehicle engine efficiency and aerodynamic loads are close to their respective maximum and minimum. Table 4 estimates GHG savings from tire improvement scenarios and lowered interstate speed limits. While proposals to lower interstate speed limits have met with considerable disapproval, it should be noted that fuel economy declines at an increasing rate as speed grows; thus savings equal or greater than those shown here could be achieved simply from enforcing speed limits to their posted levels.

Given the numerous technically feasible options to improve fuel efficiency and the demonstrated inability of the market to favor fuel efficiency over other vehicle, fuel economy standards are an important part of ensuring a fuel efficient vehicle fleet.

Table 3. Potential GHG Reductions from Shift to Vehicle Technologies

	Technology	FE Benefit (%)		Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE/yr)	Annual Savings (MMTCE)	Percent of U.S. GHG Emissions	Annual Savings (MMTCE)	Percent of U.S. GHG Emissions
		Low	High						
	Base Vehicle (2007 fleet average)	--	--	20.5	4.27	Vs. Average Vehicles		Vs. New Vehicles	
	Base Vehicle (MY 2007 achieved)	--	--	26.7	3.28	0.991	0.051		
Conventional Technologies	*Engine Technology*								
	Cylinder Deactivation	3	8	28.2	3.18	1.087	0.056	0.095	0.005
	Direct Injection	1	3	27.2	3.24	1.024	0.053	0.032	0.002
	Turbocharging	3	7	28.0	3.18	1.087	0.056	0.095	0.005
	Valve Event Manipulation (VEM)	1	7	27.8	3.24	1.024	0.053	0.032	0.002
	Transmission Technology								
	Automatic or Continuously Variable	1	8	27.9	3.24	1.024	0.053	0.032	0.002
	Aggressive Shift Logic	1	5	27.5	3.24	1.024	0.053	0.032	0.002
	Vehicle Design								
	10% Mass Reduction	4	10	28.6	3.15	1.117	0.058	0.126	0.007
	Improved Aerodynamics	1	2	27.1	3.24	1.024	0.053	0.032	0.002
	Accessory Electrification	1	5	27.5	3.24	1.024	0.053	0.032	0.002
	Low RR Tires	1	2	27.1	3.24	1.024	0.053	0.032	0.002
	All Conventional Technologies	17	57	36.6	2.39	1.876	0.097	0.885	0.046
Advanced Drivetrain Technologies	Diesel	20	40	34.7	2.74	1.524	0.079	0.532	0.028
	Diesel w/ Conventional Technologies	29	72	40.2	2.37	1.897	0.098	0.906	0.047
	HEV	17	30	33.0	2.65	1.615	0.084	0.624	0.032
	HEV w/ Conventional Technologies	34	87	42.9	2.04	2.226	0.115	1.235	0.064
	PHEV 40 (Coal-fired)				2.24	2.029	0.105	1.037	0.054
	PHEV 40 (Renewable)				1.02	3.247	0.168	2.256	0.117
	PHEV 40 (Grid Average)				1.78	2.491	0.129	1.500	0.078

	Technology	FE Benefit (%)		Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE/yr)	Annual Savings (MMTCE)	Percent of U.S. GHG Emissions	Annual Savings (MMTCE)	Percent of U.S. GHG Emissions
		Low	High						
	PHEV 40 (Clean Grid)				1.55	2.718	0.141	1.727	0.090
	PHEV 40 (Clean Grid and CCS)				1.19	3.081	0.160	2.090	0.108
	PHEV 60 (Coal-fired)				2.34	1.930	0.100	0.939	0.049
	PHEV 60 (Renewable)				0.51	3.758	0.195	2.767	0.143
	PHEV 60 (Grid Average)				1.64	2.623	0.136	1.632	0.085
	PHEV 60 (Clean Grid)				1.30	2.964	0.154	1.973	0.102
	PHEV 60 (Clean Grid and CCS)				0.76	3.508	0.182	2.517	0.130

Notes: Base vehicle fuel economies from Davis and Diegel (2007), Technology fuel economy benefit estimates from Jones et al. (2008), Fuel economies assume mid-point of fuel economy benefit range, PHEVs improve upon HEV with conventional technologies, PHEV 40 has 50 percent of driving electrified, PHEV 60 has 75 percent of driving electrified, PHEVs operate at electric efficiency of 333 kWh-grid/mi (Gremban 2006), electric carbon intensities from Table 1 with additional 7 percent efficiency loss for transmission and distribution, fuel carbon intensities from Table 2

Table 4. Potential GHG Reductions from Transportation Policies

Speed Limits	Speed (mph)	FE Loss (%)	Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent U.S. GHG Emissions
Base Urban Interstate (65 mph)	65	9.7	18.5	0.865	Vs. Base Urban	
Lowered Urban Interstate (55 mph)	55	--	20.5	0.781	0.084	0.004
Base Rural Interstate (70 mph)	70	17.1	17.0	0.509	Vs. Base Rural	
Lowered Rural 1 (65 mph)	65	9.7	18.5	0.467	0.042	0.002
Lowered Rural 2 (55 mph)	55	--	20.5	0.422	0.087	0.005
Combined Urban and Rural 1				1.248	0.126	0.007
Combined Urban and Rural 2				1.203	0.171	0.009
Tires	Tire Pressure (psi)	FE Change (%)	Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent U.S. GHG Emissions
Underinflated Tire	24	-2.2	20.1	4.639	Vs. Underinflated/Non-RR	
Maintained Tire Pressure	32	--	20.5	4.535	0.104	0.005
Low Rolling Resistance Tires	32	2.5	21.1	4.425	0.111	0.006
Gas taxes	Price with Tax	Percent Price Increase	Gasoline Consumption Saved (mbd)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent U.S. GHG Emissions
No tax increase	4.00	0.0	0.00	4.677	Vs. Present Tax	
$0.50/gal gas tax increase	4.50	12.5	83.88	4.644	0.032	0.002
$1.00/gal gas tax increase	5.00	25.0	167.77	4.612	0.065	0.003
$1.50/gal gas tax increase	5.50	37.5	251.65	4.579	0.097	0.005
$2.00/gal gas tax increase	6.00	50.0	335.54	4.547	0.130	0.007

Notes: Fuel economy losses from speeds from West et al. (1997). Interstate VMTs from BTS (2008) Table 1-33. Fuel economy loss and gain from tires from NHTSA (2004) and NRC (2006). Gas tax savings based on elasticities from Hughes et al. (2007). Gas tax assumed to apply to motor gasoline only. Annual motor gasoline consumption from EIA (2007).

Corporate Average Fuel Economy (CAFE) standards require that manufacturers' fleet averaged fuel economies meet a mandated level determined on the basis of technological feasibility, economic practicability, effect of other standards on fuel economy, and the need of the nation to conserve energy. After years of stagnation (EPA 2006a) CAFE standards were raised in 2007 to 27 mpg for passenger car fleets and 22.5 mpg for light duty truck fleets, set to rise to an overall fleet average of 35 mpg by 2020. This standard trails much of the developed world and proposed standards of U.S. states (An and Sauer 2004). It also lies below estimates of technically feasible fuel economy: midpoint and maximum estimates of fuel economy in conventional vehicles using the ranges suggested by Jones et al. (2008) are 36.6 mpg and 41.9 mpg. Finally, the new 2020 CAFE target is well below a level of fuel economy that economically rational consumers would find cost effective with gas prices at $3.55 per gallon (43.4 mpg) assuming they discount fuel savings at 3 percent annually . While the timeline on these estimates of technical feasibility is 15 years (to mature by 2023), and while consumers may expect greater return on their investment in fuel economy given that vehicles are depreciable assets, there is reason to believe manufacturers can achieve more stringent fuel economy standards.

An often raised concern about advanced vehicle technologies is their efficacy from a full lifecycle perspective. Moon et al. (2006) study the vehicle-cycle and total energy-cycle of special, low-weight ("lightweighted") vehicles and HEVs compared to conventional vehicles. Advanced vehicles have a more CO2 intensive materials manufacture phase because of the increased use of aluminum (to reduce weights) and more advanced batteries (HEVs). However, over the total vehicle lifecycle the reductions in GHG emissions from more fuel efficient use phases far outweigh the more energy intensive materials production.

In recent decades the purchase of a new vehicle has not been justified from an energy or CO2 savings standpoint because the improvement in fuel efficiency in successive model years has been so slow (Kim et al. 2003). The appearance of advanced drivetrain vehicles which offer substantially improved fuel economies means accelerated vehicle replacement can reduce GHG emissions. Vehicle ownership durations are, however, increasing as vehicle designs improve. Median vehicle age has increased to 9.0 years for passenger cars and 9.6 years for light trucks (from 7.9 years and 7.7 years in 1996) while scrappage rates have fallen to 4.5% and 4.1% annually for passenger cars and light trucks (from 6.4% and 7.4% in 2000). From a policy standpoint, accelerated vehicle replacement could be encouraged through measures that make consumers value fuel economy more (e.g., higher gas taxes) subsidies and/or tax credits for purchasing more fuel-efficient vehicles, and preference for fuel efficient vehicle lanes (in HOV lanes, for instance).

Passenger Travel Demand Management (TDM)

TDM strategies with potential to abate transportation GHG emissions include shifting travel to more efficient modes, reducing overall passenger travel, and shifting travel to more efficient operating conditions (e.g., non-peak hours). These strategies typically use existing assets thus avoiding the cost or time-lag of new technologies, but institutional and attitudinal factors often work against TDM.

Pricing strategies send market signals which reflect the true costs of driving. Gas Taxes in the U.S. contribute, on average, only 40 cents per gallon to the price of gasoline (EIA

2008). *Gas taxes* in the majority of other industrialized countries are significantly higher (e.g., 2.5, 2.6, 1.8, 1.8, and 2.7 times higher in France, Germany, Japan, Norway, and the UK [EIA 2008]). Economists find that gas taxes diminish demand for gasoline either via reduced driving or improved fuel efficiency. A recent estimate places the own-price elasticity of demand for gasoline at -3.4 to -7.7 percent (Hughes et al., 2008). Table 4 shows the reduction in GHGs expected from various levels of gas taxation increases, using this elasticity. One caveat is that the reductions could be as much as 2-3% smaller in the short run and 10-15% smaller in the long run via a rebound effect from increases in fuel efficiency (Small and Van Dender 2007). *Pricing Parking* can be an effective travel demand reduction tool because it overcomes the temporal lapse between costs drivers pay and when they decided to travel. Studies on elasticity of travel demand with respect to parking price find a 10 to 30 percent range, with variation due to numerous factors including trip purpose, location of parking, availability of substitute modes or other free parking, and price and fee structure (e.g., hourly, first hour free, etc.). Other pricing strategies such as congestion pricing, tolls, and HOT lanes can similarly diminish demand for driving and thus reduce GHG emissions, but are not quantified here.

Mode Shifts from private vehicle travel typically reduce GHG emissions by using energy more intensively thus emitting lower GHG per passenger-mile (pax-mi). Shifting travel to transit also enables easier adoption of alternative fuels and technologies to improve vehicle efficiency. The baseline for mode shifts here is private vehicle travel, which accounts for the majority of passenger travel (NHTS 2001). Tables 5 and 6 show the potential GHG savings from shifting passenger travel from single and average occupancy vehicles with the alternative mode at average and full occupancy. For daily travel (i.e., intracity trips of less than 50 miles) two or more passengers make automobiles the most efficient mode. Average automobile occupancy is only 1.63 passengers, and occupancy is even lower for certain crucial trip types (e.g., 1.14 passengers for home to work trips). Clearly opportunities for carpooling abound. At average occupancies, rail outperforms driving while buses and driving are competitive (on a Btu/pax-mi basis). Rail savings are often dependent upon the carbon intensity of the electricity they run on and could fall with improvement in electricity generation. Buses, if running at low occupancies, actually result in a GHG emission increase; an occupancy slightly higher than average is needed to make buses less CO2 intensive than driving, though running buses on alternative fuels can change this. Moreover, to the extent that bus use encourages walking and shorter trips (in order to access bus stops and reduce bus travel times) and more clustered land use patterns (to reduce access costs and trip distances), a one-to-one passenger-mile comparison is imperfect. Of course, much underutilized capacity exists on alternative modes, so a more accurate illustration of the GHG savings from shifting away from single occupant vehicles (SOVs) may simply be the reduction from eliminating one percent of SOV VMT. This shift could also be achieved through biking, walking, telecommuting, shorter trip lengths, and other measures aimed at reducing demand for travel altogether. Intercity travel is similarly dominated by personal vehicle travel which accounts for 90 percent of PMT (air, bus, and train account for 7, 2, and 1 percent); personal vehicles tend to dominate for trips less than 300 round trip miles while air dominates for trips of more than 2,000 round trip miles (NHTS 2001). In intercity travel as in intracity travel, driving becomes competitive at higher occupancies. Air travel is presently more efficient than driving solo due to its high average occupancies, though occupancy level, vehicle fuel economy, and trip length cause variation in air travel emissions.

Table 5. Potential GHG Reductions from Shift from SOV to Carpool or Alternative Mode at Average Occupancies

	Mode Alternative	Average Occupancy (pax)	Average Capacity (pax)	Energy Intensity (Btu/pax-mi)	1 Percent of PMT (MMTCE)	Annual GHG Savings (MMTCE)	% of U.S. GHG Emissions
Intracity Travel	Drive (SOV, gas)	1	4	6049	5.28	--	0.273
	Drive (Avg. HBW occ., gas)	1	4	5306	4.63	0.65	0.034
	Drive (Avg. occ., gas)	2	4	3711	3.24	2.04	0.106
	Drive (2 passengers, gas)	2	4	3024	2.64	2.64	0.137
	Drive (3 passengers, gas)	3	4	2016	1.76	3.52	0.182
	Drive (4 passengers, gas)	4	4	1512	1.32	3.96	0.205
	Bus (Diesel fuel)	9	52	4230	3.59	1.68	0.087
	Bus (B20)	9	52	4230	3.11	2.17	0.112
	HRT (Electric Fuel)	23	82	860	1.45	3.83	0.198
	LRT (Electric Fuel)	25	100	1159	1.95	3.32	0.172
	Commuter Rail (Diesel)	31	114	2996	2.54	2.73	0.142
	Biking/Walking	1	1	0	0.00	5.28	0.273
Intercity Travel	Drive (SOV, gas)	1	4	6049	2.13	--	--
	Drive (Avg. occ., gas)	2	4	3711	1.31	0.82	0.043
	Drive (2 passengers, gas)	2	4	3024	1.07	1.07	0.055
	Drive (3 passengers, gas)	3	4	2016	0.71	1.42	0.074
	Drive (4 passengers, gas)	4	4	1512	0.53	1.60	0.083
	Bus (diesel fuel)	9	52	4230	1.45	0.68	0.035
	Air	99	125	3266	1.01	1.12	0.058
	HSR (IC-3: Diesel 99 mph)	--	138	103	0.04	2.10	0.109
	HSR (TGV: Electric 99 mph)	--	485	487	0.33	1.80	0.093
	HSR (Mag-lev: Electric, 300 mph)	--	156	1187	0.81	1.32	0.069

Notes: Annual Passenger Miles Traveled (Davis and Diegel 2007), Annual Long Distance Passenger Miles Traveled (NHTS 2001), Passenger vehicles get 22.4 mpg (fleet average based on [Davis and Diegel 2007]), HSR Options assumed to have 70% occupancy, HSR modal efficiency from Center for Clean Air Policy and Center for Neighborhood Technology (2006).

Occupancies and aircraft fuel economies are both trending upwards: passenger load factor is up from 62.4 in 1990 to 78.8 in 2006 (Davis and Diegel 2007) while technological advancements including modern high-bypass turbofans and new, lightweight, high-strength materials have improved energy and aerodynamic efficiency. Improved aircraft fuel economy is limited by turnovers in aircraft (which tend to have 35-40 year useful lives) and capacity additions; fuel economy is forecast to improve 16% compared to a 2001 baseline and 70% of aircraft should be post-2002 additions by 2020 (FAA 2005). Air travel GHG emissions also vary with trip length as aircraft take-off and landing are larger energy drains than constant elevation flying.

According to the World Resources Institute (WRI 2006) 0.53 lbs CO2/pax-mi is emitted for a short trip, 0.43 lb/pax-mi for medium trips, and 0.4 lb/pax-mi for long trips [7]. Finally, air travel emissions may be conservatively estimated due to failure to account for indirect emissions from airport access and egress, supportive airport vehicles, and auxiliary power units at airports as well as concerns that emissions at higher altitudes (as 90% of air travel CO2 emissions are [FAA 2005]) may have a higher GWP.

High Speed Rail (HSR) is a mode not currently available in the U.S. that has been successfully deployed around the world and proposed for many corridors domestically (in particular, California). [8] Based on per-passenger energy intensities from train technologies existing in other countries (Denmark's IC-3 and France's TGV) or explored by the Army Corps of Engineers and assuming HSR nets an occupancy of 0.7 similar to flying, HSR is very competitive with driving, even with vehicles at high occupancies. The ability to reduce the carbon intensity of HSR via improvements in electricity generation may give it a further edge.

Freight Transportation Efficiency

Freight transport contributes 38% of transportation's GHG emissions, and 11% of all U.S. GHG emissions (EPA 2006b). The five major freight modes, truck, rail, air, water and pipeline carry 28.5, 38.2, 0.3, 13.0, and 19.9 percent of freight ton-miles and comprise 60, 6, 5, 13, and 16 percent of freight GHG emissions, respectively (Frey and Kuo 2007).

Freight transport is growing rapidly as a source of GHG emissions, primarily due to a decline in efficiency (as opposed to increases in shipping activity). Between 1990 and 2005, freight transport emissions increased 69 percent while ton-miles grew less than 30 percent.

Two major trends help to explain efficiency losses which have driven rapid growth in freight GHG emissions. First, trucking's market share has increased at the expense of other, more efficient modes (in particular waterborne and pipeline transport) businesses have come to value the scheduling and routing flexibility of trucking for higher value goods that must be shipped on quicker timelines. Second, the energy efficiency of trucking has dropped markedly (12 percent between 1990 and 2005). While the fuel economy of trucks has not seen much drop off, operational efficiency has declined.

[7] The average short trip is roughly 200 miles, medium trip is 700 miles, and long trip is 1500 miles; the numbers in Table 5 and 6 correspond to 0.63 lbs CO_2e/pax-mi.

[8] The Acela Express in the northeast corridor - which has an average speed of 70 mph and can reach peak speeds of 150 mph - is classified as HSR in the U.S., but is relatively low speed by international standards.

Table 6. Potential GHG Reductions from Shift to Alternative Mode at Full Occupancies

	Mode Alternative	Occupancy (pax)	Average Capacity (pax)	Energy Intensity (Btu/pax-mi)	1 Percent of PMT (MMTCE)	Annual GHG Savings (MMTCE)	% of U.S. GHG Emissions	Annual GHG Savings (MMTCE)	% of U.S. GHG Emissions
Intracity Travel	Drive (Avg. occupancy, gas)	1.63	4	3711	3.24	Vs. Avg Occupancy		Vs. 4 Person Carpool	
	Drive (4 passengers, gas)	4	4	1512	1.32	1.92	0.10		
	Bus (Diesel fuel)	9	52	711	0.60	2.63	0.14	0.72	0.04
	Bus (B20)	9	52	711	0.52	2.71	0.14	0.80	0.04
	HRT (Electric fuel)	23	82	237	0.40	2.84	0.15	0.92	0.05
	LRT (Electric fuel)	25	100	291	0.49	2.75	0.14	0.83	0.04
	Commuter Rail (Diesel)	31	114	822	0.70	2.54	0.13	0.62	0.03
	Biking/Walking	1	1	0	0.00	3.24	0.17	1.32	0.07
Intercity Travel	Drive (Avg. occupancy, gas)	2	4	3711	1.31	Vs. Avg Occupancy		Vs. 4 Person Carpool	
	Drive (4 passengers, gas)	4	4	1512	0.53	0.77	0.04		
	Bus (diesel fuel)	9	52	711	0.24	1.06	0.06	0.29	0.01
	Air	99	125	2574	0.80	0.51	0.03	(0.27)	(0.01)
	HSR (IC-3: Diesel 99 mph)	--	138	72	0.02	1.28	0.07	0.51	0.03
	HSR (TGV: Electric 99 mph)	--	485	341	0.23	1.08	0.06	0.30	0.02
	HSR (Mag-lev: Electric, 300 mph)	--	156	831	0.57	0.74	0.04	(0.03)	(0.00)

Notes: Annual Passenger Miles Traveled (Davis and Diegel 2007), Annual Long Distance Passenger Miles Traveled (NHTS 2001), Passenger vehicles get 22.4 mpg (fleet average based on [Davis and Diegel 2007]), HSR Options assumed to have 70% occupancy.

Table 7. Potential GHG Reductions from Adoption of Truck Technologies

Technology	FE Benefit (%)	Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent of U.S. GHG Emissions	Potential Add On
All Trucks						
Base Truck	--	9.0	0.750	Vs. Avg. Truck		--
Improved Aerodynamics - Airfoils, baffles, wheel covers, leading edge curvature	4.0	9.4	0.722	0.029	1.50E-03	Yes
Low Rolling Resistance Tires	2.5	9.2	0.732	0.018	9.49E-04	Yes
Advanced Transmission	2.0	9.2	0.736	0.015	7.63E-04	No
Light Medium & Heavy Medium Only						
Base Truck	--	10.4	0.271	Vs. Avg. MDT		
Mass Reduction	5.0	10.9	0.258	0.013	6.69E-04	No
Engine Turbocharging	6.5	11.1	0.255	0.017	8.57E-04	No
Integrated Starter/Alternator, Auxiliary Electrification, & Idle-Off	5.0	10.9	0.258	0.013	6.69E-04	No
Improved Engine - low friction, better injectors, efficient combustion	9.0	11.3	0.249	0.022	1.16E-03	No
Hybridization	40.0	14.6	0.194	0.077	4.01E-03	No
All Improvements w/o Hybridization	34.0	13.9	0.202	0.069	3.56E-03	--
All Improvements w/ Hybridization	74.0	18.1	0.156	0.115	5.97E-03	--
Heavy Duty Only						
Base Truck	--	6.2	0.635	Vs. Avg. HDT		--
Pneumatic Blowing	5.0	6.5	0.604	0.030	1.57E-03	Yes
Single Wide Tires	3.0	6.4	0.616	0.018	9.58E-04	Yes
Mass Reduction	10.0	6.8	0.577	0.058	2.99E-03	No

Technology	FE Benefit (%)	Fuel Economy (mpg)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent of U.S. GHG Emissions	Potential Add On
Auxiliaries Electrified	1.5	6.3	0.625	0.009	4.86E-04	No
Improved Engine - low friction, better injectors, efficient combustion	10.0	6.8	0.577	0.058	2.99E-03	No
Improved Thermal Management	10.0	6.8	0.577	0.058	2.99E-03	No
All Improvements	48.0	9.2	0.429	0.206	1.07E-02	--
Idle Reduction						
Direct-Fired Heating Units	3.4	6.4	0.161	0.005	2.82E-04	Yes
Auxiliary Power Units	9.0	6.8	0.152	0.014	7.10E-04	Yes
Truck Stop Electrification	versus running from engine		0.007	0.044	6.22E-04	N/A

Notes: Fuel Economy benefits adapted from Vyas et al. (2002). Number of trucks in each class from U.S. Census Bureau (2004). Idle Reduction technologies assumed to apply only in sleeper trucks.

Table 8. Potential GHG Reductions from Freight Operational Efficiency Strategies

Mode Shift	Energy Efficiency (Ton-mi/lb CO_2)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent of U.S. GHG Emissions
Trucking	2	1.038	Vs. Trucking	
Rail	18	0.089	0.949	0.049
Waterborne	5	0.294	0.744	0.039
Air	1	2.715	-1.677	-0.087
Logistics	Annual Empty Miles (mi/truck)	1 Percent GHG Emissions (MMTCE)	GHG Emissions Saved (MMTCE)	Percent of U.S. GHG Emissions
Base Long Haul Truck	15000	0.229	Vs. Avg. Empty Miles	
Reduced Empty Miles	14850	0.227	0.002	1.19E-04

Modal energy efficiencies from Davies (2007). Annual trucking freight activity from BTS (2008). Annual Average empty miles from EPA (2004). Logistic improvements assumed to apply in heavy duty trucks only.

Encouragingly, rail's mode share actually outgrew trucking's share and rail energy efficiency increased 23 percent during the same period. Nevertheless, trucking seems to be a baseline against which GHG reduction strategies must be compared. Routes to improve trucking efficiency include fuel economy improving technologies and improved operations.

Trucking fuel economy has, since 1996, improved slightly in single unit trucks (1.9 percent annually) but declined slightly in combination trucks (1.6 percent annually).A variety of technologies that reduce losses from aerodynamic drag, rolling resistance, accessory loads, and transmission and engine inefficiencies are available that could dramatically improve fuel economy. Table 7 summarizes potential GHG emission reductions from the deployment of a range of technologies using fuel economy improvement estimates from Vyas et al. (2002). Several of these technologies are potential add-ons which are currently employed in only a small percentage of the fleet, and most are mature technologies or will be by 2010. Hybridization has also been discussed for medium duty trucks, and could be especially beneficial for delivery-type trucks, a growing share of the fleet given growth in Just-in-Time delivery. In fact 61 percent of MDTs have a range less than 50 miles (US Census 2004). Idling is another significant source of energy loss for trucks which can be readily addressed. A typical truck engine consumes 0.85 gallons of fuel per hour powering air conditioning and electric accessories while at rest stops (Lutsey et al., 2004) and an average truck used for long-haul purposes may accumulate 1830 hours of parked idling annually. Technologies with the potential to reduce idling losses include direct-fire heaters and auxiliary power units (APUs). Only 6 percent of heavy trucks had idle-reduction technology in 2002 (U.S. Census Bureau 2004). Truck Stop Electrification (TSE) is another option to reduce fuel use while idling at select truck stops. Table 7 presents potential GHG reductions from these idling reduction strategies.

Improving trucking operational efficiency and using substitute modes with energy efficiency advantages are also classes of strategies that offer great potential for freight GHG emissions abatement. Operational efficiency declines in trucking seem to be the result of an industry that has yet to adjust logistically to new demands. A typical long haul truck may drive 15 percent of its miles empty (EPA 2004). Better utilizing existing trucking capacity is achievable by improving routing, improved load matching, and improving loading and unloading procedures. The greatest potential could be through intermodal movements. Rail enjoys a tremendous advantage in energy efficiency over trucking, while waterborne shipping is also more efficient; both are substitutes for some major shipping routes. While numerous factors could limit shifts from trucks to rail or ships such as distance, availability of infrastructure, size of cargo, schedule, durability, and availability of facilities (Frey and Kuo 2007). Improved intermodal facilities could enable rail to take over haul lines with trucking employed for pick-up and delivery (possibly taking advantage of hybridization). Table 8 illustrates possible savings from modal substitutions of one percent of annual trucking activity (1,293,326 ton-miles) and reducing one percent of empty truck miles.

BEYOND THE SCOPE OF THIS CHAPTER

While the emissions of the residential and commercial sectors are largely dictated by the carbon intensity of the electricity they use, improving downstream efficiency can reduce the amount of electricity which must be generated, with all the attendant losses. Residential efficiency can be improved in various ways, by smaller buildings with shared walls and ceilings, wall and ceiling insulation improvements, more efficient building equipment (HVAC systems, water heaters, and heaters), improved building envelopes (to lower heating and cooling loads), appliance efficiency standards, and the introduction of heat pumps (particularly of the geothermal variety) (Kockelman et al., 2008). Commercial efficiency meanwhile should target lighting and opportunities for co-location centered around shared distributed power generation (Brown et al., 2005). The industrial sector is not addressed in this chapter due to the degree of heterogeneity in emissions sources (which precludes abatement via a single widespread technology or behavioral change) as well as the fact that U.S. industrial emissions of GHGs are falling (as the nation transitions to a less manufacturing oriented economy), though clearly this key sector (producing 36% of U.S. GHGs), will also need to cut emissions. In addition to reducing the GHG intensity of specific industrial activities, policies involving carbon taxes, cap-and-trade schemes, and GHG emission offsets are likely to prove key strategies for incentivizing lower energy demand and GHG emissions across all sectors.

Table 9. Comparison of Selected GHG Control Options

Strategy	Potential Savings (MMTCE)	Percent of U.S. GHG Emissions	Percent of 80% Reduction
Renewable Electricity Generation (vs. Coal-Fired)	10.166	0.527	0.642
CCS Coal Electricity Generation (vs. Coal-Fired)	8.641	0.448	0.546
Renewable Electricity Generation (vs. Grid Average)	6.308	0.327	0.399
"Clean Grid" w/ CCS Electricity Generation (vs. Grid Average)	4.919	0.255	0.311

Table 9. (Continued)

Strategy	Potential Savings (MMTCE)	Percent of U.S. GHG Emissions	Percent of 80% Reduction
CCS Coal Electricity Generation (vs. Grid Average)	4.783	0.248	0.302
PHEV-60, "Clean Grid" w/ CCS & E85 Cellulosic	3.903	0.202	0.247
HEV w/ All Conventional Improvements, E85 Cellulosic	3.804	0.197	0.240
Pass. Car, All Conventional Improvements, E85 Cellulosic	3.725	0.193	0.235
PHEV-60, Clean Grid w/ CCS	3.508	0.182	0.222
PHEV-60, "Clean Grid," E85 Cellulosic	3.359	0.174	0.212
Avg Occupancy Drive to Full Capacity HRT, "Clean Grid" w/ CCS Electric (Local Travel)	3.151	0.269	0.199
PHEV-60, Average Grid, E85 Cellulosic	3.018	0.156	0.191
PHEV-60, Clean Grid	2.964	0.154	0.187
Avg Occupancy Drive to Full Capacity HRT, Electric (Local travel)	2.838	0.147	0.179
Avg Occupancy Drive to Full Capacity Bus, Diesel (Local travel)	2.633	0.136	0.166
PHEV-60, Average Grid	2.623	0.136	0.166
HEV w/ All Conventional Improvements	2.226	0.115	0.141
Avg Occupancy Drive to 4 Person Carpool (Local travel)	1.918	0.099	0.121
"Clean Grid" Electricity Generation (vs. Grid Average)	1.895	0.098	0.120
Pass. Car w/ All Conventional Improvements	1.876	0.097	0.119
Avg Occupancy Drive to HSR, Diesel	1.283	0.066	0.081
Avg Occupancy Drive to 4 Person Carpool (Long Distance Travel)	1.064	0.055	0.067
Heavy Duty Truck to Rail Shift	0.949	0.049	0.060
Avg Occupancy Drive to Full Capacity Bus, Diesel (Long Distance Travel)	0.775	0.040	0.049
Hybrid MDT, All Improvements, B20	0.135	0.002	0.009
Hybrid MDT, All Improvements	0.115	0.006	0.007

CONCLUSION

Table 9 compares selected GHG control strategies to top emissions reducing strategies, based on the analyses described above. The list includes combinations of vehicle technologies and alternative fuels, and all strategies are considered in terms of the share they could achieve of the 80 percent reduction in 2000-level emissions estimated to be needed to avoid dangerous effects of climate change. The biggest impacts are felt by changing electricity generation technology and addressing the footprint of older-generation coal technology. Simply increasing the share of renewables in the grid without addressing the high emissions emerging from existing, older coal-fired power plants could result in a dramatic emissions-reduction shortfall.

A “clean grid” with 100% implementation of CCS technology in coal plants and 50% of generation from renewables or nuclear is expected to provide 31 percent of the target reduction; absent CCS only 12 percent of this goal may be achieved. A passenger vehicle fleet of PHEV 60s running on a “clean grid” with CCS electricity and cellulosic E85 is expected to provide 24 percent of the needed reduction; but, notably, the use of cellulosic E85 is only responsible for 2 percent of this (due to the high fraction of electrified miles). In contrast, the use of cellulosic E85 can more than double the contributions of improved conventional vehicles and HEVs. PHEVs running on an average grid electricity mix offer little advantage over an HEV, and an HEV in turn offers little advantage over an improved conventional vehicle. Shifting 10 percent of local passenger miles to a full occupancy HRT could account for another 1.8 percent of the needed reduction, and this could climb to 2 percent if combined with a clean grid with CCS. Shifting to 10 percent of local (intra-urban) passenger miles to 4 person carpools, meanwhile, could meet 1.2 percent of needed GHG savings. Simply employing available technologies for conventional vehicles could equate to 12 percent of the needed reduction. Long-distance passenger travel and freight movement changes do not appeal to be key players.

From a more qualitative perspective, this analysis reveals the needs for concentrated and collaborative investment into various forms of infrastructure and strategies to manage demand for existing assets. All of the technologies discussed here have the potential to be affordable, and in many cases cost-saving, given sufficient research and development and production volumes. The full realization of benefits from many, though, is contingent upon proper supportive infrastructure (e.g., transmission and distribution networks for renewables, refining and refueling infrastructure for alternative fuels, and improvements of the electric grid for PHEVs) and the matching of demand to capacity to ensure more efficient utilization of all resources (particularly with respect to off-peak electric generating capacity and untapped transport supply, in the form of carpooling and existing transit). This chapter also reveals powerful synergies across sectors and technologies. In a truly ideal scenario, combining a clean grid with CCS with a fleet of PHEVs and the use of cellulosic E85 could account for 56 percent of the required 80 percent reduction (the sum of these two strategies, from Table 9).

Clearly, contributions from other transportation strategies as well as improvements in the residential, commercial, and industrial sectors will still be needed, to hit the overall 80-percent emissions-reduction target. Fortunately, the U.S. has the assets and technical understanding needed to meet the challenge of reducing its GHG emissions by such levels; public engagement, political will, and comprehensive thinking will be key.

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Chapter 2

TOWARD A SUSTAINABLE ENERGY TRANSITION IN THE BUILT ENVIRONMENT

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ABSTRACT

The world is undergoing the largest wave of urban growth in history. In the actual context of growing interests in environmental issues, urban areas are known to present high potentialities in terms of energy reduction. However, existing models and regulation often adopt the perspective of the individual building as an autonomous entity, and neglect the importance of phenomena linked to larger scales, while decisions made at the neighbourhood and the city scales have important consequences on the performance of individual buildings, on the transport habits of the inhabitants and on the potential mutualisation of renewable energy production. This chapter examines strategies toward a sustainable energy transition in the built environment. The chapter summarizes and put into perspectives findings from numerous studies that have investigated parameters influencing energy consumption of the built environment including location, urban form, density, mix use, mobility patterns, buildings insulation, energy mix and inhabitants' behaviours. This chapter contributes to the important area of understanding how to facilitate a sustainable transition in the built environment through urban and suburban renewal.

Keywords: low-energy neighbourhoods and buildings, transport energy consumption, energy mix, inhabitants' behaviours, urban and suburban renewal

INTRODUCTION

The world is undergoing the largest wave of urban growth in history. In 2008, for the first time, more than half of the world's population (that is to say 3.3 billion people) lived in urban

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areas. By 2030, this number will swell to nearly 5 billion (UNFPA, 2007). As the built environment is now known to be responsible for the majority of greenhouse gas emissions and energy consumption (Robinson & Quiroga, 2009), it becomes urgent to reduce its environmental impact and to identify how to improve existing and new urban and suburban neighbourhoods and how to make them more sustainable. Urban areas are supposed to present high potentialities in terms of energy reduction. This is why the Directive on the Energy Performance of Buildings (EC, 2003) came into force in Europe in 2002 with legislation in European Member States by 2006. However, existing models and regulation often adopt the perspective of the new individual building as an autonomous entity, and neglect the importance of phenomena linked to larger scales (Ratti et al., 2005) and to the existing building stock (Reiter & Marique 2012), which have important consequences on the performance of individual buildings and on the transport habits of the inhabitants. Moreover, collective infrastructure (e.g., heating networks) is often more efficient and less expensive than equipment intended for individuals (Hanson, 1996) and allows potential "mutualisation" of renewable energy production (Marique et al., 2013a). Sustainability transitions are an emerging field of research (Markard et al., 2012). In the past few years, it has been the topic of numerous contributions, both in the scientific literature and in general policies dealing with the adaptation of our society to more sustainability, as far as socio-economic questions, production of goods, transportation, agriculture, energy, and many others fields are concerned (e.g., Geels, 2005; Meadowcroft, 2011; van den Bergh, 2013). However, following Coenen et al. (2012: p.1), "transition analyses have often neglected where transitions take place, and the spatial configurations and dynamics of the networks within which transitions evolve". These authors highlight two major shortcomings relating to the spatial structure of the territories: the failure to "explain if and how spatial contexts matter" and the "problematic usage of scale in existing transition analyses". This chapter attempts to address these limitations.

The chapter aims at investigating strategies toward sustainable energy transition in the built environment, at different scales. It summarizes and put into perspectives findings from various studies that have investigated parameters influencing energy consumption of the built environment including location, urban form, density, mix use, mobility patterns, buildings insulation, energy mix and inhabitants' behaviours. The first section studies the energy consumption of buildings and transport for daily mobility. It discusses the issues of the urban context, the "compact city" model, the "sprawled city" model and the influence of the spatial scale of the urban studies. The second section analyses the energy mix and the influence of renewable energies. The third section focuses on inhabitants' behaviours. In the fourth section, main parameters that act upon the energy balance of cities and neighbourhoods are combined to propose concrete strategies to improve our built environment and move toward more sustainability through urban and suburban renewal.

BUILDINGS AND TRANSPORT ENERGY CONSUMPTION

Urban Context

One major challenge to favour a sustainability transition of our built environment consists in improving the energy efficiency (buildings + transportation) of the existing urban and suburban fabrics. If politicians, stakeholders and even citizens are now aware of the issue of energy consumptions in buildings, efforts and regulations to control transport needs and consumptions stay more limited. However, transport and mobility are crucial in terms of households' energy consumption. The physical expansion of urban areas, commonly referred to as urban sprawl, is known to represent a significant contribution to the overall energy consumption of a territory. Due to the combination of rapidly declining transport costs and increasing travel speed (Ewing, 1994), the accessibility of outlying areas and vehicle miles of travel (VMT) per capita have increased substantially over the recent past and have favoured the development of suburban neighbourhoods. Sprawl is believed to be facilitated by car ownership and use and also to contribute to it, in a positive feedback loop that reinforces both low-density development and motorisation (Gilbert & Perl, 2008). The environmental impacts of urban sprawl have been studied in depth (He et al., 2010; Urban Task Force, 1999) and urban sprawl has been identified as a major issue for sustainable development (European Environment Agency, 2006).

The problematic of urban sprawl and its numerous environmental, economic and societal impacts refer inevitably to the question of "urban form" and its densities, and, in particular, the validity of two prevailing and opposite models: the "compact city" and the "sprawled city". Connecting urban form to buildings energy use, lower density and detached housing tend to require more energy than multi-unit developments or attached housing (Steadman et al., 1998; Steemers, 2003; Ewing & Rong, 2008; Marique & Reiter, 2012b). In the transportation sector, urban sprawl increases energy consumption due to commuting by car. Various scientific articles have studied the relationships between transport energy consumption and building density. Based on data from 32 big cities located all over the world, Newman and Kenworthy (1999) have highlighted a strong inverse relationship between urban density and transport consumption. In studies on Nordic cities, Naess (1996) observed also that the use of energy for transportation is reduced with higher urban densities. Banister et al. (1997) explains the influence of urban density on energy consumption related to mobility by the average home-to-work distance reduction and the more amenable public transport supply in dense urban areas. But Breheny (1995) argues that there are not strong evidences that containment policies promote transport energy savings. Different studies underline also the importance of the price of travel and the influence of socio-economic factors on transport behaviors (Boarnet and Crane, 2001 ; Van de Coevering and Schwanen, 2006). Souche (2010) studying 10 cities around the world (through the IUTP database) shows that the two variables the most statistically significant for transport energy consumption assessment are the transport cost and the urban density.

On the basis of various case studies, Ewing and Cervero (2001) evaluated quantitatively the impact of urban density, local diversity, local design and regional accessibility on the mean vehicle travel distances. The elasticity was evaluated at -0.05 for urban density, -0.05 for local diversity, -0.03 for local design and -0.2 for regional destination accessibility. It means that if the density of a district is multiplied by two, private car commutes are only reduced by 5%. Note that the impact of the destination accessibility is larger than the three others parameters combined, suggesting that areas of high accessibility, such as city centres, may produce substantially lower transport energy consumption than dense and mixed developments in less accessible areas. Ewing et al. (2008) found that the most compact metropolitan areas in the US generate 35% less mean vehicle travel distances per capita than the most sprawling metropolitan areas. Ewing and Cervero (2010) showed that a 10%

reduction in distance to downtown reduces mean vehicle travel by 2.2% and a 10% increase in nearby jobs reduces mean vehicle travel by 2%. Finally, more compact developments (including density, functional mix, and transit accessibility) can reduce mean vehicle travel per capita by 25-30% (Ewing and Cervero, 2010).

Opponents of sprawl articulates the "compact city" model, in opposition to the "sprawled city" model, around the concepts of centrality, high density, mix use and performing urban transportation systems. However, the concrete feasibility of this model is questionable. Numerous research and policies, at the national, regional or local level, pretend that it is crucial to favour compactness of cities and to thwart urban sprawl but do not propose adequate tool or policies that could concretely be implemented to meet these goals. Although it is usually argued that more compact urban forms would significantly reduce energy consumption both in the building and transportation sectors (Urban Task Force, 1999; Ewing et al., 2008; Gillham, 2002; Newman and Kenworthy, 1999; Steemers 2003), suburban developments continue to grow (Marique et al. 2013b). Moreover, several impacts linked to high compactness (such as congestion, pollution, increase of land prices, etc.) are not really addressed.

At the opposite, the "sprawled city" model is often defined in terms of "undesirable" land-use patterns (Ewing, 1994; Urban Task Force, 1999) in the scientific field. Sprawl however often induces lower land prices and more affordable housings (Gordon & Richardson, 1997). Low-density developments also mean more room and a higher standard of living for numerous households and constitute one of the preferred living accommodations (Berry & Okulicz-Kozaryn, 2009; Couch & Karecha, 2006; Gordon & Richardson, 1997; Howley, 2009). However, continuing to promote such development model, even at very high construction standards (low energy or passive standards, that limit the heating energy requirements of buildings at, respectively, 60 and 15 kWh/m².year), will not help to solve numerous problems relating to urban sprawl, such as soil waterproofing, car dependency or costs of infrastructure, networks and services. Such low-density developments are found all over Europe, the United States and even emerging countries (Nesamani, 2010; da Silva et al., 2007; Yaping & Min, 2009). Even new districts that set themselves up as "eco" or "sustainable" are sometimes built far from city centers and are not necessarily very sound from an ecological point of view because of higher transport energy consumption (Harmaajärvi, 2000).

More problematical, none of these models (the "compact city" and the "sprawled city") propose solutions relating to the existing building stock, that already represents a very large part of the building stock in 2040, due to the great inertia of the existing building stock in most countries. In numerous European countries, the renewal rate of the building stock is quite low, which means that the main challenge to address concerns this existing building stock and its transition towards more energy efficiency and more sustainability. The most important actual energy policy measure in the EU is the Directive on the Energy Performance of Buildings, EPB (Directive 2002/91/EC). It focuses on energy efficiency when new buildings are built or when big buildings (larger than 1000m²) undergo a major renovation. However, energy efficient measures that are environmental efficient and cost effective need also to be applied on the existing residential building stock, on smaller buildings and/or lighter renovation processes. Forecast scenarios on future energy policies at the city scale (for the city of Liège in Belgium) confirm that the European Directive on the Energy Performance of Buildings and even more selective energy policies applied only on new buildings are not sufficient to widely decrease buildings energy consumptions at the city scale, while the renovation of the existing building stock has a much larger positive impact on city energy consumption reductions (Reiter & Marique, 2012). Moreover, retroffiting a huge number of buildings to medium standards seems to be more energy efficient than achieving higher standard on fewer buildings (Reiter & Marique, 2012).

Spatial Scale

The issue of scale should also be addressed as past energy research and studies mainly consider large and dense urban areas and neglect less dense areas. Owens (1986) found that different characteristics of the spatial structure are important in terms of the energy efficiency across different scales. Regarding the impact of land use on transportation, Van Wee (2002) distinguished several spatial levels: the direct surroundings of the dwellings, the neighbourhood, the town/city, the region, a sub-set of a country, the entire country and the international scale. Since 1993, the International Energy Agency (IEA) has provided projections about global energy consumption using a World Energy Model. In 2008, the World Energy Outlook recognized that the factors that were influencing city energy use were different from the energy use profiles of the countries the cities were in as a whole (OECD & IEA 2008). Friedman & Cooke (2011) prove the same for New York City and the US database. The IEA suggests that, in industrialized countries, the energy use per capita of city residents tends to be lower than the national average. By contrast, urban residents in China use more energy per capita than the national average due to higher average incomes and better access to modern services in cities (OECD & IEA 2008). Nonetheless, the issue of geographical scale is often neglected in discussions about the compact city and transport energy savings that too often “elide scale” (Neuman, 2005).

Marique et al. (2011a) namely address this issue by showing that a local scale approach is useful to highlight the existence of secondary suburban and rural cores presenting low transport energy consumption. In this respect, distance from home to destination is paramount while the mode of transport used has a lower impact. This can partly be explained by the relationship between distance and mode choice. The current mobility policies should thus favour the reduction of distances through a better mix of functions at the living area scale and be more context-specific by addressing the sustainability of transport also at the local scale. (Marique et al., 2011a). In Marique et al. (2013b), three indexes (the energy performance index, the modal share index and the distance travelled index) are developed and mapped to investigate the interdependences between urban structure of the territory, urban sprawl and travel energy consumption for commuting at several territorial scales. When specifically analyzing suburban areas, they found that two distinct phenomena co-exist in the suburban areas: the « metropolisation » and the « territorial recomposition » (Marique et al., 2013b). Metropolisation induces higher commuting distances in the suburbs of attractive cities. The influence area of these main poles can reach 40 or 50 kilometers in Belgium. The territorial recomposition generates secondary employments centers over the last years and allows the local population that used to travel to main cities for work to instead find work closer to their homes. This allows for shorter commuting distances and thus lower scores for the local energy performance index. In the case of territorial recomposition, the suburbanisation of housing is accompanied by a local reconcentration of employment in secondary urban or suburban cores, sufficiently dense and equipped. The two parameters that have the strongest impact on the variation of transport energy consumption are the variation of functions (residences, shops, work places, leisure, etc.) in the neighbourhood and its built density. In operational terms, the main findings of these research recommend that the current mobility policies should favour the reduction of distances through a better mix of functions at the living area scale and be more context-specific by addressing the sustainability of transport also at the local scale.

At the city scale, Reiter and Marique (2012) proposed a method that uses an Urban GIS and statistical treatments of urban and transport data to develop an energy model, combining building and transport energy consumption studies. The method combines also national statistics, that are not associated with buildings and transport (top-down approach), with local data related to buildings and transport (bottom-up approach). From this energy model, the forecast evolution of demographic data is deducted from global trends of recent years (top-down approach), while the energy consumption of transport and buildings are obtained thanks to empirical data and results of energy modeling (bottom-up approach). This combined approach provides a set of data as accurate as possible and the opportunity to compare different urban design strategies for limiting energy consumption in cities.

At an intermediate scale, the “sustainable neighbourhood” can be considered as the meeting point between the individual sustainable building and the management of a sustainable city, which are two fields in which actors have evolved independently for a long time. The neighbourhood is more homogeneous than the city and constitutes the ideal scale at which to experiment with new technologies and methods to improve urban sustainability. The urban fragment is large enough to guarantee the transversality that constitutes the core of the sustainable development and is small enough to more easily mobilise inhabitants and gain their participation in the project (Riera Pérez and Rey, 2013). Marique and Reiter (2012a) have developed a detailed method to assess transport consumptions at the neighborhood scale. The method takes into account transport energy consumptions of residents for four purposes of travel (work, school, shopping and leisure). An application of this method and a sensitivity analysis are presented concerning the comparison of four suburban districts located in Belgium. Note that the unit of energy chosen to express the energy efficiency of daily trips (kWh) was chosen to allow for a comparison between energy consumption in transport and energy consumption in the residential building sector (heating, appliances, electricity, etc.). This comparison is presented in Marique and Reiter (2012b).

In Marique and Reiter (2012b), main parameters that act upon the energy balance of suburban neighbourhoods are highlighted based on four case studies in Belgium. Energy consumed by the heating of buildings is the most important portion of calculated consumption at the neighbourhood level in this temperate climate. Depending on the available bus services and distance to the city centre, transportation represents 11.9% to 35.9% of the consumption of a neighbourhood. Sensitivity analysis was performed to identify the most relevant factors for improving the energy efficiency (building + transportation) of the neighbourhoods under study. These factors included insulation (up to the actual standard for new buildings), orientation of the neighbourhood and building distribution (terraced houses instead of detached houses), both relating to urban form, and the impact of location (in terms of distance to city centre and bus services), vehicle performance and travel distance on the overall energy consumption. The results indicate that improving building insulation is the most relevant strategy in the reduction of overall energy consumption. Assuming that all the houses were retrofitted to fit the energy requirements for new buildings in 2008 (the regulation was strengthen after this date), the overall consumption is reduced by 45.6%, 51.1%, 33.6% and 50.5% in the four neighbourhoods, according to their previous level of insulation and their date of construction. These results are mainly due to the low rate of insulation in the Walloon region of Belgium in relation to the temperate climate. In terms of orientation, energy consumption in buildings varied only marginally (less than 2%) with the orientation of the neighbourhood and the solar energy effect on vertical façades and roofs. This is due to the lack of optimization for solar accessibility in these types of neighbourhoods. The impact of building distribution was tested for three areas with detached houses. The number of houses in each neighbourhood was held constant, but we assumed the houses were grouped in fours (two terraced houses and two semi-detached houses). In these configurations, overall energy consumption decreased by 24.2% in the first case, 16.2% in case 3 and by 15.1% in case 4 (case 2 already included terraced houses), confirming the influence of building distribution on energy consumption. Building distribution is more significant for buildings with less insulation. The impact of location on overall energy consumption is also huge. If the first, third and fourth cases had the same benefits as the second (better bus services and proximity to urban centres), the overall energy consumption would decrease by 21.0%, 7.2% and 11.7%, respectively, mainly from a reduction in the number and distance of car trips. Improving the performance of private and public vehicles and favouring shorter travels to work and school (by better housing locations) are also strategies for the improvement of energy efficiency in suburban areas. As older Belgian houses are poorly insulated, the priority is to improve insulation in existing buildings. However, households' location (that allows to reduce travel distances) and the performances of the vehicles will be more significant for new buildings and neighbourhoods because the passing of the EPBD guarantees that new buildings are well insulated and more energy efficient.

Marique et al. (2011b) investigates the influence of an increase in built density, in existing suburban neighbourhoods. The idea is to favour a higher built density in existing neighbourhoods instead of building new low-density neighbourhoods on unbuilt areas. Moreover, increasing the built density in existing neighbourhoods allows to preserve unbuilt areas and to limit the need for new infrastructures and networks, which should help suburban areas to become more sustainable. The analyses highlight that, for the studied existing suburban neighbourhood, the benefits of an increase in built density are significant in terms of both energy consumption and surface area of land saved. These findings are important because they support the densification of existing low-density neighbourhoods as a strategy toward sustainable energy transition of the built environment.

In Marique and Reiter (2013), three scenarios, focused on the evolution of the existing building stock, are modelled (the retrofitting of existing neighbourhoods, an increase in the built density and demolition/reconstruction) to answer two main questions: "how to intervene in suburban areas?" and" where to intervene? ". From an energy point of view, all the scenarios present interesting results (from -7.3% if only the roofs of the existing buildings are insulated to -70.4% if more compact urban forms are promoted, at the actual energy requirements standard). For one fixed level of insulation (e.g., the actual energy requirements fixed in the European Directive on the Energy Performance of Buildings, but the trends is the same in the case for low energy and passive standards), the most efficient strategies consist in rebuilding the existing neighbourhoods in a more compact urban form (urban blocks or apartment buildings). These scenarios allow, for example, a reduction of respectively 41.8%

and 45.9% in comparison with a re-building of detached houses, which highlight the low energy efficiency of this kind of urban form, even at better insulation standards (and for the same level of insulation). Of course, the previous scenarios, especially those dealing with the density and the demolition/reconstruction of neighbourhoods cannot be recommended all over the territory. It is crucial to take into account the impact of the location of the neighbourhoods on travelled distances and transport energy consumption. For example, re-building a mix and dense neighbourhood, or increasing the density of an existing neighbourhood, very badly located (far from city centre, shops and others services with very low bus services) is obviously counter-productive.

These findings show that, beyond the traditional polarization of the debates on energy efficiency of our built environment between the "compact city" and the "sprawled city", a new pragmatic paradigm, focused on the sustainability transition of suburban areas by densification, can make suburban areas evolve towards more sustainability. However, numerous brakes, in particular those relating to the existing regulation framework and the societal acceptability of an increased density exist and should be investigated in further research to be surpassed.

ENERGY MIX AND INFLUENCE OF RENEWABLE ENERGIES.

The influence of the energy mix of different countries on their GHG emissions is a recent research subject found in the literature, that it is generally studied at national scale, working on demand profile changes, varying electricity supply and economic issues (Burke, 2010; Hennicke, 2004; Luickx et al., 2008; Marrero, 2010; Foidart et al., 2010). These studies highlight how a shift in the energy mix toward renewable sources would yield significant reductions in per capita emissions at the national scale, even without reducing energy consumptions, but do not give solutions at the local scale. At the local scale, Rossi et al. (2012 a; 2012b) studied the life cycle assessment (LCA) of two residential buildings in three different climates: Belgium, Portugal and Sweden. A different life cycle scenario is taken into account for each location, in which the monthly temperatures, buildings insulation thicknesses, energy mix, heating and cooling systems are defined. Rossi et al. (2012a) show that the phase with the highest environmental impact for current buildings is the operation phase, representing approximately 62 to 98% of the life cycle total impacts, while the construction phase accounts for a total of 1 to 20% and the dismantling phase represents less than about 0.2 to 5%. So, trying to reduce uses (energy, water and waste) of the building stock during the utilisation phase seems to be the first action to achieve. Rossi et al. (2012b) studied the influence of the energy mix on the environmental impacts of these three houses, at different LCA stages. It also shows the complex interactions between building conception, climate, energy mix, materials and energy systems into the building. This paper highlights that the energy mixes strongly influence the Operational energy and Operational carbon especially when district heating is considered. It shows how a shift in the energy mix towards renewable sources yields significant reductions at the building scale, even without reducing energy consumptions. This is especially true in Sweden where a very cold weather inducing quite high heating demand is nevertheless responsible for less environmental impacts. The consequence of such decrease is that the Embodied impacts take a more representative place within the buildings life-cycle analysis when the energy mixes are more environmental. And, in those cases, LCA and green materials become of great interest.

The findings of Gustavsson and Joelsson (2010) on residential buildings show that the choice of energy supply system (cogenerated district heating, heat pumps, electric space heating, etc.) has a greater effect on the primary energy use than the energy efficiency house envelope measures. The CO_2 emissions from the building operation heavily depend on the carbon content of the fuel used in the supply systems. Studying the influence of the energetic performance of a building and the influence of occupants' behaviours on the environmental impacts of this building, Blom et al. (2011) developed a sensitivity analysis on different electricity mixes. Although each statement depends greatly on the location and the type of building that is considered, the conclusions of this study are that:

- The fraction of the environmental impact due to electricity consumption is higher than the proportion of electricity in the total energy content for all the studied scenarios. Therefore, the electricity mix used in the analysis widely influences the LCA of the building.
- A comparison between the Dutch electricity mix and an alternative electricity mix, using 35% renewable sources, based on European policy goals for 2020, shows that the 35% renewable sources scenario will not significantly reduce all the environmental impacts and will result in a maximum reduction of 14% in the Global warming potential.
- All the renewable energies have not the same environmental impact. The type of sustainable energy sources used to produce electricity greatly influences the environmental impact of the energy mix.

The use of renewable energy is also widely studied in the scope of the "Zero-Energy" objective. Zero-Energy Building (ZEB) is arousing more and more interest internationally, both in policies aiming at a more sustainable built environment and in the scientific literature. As far as policies are concerned, the recast of the European Performance of Buildings Directive (EPBD) requires, for example, all new buildings to be "nearly Zero-Energy" Buildings (nZEB) by 2020 and will be extended to existing buildings undergoing major retrofitting works (EC, 2010). In the United States of America, the Energy Independence and Security Act (U.S. Government, 2007), that concerns the energy policy of the whole country, aims to create a nationwide net Zero Energy initiative for commercial buildings built after 2025. More concretely, several buildings have recently been built and prove that Zero Energy, at the building scale, is feasible. These buildings bring together architectural design, energy efficiency and the local use of renewable energies to reach an equalised annual energy balance (Voss & Musall, 2011). Most of these existing Zero Energy Buildings are (small or large) residential buildings and office buildings (IEA, 2012; Voss et al., 2011). Renovations to Zero Energy and Zero Energy at larger scales remain still quite rare. One interesting development, at the neighbourhood scale, is the BedZED sustainable neighbourhood that aimed to be the UK's largest mixed use Zero Carbon community. However, the Zero Carbon objective was not achieved.

In the literature, the Zero Energy objective is most often considered at the building scale. Several papers propose thus definitions of Zero Energy Buildings (Voss & Musall, 2011;

Sartori et al., 2012), calculation methodologies (Marszal et al., 2011) or support tool for early stages of design (Attia et al., 2012). These definitions are commonly articulated around an annual energy balance equal to zero. But, in spite of its huge interest in terms of energy efficiency in buildings, the “Zero Energy Building” concept still considers the individual building as an autonomous entity. Research and papers dealing with Zero Energy at larger scales are not numerous: a few papers study the Zero Energy City (Kennedy & Sgouridis, 2011) or the role of simulation tools in the ZEB objective, at the city scale (Todorovic, 2012). Marique et al. (2013a) investigate the “Zero-Energy Neighbourhood” concept, described as a neighbourhood in which annual energy consumption for buildings and transportation of inhabitants are balanced by the local production of renewable energy. This article proposes a calculation method that takes into account three main topics: the energy consumption of buildings, the impact of the location of buildings and neighbourhoods on the energy consumption for daily mobility and the use of renewable energies to product energy and electricity. An application of this calculation method to two representative case studies (one urban neighbourhood and one suburban neighbourhood) is proposed. Main parameters that act upon the energy balance are highlighted and combined to propose concrete results to improve our built environment and move towards more sustainability. This article highlights also the potential “mutualisation” of energy production at the neighbourhood scale. For example, if photovoltaic panels are only located on the roofs that received more than 90% of the maximum solar energy and if the electricity production is mutualized at the neighborhood scale, the efficiency (kWh produced per m² of panel) increase (+10.7% in the urban case study and +5.0% in the suburban case study). The same amount of photovoltaic electricity can thus be produced by installing fewer panels than if all the individual roofs were used. Another example of mutualisation that will be further investigated is the use of electrical vehicle to store electricity production. As far as monthly production and consumption are concerned, it is interesting to highlight the gap between the production and consumption peaks, namely for solar energy (max in summer) and heating consumption (max in winter). This challenge (as well as hourly curves) are of crucial importance in the scope of a Zero Energy objective and will be addressed in further research. The third challenge to further investigate to operationalize the Zero Energy Neighborhood is the connection to the grid, the use of smart grids and the storage of energy.

INHABITANTS’ BEHAVIOURS

In the past few years, European budgets were granted to demonstrate, in real conditions, how to improve the sustainability of new and existing urban districts and how to foster the transfer of knowledge and best practices in the field of urban planning, for example, through the European Urban Knowledge (EUKN) and Energy Cities Networks. Several pilot urban neighbourhoods, often set themselves up as “sustainable”, were developed or retrofitted in this context. They were widely praised as best practices in terms of sustainable urban planning and low energy architecture. Although these “sustainable neighbourhoods” receive a great deal of media coverage, they seem to stay “single” experiments and are rarely repeated in other territories or at larger scales. Marique and Reiter (2011) proposes a rereading of eight famous sustainable neighbourhoods to highlight good practices to repeat and weaknesses to avoid. The paper gives several guidelines to promote energy efficiency and sustainability at the urban scale in order to support the planning of more sustainable urban projects. This paper focuses on six new and two retrofitted sustainable districts to allow a range of development situations to be explored: [BO] BO01 in Malmo (S), [HS] Hammarby Sjöstad in Stockholm (S), [BZ] BedZed in Sutton (UK), [KR] Kronsberg in Hanover (D), [FR] Vauban in Fribourg (D), [EL] Eva-Lanxmeer in Culemborg (NL) and [VS] Vesterbo in Copenhagen (DK). In these neighbourhoods, the environmental approach is pluralistic and mainly concerns energy but also water waste, mobility and transportation, biodiversity and materials, among others. "Low technologies" and "high technologies" are mobilised to fulfil the objectives as well as to demonstrate and test new technologies in real conditions. The economic and social points of view are often neglected in new developments, most likely because European and national grants were mainly oriented towards environment in the nineties. Although the social dimension of a sustainable project cannot be reduced to the question of the affordability of the dwellings, a minimum percentage of social dwellings is imposed in the specifications. The will to break with traditional practices is also obvious in the urban forms promoted: collective dwellings, urban linear blocks oriented toward the south or open housing blocks, high density mixed together with large green spaces, the repartition of private and public spaces, green flat roofs, the use of colour or the visibility of the water cycle, among other elements.

Their objectives in terms of sustainability are ambitious, especially as far as energy consumption is concerned; the sustainable neighbourhood aims to vastly reduce consumption and greenhouse gas emissions in comparison with neighbouring districts (60% in [KR] or 50% in [BZ] and [FR]), to supply the energy needs of the community using local renewable resources (up to 100% in [BO]), or to become self-sufficient in [EL], even in terms of the production of food. However, even if the measured performance following the completion of the studied projects is better than standard requirements, it is not always as positive as expected because the behaviour of the occupants was not accounted for in the previous forecasts. In [BZ], for example, measured consumption varies from 1 to 6 according to the household. In Hammarby, the high level of the equipment (especially in the kitchen) that is furnished to the inhabitants to improve the quality of the dwellings leads to huge energy consumption, even if heating loads are reduced. Finally, new technologies are sometimes difficult to understand and difficult for inhabitants to assimilate, which can reduce the expected performance. This is especially true in retrofitted projects because inhabitants are not always looking for changes in their habits or in neighbourhoods aiming at very high quality; these projects also attract wealthier people more interested in the neighbourhood's proposed quality of life than in its sustainable aspects. Best practices experiments are useful because they have proved that it is technically possible to retrofit and build more sustainable urban projects. However, a crucial goal seems to heighten public awareness of the importance of our lifestyles and behaviours.

To widely investigate this issue, de Meester et al. (2013) investigate the influence of three parameters related to human behaviour through their modes of occupations (based on family size, management of the heating system and management of the heated area) on the housing heating loads of a standard dwelling in Belgium. Seven levels of insulation were tested: no insulation, two intermediate levels corresponding to 3 and 6 cm of insulation, the current standard for new buildings in Belgium, the low energy standard, the very low energy standard and the passive house standard. Multi-zone simulations were performed with a dynamic thermal simulation software. The impact of occupants' lifestyle and the interactions between occupation modes and insulation levels are highlighted. These results prove that the more the building is insulated, the more the lifestyle proportionally influences the heating loads. One important strategy for reducing heating consumption during the whole life cycle of the building is adapting the size of the house and its occupation modes to the evolution of family size. However, insulation is paramount, and increasing the insulation of the house provides generally better results than merely adapting the occupation mode. In addition, if the occupation is lower than the “capacity” of the house, the consumption will be more significant in proportion to the occupied and heated square metres. It is thus essential to choose a home whose size is adapted to the actual occupational needs. When the family size is reduced, a solution is to divide the house and to rent a part of it or to move to a smaller dwelling. Moreover, in the case of the under-occupancy of a house, it is better to limit the number of heated rooms in winter. To reduce the heating consumption of a given house during its whole life cycle, people should adapt their house size according to their family size. Optimal thermostat management, for example by reducing the heating temperature during hours when the building is unoccupied, is also a very useful parameter to reduce housing heating or cooling consumption, especially for poorly insulated buildings. However, the balance between optimal comfort and good energy management is sometimes very tenuous, particularly if people have varied schedules. It is thus quite advantageous to be able to switch on the heating and ventilation systems by remote control.

de Meester et al. (2013) show that to evaluate the heating consumption of a household, it is important to focus (1) on heating loads in function of the occupied and heated area of the house rather than just on total surface area of the house and (2) on heating loads in function of the number of inhabitants rather than on total housing energy use. This paper also shows that if the insulation of the house is low, the parameters ranking with the biggest impact, among the three studied parameters, are: (1) thermostat, (2) heated area and (3) occupation mode. If the house has a very good insulation then ranking becomes: (1) occupation mode, (2) thermostat and (3) heated area. These results allow to estimate the priorities and to design more adaptive houses to the time, to the inhabitants, etc. according to the insulation level of the house. Thus heightening public awareness of the impact of their lifestyle is crucial and could quickly lead to significant reductions in the total energy consumption of a household.

CONCLUSION: STRATEGIES TOWARD A SUSTAINABLE TRANSITION IN THE BUILT ENVIRONMENT

The literature review on energy consumption of the built environment presented in this paper firstly showed that density tends to receive the greatest scientific attention, although, alone, its impacts on energy consumption of urban and suburban areas remain modest. It is therefore important to make a distinction between density as an isolated parameter and compact development or smart growth, sometimes studied under the term “density”, that reflect the cumulative effects of various land use factors such as density, functional mix, transit accessibility, walkability or parking management. That is the combination of these paramount factors that is crucial and could lead to significant energy reduction in our built environment.

This review chapter has then highlighted that, to favour a sustainability energy transition of our built environment, strategies and actions dealing both with the building and the transportation sectors are needed. Although energy consumption in the building sector is the most studied, the impact of location on transport energy consumption is also of major importance in a general goal of sustainability.

Addressing urban areas but also suburban areas with specific responses is also crucial because these two types of areas present specifities, as far as energy consumption is concerned. Finally, the complementarity between several scales (the building scale, the neighbourhood scale, the city scale) has been highlighted and illustrated from several topics linked to energy consumption.

The main findings presented in this paper could have huge positive impacts and lead to a significant reduction in energy consumption of our built environment, namely if adapted policies and strategies are adopted at the right scale. To conclude this paper, we propose thus five main general strategies that could help to renew our urban and suburban areas and help to twarth urban sprawl and nine operational guidelines that could be widely implementing in future urban projects.

The first general strategy to promote is often mobilized in current policies. It consists in favouring the urban renewal of city centres well located and well equipped (close to numerous shops, work places, schools, etc. with good public transportation) by retroffiting existing dwellings and adapt them to new comfort (houses with garden for family, acoustic comfort, etc.), occupation (adequation between the size of the household and the size of the dwelling) and insulation standards.

The second strategy, that follows the same goal than the previous one, is the building of new sustainable neighbourhoods, close to good transportation hubs, with attractive green and public spaces, high quality of life, etc., namely on these brownfields that are numerous in many European cities. In complementarity with these strategies, the third one consists in adapting the regulation framework to prohibit the urbanization of new neighbourhoods on plain area located far from existing cores. This strategy is however less realistic because of the numerous financial consequences that it supposes (compensation for land depreciation, etc.) and is only feasible at a large (national) scale to be efficient. These scenarios, especially the first two ones, could favour a soft and progressive transition of our built urban environment towards more sustainability and more quality of life but there are not sufficient because there do not consider the future of the numerous existing low-density neighbourhoods.

We propose the two last strategies to address the sustainability transition of these existing low-density neighbourhoods. The fourth strategy consists thus in an increase in the built density and in the mix use of existing neighbourhoods, by the building of new houses and apartments (but also work places, shops, and schools were this is needed) where land opportunities are available, namely by dividing existing plots into smaller ones. This strategy is especially recommended in these numerous low-density residential areas located in, or close to, city centres and secondary cores, where the size of the plots is often very large. The fifth strategy remains more theoretical and consists in investigating the energy efficiency of the demolition of selected existing neighbourhoods followed by the re-building of new ones, presenting different characteristics as far as density, urban compactness, mix use and accessibility are concerned.

At a more operational level, the following main guidelines could be promoted in future urban projects:

- One of the major energy challenges for the built environment remains the retrofitting of the existing building stock and its adaptation to contemporary insulation and comfort standards.
- The impact of the location of residences, work places and services on daily mobility patterns and their related energy consumption is huge and must be taken into account when the development of new urban projects (construction of new neighbourhoods or intervention in existing ones) is studied.
- The neighbourhood scale is particularly interesting from an operational point of view and allows to take into account numerous interactions that occur at a scale larger than the building one (potential mutualisation of energy production, etc.).
- Parameters linked to the urban form have a huge influence on the energy efficiency of buildings, the choice and the efficiency of renewable energy sources.
- The legal framework and requirements need to be adapted to new technologies and goals. A more proactive attitude must be adopted by the public as far as sustainable development is concerned. Public authorities should take leadership in urban projects (namely, through land ownership) and impose more strict requirements on private developers by putting them on concurrence to improve the quality and environmental performance of a project.
- Environmental requirements should be added to the specifications of urban projects, which must specify clear objectives and expected consumptions.
- Controls are necessary to ensure that initial requirements of urban projects will be respected. It is better to initiate quality upstream and to control it downstream.
- Information, formation and public awareness are crucial to mobilise citizens to promote sustainable development and to gain their adherence to this aim. This will help to reduce their energy consumptions and adopt a more efficient behaviour, namely as far as heating and mobility habits are concerned.
- Social quality and economical viability are also part of sustainability and must not be neglected.

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Chapter 3

ENERGY PERFORMANCE OF BUILDINGS: A STUDY OF THE DIFFERENCES BETWEEN ASSESSMENT METHODS

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ABSTRACT

The energy consumption of buildings has grown hand in hand with the improvement of the lifestyles of the occupants. This growth in consumption of housing affects the environmental and ecological conditions. Today, the main challenge is to increase the awareness of the users, on the one hand, by maintaining a high lifestyle, and on the other hand by reducing consumptions so as to minimize the impact on the environment.

In a construction sector constantly looking for new technologies for energy saving and energy efficiency, the role of the end user becomes crucial for the optimal management and responsible use of resources.

The operating conditions of the macro "building-plant-users" system are determined or verified by methods of the energy performance calculation shown in the European Standard, EN 15603:2008. These methods have a different degree of detail depending on the purpose. The standard calculation methods used in energy certification are useful for evaluating the energy condition of the building stock or for comparing the consumptions of several buildings. The design and tailored calculation methods based on design data and real consumption, however, allow the characteristics of the building envelope, plant and user's behaviour to be analysed in order to identify the real energy needs and any malfunctions, performing an energy audit of the system that allows the current status of energy use to be photographed.

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The standard method is based on a steady state approach in which use and climate profile are represented according to standard conditions and how the building was built. The design method is based on standard and climate use but the building is represented as it was designed. The tailored method uses actual data for use, climate and building. Finally, the standard includes the measured or operational method based on real energy consumption and the characteristics of the building.

In this work the methods are evaluated and the results are compared, using a case study.

Keywords: Consumption, assessment method, user’s behaviour, diagnosis

INTRODUCTION

The civil sector (residential + tertiary) has historically been responsible for a significant portion of a nation´s primary energy consumption. The evaluation of the data collected by the International Energy Agency -IEA- related to energy end-use (so called Total Final Consumption -TFC-) confirms this trend in all latitudes and longitudes. Figure 1 shows the distribution of the energy consumption of 10 countries in different sectors: the diagram shows how the residential sector is responsible for a high percentage of the TFC, with an average of the countries concerned at around 25%.

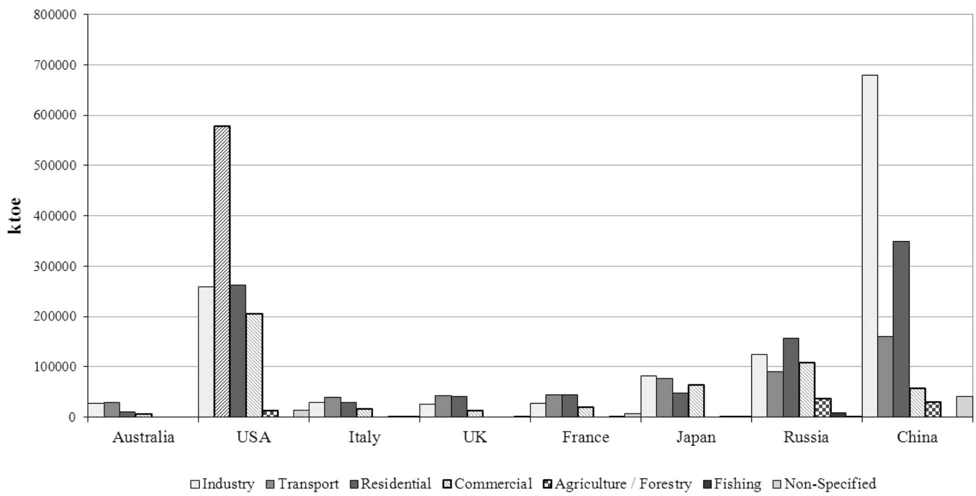


Figure 1. TFC data processing by the IEA Reports 2009.

In recent years, several national and international initiatives for the reduction of final energy consumption in the building sector have been undertaken, with directives (Directive 2002/91/EC, Directive 2010/31/EU) and standards, at an international (CEN Standard, EN 15603:2008) and national level (Italian Standard, UNI 11300-1:2008; Italian Standard, UNI 11300-2:2008) being adopted and aimed at increasing the energy performance of building.

These frameworks are mostly applied to new buildings or buildings subject to important refurbishments. The existing buildings, which are the most energy-consuming, are normally excluded. Any actions taken have to be concentrated on this sector in order to get greater results, through the application of energy diagnosis.

The local directives define different ways of assessing the energy performance of the building, regarding the purpose and the level of detail. The result is a fragmentation of the market of tools used for the energy performance calculation. On the one hand, monthly calculation methods support the design phase and the energy certification. On the other hand the detailed methodologies (such as hourly or sub-hourly dynamic simulation) support the energy diagnosis. In order to define retrofits and to assess their effectiveness, the energy diagnosis is used as a tool that allows the conditions and behaviour of the building components to be evaluated.

The energy diagnosis, as defined by European Directive, 2012/27/UE, aims to detect the energy consumption of a building, to identify and to quantify the opportunities for energy savings, outlining the economic feasibility in terms of costs-benefits. The competent professional should be able to evaluate the causes of the inefficiency and propose technical solutions to fix the detected anomalies and to improve the energy performance of the building.

The energy diagnosis is therefore a necessary tool for upgrading the energy efficiency of the existing building stock in order to fulfil the commitments regarding greenhouse gas emissions and primary energy consumption.

The influence of human behaviour on building consumption within the framework of energy diagnosis has not been fully analysed. Some studies have shown how this variable has an important role on energy consumption: setting a correct set-point temperature, using smart meters to control the indoor conditions or managing the correct operation of appliances, are just some of the devices that could reduce energy consumption.

From these premises, this treatment intends to investigate, on the one hand, the impact human activities have on the energy consumption of a building and, on the other hand, compare the calculation methodologies of energy performance provided by the current standards in force.

HUMAN BEHAVIOUR AND ENERGY CONSUMPTION

In general, the factors influencing the energy behaviour of buildings can be subdivided into seven categories:

- Climate;
- Building-related characteristics;
- User-related characteristics;
- Building services systems and operation;
- Building occupants' behaviour and activities;
- Social and economic factors;
- Indoor environmental quality required.

All categories are not stand-alone but rather interact with each other in the "building-plant-users" perspective, determining energy consumption of the buildings. In this dissertation the user's behaviour is analysed in order to assess how it influences the building behaviour.

Energy use in residential buildings is influenced by the occupants' behaviour in various ways. Omitting consumptions linked to everyday life (cooking, lighting, etc.), user's behaviour is aimed at achieving levels of internal comfort.

Different studies (Martani et al., 2012; de Meester et al., 2013; Iwashita & Akasaka, 1997; Fabi et al. 2011) show how users are influenced by both external factors, related to building physics, and internal factors, related to the social sphere. The users respond to the stimuli caused by these factors with one or more actions which allow the initial balance condition to be restored. (for example, the set-point temperature is increased following a cold stimulus with an effect on the regulation of the plant.)

The Technical Report "Driving forces of energy-related behaviour in residential buildings" of IEA Annex 53, summarises the factors in five groups: physical environmental (temperature humidity, etc.), contextual (insulation, orientation, etc.), psychological (satisfaction of thermal comfort, visual comfort, etc.), physiological (age, gender, etc.) and social (interaction between occupants). Each factor has a positive or negative influence on user's behaviour.

The tools for assessing the energy performance of buildings address the issue of user's behaviour with different approaches, depending on the level of detail and the implemented methodologies. Two main paths are followed: the first, typical of simplified simulation tools, provides the assignment of standardised parameters to the effects of human activity (appliance use, opening windows, etc.), the second, typical of detailed and dynamic simulation tools, uses profiles at hourly or sub-hourly steps able to simulate the user's real behaviour.

ENERGY PERFORMANCE OF BUILDING

The CEN Standard, EN ISO 15603:2008 provides the general framework for the assessment of the overall energy consumption of the building, specifying the calculation methods according to the different intended purposes. Table 1 shows a summary of these methodologies, identified as calculated and measured methods, the first based on physical algorithms, the second based on monitoring data.

The calculated method is divided further into three sub-categories according to the scope of calculation: design, standard and tailored. The design method, applied to the design phase and aimed at defining the physical characteristics of the building (envelope and plant), is used for energy certification purposes and in the assessment of minimum requirements for new buildings. The standard method, using standard input data (climate, use profiles, etc.) is the methodology for energy certification, providing calculation transparency and reproducibility. Finally, the tailored method allows the interaction of three inseparable and competing actors to be evaluated, that is to say: building envelope, plant and user's behaviour. This last methodology is the basis for the energy diagnosis.

The measured method is based on the monitoring of energy consumption and other physical parameters of buildings during the operational phase. This pragmatic approach allows the real energy performance of buildings to be evaluated. This method is time-consuming and requires invasive operations to monitor the real data, so it is suitable for measurements of some relevance. A simplified solution is the Energy Signature method that allows energy performance linking the energy consumption with an external parameter to be assessed, such as external temperature. An extended description of the method is provided below.

Table 1. Rating of energy performances of buildings

Type	Name	Input data			Utility of purpose
		Use	*Climate*	*Building*	
Calculated	Design	Standard	Standard	Design	Building permit, certificate under conditions
	Standard	Standard	Standard	Actual	Energy performance certificate, regulation
	Tailored	Depending on purpose		Actual	Optimisation, validation, retrofit planning
Measured	Operational	Actual	Actual	Actual	Energy performance certificate, regulation

The two methodological categories -calculated and measured- start from different assumptions, the first from input data to define energy consumption, the second from energy consumption to define performance. Due to these differences, it is normally difficult to compare the two methods, however a comparison of results can be used, on the one hand to assess in detail the energy performance of a building and, on the other hand, to harmonize the methodologies.

CALCULATED METHOD

The International Standard, EN ISO 13790:2008 describes the calculation methods for the assessment of the energy requirement for heating and cooling of residential and non-residential buildings. A major distinction between methods is as follows:

- quasi-steady-state methods, calculating the heat balance over a sufficient time, which allows dynamic effect to be taken into account by an empirically determined gain and/or loss utilization factor;
- dynamic methods, calculating the heat balance with short time steps taking into account the heat stored and released from the mass of the building.

The main difference is due to how the mass of dynamic effect of inertial mass of buildings is treated. In quasi-steady-state methods the dynamic effect is expressed by a utilization factor, depending on the time constant of buildings. Dynamic methods consider the real capacitance and resistance of the buildings instead.

The standard provides guidance for three methods:

- monthly quasi-steady-state calculation method;
- simple hourly calculation method;
- dynamic simulation method.

The monthly method is based on a quasi-steady-state balance between losses (heat losses by transmission and ventilation) and gains (internal and solar). The gains are corrected with the dimensionless utilization factor, η, as a function of the heat balance ratio and the global capacity of buildings. This factor expressed the capacity of the building to use free gains: the higher the heat capacity, the greater the ability to use free gains with a reduction of energy requirements, both in the heating and the cooling period.

The standard provides a second simplified hourly-based method that allows dynamic aspects with few inputs to be considered, starting from the hourly profile (set- point temperature, ventilation, shutters, ect.). The approach is based on a Resistance-Capacitance model with a distinction between air and mean temperature surface so as to take into account the radiative and convective part of solar, lighting and internal heat gains.

Finally, the dynamic methods allow the thermal behaviour of buildings to be defined with a hourly or sub-hourly steps, taking into account the inertia of building components and investigating the real behaviour of the thermal flux (for ventilation, transmission, etc.).

These calculation methods are implemented in operational tools as a support for practitioners.

Quasi-Steady-State Monthly Balance Method

The monthly balance calculation tools are aimed at designing the building-plant system from a thermo-physical point of view, using simplified calculation algorithms requiring few inputs. Over the years these tools have also been applied to the evaluation of thermal performances and for the energy certification of buildings. The limitations are due to the quasi-steady-state balance that only allows monthly variations of buildings behaviour to be considered with a simplified approach to the inertial aspects. Moreover, these tools provide a constant usage profile of buildings both for users and for the plant. The monthly method does not fully suit the building energy diagnosis for these characteristics.

The monthly method is based on the thermal balance of the thermal zone between losses, transmission and ventilation ($Q_{H,ht}$, $Q_{C,ht}$), and gains, internal and solar ($Q_{H,gn}$, $Q_{C,gn}$), for heating and cooling.

The coefficients $\eta_{H,gn}$ and $\eta_{C,ls}$ respectively represent the utilization factor of free gains in the heating period and the reduction factor of losses in the cooling period. The result of the balance is the thermal requirement for heating or cooling of the thermal zone.

Simple Hourly Calculation Method

The aim of the simple hourly calculation method is to reduce the uncertainties and to simplify the dynamic method, which is notoriously complex due to the algorithms, and to the amount and quality of input data required.

By electrical analogy, this method is based on a resistance-capacitance model (R-C) in which all components, opaque or transparent, are described by a thermal resistance and opaque ones by a thermal capacity. In particular, the model described in the International Standard, EN ISO 13790:2008 consists of 5 resistances and 1 capacitance, the so called 5R1C (see Figure 2).

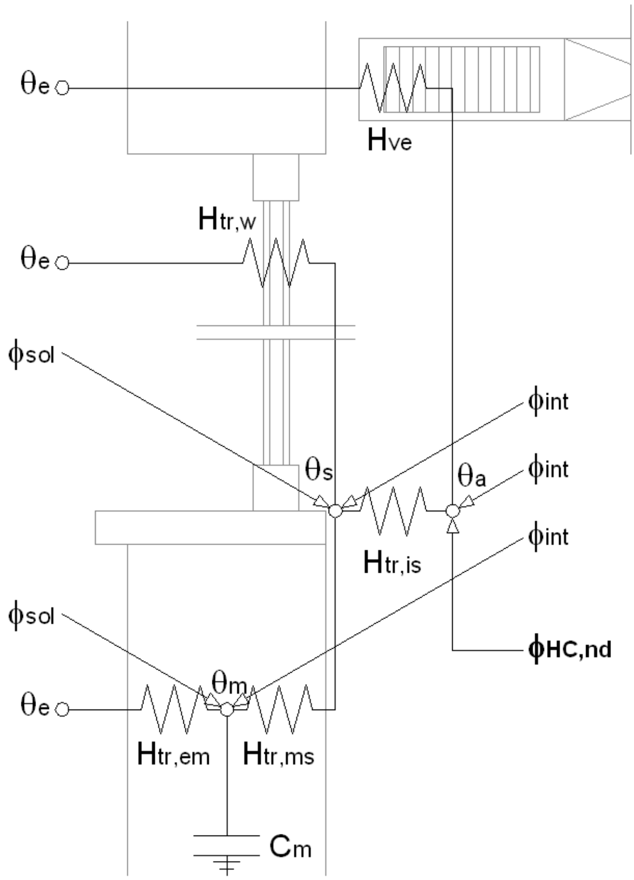


Figure 2. Simple hourly method scheme.

The model provides 5 nodes to represent the temperature conditions and to describe the different heat transfer processes, so defined: internal air temperature (θ_{air}), standard temperature (θ_c) representing a mix of air temperature and mean radiant temperature, building mass temperature (θ_m), external temperature (θ_e) and supply air temperature (θ_{sup}) for the ventilation system, that can be the same as the external temperature in the case of natural ventilation. The model provides a thermal capacity referred to the building mass.

The Heat transfer coefficients by transmission, H_{tr}, and ventilation, H_{ve}, described the heat exchange between the different nodes. In particular the heat transfer coefficient of opaque components, $H_{tr,op}$, is subdivided into two parts: the coupling conductance between the external air temperature node and the temperature node that represents the mass of the building, ($H_{tr,em}$), and the coupling conductance that connects the temperature node that represents the mass of the building with the central temperature node, ($H_{tr,mc}$). The network is completed by defining a coupling conductance between the internal air temperature node and the central node ($H_{tr,is}$).

Ventilation losses, internal and solar gains are calculated in the same way as the monthly method. An algorithm allows free internal and solar gains to be divided into the three internal nodes -θ_{air}, θ_c and θ_m.

Detailed Simulation Method

The dynamic simulation methods allow very detailed analyses on the energy performance of a building -or part of it- to be carried out, providing specific output data. The application of these tools requires a very thorough knowledge of the building under study with consequent need of a large number of input in order to define an appropriate model. These tools support very short calculation steps, hourly or sub-hourly.

Dynamic calculation is based on three different approaches, described by ASHRAE Handbook-Fundamentals (ASHRAE, 2009): the Heat Balance Method (HBM), the Weighting Factor Method (WFM) and the Thermal-Network Method (TNM). Generally, the commercial tools implement the first two approaches, the HBM and the WFM.

The HBM is based on the first law of thermodynamics and on the principles of matrix algebra. Several tools available on the market are based on this approach (Energy Plus, BLAST, etc.). The HBM allows the instantaneous sensible heating and cooling load on the space air mass to be calculated. Building behaviour is described by balance equations for each surface plus one for the air. The definition of the boundaries system is an important step in order to be able to write these equations. The boundaries are the technical elements (walls, ceiling, roofs, etc.) that separate the indoor environment to the outdoors. It is assumed that each of these surfaces has a uniform temperature at any time. At any plain boundary, the flux entering the boundary must equal the flux leaving the boundary. Thus on the inside surface of any wall, the heat flowing into the surface is balanced by the conductive flux leaving the surface.

The WFM is a compromise between the steady state methods and detailed simulation methods. The WFM (used for example by DOE-2) ensures that the heat gains at constant space temperature are determined beginning from a physical description of the building, the environmental weather conditions and use profiles. The basis of the method is the Z-transfer function.

The TNM is an improvement of the HBM in many ways: if HBM uses one node to represent the air, the TNM uses multiple nodes, if the HBM describes technical elements with two nodes, one for the internal and one for the external surface, the TNM considers different nodes. Thus this method allows for a deeper description of the thermal and energy exchanges of a building.

Between the three methodologies, TNM is the most flexible and has the greatest potential for high accuracy. However, it also requires a longer computation time, and, in current implementations, a greater user effort to take advantage of the flexibility.

The Computational Fluid Dynamic (CFD) method can be also mentioned among the numerical methods used in the design of buildings (Comini, 2008). In recent years, the increasing availability of computer tools has greatly expanded the range of problems that can be solved by numerical methods. At the same time technological progress has led to the use of more accurate computational models that resort to numerical solutions. Such models are not yet widespread due to the high degree of complexity in carrying out energy performance simulations. In fact, the formulation of mathematical models, which represent the thermo-fluid dynamic aspects in general terms, are solved by discretization to differential balance equations (conservation of mass, energy and momentum, etc.) for each node. These equations allow the thermal field and the motion field in the processes of heat transmission to be determined (Deltour et al., 2011).

The monitoring of real energy use in energy-efficient buildings frequently shows major differences with respect to the predicted performance. Building energy performance simulation (BEPS) models, which have proven to be very useful in comparing buildings design alternatives, have difficulties in capturing the real complexities of the actual building energy performance.

A significant reduction in the difference between real and predicted energy behaviour in a building can be obtained by coupling to dynamic simulation with calculation algorithms for measuring and the optimization of the real building energy performance (e.g., a predictive analysis with a calculation tool and consequent adaptive behaviour instantaneous of the plant).

MEASURED METHOD

The measured method consists in the assessment of real energy consumption of buildings through the analysis of annual bills or operational monitoring campaign, evaluating the real performances of building. The Energy Signature (Annex B of the CEN Standard, EN ISO 15603:2008) is the operational tool of this methodology, a holistic method able to identify any malfunction of the building-plant system starting from real energy consumption and recorded in regular steps. Unlike the calculated method, the Energy Signature is not an absolute method aimed at defining the energy performance of building in standard conditions, but a relative assessment method of the energy behaviour of buildings in real operational conditions, which are sensitive to external variables. Thanks to this peculiarity, this methodology is able to evaluate the contribution of different variables that contribute to the overall energy consumption.

The Energy Signature can be applied to different energy consumptions, heating, cooling and electrical. Its application to different final uses requires the choice of the most suitable climatic variable and of the most appropriate detection period. The external temperature or the degree-days are the reference variables and the weekly step is the reference period for heating. The weekly detection allows any sudden weather changes to be mediated.

From an operational point of view, the Energy Signature is the curve in a Cartesian graph that best fits the detected consumption referred to the external variable, as shown in Figure 3.

Transforming the detected consumption into the corresponding thermal power, the graph of Energy Signature highlights the thermo-physical behaviour of the building:

- The slope of the fitting curve represents the total heat transfer coefficient of the building (transmission + ventilation), which expresses the trend of the building to disperse heat towards the outside or another unconditioned space. The smaller the coefficient, the greater the insulating capacity of the building.
- The intercept of the fitting curve represents the power at 0°C. Starting from the design external temperature which the thermal power is referred to, it is possible to determine the correct sizing of the heat generator in the operational phase.
- The consumption located below the graph of Energy Signature testifies an optimal exploitation of the free contributions (indoor and solar); while those that are located above the graph of Energy Signature show anomalous thermal dispersions.

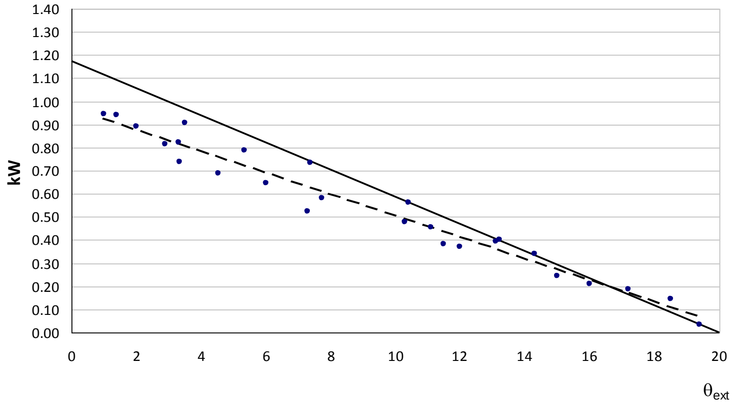


Figure 3. Graphical representation of Energy Signature for heating period.

Table 2. Comparison of methodologies

	Monthly	Hourly	Dynamic	Measured
Calculation method	Building balance method	Resistance-capacitance model	WFM, HBM, CFD	Detection of real consumption
Climate data	Standard monthly climate data	Standard hourly climate data	Complete climate data	Real climate data
Total heat transfer by transmission	Monthly average losses by transmission	-	Heat balance surface (inside - outside)	-
Transmission heat transfer coefficient	Due to thermal transmittance and thermal bridges			Slope of fit line
Total heat transfer by ventilation	Monthly average losses by transmission	-	Air heat balance	-
Ventilation heat transfer coefficient	Due to air change per hours			Slope of fit line
Internal heat gains	Monthly average heat gains	Hourly use profile	Sensible + latent Hourly use profile	-
Solar heat gains	Monthly average solar gains	Hourly solar gains	Heat balance surface (inside - outside)	-
Dynamic parameters	Gain/loss utilization factor	Coupling thermal mass	Transfer functions	-

Real detected energy consumptions are compared with a reference curve called Design Energy Signature whose slope is represented by the design overall heat transfer coefficient by transmission and ventilation of the building and intercept is the design heat power calculated at 0°C (Belussi & Danza, 2012). This comparison allows the real energy behaviour of the building to be assessed with respect to that expected at the design phase, outlining any non-compliance.

Table 2 summarizes the difference between the assessment methods presented above.

APPLICATION TO A CASE STUDY

In order to assess the sensitivity in relation to the different variables involved, the calculation/measurement methodologies for the evaluation of the energy performance of the building described below have been applied to a real case study.

Description of the Case Study

The building case study is a single dwelling located on the first floor of a new small building located near to Modena, Emilia Romagna (2258 DD).

The dwelling has a conditioned floor area of 90m^2 and it is subdivided as shown in Figure 4. It borders to the North and South on the outside, on an unconditioned stairwell and on another conditioned apartment to the East and on one more conditioned apartment to the West. Both the floor and the ceiling border on other dwellings. Thus the dispersive surfaces are those exposed to the North and to the South and the one towards the stairwell.

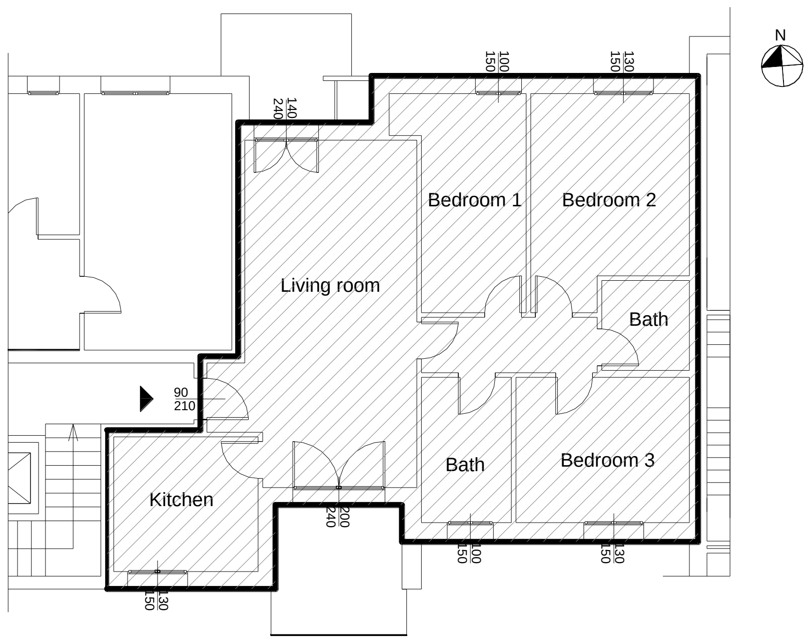


Figure 4. Dwelling plant.

The thermal transmittance and heat capacity of the envelope components are shown in Table 3.

Table 3. Thermal transmittance and heat capacity

Envelope component	Transmittance [W/m^2 K]	Internal heat capacity [kJ/m^{2}K]	External heat capacity [kJ/m^{2}K]
External wall 30cm (North-South)	0.30	46.74	63.06
Internal wall 30cm (stairwell)	0.79	46.83	46.83
Internal partition 10cm	-	35.08	35.08
Ceiling	-	73.32	59.96
Floor	-	59.96	73.32
Entrance door	2.20	-	-
Windows: 130x150 100x150 140x250 200x250	 1.37 1.42 1.32 1.27	 - - - -	 - - - -

An experimental monitoring campaign allowed climate data (external and internal temperature, solar irradiance) referred to the period from 15th October 2010 to 15th April 2011 to be detected. Other information on the dwelling is: set-point temperature and time setting for heating, use profile of windows and shutters, and heating period (see Table 4). Thus the case study is defined.

Table 4. Variables

Variable	Users' behaviour profile
Set-point temperature Dwelling thermostat	Monday to Friday from 07:00 to 08:00 - 20°C from 17:00 to 21:00 - 20°C other hours - 18° Weekend Manual set-point
Heating use profile	Turned on according to thermostat setting
Windows use profile	Open about 15 minutes by day

Climate Data

The described methodologies use aggregations and different types of climate data, according to the purpose of the study.

Table 5. Standard weather data, temperature (°C) and solar irradiance (W/m^2) for the monthly method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
θ_e	1.4	3.5	8.6	13.3	17.2	21.8	24.3	23.8	20.1	14.0	8.1	3.1
$\theta_{e,heat}$	1.4	3.5	8.6	12.2*	-	-	-	-	-	12.5[1]	8.1	3.1
$I_{sol,N}$	19.56	28.94	43.17	63.90	92.82	112.91	108.03	75.59	49.62	34.72	21.76	17.48
$I_{sol,S}$	82.25	103.62	130.29	129.52	121.33	117.26	126.63	134.38	146.42	146.56	98.86	88.07
$I_{sol,H}$	50.93	81.02	136.57	199.07	250.00	277.78	289.35	234.95	174.77	115.74	61.34	47.45

* Mean external temperature referred to heating period on April (from 1st to 15th) and on October (from 15th to 31th)

The monthly method uses standard climate data, defined by local standards. For the case study, the climate data are reported in Italian Standard, UNI 10349. This Standard collects the monthly average of the external temperature, solar radiation on different planes (horizontal and other vertical expositions), relative humidity and vapour pressure of all Italian regional capitals. In addition, the Standard provides the methodology to calculate the weather data for all municipalities.

Table 5 shows the climate data used for the case study for the monthly method.

The application of the hourly and the detailed method requires more accurate climate data with hourly steps. The climate data, provided by CTI (Italian Thermotechnical Committee), referring to a 4-year monitoring period and processed according to CEN standard, EN ISO 15927-4, were used for this purpose. Table 6 shows the lower, the average and the higher values of the external temperature and solar irradiance on a horizontal plane relative to the heating period. The solar irradiance on sloped and directed surfaces is calculated according to the methodology described by Duffie & Beckman, 2006.

Table 6. Value of external temperature (°C) and solar irradiance on a horizontal plane (W/m^2)

	θ_e (°C)	$I_{sol,H}$ (W/m^2)
Min	-4.9	0.0
Avg	7.5	87.4
Max	21.3	854.0

For the application of the measured method, the real climate data detected by the weather station of Modena Urban[1] are used. The hourly data are then processed and aggregated in weekly data for the application of the Energy Signature. The figure 5 shows the trend of the daily and weekly average temperature detected from 15th October 2010 to 15th April 2011.

User's Behaviour

The occupancy profile is the main difference between the standard and the tailored method. Consumptions can be carefully estimated thanks to a collection of data containing the different detected behaviours. In particular, the management of the plant (set-point temperature and user profiles), the air exchange, the management of mobile shields and shutters, and the profile of occupancy all help determine the conditioning period.

Internal Gains

The simulation of the internal gains and the user's behaviour is managed differently in the described calculation methods: the monthly and hourly methods refer to the standard schedule of heat flow for metabolic rates from occupants and dissipated heat from devices

[1] Weather station Arpa Emilia Romagna (Agenzia Regionale per la Prevenzione e l´Ambiente dell´Emilia-Romagna - Regional Agency for Environmental Protection and Prevention in the Emilia-Romagna Region, Italy.

(Haldi & Robinson, 2011), defined at national level. The dynamic method allows the hourly profiles reflecting the real conditions to be define. In the measured method, the knowledge of the user's behaviour allows certain anomalies in the evaluation of consumption data to be left out and provides useful information on how to reduce consumption, optimizing the users' management of the internal loads.

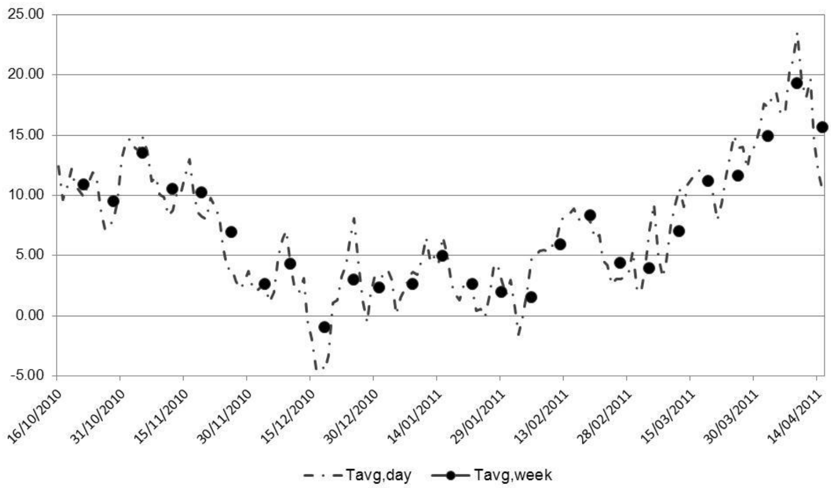


Figure 5. Daily and weekly average temperature trend.

The monthly method, described by Italian standard, UNI TS 11300-1 was used for the application to the case study. In particular, for residential buildings, the internal gains (metabolic rates and devices) are parameterized as a function of the conditioned floor area, A_f. In order to apply the hourly method and dynamic simulation, standard use profiles are used. These are divided in time steps, working days (from Monday to Friday) and weekends (Saturday and Sunday), depending on the thermal zone (Table 7).

Table 7. Hourly profile of use, residential buildings

	Hours	Living room plus kitchen [W/m^2]	Other conditioned areas [W/m^2]
Monday to Friday	07.00 to 17.00	8.0	1.0
	17.00 to 23.00	20.0	1.0
	23.00 to 07.00	2.0	6.0
	Average	9.0	2.67
Saturday and Sunday	07.00 to 17.00	8.0	2.0
	17.00 to 23.00	20.0	4.0
	23.00 to 07.00	2.0	6.0
	Average	9.0	3.0
Average		9.0	3.0

Source EN ISO 13790.

Shutter Management

The effect of the shutters consists of an increase of the thermal resistance of the transparent component.

Both the monthly and the hourly methods, described in International Standard, EN ISO 13790, estimate this contribution in terms of a correction factor, f_{shut}, defined as the dimensionless fraction of the accumulated temperature difference of the period with shutter closed. In the monthly method, according to the Italian Standard, a value equal to 0.60 is assumed.

In order to define the correct use profile of the shutter, the hourly method and dynamic simulation require an accurate evaluation of the thermal transmittance of the transparent elements, considering a value of f_{shut} equal to 1 in the case of the shutter completely closed and f_{shut} equal to 0 in the event of the shutter completely open. The average value used is equal to 0.36.

Mobile Shields Management

The effect of a mobile shield, such as drapes, is a reduction of solar radiation on a transparent component. The mobile shield management optimizes the utilization of solar gains through the transparent components, maximizing them during the winter and minimizing them in the summer. In the standard evaluation, only the effect of a permanent shield is taken into account. The permanent shields are integrated into the building envelope and are not freely assembled and disassembled by the user. In the tailored method, instead, all mobile shields are considered. On a reference level, the management of these systems is considered through the use of a reduction gains factor, $f_{sh,gl}$, which allows the solar factor, g_{gl}, of the transparent component to be reduced. In the case of the hourly and dynamic simulation the profiles listed in Table 8 are considered.

Table 8. Hourly profile of use, residential buildings

	Profile	*Living room plus kitchen [hours]*	*Other conditioned areas [hours]*
Monday to Friday	open	07.00 to 22.00	07.00 to 08.00
Saturday and Sunday	open	08.00 to 22.00	08.00 to 12.00

Source EN ISO 13790.

Intermittent Heating

The internal temperature of the conditioned space is a fundamental factor that strongly influences the energy consumption of the building. The possibility of adjusting the conditioning temperature, in fact, allows the users to set a different indoor temperature respect to that provided by the reference values defined in local regulations (for example, in a residential building the winter set-point temperature is 20°C), which leads to an increase in both energy consumption and thermal losses.

In the case study, the operating mode of the heating system is considered intermittent. A daily time not exceeding 14 hours has been considered for the switch-on of the heating generator with a set point temperature equal to 20°C, according to the standards in force.

The profile of the indoor average temperature is assessed according to the evaluation of the indoor conditions described in EN ISO 13790, which describes the criteria to be used for the following heating and cooling modes:

- Continuous or quasi-continuous heating and/or cooling at constant set-point;
- Night-time and/or weekend reduced set-point or switch-off;
- Unoccupied periods (e.g., holidays);
- Complicated situations, such as periods with boost modes, with (optionally) a maximum heating or cooling power during the boost period.

The mode that best approximates the behaviour of a residential building is the second one, “night-time and/or weekend reduced set-point or switch-off”. The standard provides the following two sub-cases:

- **Mode 1**

If the set-point temperature variations between normal heating or cooling and reduced heating or cooling periods are less than 3 K, and/or if the time constant of the building is less than x 0.2 the duration of the shortest reduced heating period, the set-point temperature for the calculation is the time average of the set-point temperatures (figure 6), where:

- ✓ θ_{set} is the set-point temperature for the calculation;
- ✓ $\theta_{set,inp}$ is the set-point temperature provided as input;
- ✓ t_{att} represents the duration of the shortest period of attenuation of the plant;
- ✓ is the time constant;
- ✓ Δθ temperature is the temperature variation between normal heating or cooling and reduced heating.

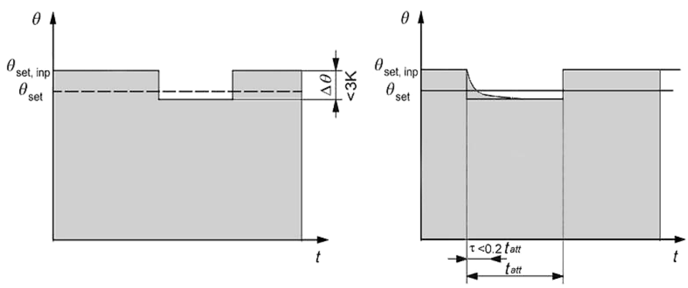
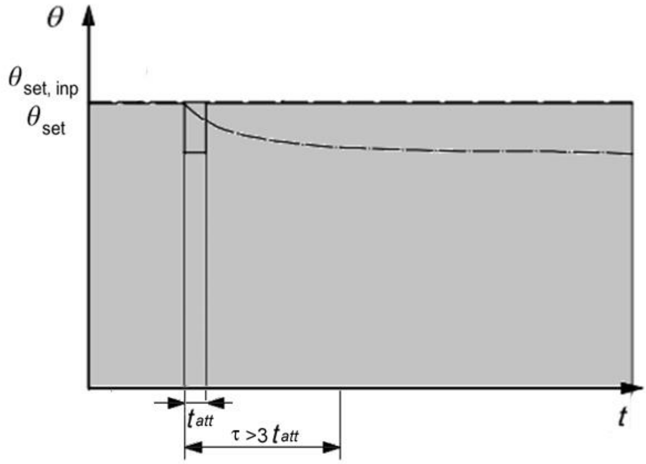


Figure 6. Mode 1: intermittent heating - Source EN ISO 13790.

- **Mode 2**

If the time constant of the building is greater than three times the duration of the longest reduced heating period, the set-point temperature has to be used (figure 7).



Source: EN ISO 13790.

Figure 7. Mode 2: Intermittent heating.

The building case study falls within the second Mode. In fact, the time constant of the building is about 77 hours, three times greater than the reduced heating period equal to 24 hours (a daily operation of the heating system is assumed), so the set point temperature is equal to 20°C.

CALCULATED METHODS RESULTS

In this chapter the results obtained with the application of calculated methods to the case study are presented and compared. One of the first important differences between the analysed calculation methods is the definition of the heating season. In Italy, the DPR 412/93 defines the heating period for the different climatic zones (see table 9).

Table 9. Heating plant switch-on period

	Degree Days	Period
Zone A	> 600	1st dec - 15th mar
Zone B	601 < DD < 900	1st dec - 31th mar
Zone C	901 < DD <1400	15th nov - 31th mar
Zone D	1401 < DD < 2100	1st nov - 15th apr
Zone E	2101< DD < 3000	15th oct - 15th apr
Zone F	DD > 3001	5th oct - 22th apr

However, the analysis of climate data shows that the heating period does not always comply with the provisions of this Decree. The International Standard, EN ISO 13790:2008 describes the procedures for defining heating days for each calculation method.

In the monthly method, the heating season depends on the ratio between thermal gains, Q_{gn}, and thermal losses, Q_{ls}.

The middle months (especially March-April and October-November) merit special attention because the thermal system may only have to be ignited for few days at a time. In these months, the heating season is determined by appropriate factors, lower than one, defined as a function of the ratio between the energy need for heating or as a function of the monthly ratio between heat gains and thermal losses.

In the hourly and detailed methods, the activation of the heating system is evaluated each hour, so in the same day there will be heating mode hours and switch-off mode hours, also as a function of envelope inertia.

Figure 8 shows the trend of average monthly (black line) and average hourly (dot line) temperatures, aggregated into daily averages, used respectively by the monthly and the hourly methods.

The monthly method assumes an ascending monotonic trend in the period from January to July and a descending monotonic from July to December. However, in the hourly methods, the daily variation of the temperature causes the activation of the heating system also in the middle "warmer" months.

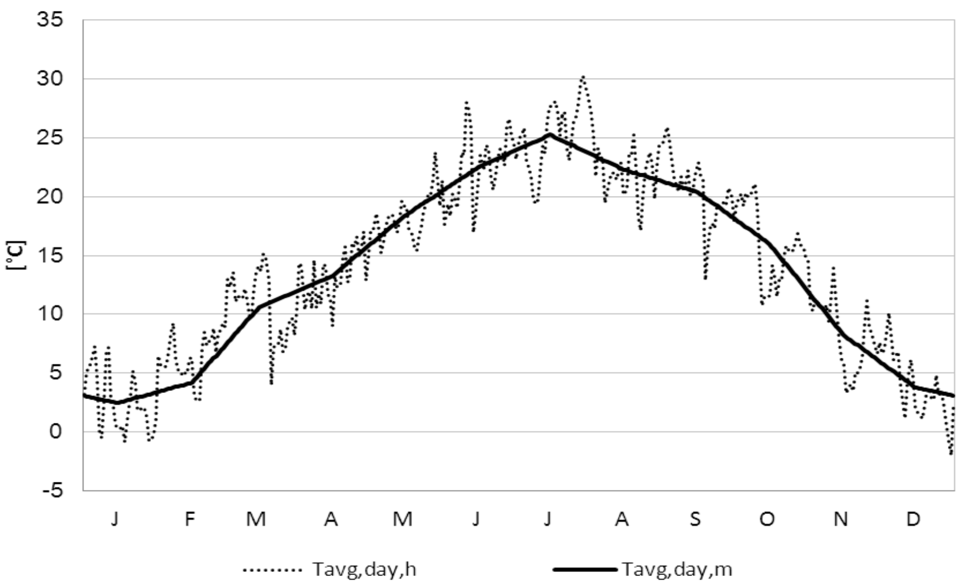


Figure 8. External temperature trend.

Table 10 reports the heating day calculated with the monthly and the hourly/detailed methods.

In April and October the methods present differences due to the climate profiles. The monthly method considers a continuous trend of climate variables without hourly differences, consequently, every single day can be in heating mode or not. The hourly and the detailed methods consider the hourly weather data and the effect of thermal inertia.

Table 10. Heating season

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hourly/detailed	31	28	31	27	0	0	0	0	0	19	30	31
Monthly	31	28	31	24	0	0	0	0	0	18	30	31

Figure 9 shows the monthly values of the net energy requirements for heating obtained through the hourly, monthly and detailed calculation methods. The detailed and the hourly results have been aggregated in order to compare them with those obtained with the monthly method.

The hourly and the monthly methods refer to the methodologies described in the International Standard, EN ISO 13790:2008, for the application of the detailed method the DesignBuilder© tool has been used.

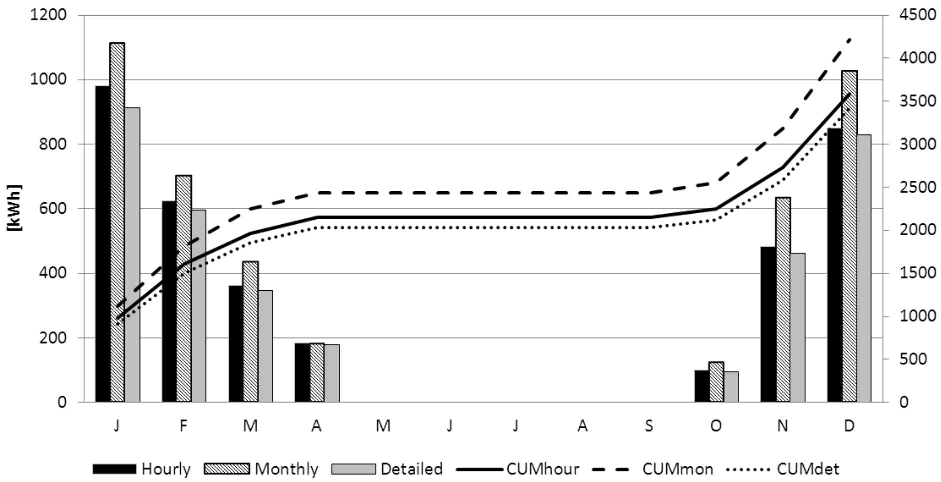


Figure 9. Net energy requirements.

The results of the different methods are coherent with the initial assumptions. The monthly method, using a "simplified" methodology, provides higher values of energy requirements.

The overall percentage difference between monthly and detailed simulation is about 21%. The hourly method, instead, gives results close to the detailed method with a difference of 6%. The total requirement of net energy for heating obtained with the monthly method is about 4214 kWh, is about 3586 kWh with the hourly approach and about 3416 kWh with the detailed method.

Application of the Energy Signature

Local climate data collection and weekly average consumption detection allow the Energy Signature method to be applied to the building as a pre-diagnosis tool aimed at evaluating the energy behaviour of buildings. The overall energy consumption of the building is equal to 3328 kWh, only for the heating mode.

The first step for the utilization of the method is the definition of the reference curve, known as Design Energy Signature, with which the weekly detections can be compared, defined as a function of the overall heat transfer coefficient of the building, H_{tot}.

Figure 10 shows the typical trend of the winter Energy Signature, where energy consumptions decrease as the temperature increases. In the same figure the detection consumption are shown.

The analysis of the Energy Signature of the building case study first of all highlights an oversizing of the heating plant. The average delivered power at θ_{ext} = -5°C is in fact equal to 2.25 kWt much lower than the maximum power of the installed heat generator, equal to 18 kWt, and the minimum modulation power, equal to 3 kWt.

Secondly, the distribution of energy consumption shows that the minimum switch-on temperature is equal to 17.3°C, represented by the intersection of the Energy Signature with X-axis. This value falls within with the typical range of residential buildings, corresponding to 16-18°C.

Theoretically, we would expect a lower value of switch-on temperature, less than 16°C due to the high thermal performances of the building envelope (with a high level of insulation of both opaque and transparent elements. However, the detected experimental value has a relative significance, considering that the Energy Signature is applied to one single apartment during its first operating year. In addition, the fact that the dwelling is equipped with a high inertia emission system (radiant panels) makes it possible for any user to turn up the heating system, aware that a relatively long period is required to bring the floor screed to the desired temperature.

Finally, looking at the trend of detected consumption, the distribution under 5°C deviates from the linearity of the Design Energy Signature.

The specific localization of these data could be due to a non-optimal setting of the regulation system or to the solar radiation at cold temperatures. A specific diagnosis could be carried out to deal with this aspect.

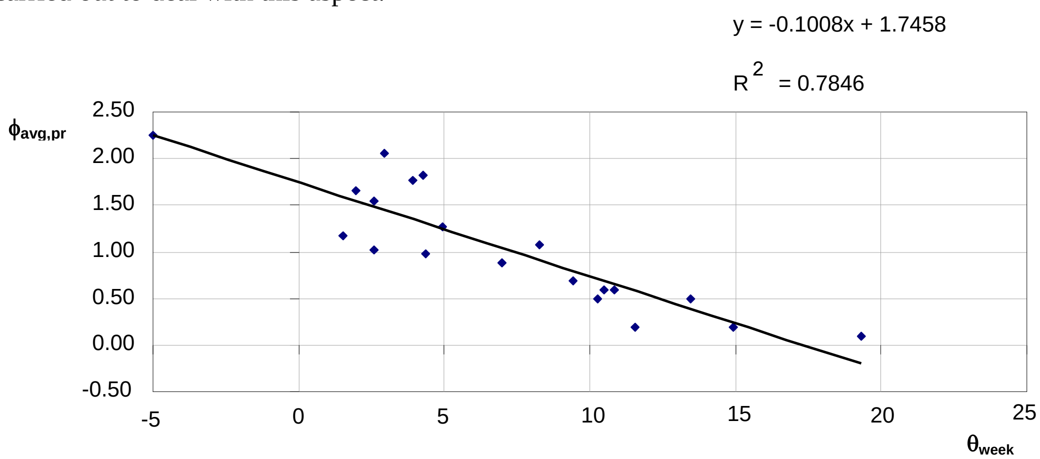


Figure 10. Energy Signature.

CONCLUSION

The European Standard, EN 15603:2008 defines two types of assessment approaches for the definition of the energy performances of buildings, the calculated method and the measured method. In this treatment both methods have been analysed in order to evaluate the differences between them and to identify the specific goal and scope.

The analysis of the different calculation methods, described by the International Standard, EN ISO 13790:2008, monthly, hourly and detailed, highlights how the assessment of the thermal performances of buildings requires a thorough knowledge not only of the thermo-physical characteristics of the building-plant-system but also of the user's behaviour profile. This latter aspect determines an important fluctuation of the results among the different methodologies. Each method requires a specific evaluation for the several variables linked to the user's behaviour to define the best value to be attributed. Thus, a background analysis on these variables has been conducted to align the final result to the real conditions.

The application of the described methodologies to a case study has shown a difference in the final results between both the calculated method and the measured ones. The percentage difference among the methods is higher for the monthly method by about 26% and decreases for the hourly and the detailed method - respectively, about 7% and 3%. These values are a result of different causes: simulation weather data not completely compliable with the real data, differences in use profiles, etc.

The results show how hourly and detailed methods allow the user's behaviour to be approximated better unlike the monthly method that considers average data. Only the application of the measured method, however, allows a real energy diagnosis to be realized. Moreover, the simplicity of the method of the Energy Signature allows the users to monitor their energy consumption, in order to improve the thermal management of the building and allows the professionals to evaluate the retrofits.

The future challenges of assessment methods could be to resort to new ways of designing a building using Decision Support System tools (DSS) which could manage all the necessary information and establish assessment criteria to evaluate and obtain feedback of the high-performance envelope in terms of: comfort, primary energy saving, CO_2 emissions, LCA analysis, retrofitting analysis.

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Chapter 4

ENERGY USE IN AGRICULTURE: ARGENTINA COMPARED WITH OTHER COUNTRIES

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ABSTRACT

This article shows that both the energy performance and the greenhouse gases emissions of agriculture, which are closely linked, suffered a significant worldwide change during the last five decades. Despite differences in estimation methods, the reviewed articles showed that energy-use intensity and energy-use efficiency of developing and developed countries radically differed. In the case of Argentina, agriculture expanded at the expense of natural forests and rangelands; but, at the same time, the energy productivity per hectare increased as a consequence of the increasing use of energy-depending inputs and the introduction of modern management practices. Although the consumption of fossil energy increased, there was a noticeable improvement of its efficiency. Results show that 0.91, 0.62 and 0.56 GJ were used in average to get 1 GJ of product during the decades of 1960, 1980 and 2000, respectively. Together with land use change, the increasing use of fossil energy by agriculture in Argentina during that period represented an increase in GHG emissions from around 0.98 to 2.44 Mg of CO_2-eq per hectare. However, the energy use intensity of the Argentine agriculture is still considerably lower (9.00 GJ ha^{-1} $year^{-1}$), and its energy use efficiency higher (0.56 Gj GJ^{-1}) in comparison with figures (>100.00 GJ ha^{-1} $year^{-1}$ and >1.00 Gj GJ^{-1}, respectively) provided by countries producing under more intensive schemes. Although it is unlikely that these differences can decisively affect the current figures of GHG emissions at the global scale, the evidence shows that Argentina and other middle-income countries pursued (perhaps unintentionally) a technological trajectory that enabled a

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minimization of GHG emissions per unit of food-energy production. Beyond speculations, this fact seems to be relevant in a world that will increasingly be threatened by the expanding food demand of a growing human population.

Keywords: Energy-intensity, energy use efficiency, GHG emissions, high- and mid-income countries

INTRODUCTION

One of the most important questions for human well-being in the planet is to elucidate if agricultural production can keep the pace with population and food demand growth. As a result of intensification, agriculture has showed an impressive gain in crop yields and agricultural output during the last 50-60 years. Cereal production has more than tripled during such period and output of major food crops is today two and a half times higher than in 1950. The average food availability has risen from 2400 to around 2800 calories per capita per day over the past five decades. Many constraints had to be overcome to reach these figures, especially those related to resource availability, ecological, financial and technological issues (Naylor, 1996).

The intensification process started first in the developed economies. Farmers in these countries abandoned traditional agronomic practices and adopted production methods that provided high returns per hour of labour, such as large monocultures, which relied heavily on fossil-fuel-dependent inputs. Most developed societies now use 7 to 8 units of fossil fuel energy for each food energy unit consumed (Leach, 1975). The amount of corn produced per hour of labour in USA is today 350 times higher than that of traditional agricultural systems, and this jump would not have been possible without large injections of fossil energy and machine power (Pimentel and Giampietro, 1993). In the middle of this revolution, scientists, technicians, environmentalists, policy makers, the mass media, and even the general public, claimed that the benefits from agricultural intensification had come at the cost of increasing the use of fossil-energy dependent inputs (seeds, fertilizers, pesticides, machinery) as well as the depletion of natural resource stocks. As a result of this intensification process, fertilizers were used to replace land, machinery to replace labour, herbicides to replace mechanical weed control practices and irrigation to replace rain-fed cropping (Ruttan, 1995). Because of the increasing amount of questions regarding these concerning issues, energy studies were emphasised, and they were particularly boosted by the 1973 oil embargo and the following increased price of fossil fuels.

Solar energy alone is not sufficient for food production; other energy inputs are necessary. In a classic work, Odum (1967) drew attention to the increased substitution of solar energy by fossil-fuel energy in high-yielding agriculture. He frequently made reference to symbolic phrases such as “prehistoric photosynthesis is subsidizing current photosynthesis” and “man is eating potatoes indirectly made from oil”. Likewise, various authors showed declining returns to inputs of energy after a certain point of agricultural intensification (Grigg, 1993). Given that energy was considered a limiting constraint on agricultural productivity, the food systems as a whole was considered vulnerable to the fuel availability and price volatility of fossil fuel-demanding inputs (Leach, 1975). Then, a clear distinction was established between low- and high-input agricultural systems (Pimentel et al., 1973).

In this chapter we present a range of data relevant to describe and compare energy issues between Argentina and other countries, by focussing on the total energy used in agricultural production, and how this relates to other cardinal factor: greenhouse gases (GHG) emission. GHG emissions and energy consumption in agricultural production are closely linked (Schneider and Smith, 2009), but emissions from land-use change (e.g., deforestation to convert natural lands into croplands) complicate estimations and foul this relation (Cowie et al., 2007). The patterns of CO_2 emissions depend strongly on the specific mix of utilized energy sources (Alcántara and Roca, 1995), and this may differ from one region or country to another.

In a complex world with specialized food systems, agricultural commodities are processed into food, livestock feed, fibre and energy. Thus, due to the interdependent industries across countries and intensive international trade, GHG emissions may vary strongly from one chain to another, and generally a trans-boundary analysis is needed to elucidate the carbon footprint of individual commercialized foods (Schneider and Kumar, 2008).

A Short History of Agriculture in Argentina

Argentina is one of the six major crop production areas of the world, being N America, W Europe, Ukraine (Russia), China and Australia the others. During its first 200 years of colonization, European settlers occupied a narrow strip of land over no more than 100 km surrounding the city of Buenos Aires. Livestock raising began in the Argentine Pampas during the 17th century, but this activity did not become important until the middle of the 18th century, Grain and vegetable farming developed merely for supplying Buenos Aires, Montevideo and Córdoba (Solbrig and Viglizzo, 1999).

The increasing demand of salted meat, leather and hides led to the gradual expansion of cattle raising during the early 19th century. Because of the spreading conflicts between settlers and native tribes that lasted 80 years, in 1879 the Argentine army removed all native encampments and opened the entire Pampas region to settler occupation. Simultaneously, the increasing demand of wheat from European countries encouraged the expansion of agriculture, being particularly rapid between 1885 and 1914 (Gallo and Cortés Conde, 1987). After a rather long stagnation period, agriculture expanded again from 1960 and, in the meantime, the cattle herd grew until 1978 and then showed a slight decrease. Since the 1960s, as an intensive model of agriculture expanded across industrialized countries (Tilman et al., 2002), low-input, rotational cattle-crop production schemes prevailed in the Argentine Pampas (Solbrig, 1997). Given that the use of inputs such as fertilizers, pesticides, concentrated feeds and machinery was slowly but persistently increasing, the Argentine Pampas represented a large scale, long-term experiment in low input farming.

Until the early 1980s, crop and livestock production in the Pampas increased through the expansion on natural lands, but once this possibility was exhausted, additional increases were achieved through more intensive use of external inputs, technology and management (Viglizzo et al., 2001). Statistical figures in the Pampas unequivocally show that croplands expanded at the expense of grazing lands during the last 40 years (Figure 1).

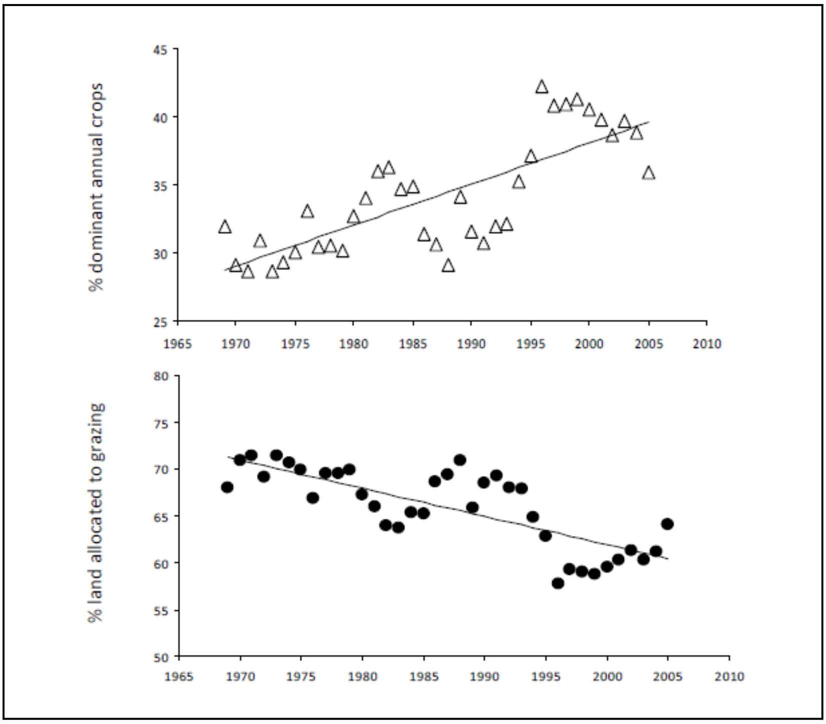

Figure 1. Historical replacement of grazing lands by croplands in the Argentine Pampas during the period 1969-2005. Source: SIIA, 2013.

At the same time, the area dedicated to soybean cultivation increased steeply and steadily at the expense of the area allocated to other traditional crops, such as wheat and corn (Figure 2). The private sector was very successful in increasing the agricultural output. Crop yields increased during such period (particularly in the case of corn) due to the increasing use of machinery and inputs (fertilizers and pesticides), the massive incorporation of genetically improved varieties and the application of modern agronomic practices such as no-till and conservation tillage methods (Figure 3).

The production model of the Pampas later expanded over a vast lands of central and NW Argentina that were dominated by natural (mostly woody) vegetation (Carreño & Viglizzo, 2007). Public research and technological organizations (like INTA, CONICET and some Universities) were strongly linked to that changing process. Besides, progressive farmers associated in groups called CREA contributed to such change by conducting their own field experiments to find ways to improve their productivity. Productivity grew across the whole cultivated land, and the process was mediated by an increasing use of capital. The rural labour force steadily declined as labour-saving machinery replaced the human work and increased labour productivity. Farmers having an extra farm machinery capacity rented land on the basis of one-year contracts, or directly offered farming operations (sowing, spraying, harvesting) as a service to other farmers. Another contract arrangements were the so-called “pools de siembra”, which consisted of capital funds provided by private investors (not necessarily coming from de rural sector) that rented land to produce grains on the basis of large-scale operations. Those funds paid for expert advice, contracted machinery and reaped savings though bulk purchase of inputs. This new arrangement contributed even more to the decrease of the rural working force in highly productive cropland areas (Solbrig and Viglizzo, 1999).

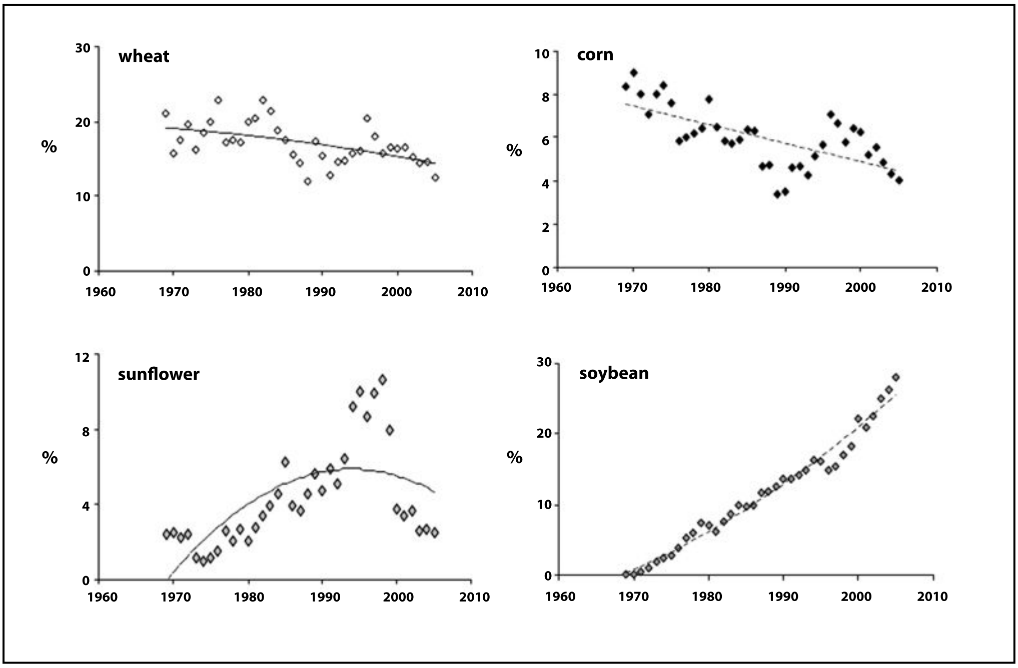

Figure 2. Historical replacement of traditional crops (wheat and corn) by soybean and sunflower in already cultivated lands of Argentine Pampas during the period 1969-2005. Source: SIIA, 2013.

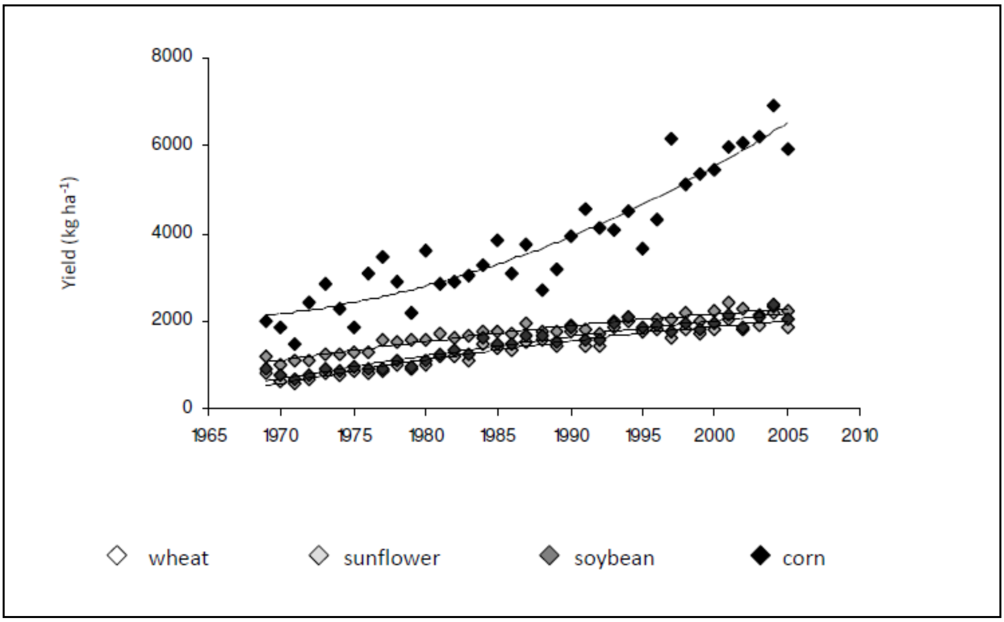

Figure 3. Yield change of four dominant crops in cultivated lands of the Argentine Pampas during the period 1969-2005. Source: SIIA, 2013.

Those novel production models were severely questioned because soil erosion and nutrient depletion continued and aggravated, and the inappropriate and increasing use of pesticides affected habitats and wildlife. In most areas, the growing productivity of land was in part supported by an over-extraction of soil nutrients, which were not balanced by means of proper fertilization schemes.

LAND TRANSFORMATION, ENERGY USE AND GHG EMISSIONS IN ARGENTINA

Once the expansion on natural lands in the Argentine Pampas was exhausted, the increasing productivity was achieved through a more intensive use of external inputs and farming operations. A consistent increase in the consumption of fossil energy per hectare was the inevitable consequence of this shift in the traditional agricultural model.

Setting aside methodological issues regarding land-use dynamics, reported results of investigations (Viglizzo et al., 2002; 2011) showed that the fossil-energy consumption per unit of energy output has been persistently declining especially in the Pampas. This may be due to the increasing use of no-till methods and the increasing transformation of land traditionally dedicated to livestock raising to crop agriculture. Historical figures on land-use/land-cover change and the estimated energy balance between 1960 and 2010 can be appreciated in Table 1. It should be noted that the consumption rate of fossil energy was in Argentina significantly lower than those achieved in other countries that showed more intensive agricultural schemes.

Table 1. Land use change and energy efficiency in agricultural lands of Argentina during the period 1960-2010. Source: Viglizzo et al., 2011)

Period	Percentage of land use*			Energy balance (GJ ha^{-1} $year^{-1}$)		
	Cropland	Grassland/ Pasture	Woodl and	Fossil Energy Input	Energy Output	Input/ Output
1960-70	14.06	60.78	22.43	5.00	5.50	0.91
1980-90	14.77	60.85	21.78	6.60	10.70	0.62
2000-10	21.12	55.08	21.20	9.00	15.90	0.57

* Estimations based on potentially cultivable land in Argentina (around 65% of total territory)

The comparison of global agricultural data (RAEC, 2009) shows that, on average, Argentina consumes less fertilizer than countries of Western Europe, North America and Latin America, but more than countries of Eastern Europe and Africa (Table 2). On the other hand, and setting aside the high W European figures, the Argentine agriculture shows relatively high consumption rates of herbicides and insecticides in relation to other countries.

Agriculture is an important source of GHG emissions, especially when natural forests and grasslands are converted to grazing lands or croplands. The greatest emission rates occur in NW Argentina, where an intense deforestation and de-vegetation has been taking place during the last two decades. Estimation of GHG emissions in Argentina may differ according to the methods applied. Certainly, the way by which land-use/land-cover change is computed in calculations may render different GHG emission results. All sources of carbon gain and loss were computed in our last research investigations (Viglizzo et al., 2011).

Table 2. Application rate of fossil inputs in Argentina and other regions of the world*

	Rate of application (kg ha^{-1} year^{-1}) for wheat production			
	N fertilizer	P fertilizer	Herbicides	Insecticides
Argentina	35.06	22.96	0.32	0.07
Western Europe	120.00	32.84	0.69	0.22
North America	49.88	25.93	0.34	0.05
Latin America	94.54	48.89	0.23	0.18
Middle East	64.69	54.57	0.01	0.01
Asia	40.74	26.91	0.07	0.03
Eastern Europe	29.13	7.41	0.54	0.08
Africa	25.43	31.11	0.01	0.01

* Figures are the average of various countries. Source: RAEC, 2009.

METHODOLOGICAL ISSUES

The quality of estimations in energy analyses varies widely. Tracing all the direct and indirect energy inputs and outputs, and their relationships, in a crop or an agricultural production system is a complex and highly demanding task. Some approximations are inevitable, and some researchers are more approximate to rigorous figures than others. So, precise comparisons are not always possible.

In simple terms, energy analysis is a method for quantifying the energy inputs required to produce a given amount of a good or service (Brown and Herendeen, 1996). Energy use in agriculture may be divided into two categories. The first is direct energy use, for example, energy inputs of fuels to power agricultural machinery at the field level. The second is indirect energy use, that corresponds to the cumulative energy required in upstream processes associated with the manufacturing and delivery of different agricultural inputs (Pelletier et al., 2011). For example, the analysis of a tractor ploughing a field includes the gross heat content of the fuel directly consumed in a traction activity, and the sum of all fuels required in oil exploration, extraction, shipping, refining, delivery to the farm etc. It also includes the energy used to provide all materials for and to build the machinery and the energy required for manufacturing the tractor, for repairs and spares, lubricating oils, etc. In many cases the total indirect energy inputs exceed the direct ones. Normally, research methods include (i) the use of statistical sources for direct energy inputs purchased by farms and factories, (ii) a detailed process analyses for major commodities such as fertilisers and tractors, and (iii) the use of national input-output tables for estimating the energy equivalents of purchases such as water, machinery, building materials, construction services, transportation, etc. A set of uniform energy conversion factors (default figures) applicable across countries (e.g., FAO factors) can be used to compensate lacking data. In all estimations it is important to distinguish between renewable (hydro, solar, biomass) and non-renewable (mainly fossil) energy sources.

Energy analysis is commonly reported as input and outputs per-hectare values, or as per unit (kg, MJ) of food output. Alternatively, it can be referred to the energy relationship between inputs and outputs as an expression of energy use efficiency. It is noticeable that a high-input agricultural system with high yields can show relatively low energy efficiency, and a low-input system with low yields can eventually show high energy efficiency.

In this chapter, calculation of fossil energy consumption (Mj ha^{-1} $year^{-1}$) for Argentine farms in the Pampas region was focused on the principal inputs (fertilizers, seeds, concentrates, pesticides) and practices such as tillage, planting, weeding, harvesting, etc. applied at the farm level (Viglizzo et al., 2006). The fossil energy cost of inputs and practices were obtained from a variety of peer-reviewed literature sources, and although it was not possible to check in detail the procedures used by those authors, we assumed that they provide reliable estimations. The fossil energy use efficiency was calculated by considering the amount of MJ of fossil energy used to get one MJ of product. Calculations were made on annual basis taking into account the proportional participation of each analyzed activity. Under this scheme, the larger the amount of fossil energy used to produce one unit of energy, the less efficient the production process was.

On the other hand, GHG emissions were estimated following a calculation model based on the standard guidelines of IPCC (2006). All gases were converted into CO_2 equivalent (Mg ha^{-1} $year^{-1}$). Calculations included emission and sequestration of carbon in response to land use change, grain cropping and cattle production activities. The use of fossil fuels is an important source of CO_2. The method included fuels used in rural activities and fuels used for manufacturing fertilizers, herbicides and machinery. Ruminants are also a significant source of GHG, since they emit methane from enteric fermentation and faecal losses. Methane has a greenhouse power that is 21 times greater than CO_2, so this figure was used to convert CH_4 into CO_2 equivalents.

Nitrogen excreted in faeces and distributed with fertilizers is another significant source of nitrous oxide (N_2O) emission, which has a greenhouse power 310 times greater than CO_2 (IPCC, 2006). Losses of N_2O occur via volatilization, leaching and runoff. Arable soils were also a direct source of greenhouse gases through fertilizers, biological N fixation and crop residues. When data from direct field measurements were unavailable, default values suggested by the IPCC were used for estimating gains and losses of carbon. In sum, the IPCC (2006) calculation method comprises: (1) CO_2 stock exchange in soils over time, (2) CO_2 stock exchange in timber biomass, (3) conversion of forests and prairies into arable land, (4) abandonment of intervened lands, and (5) emission of CO_2 from fossil fuels burning in different agricultural activities; CH_4 emissions from three sources: (1) enteric fermentation from domestic animals, (2) faecal emissions, and (3) rice crop emissions; and finally, emission of N_2O from: (1) faeces and urine from domestic animals, (2) volatilization, runoff and infiltration from synthetic fertilizers and animal excrements (urine and faeces), and (3) arable soils, through chemical fertilizers, biological N fixation and crop residues.

RESULTS AND DISCUSSION

Comparing the Energy Balance at the Country- and the Farm-Scale

The energy consumption patterns of agriculture have varied substantially from one country to another, and changes across time have also been different. The integration of data from different sources (Figure 4) allows us to appreciate that the level of energy consumption in countries of intensive production such as that of Denmark, France and USA is considerably higher (7-20 times) than that of countries of extensive production such as Argentina and India.

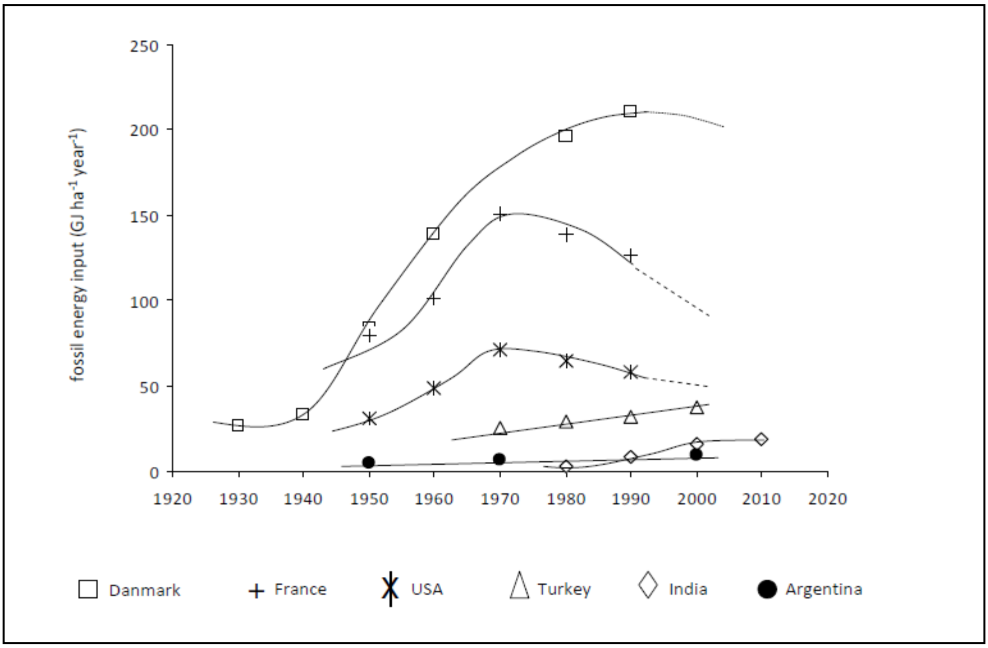

Figure 4. Energy input of agriculture (GJ ha^{-1} $year^{-1}$) across time in countries that differ in production intensity. Curves were estimated from data provided by different sources (Bonny, 1993; Schroll, 1994; Cleveland, 1995; Conforti and Giampietro, 1997; Oskan et al., 2004; Viglizzo et al., 2011, Jha et al., 2012; Frank, 2013). Dotted lines are the time projection of historical trends.

From the pioneer works on energy analysis mentioned in Figure 4, one can see agriculture has often been thought to be an increasingly heavy consumer of energy. Energy use of agriculture in industrialized countries tended to increase throughout the 20th century (Martin, 1991) and, as Pimentel et al. (1973) demonstrated, with the advent of the second agricultural revolution in the 1940s, agriculture became an increasingly heavy consumer of energy. However, the shape of energy consumption curves varies strongly between countries that differ in their levels of agricultural intensity. Despite the low production intensity of agriculture in Argentina, India and Turkey, these countries show a tendency to intensify their production schemes in the long term, and this fact would tend to confirm the assumption of a persistent increase predicted by pioneer studies.

However, data from different sources (Bonny, 1993; Schroll, 1994; Cleveland, 1995; Conforti & Giampietro, 1997; Oskan et al., 2004; Viglizzo et al., 2011; Jha et al., 2012; Frank, 2013) showed a decreasing trend in fossil energy consumption per ha since the 1970s in countries where intensive agricultural schemes had predominated during many decades, such as USA, Germany and France. Energy use falls occurred before in the UK and later in Denmark (Bonny, 1993). Thus, the long-term trend of curves describing energy intensity in developed countries are frequently bell shaped with the top of the curve on the 1960s or 1970s and a persistent decrease thereafter (Figure 4). The downward trend of energy consumption in the second part of the curve is generally attributed to the rise in oil prices during the 1970s oil crisis.

On the other hand, the energy-efficiency ratio (amount of fossil-energy GJ needed to get 1 GJ of agricultural product) can vary largely depending on total energy consumption and the relative participation of animal and plant products in the total output. Because of their higher position in the trophic pyramid, animals are generally less efficient than plants to convert fossil energy into energy products. Within crop plants, the high-yielding crops tend to show a more efficient performance than the low-yielding ones. In line with this, according to the levels of fossil-energy consumption and the relative participation of various farming activities in the total national figures, the agricultural sectors in different countries may differ substantially in their energy-efficiency ratio. A comparison of the number of GJ required to produce one GJ of agricultural product in Argentina and various countries differing in their economic income is displayed in Figure 5.

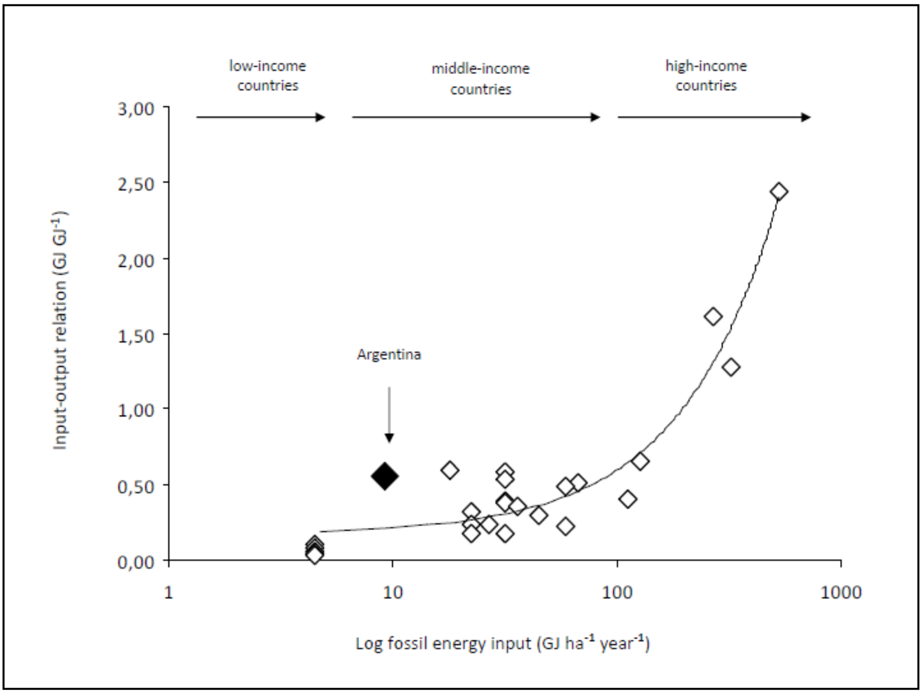

Figure 5. Number of Gj required to produce one Gj of product in argentine agriculture and countries that differ in the rate of fossil energy consumption. Note that the relative lower efficiency for fossil energy conversion occurs in high-income countries. Figures were estimated from Conforti and Giampietro (1997), Frank (2007), Carreño and Viglizzo (2010) and Viglizzo et al. (2011).

As expected, the high-income countries that consume more fossil energy show a less favorable ratio than low- and mid-income countries that consume from moderate to low levels of support-energy. Moreover, the ratio tends to worsen as the level of energy consumption in countries increases. It should be noted that despite being a middle-income country, in this comparison Argentina shows an advantageous position relative to other countries, which consume more GJ of fossil energy to get 1 GJ of agricultural product. A possible explanation for this apparent advantageous position is that agriculture in Argentina is still taking advantage of current high natural assets of soil nutrients, thus preventing a more intensive use of commercial fertilizers. This position may decline when the mineral assets of the soil degrade within a few years if the extraction continues at current rates.

Beyond these national-scale comparisons, and despite the notable lack of comparable data, a farm-scale comparison of the energy-efficiency ratio of production systems between countries may be quite illustrative to interpret differences. Results showing production system cases from UK (Leach, 1975) and Argentina (Frank, 2007), all of them producing some crops and some animal products, are presented in Figure 6. While data are displayed on the basis of the total acreage of the studied farms, UK farm-values are presented by means of white and those from Argentina through black symbols. It should be noted that the analyzed activities that integrated the production systems were more diverse and intensive in the case of UK. Both in Argentina and in the UK, the energy-efficiency ratio tended to improve as the proportion of annual crops increased in the analyzed production systems. As the proportion of total energy outputs accounted for by animal products rises from 2% (large cereal farms) to 93% (small specialist dairy farms), the energy ratio plummeted down almost tenfold in UK.

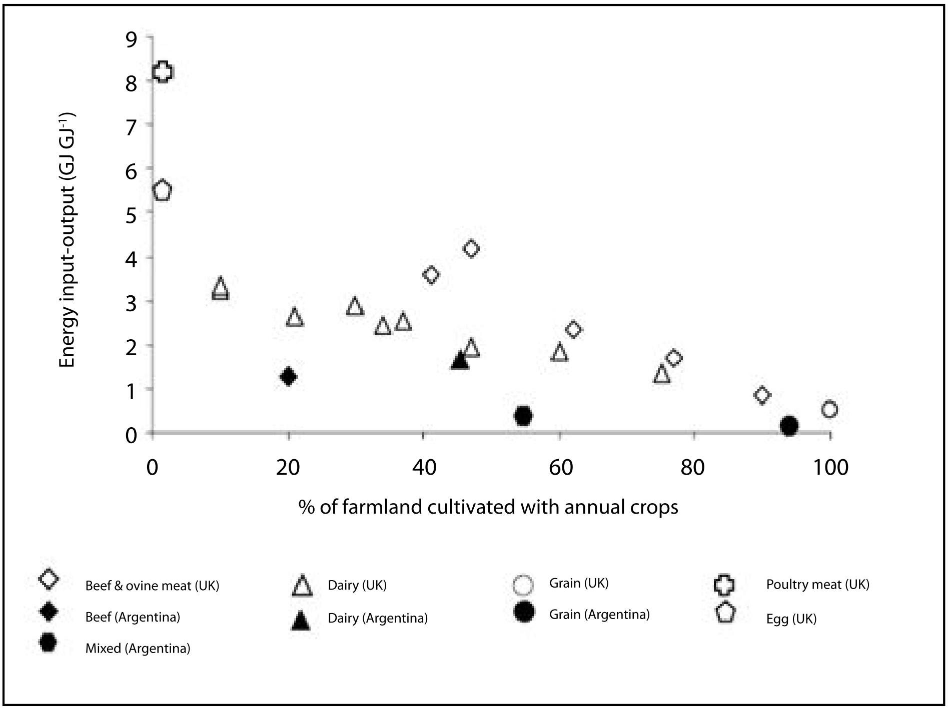

Figure 6. Number of Gj required for producing one Gj of product in different production systems of UK and Argentina. Figures were estimated for UK (Leach, 1975) and Argentina (Frank, 2007).

In general, the energy-efficiency levels tended to be significantly greater in Argentina than in the UK since less GJ of fossil energy were required to synthesize one GJ of agricultural product. Again in this case the differences could be explained by the greater mineral asset of soils in Argentina that prevent the use of fertilizers that demand large amount of fossil energy to be manufactured.

THE QUESTION OF GHG EMISSIONS

Historically, agriculture and land use changes related to agriculture have been a major source of GHG emissions. Although food production only represents a very small part of net carbon dioxide flux, it accounts for half of the anthropogenic methane and nitrous oxide emissions (Smith et al., 2008). During the 19th century, the rapid agricultural expansion led to a widespread clearing of land, losses of organic carbon in soils and increased use of fossil energy and inputs (Paustian et al., 1998). As long as agriculture remains dependent on fossil sources of energy, food production will be a significant contributor to anthropogenic GHG emissions. However, agriculture can also play a role in reducing emissions through a number of mitigating options (for instance, reducing fuel use and replacing fossil fuels with biofuels).

The quantification of GHG emissions from agriculture is fundamental to a number of purposes such as national planning for low-emissions development, generating and trading carbon credits, certifying sustainable agriculture practices, assessing product supply chains, and supporting farmers in adopting less carbon-intensive farming practices. However, estimations usually differ in their methods of estimation, level of certainty, scale of analysis, system boundaries and units of reference (e.g., per ha and per kg of product) thus complicating their comparability across systems and repeatability over time. Given that inter-countries comparisons can mislead interpretations, numerical data must be assigned a relatively high level of uncertainty.

Table 3. Estimation of GHG emissions per hectare

Country/region	Agricultural GHG emissions (Mg CO_2-eq ha^{-1} $year^{-1}$)
Mexico	1.03
Argentina	4.82
Peru	3.9
Brazil	7.10
Ecuador	7.16
Chile	8.73
Colombia	9.47
Total Latin America	6.04

Source: Vosti et al., 2011.

Values of GHG emissions from agriculture in Argentina have been reported to increase from 0.98 Mg CO_2-eq ha^{-1} $year^{-1}$ in the 1960s to around 2.44 in the beginning of the 21st century (Viglizzo et al., 2011). However, these figures are difficult to compare with emissions in other countries, since estimations are usually not referred to a land area unit. GHG emissions at the national level by sectors in most studies are expressed as total budgets (e.g., Houghton and Hackler, 2001; Smith et al., 2007b), and obtained by simply multiplying emission rates times number of ha or number of heads. Besides, the system boundaries are not always explicit, so it is impossible to refer values to a specific area in order to allow comparisons.

One example of comparisons among countries was indirectly obtained from Vosti et al. (2011). In order to address the effectiveness of mitigation policies, the authors modelled and compared emission changes in Latin America and the Caribbean in the period 2010-2030. By dividing national emissions by the corresponding agricultural areas, a great disparity among countries can be observed (Table 3).

Since there is no land use change involved (the evaluated policy was a complete agricultural land expansion ban), the values per ha are surprising. For example, it would be hard to explain why agriculture in Brazil emits almost ten times the amount of GHG than in Mexico.

On the contrary, there are a lot of studies that estimate GHG emissions of different crop and cattle productions, separately. For example, in Figure 7 a comparison between yield crops from Argentina and from other countries is shown. CO_2-eq emissions from winter (mostly wheat), summer (mostly maize) and rotational crops (different combinations of wheat, maize and soybean) in Argentina were substantially lower than the corresponding emissions from Canada, USA and Italy. Since these values are expressed by agricultural area (ha) and assume no land use change, it is not surprising that low-input agriculture in Argentina emits less GHG than in Europe and North America. Another thing to notice is the higher emission rates in summer crops compared to winter crops in international figures, possibly associated to more fossil energy consuming inputs. Nevertheless, these figures would probably show a different behaviour if soil C losses were considered and/or if results were expressed per kg of grain instead of per ha.

On the other hand, GHG emissions in cattle production are usually expressed as CO_2-eq per unit of product obtained (kg of carcass live weight or kg of energy corrected milk). Literature review showed that main cattle production systems in Argentina were not always less GHG emissive than reviewed values from around the world (Figure 8). First, beef extensive production systems (with limited or no supplementary food associated) were inside the range but little higher than values from South Africa (where very low input foraging systems predominate) and values from Ireland and England (where meat productivity is higher).

Lower emissions may be explained, in the first case, by a extremely extensive pastoral system (including nomadic foraging) and in the latter by greater meat productivities. Regarding intensive beef production (where at least half of the food is supplied besides foraging) GHG emissions per kg of meat product were higher than in extensive farms. Besides, values from Argentina were similar to the mean value found among fourteen cases, mostly from UK, USA, Japan and Sweden.

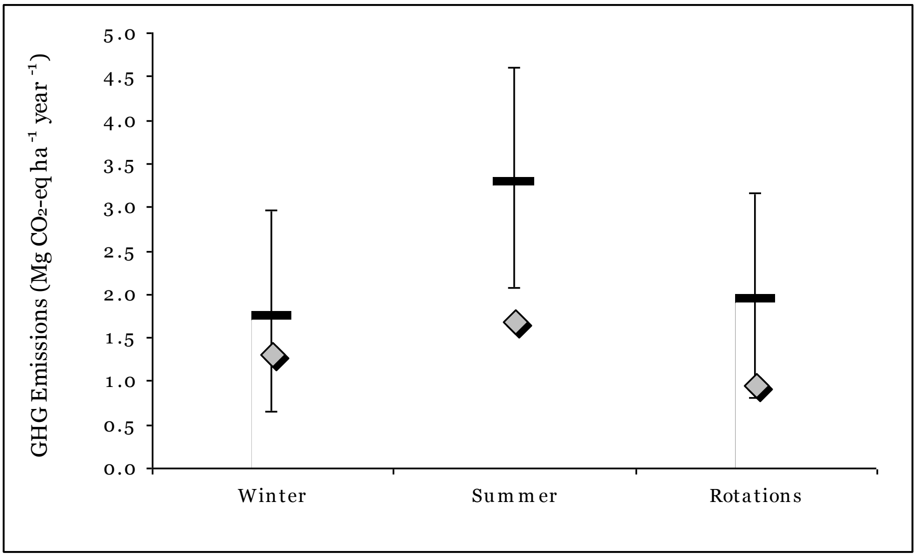

Figure 7. Comparison of GHG emissions in main crop systems in Argentina (grey diamonds) and other countries (black lines). Values for Argentina from Viglizzo et al. (2011) and Frank (2013). Values for other countries (mean+sd) for winter crops (n=5) from Khakbazan et al. (2009), Brandão et al. (2011) and Goglio et al. (2012). For summer crops (n=8) from Casey and Holden (2006), Meyer-Aurich et al. (2006), Adviento-Borbe et al. (2007), Goglio et al. (2012) and Pishgar-Komleh et al. (2012). Values for crop rotations (n=12) from Meyer-Aurich et al. (2006), Adviento-Borbe et al. (2007) and Snyder et al. (2009).

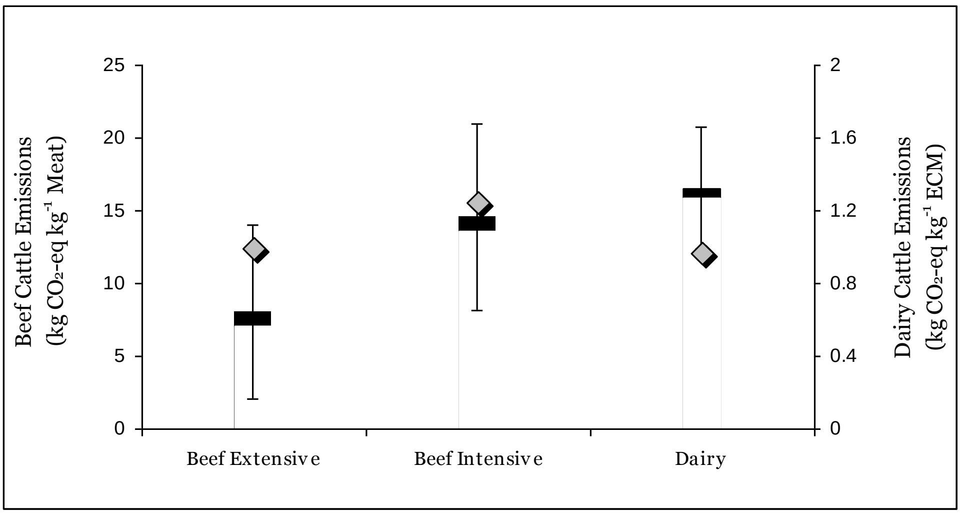

Figure 8. Comparison of GHG emissions in cattle production systems in Argentina (grey diamonds) and other countries (black lines). Values for Argentina from Viglizzo et al. (2011) and Frank (2013). Values for other countries (mean+sd) for extensive beef (n=4) from Subak (1999), Casey and Holden (2006) and Weiske and Michel (2007). Values for intensive beef (n=14) from Cederberg (2002), Ogino et al. (2004), Casey and Holden (2006), Adviento-Borbe et al. (2007), Weiske and Michel (2007) and Bonesmo et al. (2013). Values for dairy farms (n=18) from Haas et al. (2001), Schills et al. (2005), Casey and Holden (2006) Weiske and Michel (2007), Flysjö et al. (2011; 2012), Kristensen et al. (2011), Kythreotou et al. (2011) Bonesmo et al. (2013) and Mc Geough et al. (2012).

Greenhouse gasses emissions per kg of energy corrected milk (ECM) showed little variability according to level of inputs (extensive vs. intensive), production system (organic vs. conventional) and, of course, country of origin (Figure 8, secondary axis). Values from several European countries, Cyprus and New Zealand ranged from 0.9 to 1.6 Mg CO_2-eq kg^{-1} ECM, and the mean value for Argentina was not different. Apparently, in dairy farms, intensification does not indicate higher carbon emission, as it does happen in beef production. This fact gives an advantage to milk- compared to beef-production systems, since intensification does not necessaryly mean higher GHG emissions, and thus, higher carbon footprints.

The Unfinished Debate over Deforestation and Competition for Land

The statistical records and the scientific evidence show that Argentina has experienced a great change both in land use and land cover during the 20th century due to the expansion of the agricultural frontier. The core of the debate is that the expansion of the area assigned to genetically modified crops and bio-energy crops is achieved at the expense of the deforestation of natural lands in the North of the country.

The “productivist” view argues that land productivity of transformed natural lands increased rapidly during the last two decades in response to the massive adoption of the “first and second green revolution” technologies (Tilman et al., 2002). In response to this, environmentalist groups argue on the one hand that agriculture expansion is causing an irreversible damage to the natural environment. Based on the *Borlaug hypothesis*, “productivist” groups state on the other hand that the increased productivity associated with the widespread adoption of improved technology has saved natural systems from being converted to agriculture. Norman Borlaug, Nobel Prize and the “father or the Green Revolution”, claimed that the intensification of agriculture from 1950 to current days has saved hundreds of millions of hectares from being brought into agricultural exploitation.

A recent investigation (Stevenson et al., 2013) has demonstrated that the increased productivity of land due to agricultural innovations have saved over the world 18-27 million hectares between 1965 and 2004. Of this total area, between 12 and 17.7 million hectares would have been saved in developing countries, including Argentina, Brazil, Paraguay and Uruguay. However, the authors consider that Borlaug hypothesis is too simplistic to explain a highly complex process that involves land transformation. They concluded that the impact of technological change on land saving is likely to have a weak effect compared with the impact of other exogenous factors driving land-use change and deforestation. The issue of land-use policy and land governance seems to be crucially important at the moment. Given that there is still a large area of savannah and woodlands suited to crop production in Argentina, this combined response to technology and governance is particularly relevant for future land-use strategies. Beyond the well-proved impact of high-yielding technology, the recent experience with better governance and monitoring of the Argentine Chaco has shown a remarkable drop in rates of deforestation, even in spite of the commodity prices that have risen sharply in recent times (Viglizzo et al., 2012).

The current evidence suggests that trends in the rural sector of Argentina have been to increase the production of food from already cultivated land following a way of less pressure on the environment and natural resources. This idea is clearly aligned with the novel concept of "sustainable intensification" (Garnett el al., 2013) that aims at (i) increasing food production while preserving the resilience of the production system through technology incorporation (e.g., tillage, precision agriculture), (ii) boosting high yielding schemes on the already cultivated land area, and (iii) selecting only suitable land for food production avoiding the use of lands that would impose unacceptable environmental cost to society.

CONCLUSION: FACING THE CHALLENGE OF INCREASING ENERGY EFFICIENCY AND REDUCING GHG EMISSIONS

The rural sector in both developing and developed countries faces the pressing imperative of increasing food production minimizing at the same time the fossil energy consumption and the emission of GHG. In mid-income countries such as Argentina, energy consumption by the rural sector is still low, but persistently increased during the last 50 years. However, despite the large inter-country differences, the world averages show that the agricultural energy use increased until the 1980s and tended to decrease slightly thereafter. In practice, this does not imply global emission savings, because applied agricultural practices drastically differ among and within countries. Furthermore, to reduce GHG emissions, the associated strategies must become cost-efficient at the farm level, either through favouring market-price conditions or specific policies which, on the other hand, may deliver unpredictable synergies and tradeoffs (Smith et al., 2007a)

Like many other countries, Argentina can take advantage of the technical progress to improve the efficiency-use of most energy-dependent inputs. Nowadays, energy-saving strategies are well known and include, among other things, genetically improved plants and livestock to increase yield, to resist pests and diseases, and to improve drought tolerance, energy-efficient machinery and irrigation systems, reduced or zero tillage, improved input-use efficiency, agronomic practices to improve water management, and site-specific nutrient and pesticide application (Schneider and Smith, 2009).

Relying on market and political incentives, energy-saving strategies can be oriented to promote the use of renewable bio-energies in order to substitute or reduce the use of fossil fuels (van Beilen and Poirier 2007). Bio-energies can be promoted through the use of livestock manure, the cultivation of energy crops, the use of plant residues and other by-products from the farming-processing industry.

Reducing fossil energy consumption decreases CO_2 emissions. Many strategies that aim at reducing fossil fuels use have the simultaneous effect of reducing GHG emissions (Edwards et al., 1996). No-till practices, for example, have a double benefit: they minimize the number of tilling operations and, as a consequence, minimize the consumption of fossil fuels by machinery. But at the same time, they favour the accumulation of carbon as soil organic matter. Likewise, an improvement of manure handling in livestock production systems may reduce both energy consumption in operations and the emission of methane and nitrous oxide emissions (van der Meer, 2008). The substitution of nitrogen fertilizers through biological nitrogen fixation by legumes in crop or crop/livestock production systems means a considerable saving of fossil fuels and CO_2 emissions linked to artificial N-fertilizers manufactory (Ellert and Janzen, 2008).

Argentina needs to reduce greenhouse gas emissions from fossil energy use in agriculture in order to accomplish two national objectives: to guarantee its internal energy security and, despite being a low-emission country, to contribute to mitigate the global impact of climate change. Nowadays, the argentine rural sector has massively incorporated both agronomic practices and input technologies to improve energy efficiency and reduce GHG emissions at the farm level. However, at a broader scale, governmental authorities should pay special attention to uncontrolled potential emissions from land-use change especially in areas where deforestation rates has been driven by the rapid expansion of the agricultural frontier (Viglizzo et al., 2011; Volante et al. 2012). Improvements in agricultural energy efficiency and decreases in GHG emissions need specific policies that will involve investments in research, technology application and education.

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Chapter 5

ENERGY CONSUMPTION ESTIMATION DURING OVEN COOKING OF FOOD

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ABSTRACT

Oven cooking of food is a traditional and widely used technology, both at a household and industrial level, which confers to foods unique organoleptic properties, which can not be accomplished using other available technologies. At the same time, it is a highly energetic intensive process, due to the fact that most foods have a high level of water content, which is partially evaporated during roasting. Any attempts to minimize energy consumption of the process must be done carefully, since the quality of the product should not be negatively affected and, on several occasions, there are security and legislative standards to comply. In this chapter the energy consumption during roasting of beef semitendinosus muscle samples has been estimated, using an electric oven. The samples were cooked at oven temperature between 172 and 223 °C until they reach a core temperature of 72 °C. A simple procedure to determine the effective power of the oven from experimental measurements is proposed, which can be applied to other situations and processes. Then, from the experimental results, energy consumption of the oven between 4 to 6.3 MJ/kg of raw sample was found, while energy consumption of sample varies between 484 to 780 kJ/kg of raw sample. So, the ratio of sample energy consumption to oven energy consumption, provide a simple estimation of the energy efficiency of the process, which was found to be between 7.7 to 18.3%. Furthermore, a mathematical model of the beef roasting process has been used to estimate the actual energy consumption of the samples, which fit well with the experimental results.

Keywords: Food roasting, energy consumption, energy efficiency, mathematical modeling

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INTRODUCTION

Oven cooking or roasting of food is a traditional and widely employed technology, both at a household and industrial level. The process involves heat and mass transfer between the dry or partially wet air and the food, generally using electric o gas ovens. Heat processing improves the taste, texture, digestibility and shelf-life of food (Bejerholm & Aaslyng, 2004; Hager & Morawicki, 2013), and is essential for the safety of several foods (Zorrilla & Singh, 2000, 2003). The success of oven cooking relies in the fact that it confers to foods unique organoleptic properties, which are highly appreciated by consumers, and typically can not be accomplished using other available cooking technologies.

At the same time, oven cooking is a highly demanding energy process (Hager et al., 2013; Khatir et al., 2012; Le-Bail et al., 2010; Purlis, 2012). This is due to the fact that most foods have a high level of water content, which is partially evaporated during the cooking process. Also the cooking equipment has a limited energy efficiency, which determines that a significant fraction of energy input is wasted. Any attempts to minimize energy consumption of the process must be done carefully, since the quality of the product should not be negatively affected and also on several occasions there are security and legislative standards to comply. Several traditional food processes, like meat roasting (Cepeda et al., 2013; Tornberg, 2013) and bread baking (Mondal & Datta, 2008; Purlis, 2012), among others, have been studied by mathematical modeling of heat and mass transfer. However, few studies bring up the estimation of process energy consumption in conjunction with a mathematical model of the process. Such estimations can include the device energy consumption, and also the actual energy consumption of the food sample. The overall growth of the world population and new large emerging markets for processed meats (Zhou et al., 2012), justify efforts trying to reduce energy consumption (Saguy et al., 2013). Particularly in the meat sector, there is an important amount of energy consumption before cooking (Ramírez et al., 2006).

This chapter focuses on the estimation of energy consumption during roasting of beef *semitendinosus* muscle samples, using both an experimental and mathematical modeling approach. We propose a simple procedure to determine the effective power of the oven from experimental measurements which can be applied to other situations and processes. Then, from the experimental cooking times and effective power, oven energy consumption of raw sample is found. So, the ratio of sample energy consumption to oven energy consumption provides a simple estimation of the energy efficiency of the process. Furthermore, results of the simulation are compared with experimental results.

METHODS

Experimental Determinations

In order to obtain experimental insight about on beef cooking, several cooking tests were performed, providing valuable information of cooking times, weight loss and energy consumption. Six half pieces of beef semitendinosus muscle (from 0.5 to 1 kg raw mass) were used to perform the experiments. Before cooking, superficial fat was removed. Then, the samples were packaged and stored at room or refrigeration temperature during several hours, and a small portion of each sample was used to determine the initial moisture content by stove drying method. The initial weight of each sample was measured for weight loss calculations. Table 1 show the details of the samples used in the cooking tests.

Cooking tests of individual sample were performed in a domestic electrical oven (ARISTON FM87-FC, Italy), using the forced convection heating mode (i.e., with the fan turned on) and using a different oven temperature for each piece. The temperature profiles at the beef surface and core, as well as temperature in the oven chamber, were measured using T-type thermocouples (Omega, USA) connected to a data logger (Keithley-DASTC, USA). Due to the difficulties to manipulate the system at high temperature, the thermocouples were placed before cooking, and then the sample was placed on a coarse netting tray in the central region of the oven chamber. Then the oven was turned on. Each experiment was finished when the core temperature reached 72 ºC since this condition is required for microbiological safety of processed meat products (McDonald et al., 2001). Also, this internal temperature corresponds to "medium" degree of doneness, according to the Beef Steak Color Guide (American Meat Science Association, 1995; López Osornio et al., 2008). Thus, the time required to reach this condition was defined as the cooking time. In order to obtain total weight loss, the samples were weighed again after cooking.

Internal transport of liquid water is due to thermal protein denaturalization which causes the shrinking of the meat fibres network, resulting in a mechanical force that expels the excess interstitial water towards the surface (Aaslyng et al., 2003; Bell et al., 2001; Bengtsson et al., 1976; Burfoot, 1987; Dhall et al., 2012; Godsalve et al., 1977; Tornberg, 2005, 2013; van der Sman, 2007a, 2007b, 2013).

This expelled liquid water can be lost by evaporation or dripping, i.e., water which is expelled directly from the surface of the sample as liquid drops (Burfoot & Self, 1989; Feyissa et al., 2013; Hung et al., 1978). Dripping losses are verified only if evaporation rate is low or moderate.

On the other hand, high evaporation rate produces the evaporation of the water available at the sample surface and the displacement of the evaporation front towards the sample core, promoting a dehydrated surface crust.

In these conditions, the water arriving from inner regions of the product will evaporate entirely in an inner evaporation front and dripping will be not observed, thus the evaporative losses equal the total weight losses. Several authors have measured the dripping losses during oven cooking of meat, and found that both dripping and evaporative losses are similar in magnitude (Bengtsson et al., 1976; Hung et al., 1978; Kondjoyan et al., 2013; Larson et al., 1992; Schönfeldt & Strydom, 2011).

As a consequence, we experimentally attempted to determine the evaporative (*EL*) and dripping (*DL*) contributions to total weight loss (*WL*). For this aim, the cooking test was done using a pan with a known mass of water below the beef sample, which collects the dripping liquid. Afterwards, the experiment is repeated using the same mass of water, at the same time and oven temperature. The mass difference between the two experiments was attributed to dripping losses.

The evaporative losses were then calculated as the difference between total and dripping losses. For further details the reader is referred to Goñi & Salvadori (2010). Also, to quantify sample shrinkage during cooking, initial and final characteristic dimensions (i.e., length, width, and height of samples) were measured using a calliper.

Table 1. Characteristics of raw beef samples

Sample	1	2	3	4	5	6
Raw mass (kg)	1.0799	0.7406	0.9718	0.6325	0.4900	0.7795
Initial temperature (ºC)	20.6	13.3	7.5	12.9	7.0	15.3
Initial water content (%, wet basis)	72.60	74.81	76.79	75.55	73.12	78.45
Raw characteristic dimensions (cm)						
High	8.2	7.3	7.7	6.5	5.7	6.7
Width	10.6	10.0	10.5	8.5	9.0	11.2
Length	17.7	15.7	17.5	14.0	13.0	14.3

Experimental Energy Consumption Estimation

In addition to cooking time and weight loss, the energy consumption during oven cooking of beef pieces was estimated. The three values are relevant to analyze the cooking process from an economical point of view: the cooking time is directly related to the process duration, the weight loss is a direct measure of the process yield and the energy consumption is one of the principal contributors to the operative costs.

In the evaluation of the total energy consumption, two features must be considered. The first one is the actual energy consumption required to cook the sample, while the second one accounts for the actual energy consumption of the oven. The ratio between both values provides a direct and simple measure of the process energy efficiency.

In order to estimate the actual energy consumption of the sample (EC_{sample}), the enthalpy difference between raw and cooked states must be calculated. This enthalpy difference is the sum of two contributions: the sensible heat and the latent one, respectively. The sensible heat can be estimated as the product of the raw mass of the sample (*RM*, kg), the average specific heat of the sample ($C_{P,ave}$) and a representative temperature difference of the initial and final system conditions (ΔT). Water is the only meat component that evaporates during cooking; therefore the latent heat can be estimated as the product of the enthalpy of water vaporization (λ) at 100 ºC and the quantity of water evaporated from the sample:

$$EC_{sample} = RM \times C_{P,ave} \times \Delta T + \lambda \times EL \tag{1}$$

The temperature difference ΔT is the difference between the final sample temperature and the initial uniform temperature. The temperature of the sample at the end of cooking is not uniform, core region is close to 72 ºC (end point of the cooking process), outer regions are close to 100ºC, and surface must present temperatures higher than 100 ºC if crust formation is observed. In order to evaluate the sensible heat contribution, an end uniform value of 100ºC was assumed. The average specific heat was calculated using an average temperature and moisture content of the sample, evaluated from the total weight loss. It is worthwhile to mention here that in this chapter only the evaporative losses (not the total weight losses) are considered in the latent heat. For other types of products, like bakery products, all weight losses are evaporative ones, consequently, the total weight loss (measured by initial and final sample weight) must be taken into account in the latent heat term.

The energy consumption of the electric oven is evaluated knowing the power consumption of the equipment and the process time (Goñi & Salvadori, 2012; Townsend et al., 1989b). The oven does not consume energy continuously; on the contrary the consumption is intermittent, ruled by the oven temperature control system: if the temperature of the oven chamber is lower than the set value, the heating resistances are turned on, when the set temperature is reached the heating resistances turn off and energy consumption stops, and so on. Therefore, the effective electric power of the oven is estimated as the nominal power of the heating system ($NP_{heating}$) multiplied by a factor of use of energy (f) (Goñi & Salvadori, 2012) and the cooking time, t. The factor of use depends on the oven charge and the cooking temperature. As all the samples used in the experimental tests of this work have similar masses the f value was considered to be only dependent on temperature. In addition to the effective electric power consumption of the oven, energy consumption due to the nominal power consumption of the fan (NP_{fan}), turn on during the whole cooking process, must be considered.

$$EC_{oven} = NP_{heating} \times f \times t + NP_{fan} \times t \tag{2}$$

In the particular case of the oven used in the experiments the fan power consumption was much lower than the heating system, therefore, this contribution was not taken into account.

The nominal power consumption was measured with the oven empty working at the maximum temperature, using a clamp tester (SEW ST-300, Taiwan), it was calculated as the circulating electric current multiplied by the supplied voltage; a value of 1.98 kW was obtained. It is worth to note that for the experiments described in this chapter, two periods can be identified (i) a first period, namely "time before regime" (t_{br}), i.e., until a regime state is reached, where the oven heating system is always turned on and the power consumption is the nominal one; (ii) a second period, namely "time after regime" (t_{ar}), where the control of the oven heating system is acting, i.e., the factor of use of energy f must be considered. The total process time is equal to the sum of both times, before and after regime. Then the energy consumption of the oven can be estimated more accurately as:

$$EC_{oven} = NP_{heating} \times \left(t_{br} + f \times t_{ar}\right) + NP_{fan} \times t \tag{3}$$

In order to estimate f values, the oven temperature profiles measured during the cooking tests were employed, according to the following procedure: (i) only the oven temperature profile after reaching a regime state was considered, i.e., during the time after regime; (ii) the heating time was calculated as the accumulated time with increasing oven temperature; (iii) finally the f value was calculated as the ratio between the heating time and the time after regime. The efficiency of the cooking process can be defined in a simple way as the ratio between the actual sample energy consumption to the oven energy consumption:

$$E_f = 100 \frac{EC_{sample}}{EC_{oven}} \tag{4}$$

SIMULATION OF BEEF COOKING

Mathematical Modeling of Beef Cooking

We have already developed a simple model to describe beef roasting, which is briefly described as follows. Food oven cooking involves convective heat transfer between air and food surface and radiation from the surrounding ambient to the food surface. For modeling purposes, meat is considered as a solid matrix, therefore conductive heat transfer is considered inside the sample:

$$\rho C_P \frac{\partial T}{\partial t} = \nabla (k \nabla T) \tag{5}$$

ρ is the density, C_P is the specific heat and k the thermal conductivity. The typical ambient temperature largely surpasses 100 ºC, and then the surface of meat rapidly achieves temperature values near 100 ºC. As a result, a significant fraction of liquid water is evaporated, which can be quantified as a water vapour flux transferred to the ambient oven, j_{evap}. As it was mentioned earlier, if the evaporation rate is low or moderate, dripping losses can be observed and the evaporation front remains in the sample surface (Hung et al., 1978). The experimental conditions considered in this chapter fall into this category, and then the heat transfer associated to evaporative flux is added in the boundary condition for the energy balance:

$$-k \nabla T = h(T_s - T_o) + \varepsilon \sigma (T_s^4 - T_o^4) + \lambda j_{evap} \tag{6}$$

h is the heat transfer coefficient, subscripts s and o indicates surface and oven, respectively, ε is the emissivity, σ is the Stefan-Boltzmann constant. As well, this mass flux depends on the water activity (a_w) at the food surface and the relative humidity (RH) on the oven ambient:

$$j_{evap} = k_g (a_w P_{sat}(T_s) - RH\, P_{sat}(T_o)) \tag{7}$$

k_g is the mass transfer coefficient and P_{sat} the saturation pressure of water vapour. For high rates of heat and mass transfer, free liquid water can evaporate. Therefore, in these situations, total weight loss is mostly evaporative, and this model offers acceptable results. On the contrary, the model does not take into account the dripping phenomena, and the total weight loss will be notoriously underestimated when the heat and mass transfer rates present low or moderate values (Goñi et al., 2008b; Obuz et al., 2002), which is the most common condition in domestic and also in some industrial ovens. Therefore, Eq. (8) is coupled to the previous ones in order to evaluate the variation of liquid water content in the beef sample:

$$m_s \frac{dc}{dt} = -K_W (c - WHC(T)) \tag{8}$$

This balance establishes that water content (c, dry basis) variation is directly proportional to water demand. The water demand is the difference between the instant water content and an equilibrium value, equal to the water holding capacity (*WHC*). m_s is the dry solid mass and K_W is an empirical parameter. At this point, it is important to mention that Eq. (8) does not consider an internal mass transfer due to diffusion and/or convection mechanisms. A similar approach has been successfully used for water and lipid content prediction in contact-heating cooking of hamburgers (Pan et al., 2000), pan frying of hamburgers (Ou & Mittal, 2006, 2007), immersion cooking of beef (Kondjoyan et al., 2013), and immersion cooking of beef and other meats (Oillic et al., 2011).

For a given process time t, the evaporative loss is predicted by surface (S) and time integration of evaporative mass flux:

$$EL(t) = \int_0^t \left[\int_S j_{evap}(S,t)dS \right] dt \tag{9}$$

As the proposed model does not consider the inner flux of water, the dripping loss at a given process time (*DL*) is estimated as the difference of liquid water content between the initial and current states:

$$DL(t) = m_s(c_{initial} - \bar{C}(t)) \tag{10}$$

where is the volume average moisture content, obtained by volume integration of the moisture profile in the whole sample domain D:

$$\bar{C}(t) = \frac{1}{V}\int_D c(D,t)dD \tag{11}$$

Finally, the total weight loss is calculated summing up both evaporative and dripping losses. For further details about the cooking model the lector is referred to Goñi et al. (2010, 2012).

Thermophysical Properties

The thermophysical properties of beef were computed according to moisture content (c_{wb}, wet basis) and temperature, considering only water and proteins as major components. Properties of individual components were determined according to Choi & Okos (1986). Thermal conductivity was considered to be anisotropic, and the parallel (Eq. (13)) and the perpendicular (Eq. (14)) values were computed from the volumetric fraction of components (Eq. (12)). Eq. (15) represents specific heat and Eq. (16) density. Subscript w and p correspond to water and protein, respectively.

$$\phi_w = \frac{c_{wb}\rho}{\rho_w(T)} \tag{12}$$

$$k_{\parallel} = \phi_w k_w(T) + (1-\phi_w)k_p(T) \tag{13}$$

$$\frac{1}{k_{\perp}} = \frac{\phi_w}{k_w(T)} + \frac{1-\phi_w}{k_p(T)} \tag{14}$$

$$C_P = c_{wb}C_{P,w}(T) + (1-c_{wb})C_{P,p}(T) \tag{15}$$

$$\frac{1}{\rho} = \frac{c_{wb}}{\rho_w(T)} + \frac{(1-c_{wb})}{\rho_p(T)} \tag{16}$$

Beef emissivity was considered equal to 0.9 (Townsend et al., 1989a), and water activity was expressed according to van der Sman (2007a, 2007b):

$$a_w = 1 - \frac{0.08}{c} \tag{17}$$

Heat and Mass Transfer Coefficient Estimation

The convective heat transfer coefficient was estimated from known relationships of Nusselt (*Nu*) vs. Reynolds (*Re*) and Prandtl (*Pr*) dimensionless numbers. For the corresponding experimental cooking conditions, Eq. (16) was used to determine the convective heat transfer coefficient (Perry & Green, 1997):

$$Nu = 0.683Re^{0.466}Pr^{1/3}, \quad 40 \le Re \le 4000 \tag{18}$$

The mass transfer coefficient was then estimated by using a heat-mass transfer analogy (Obuz et al., 2002):

$$k_g = \frac{h}{64.7\lambda} \tag{19}$$

Geometric Modeling and Numerical Solution

For simulation purposes beef samples were considered as three-dimensional irregular objects. A previously developed methodology was used to obtain the geometrical representation of each sample (Goñi et al., 2007, 2008a). The geometric models were obtained from the cooked samples, which were actually different from the raw ones since a significant volume change (i.e., shrinkage) occurred during the process. Then, to obtain the geometric model corresponding to the raw samples, the geometric models for the cooked samples were scaled using three scaling factors calculated as the ratio between raw and cooked characteristic dimensions of sample, i.e., length, width and height. For further details about obtaining geometric models the lector is referred to Goñi et al. (2010).

Simulation of beef cooking model was performed using the finite element method in COMSOL™ Multiphysics (COMSOL AB, Sweden). Initial uniform temperature and moisture content were considered for all simulations (obtained from experimental measurements). For each sample, the corresponding geometric model and the oven temperature profiles recorded during the cooking tests were used. The solver used is an implicit variable time-stepping scheme combined with Newton's method to solve the resulting nonlinear equation system.

Energy Consumption Estimation

Most mathematical models used to describe roasting of foods have the intrinsic capacity to predict the actual energy consumption of the sample (for instance the reader is referred to Alamir et al., 2013 and Khatir et al., 2013), but typically such aspect is not taken into account. For considering the energy consumption it is necessary to include a few equations in the roasting model. Since roasting models are derived from an energy conservation equation, the same energy balance can be used to predict energy consumption.

For the case considered in this chapter, it is necessary to consider the enthalpy difference between raw and cooked states, as it was previously stated this value is composed by sensible and latent heat terms. The sensible heat can be calculated integrating the local accumulation of energy in the simulation domain (i.e., from the energy balance equation which is already used), and then integrating in time such value:

$$E_{sensible}(t) = \int_0^t \left[\int_D \rho C_P \frac{\partial T(D,t)}{\partial t} dD \right] dt \tag{20}$$

Similarly, the latent heat can be calculated integrating over the surface of the simulation domain the energy associated to evaporative flux, and then integrating in time such value:

$$E_{latent}(t) = \int_0^t \left[\int_S \lambda\, j_{evap}\left(S,t\right) dS \right] dt \tag{21}$$

The actual energy consumption of the beef sample is then obtained as the sum of both sensible and latent heats.

RESULTS

Figure 1 shows the representative temperature profiles obtained during the cooking tests. As it was mentioned before, the oven temperature profile presents two periods, "time before regime" (t_{br}) (ca. 15 minutes in Figure 1), and "time after regime" (t_{ar}). During this last period, the control system of the oven controls the temperature around the set value with an accuracy of about ±5 ºC. The oven temperature values summarized in Table 2 correspond to the average value of this period.

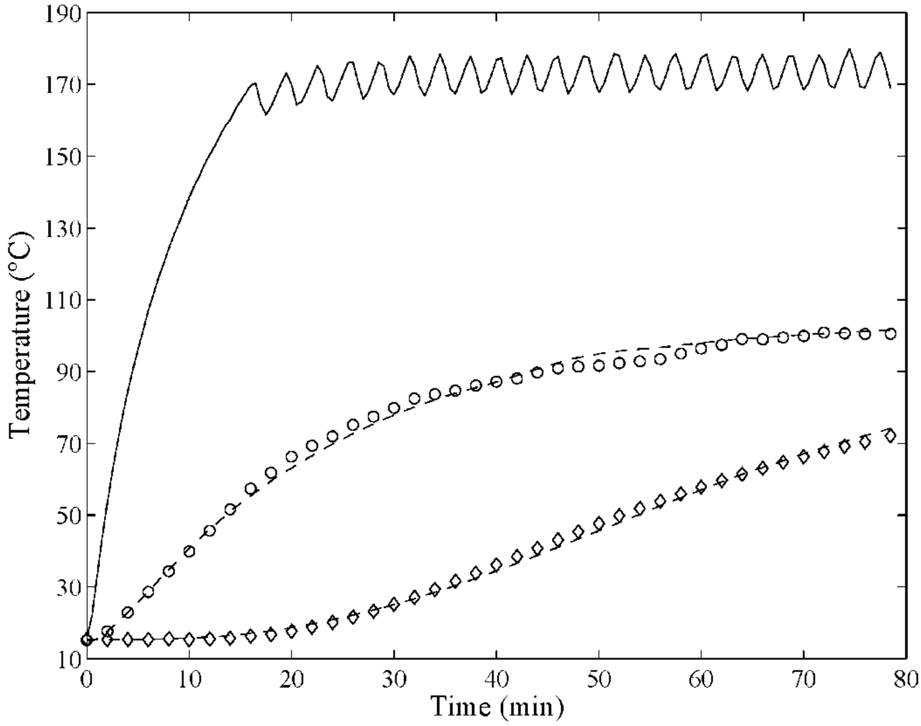

Figure 1. Measured temperatures for sample 6: (◇) core; (○) surface. Continuous line is oven temperature. Dashed lines are the model prediction for the same locations.

Regarding beef measured temperatures, at long process times, the surface temperature remains close to 100 ºC. This behaviour can be correlated with a constant drying rate period, in which the surface is sufficiently wet and water evaporation takes place, therefore limiting a temperature increase. So, the evaporative front is maintained near the surface, avoiding the formation of a dehydrated outer layer. Other authors found similar behaviour during meat cooking in domestic ovens (Bengtsson et al., 1976; Singh et al., 1984; Obuz et al., 2002). The experimental surface temperature shows that the energy transfer problem can be reduced to an imposed temperature boundary condition (like a Dirichlet problem) (Skjöldebrand & Hallström, 1980). This means that increasing oven temperature or heat transfer coefficient will have a minor effect in the cooking time, since the evaporation front is limiting the energy transfer to the surface. Although the evaporation front can move towards the core of the sample, it will continue to limit heat transfer, and the cooking time will not substantially change. The cooking time can be affected in the first period of the cooking, until an evaporative front is established. So, some strategies can be adopted, like using a high temperature in the first period of cooking and then change oven temperature to lower values.

Table 2 summarizes the experimental cooking times obtained for all tested samples, as well as the cooked mass and the contribution of both evaporative and dripping mechanisms on the weight loss, and the cooked characteristic dimensions. Based on measured values, the dripping contribution to weight loss was of the same order of evaporative losses. On average, 53.22% of the total weight loss was produced by dripping. Average total weight loss was 28.72% (with respect to raw mass).

Table 2. Experimental results of the cooking tests

Sample	1	2	3	4	5	6
Oven temperature (ºC)	212.9	223.5	185.4	193.8	197.3	172.8
Cooking time (min)	87.5	75.0	91.5	74.0	63.0	78.5
Cooked mass (kg)	0.6731	0.513	0.7044	0.4646	0.3765	0.5714
Weight loss (kg)						
Total	0.4068	0.2276	0.2674	0.1679	0.1135	0.2081
Evaporative	0.2358	0.1154	0.1214	0.0785	0.0338	0.1042
Dripping	0.1710	0.1122	0.1460	0.0894	0.0797	0.1039
Cooked characteristic dimensions (cm)						
High	8.5	8.2	8.1	7.1	6.4	7.5
Width	8.0	8.0	8.0	7.6	7.5	9.3
Length	14.6	12.2	13.9	11.5	10.7	11.3

Figure 1 also shows the simulated temperature profiles for the same sample. As it can be seen, the model well describes core and surface temperature. In general, simulated core temperature is slightly higher than the experimental one, producing a small under-prediction of the process time, equivalent to 3.17 min, on average. The simulated cooking times are shown in Table 3.

Concerning the prediction of cooked mass, Table 3 shows the predicted values for all beef samples. The absolute difference between experimental and predicted cooked mass was 0.0152 kg on average, equivalent to an average absolute relative deviation of 3.02 %. This result is a good indicator that the proposed model is accurately representing the water loss occurring during beef cooking under the conditions used.

Table 3. Predictions obtained with the cooking model

Sample	1	2	3	4	5	6
Cooking time (min)	82.5	71.5	87.5	70.5	62.5	76.0
Cooked mass (kg)	0.6836	0.4875	0.7108	0.4410	0.3630	0.5598
Weight loss (kg)						
Total	0.3963	0.2531	0.2610	0.1915	0.1270	0.2197
Evaporative	0.1928	0.1257	0.1191	0.0783	0.0663	0.0696
Dripping	0.2035	0.1274	0.1419	0.1132	0.0607	0.1501

The energy consumption for each beef sample was estimated from experimental data using Eq. (1); an average specific heat of 3500 J/kg ºC was considered for all samples. Table 4 shows the obtained results, including the proportion of energy associated to water evaporation. As it can be seen, the energy associated to water evaporation is substantial (49.6% in average), and is greater for large samples. Using a system modeling approach for bread baking, Paton et al. (2013) found that the energy required for moisture evaporation was slightly higher than the sensible heat; similarly during contact baking of pancake batter, Feyissa et al. (2011) found that the energy required for evaporation was much higher than the sensible heat. Considering the sample energy consumption values calculated using the Eq. (1) and the raw mass of each sample, the sample specific energy consumption were between 484 and 780 kJ/kg raw mass, being higher for large samples.

Also the energy consumption for each beef sample obtained with the cooking model is shown in Table 4.

The simulated energy consumption were well correlated with the values obtained using Eq. (1); the differences obtained can be mainly attributed to differences in the prediction of evaporative loss. Figure 2 shows a representative example of the energy consumption obtained using the cooking model (Eqs. (20)-(21)). As it can be seen long process time the sensible heat shows a slow variation, whereas the latent heat increases almost linearly with time. For the same sample, the estimated energy consumption from experimental values was included.

The differences between experimental and predicted values also arise from differences in the predicted cooking times.

Table 4. Estimation of energy consumption of samples and oven, and energy efficiency

Sample	1	2	3	4	5	6
Sample energy consumption, calculated from experimental results						
Energy consumption (kJ), Eq. (1)	842.4	490.2	593.7	373.3	237.2	470.6
Specific energy consumption (kJ/kg)	780.0	661.9	611.0	590.1	484.2	603.8
Energy associated to water evaporation, %	64.4	54.1	47.0	48.4	32.8	50.9
Sample energy consumption, predicted from cooking model						
Energy consumption (kJ), Eqs. (20-21)	767.8	521.7	607.0	373.9	318.2	356.2
Specific energy consumption (kJ/kg)	711.0	704.4	624.6	591.1	649.4	457.0
Energy associated to water evaporation, %	59.7	57.8	46.1	53.0	49.0	43.2
Energy factor of use	0.73	0.72	0.61	0.64	0.65	0.57
Oven energy consumption						
Energy consumption (kJ), Eq. (3)	4613.8	3933.7	3894.4	3650.0	3075.1	3290.5
Specific energy consumption (kJ/kg)	4272.5	5311.5	4007.4	5770.9	6275.7	4221.2
Energy efficiency	18.26	12.46	15.25	10.23	7.71	14.30

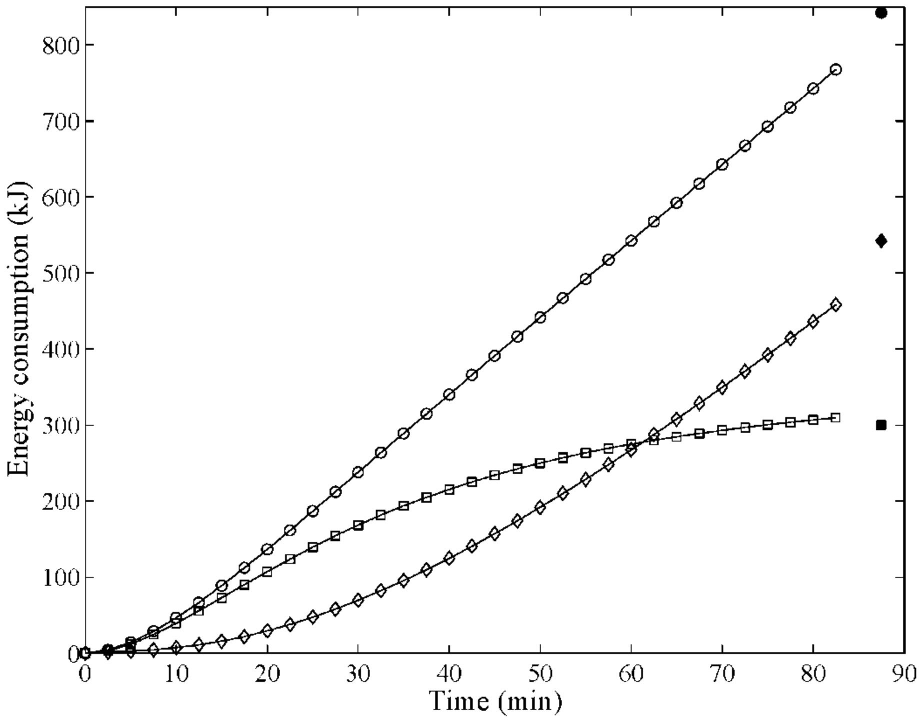

Figure 2. Simulated energy consumption coupled to the cooking model for sample 1. (◇) latent heat; (□) sensible heat; (○) total energy consumption. Filled symbols correspond to estimated energy consumption from experimental values.

Also the energy consumption of the oven was estimated. Figure 3 depicts the employed procedure to obtain the factor of use of energy and Table 4 shows the values obtained for each condition.

It is worth noting that during the cooking test a fraction of the water used in the pan to collect the dripped liquid evaporates, which affects the factor of use of energy. Then, in order to account only the energy associated to cooking, the energy needed to evaporate water from the pan was subtracted to the total energy consumption. So, the energy consumption of the oven takes into account the energy consumption of the sample and the loss of energy. The specific energy consumption of the oven was between 4007 and 6275 kJ/kg raw mass, being lower for larger samples. Carlsson-Kanyama & Boström-Carlsson (2001) indicated that oven cooking is more suitable for large samples or a greater number of portions.

The resulting energy efficiency was between 7.71% and 18.26% (see Figure 4), being higher for larger samples. The average energy efficiency was 13.04%, similar to the 12.15% value reported by Hager et al. (2013) and 12.7% reported by Bansal et al. (2011).

Although for a given sample and equipment both values of energy consumption can be estimated with more or less difficulties, another important aspect related to food cooking, which is more challenging to treat, exists. For instance, DeMerchant (1997) concluded that consumers' behavior can duplicate the energy consumption to prepare the same food. Also, consumers' opinion must be considered in the design of new equipment. Sometimes, promising designs in the sense of reducing energy consumption are unacceptable to consumers (for instance, the use of unglazed doors) (Lane, 2001).

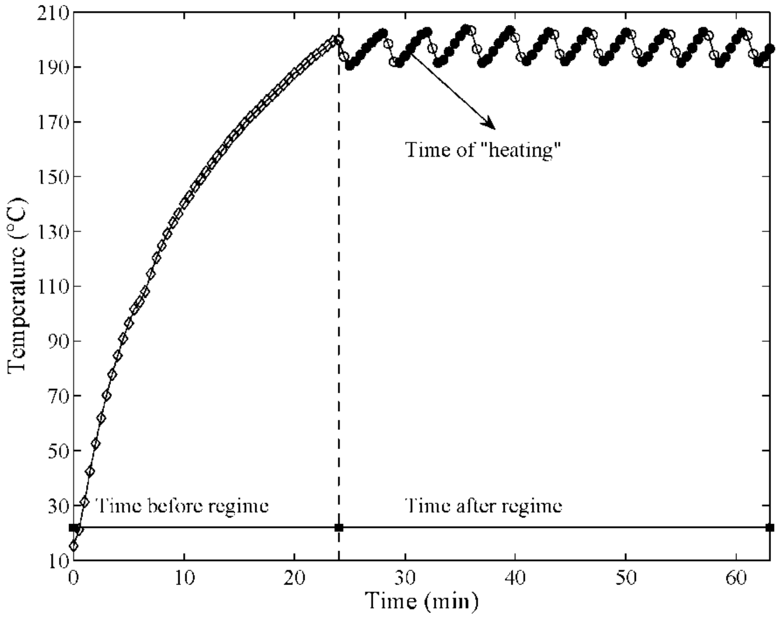

Figure 3. Procedure employed to estimate the factor of use of energy from an experimental oven profile, indicating the different times involved in its definition. Data correspond to sample 5.

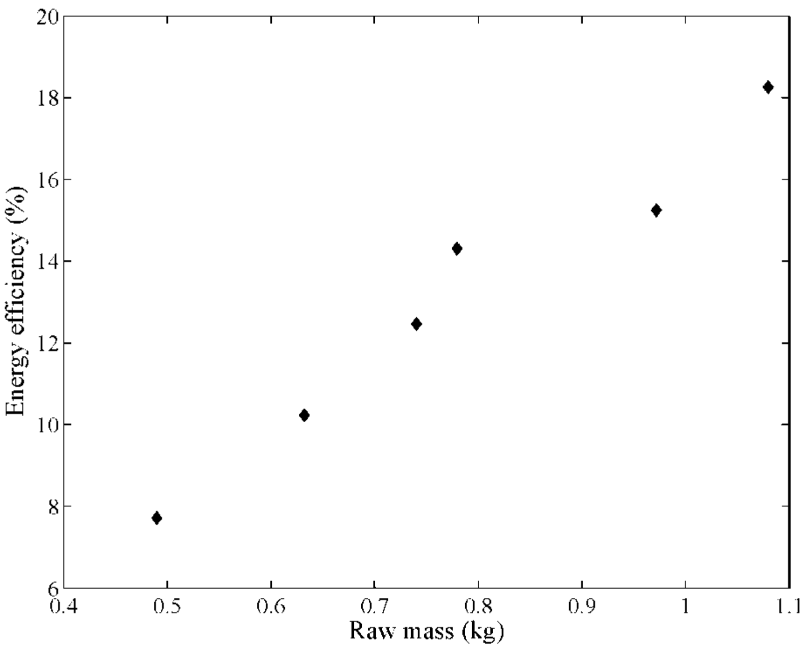

Figure 4. Energy efficiency in function of raw sample mass.

CONCLUSION

In this chapter, the estimation of the energy consumption, both the required to cook the food sample and the ones demanded by the oven, were estimated in a simple way. The specific energy consumption needed to cook the sample was higher for large samples, whereas the specific energy consumption of the oven was lower for larger samples. From these estimations the energy efficiency of the oven was obtained, which was higher for larger samples. A mathematical model of the cooking model was used to couple the estimation of the energy consumption of the sample, and their predictions were in good agreement with experimental results. The cooking modeling approach allows analyzing the behavior of the system under different conditions in a simple and cheap way, and can be extended to another type of meat samples and cooking equipment.

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Chapter 6

Is the Next Generation Prepared? Understanding Barriers to Teenage Energy Conservation

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Abstract

An important factor in shaping future patterns of energy consumption is the understanding of the problem by younger generations and their willingness to address it. Teenagers are not the principal decision-makers within the household, but are a key population to consider in relation to present and future energy consumption. Teenagers' attitudes and behaviours will determine their current and future behaviour, and teenagers are well placed to have an impact, both by changing their own behaviour and by influencing others within the family, their social network and the public sphere (Larsson, Andersson & Osbeck, 2010). We know little about teenagers' understanding and behaviours in relation to energy consumption. Some studies involving teenagers have presented a negative picture of their behavior (Thøgersen & Grønhøj, 2010; BBC, 2006; Toth, Little, Read, Fitton and Horton, 2013). This chapter examines teenagers' understanding of and attitudes towards their personal energy consumption. The chapter presents findings from several studies, both quantitative and qualitative, that have investigated teenagers' attitudes towards their personal energy consumption, their understanding of its impact, and their attitudes towards reducing their consumption. The findings inform our understanding of current barriers that hinder teenage awareness of energy related impacts and challenges and teenage motivation to adopt changes in behaviour to mitigate these problems. This chapter contributes to the important area of understanding how to facilitate reduction in energy consumption.

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Keywords: Teenagers, barriers, energy

INTRODUCTION

Excessive and unnecessary energy consumption will have important deleterious consequences for current and future generations of the world's population (Hinrichs & Kleinbach, 2011).

While it is imperative that all individuals adopt energy-saving attitudes and behaviours, in order to reduce energy consumption on a global level, one population that may be particularly important to involve in issues of climate change are teenagers.

Research indicates many teenagers are excessive users of energy; it is estimated that the average teenager uses approximately 20% more electricity than the average adult (Gram-Hanssen, 2005).

Teenagers are also the adults of tomorrow, and are responsible for the future of environmental policy and decision making. As such, creating pro-environmental attitudes and behaviours amongst this population now may not only have positive impact on energy issues today, but also a long-lasting impact that lasts for generations to come. Teenagers may also represent a particularly interesting and unique population to examine with regards to energy-reduction.

Paradoxically, research has demonstrated that while many teenagers hold generally pro-environmental attitudes, which are often stronger than those held by the adult population, this is not necessarily translated into pro-environmental behaviour and action (Diamantopoulos, Schlegelmilch, Sonkovics, & Bohlen, 2003; Grønøj & Thøgersen, 2009; Johnson, Bowker & Cordell, 2004). Understanding the barriers faced by teenagers when trying to save energy may mark the first step towards creating pro-environmental behaviour change amongst this age group.

Overview of Chapter

Five studies conducted by ourselves, as part of a three year research project, are presented in this chapter. A range of methods were utilised in these studies including both quantitative and qualitative methods. This chapter is structured as follows:

- Outline of existing research that has sought to understand the barriers to energy conservation
- Summary of the methods used in our five studies
- Overview of the five studies (table 2)
- Ethical issues
- Details of each study
- Summary of the barriers from all five studies
- Discussion of how this knowledge can be utilised in order to create positive pro-energy conservation behaviour change amongst the teen population

Table 1. Research exploring barriers related to saving energy, climate change and pro-environmental behavior

			Barriers						
Authors	Topic	Sample	Lack of knowledge & information	Uncertainty & skepticism	Lifestyle	Cost	Detached from the issue	Cultural-normative	Social
Lorenzoni, Nicholson-Cole & Whitmarsh (2007)	Climate change	Three studies, total *N* =1131	X	X	X		X		X
Semenza, Hall, Wilson, Bontempo, Sailor & George (2008)	Climate change	*N* = 1202	X		X	X			
Spence, Poortinga & Pidgeon (2012)	Climate change in relation to psychological distance	*N* = 1822		X					
Perera & Hewege (2013)	Climate change	*N* = 20 (Involved in environmental activities)	X				X		
Throne-Holst, Strandbakken & Sto (2008)	Saving energy & households	*N* = 22	X			X		X	

Table 2. Overview of studies

Study	Aim	Method	Key findings
Study 1	To explore teenagers attitudes towards energy.	Multiple qualitative methods: Diaries Stories Focus groups	Seven barriers to energy-saving were identified: Knowledge, Lifestyle, Detached from the problem, Financial cost, Habit, Peers, Effort
Study 2	To validate the themes developed in study 1.	Qualitative study with teenagers asked to draw a model about 'what would make you reduce your energy use'.	Six of the seven barriers from study 1 were confirmed (Knowledge, Lifestyle, Detached from the problem, Financial cost, Peers, Effort). However, there was limited support for both the lifestyle and peers barriers. Habit was not confirmed as a barrier.
Study 3	To examine teenagers' barriers towards saving electrical energy.	Questionnaire consisting of 12 barriers to saving electrical energy, completed both individually and in small groups. Qualitative data was collected as participants discussed the questions in groups.	Eleven barriers were confirmed: Responsibility, Lifestyle, Habit, Detached from the problem, Financial cost, Time, Effort, Cool, Parents, Peers, Information. Knowledge was not confirmed as a barrier.
Study 4	To explore teenagers' knowledge about how much electrical energy appliances use.	Teenagers ordered twelve electrical energy appliances based on how much electrical energy they used. The items were selected based on items mentioned during study 1.	Highlighted knowledge as a barrier to saving energy. In particular, it demonstrated the inaccuracies in teenagers' knowledge surrounding electrical energy use.
Study 5	To explore teenagers' knowledge, attitudes and behaviours about saving energy	Online survey that included 36 statements about barriers towards saving electrical energy.	Lifestyle emerged as the barrier which prevents teenagers the most from saving electrical energy. In contrast, knowledge was the barrier which prevents teenagers the least from saving electrical energy. Gender differences were found for both the lifestyle and peers barriers, with both barriers rated as a stronger barrier by males than females.

Existing Research into the Barriers to Energy Conservation

In order to help teenagers reduce their energy consumption, it is crucial to understand the barriers to teenage energy conservation. Previous research has provided insights into barriers related to saving energy, climate change and pro-environmental behaviour (see Table 1). This research has predominantly involved adults, but provides insights into potential barriers faced by teenagers.

In addition to the research outlined in Table 1, Kollmuss and Agyeman (2002) reviewed models regarding pro-environmental behaviour and highlighted the following factors that influence pro-environmental behaviour: *'demographic factors', 'external factors: institutional factors, economic factors, social and cultural factors', 'internal factors: motivation, environmental knowledge, values, attitudes, environmental awareness, emotional involvement, locus of control, responsibility and priorities'*(Kollmuss & Agyeman, 2002, p. 248-256).

The above research provides insights into barriers to energy conservation for adults. However, we cannot assume that the same barriers will apply to the teenage population. Teenagers have different lifestyles and responsibilities, for example they tend not to pay the energy bills within their home. It is important to understand the barriers faced by this population in order to inform behaviour change interventions to reduce teenage energy consumption. This chapter presents a collection of studies that aim to provide insight into the barriers to teenage energy conservation.

Overview of Methods

The following studies used a combination of qualitative and quantitative methods. Initial studies were based on time-intensive, in-depth qualitative methods (diaries and focus groups) that allowed a more exploratory approach to understanding teenagers' attitudes and barriers to saving energy. A significant element of this exploratory approach was not giving participants a definition of energy, which meant we could investigate their own conceptions of energy, and energy saving.

The data from the initial, open-ended studies informed the design of further studies using more structured measures such as questionnaires, in which we explored specific attitudes and barriers in greater detail. The studies were primarily conducted in the North East of England by research staff at Northumbria University. Each study built upon the findings of the previous studies in order to further explore energy use with teenagers. An overview of these five studies is shown in Table 2.

Ethical Issues

Ethical approval was sought and received for each study prior to commencement from the appropriate ethics board. Studies one to four utilised an opt-in method of consent. Parents and guardians of teenagers aged under 16 years were presented with information and asked to provide written consent. Parents and guardians of teenagers aged 16 and 17 years were notified of the study but were not asked to provide consent. All teenagers were provided with information about the study and asked to provide written consent if they would like to take part.

Study six used an opt-out method of consent. Teenagers were recruited to take part from schools and organisations. The head teacher of each school was asked to provide consent for all teenagers to take part in the study (online survey). Subsequently, parents and guardians of teenagers aged under 16 years were informed of the study by letter and provided with information about the study. Parents and guardians were asked to inform the school in writing within three days if they did not wish their child to participate. All teenagers were provided with information and asked to provide consent online, as part of the survey.

STUDY 1

The aim of this study was to explore teenagers' attitudes towards energy consumption. Multiple qualitative methods were used (diaries, stories and focus groups) with teenagers taking part in some or all parts. This section provides a brief overview of the study and focuses on the results relating to barriers to saving energy. For a comprehensive description of this study, see Toth et al. (2013).

Participants

Participants were recruited from nine schools and organisations in the North East of England. The sample was 114 teenagers comprising of 39 males and 75 females, aged 10 to 19 years. Teenagers took part in at least one activity (diaries, stories and focus groups). Table 3 details the participants for each part.

Table 3. Participant details for each part of study 1

Part of Study	Number of Participants	Gender	Age (years)
Diaries	60	24 males and 36 females	10-17
Stories	96	38 males and 58 females	10-18
Focus Groups	40	9 males and 31 females	11-19

METHOD

Diaries

Teenagers were asked to complete a paper diary for seven days to record their energy use. The researchers did not specify the meaning of energy and therefore, the teenagers interpreted the term themselves and chose what to include within the diary. The diary included instructions followed by two pages per day to complete. The diary included a table to complete for each day which included the time, what they did, what they used and how long they used it for. Teenagers were asked to bring the diary with them to the following story session.

Stories

The story activity involved teenagers creating a story about their energy use during a week day and weekend. Teenagers could use their diaries as a prompt for this activity, although some teenagers completed the activity without a diary. Teenagers were provided with a written brief and a range of materials: paper, pens, pencils, felt tips, glue, catalogues. Teenagers selected how they documented their story, e.g., written story, drawing. The activity lasted approximately 30 to 60 minutes. An example of a story is shown in figure 1.

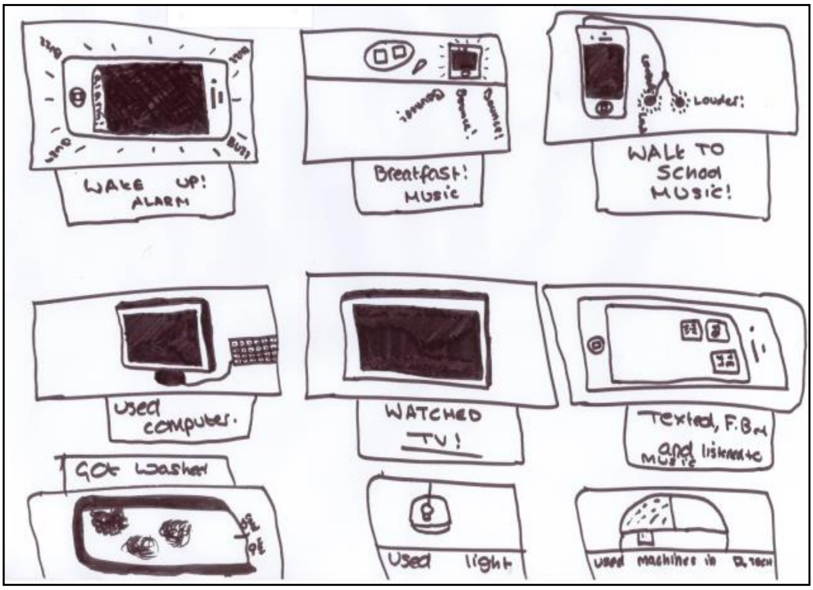

Figure 1. Example of story.

Focus Groups

Written scenarios were created by the researchers based upon the initial findings from the stories and diaries. The scenarios detailed teenage energy use and were 150 to 300 words in length. Scenarios were created for junior (10-15 years) and senior (15-19 years) teens due to differences emerging from the diaries and stories. The scenarios included male and female scenarios and good and bad versions of energy use.

Focus groups were carried out with junior and senior teens. An interview schedule was used to structure the focus groups and covered the scenarios, energy use and saving energy. The scenarios were used at the beginning of each focus group to generate discussion and were read aloud by the participants or the researcher. The focus groups were audio recorded and lasted approximately 25 to 60 minutes.

Table 4. Barriers to saving energy

Barrier	Brief description	Examples of quotes
Knowledge	Lack of knowledge	*'I think sometimes it's a lack of knowledge as well, like you don't realise. I remember I used to always leave my TV on standby until I saw an advert on the TV saying it uses just as much energy as if you had it on or even more sometimes…'*
Lifestyle	Teenagers tend not to want to change their lifestyles and think it can be inconvenient to save energy	*'…people aren't ready to give up like texting all day and playing on the (games console) they just want to live their normal lives so like they all like they do realise it's a problem but they can't be bothered to do anything about it cos it's too much hassle'*
Detached from the problem	Teenagers can feel detached from the problem due the consequences taking place in the future	*'I think it's quite it can be a needless task that some that's what people can see it as…cos it's like well we don't how it's going to matter and we're not going to be around when it changes…'*
Financial costs	Teenagers tend not to be responsible for paying the energy bills at home	*'I don't think when you're a teenager you really worry about it* (energy use) *you don't really think about it its usually adults cos they do all the paying the bills for the energy'*
Habit	The use of energy and saving energy can be a habit	*'It's just a routine that you get into, what you turn off and don't it's hard to change'*
Peers	Peers' views of saving energy	*'A lot of people dismiss it as oh yeah it doesn't matter I'm too cool for this'*
Effort	Due to the design of appliances, effort is required to save energy	*'I don't don't understand why they've they've been made like that* (TVs)*, if you turn it off there's a little red light on it in the corner. The only way to turn that off is to unplug it'*

Analysis

An initial analysis of the diaries and stories was conducted to develop the written scenarios. The focus groups were transcribed verbatim and the transcripts were uploaded into NVivo. The diaries, stories and focus groups were analysed using thematic analysis (Braun & Clark, 2006).

Results

An overview of the main themes were: *energy use, locations of energy use, sources of information, impact of energy use, barriers* and *green teens*. See Toth et al. (2013) for full details of the themes. It is important to note that as mentioned the researchers did not specify the meaning of energy, however the main type of energy discussed was electrical energy within the home. One major theme that emerged was barriers to saving energy. Seven barriers to saving energy were discussed; knowledge, lifestyle, detached from the problem, financial costs, habit, peers and effort. Table 4 presents the barriers including a brief description and examples of quotes.

In summary, the theme ’barriers’ included seven sub-categories. All of the main themes from study 1, including the barriers, informed study 2. A top-down approach was utilised in study 2 with the themes from study 1 used as a framework to analyse the data collected.

STUDY 2

The aim of this study was to confirm the themes from study 1. This study involved teenagers completing a modelling activity about what would make them reduce their energy use. Modelling is a technique to elicit people’s understanding of a topic, and often psychological theories are based on this approach.

Participants

18 teenagers, 2 males and 16 females, took part in this study. Participants were aged 17 to 18 years and were studying A-level Psychology at a college in the North East of England.

Method

The main researcher described the activity verbally using visual aids. The researcher introduced the idea of modelling to participants. Participants were provided with examples which were not related to energy use, for example, what influences school attainment. Teenagers were asked to draw a model about ‘what would make you reduce your energy use’. Participants were provided with paper and pens to complete the task. Figure 2 displays an example of a model.

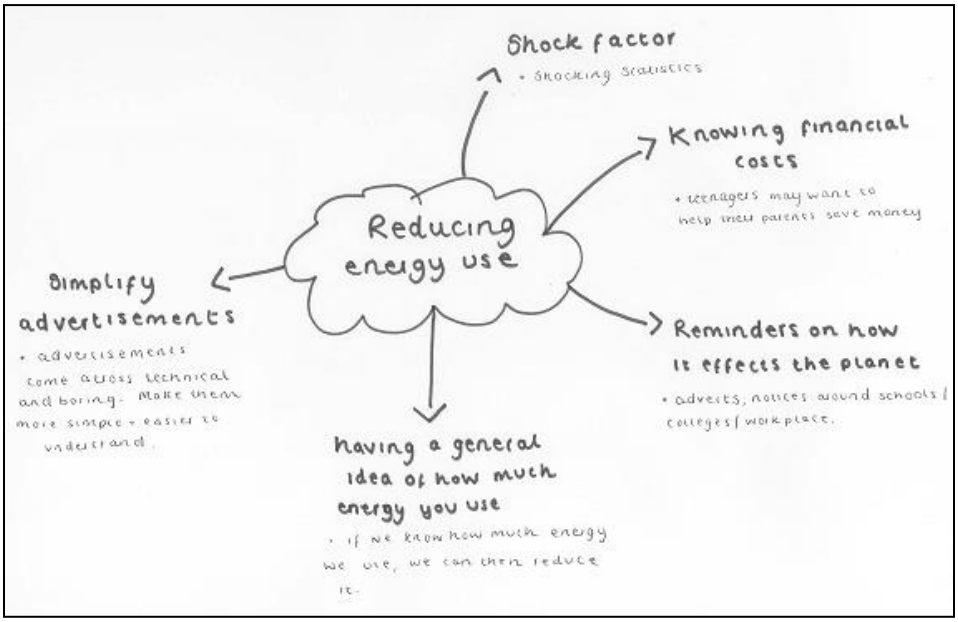

Figure 2. Example of a model.

Results

The models created were coded into the themes from study 1. Overall, the themes were confirmed with the majority of the aspects included within the models mapping onto the themes. In relation to the barriers, six of the seven barriers were confirmed by the models, although there was limited support for the lifestyle and peer influence barriers. The habit barrier was not confirmed, as no participants included habit as a factor in their model. Table 5 displays example quotes from the models that confirm the barriers, and the percentage of participants that made reference to each barrier in their model.

Table 5. Barriers, example quotes and the percentage of participants that made reference to each barrier

Barrier	Example Quote	Percentage of participants that mentioned barrier
Knowledge	*'If more was understood about how we could reduce our energy use'*	22%
Lifestyle	*'Convenience'*	11%
Detached from the problem	*'If I saw the effects of global warming first hand'*	39%
Financial costs	*'Bills – if you have to pay for it'*	22%
Habit	Not confirmed (links to lifestyle barrier)	0%
Peers	*'Direct encouragement from friends/family'*	6%
Effort	*'If things switched off automatically'*	44%

The findings from study 2 provide support for four barriers (knowledge, detached from the problem, not responsible for paying the bills and effort) and limited support for two barriers (lifestyle and peer influence). Although the findings did not support the habit barrier, there appears to be links between the habit and lifestyle barriers. A habit is typically defined as an automated behaviour that form part of an individual's day to day activities (Verplanken & Orbell, 2003), i.e., becomes part of their lifestyle. Attempting to break the habit, may be perceived as inconvenient, since it interferes with their everyday lifestyle. Thus the distinction between the lifestyle and habit barrier is blurred, and it may be more appropriate to conceptualise them as parts of the same barrier.

STUDY 3

This research aimed to identify the barriers teenagers' reported to be the most potent in inhibiting saving electrical energy. Furthermore, gender and age differences were examined. Based on study 1 and 2, along with a review of the literature, the researcher developed eleven barrier statements. The barriers, which were identified in previous research, were knowledge, responsibility, lifestyle, habit, detached from the problem, financial costs, time, inconvenient appliances, cool, parents and information according to how important they perceived them to be and to confirm that they existed. Teenagers rated the barrier statements both individually and in small groups.

Participants

101 participants (57 males and 45 females) completed the questionnaires, with an age range of 12 to 15 years. Participants were from four secondary schools within the North East of England and completed the activity during an engagement day at a local university.

Materials

Two questionnaires were completed by participants, an individual questionnaire and a group questionnaire. Each questionnaire consisted of 12 statements, one relating to each of the barriers. In both questionnaires, the same statements were used however the wording differed, for example 'we' was used instead of 'I' for the group questionnaire.

The individual questionnaire statements are as follows, with the barrier included in brackets:

1. I do not understand why it is important to save electrical energy. (Knowledge)
2. I do not feel responsible for saving electrical energy.(Responsibility)
3. My lifestyle gets in the way of saving electrical energy. (Lifestyle)
4. I am not bothered about saving electrical energy because I will not see the benefits of it. (Detached from the problem)
5. I do not pay the electrical energy bills. (Financial cost)

6. I find it hard to remember to turn appliances off at the wall after using them. (Habit)
7. My friends are not bothered about saving electrical energy (Peers)
8. It is not cool to save energy (Cool)
9. It takes time to turn an appliance off at the wall. (Time)
10. Appliances are designed inconveniently when you have to turn them off at a wall.(Effort)
11. My parents are not bothered about saving electrical energy therefore neither am I. (Parent)
12. There is not enough information available about saving energy. (Information)

Participants rated each of the statements based on their perception of how much the barrier prevents them from saving electrical energy. The rating scale was strongly disagree (1) to strongly agree (5). Therefore the higher the rating given the more that barrier prevents teenagers from saving energy. A Dictaphone was used to record participants as they discussed each of the barriers in groups.

Procedure

Participants were informed that the study consisted of rating each of the statements on how much the concept prevented them from saving electrical energy. Firstly, participants completed the individual questionnaire rating each of the statements and this took approximately five minutes. Participants were then allocated to groups of four to six by the researcher. Each group completed the second version of the questionnaire through discussion of each statements and deciding on an answer together. This took a further ten minutes. Once participants had finished both questionnaires, they discussed each of the barriers overall with the researcher. The questionnaires were collated for further analysis.

Results

No significant differences were found between the scores on the individual questionnaire and the group questionnaire. The descriptive statistics for the individual scores were examined to confirm which barrier was the most potent in inhibiting energy saving behaviours.

Table 6 shows the barrier that prevents teenagers from saving electrical energy the most is financial responsibility, whereas the barrier which prevents teenagers the least from saving energy is knowledge. These findings are supported by the qualitative data, where teenagers expressed that they do not know the price of electricity, but if they did pay the bills they would not want a large bill every month;

> *"If I did pay the bills I would definitely be more conscious about how much electric I was using, I would want to save money."*

With regards to knowledge, the qualitative data indicated most teenagers expressed that they did feel they understood how to save electrical energy, as they learn such knowledge in school and also on the television. They therefore felt they had sufficient knowledge with regards to energy-saving and that this was not a barrier for example:

> *"Yes we do understand we learn about it in science."*

Table 6. Mean scores (and standard deviations) for each of the barriers, the higher the score the more that barrier prevents teenagers from saving energy

Barrier	Mean scores (SD)
Financial costs	4.36 (1.15)
Peers	3.39 (1.07)
Lifestyle	3.32 (1.10)
Habit	3.28 (1.23)
Parents	3.17 (.99)
Information	2.93 (1.17)
Effort	2.79 (1.02)
Responsibility	2.65 (.85)
Time	2.50 (1.16)
Cool	2.48 (1.11)
Detached from the problem	2.39 (1.04)
Knowledge	2.05 (.98)

Gender and Age

To examine age and gender, multiple regression analysis were conducted for each barrier, with age and gender both inserted as predictor variables into each model.

Table 7. Quantitative and qualitative findings for gender and age

Barrier	Quantitative Findings	Qualitative Findings
Lifestyle	Gender was a significant predictor of lifestyle, $\beta = -.29$, $p<.01$, though age was not, $R^2 = .09$, F (2,98) = 4.47 , $p < .05$. Examination of the means revealed that males rated lifestyle as a significantly stronger barrier to energy-saving (M = 3.59, SD = 1.09), than females (M = 2.95, SD = 1.02).	*"I agree with this personally because my lifestyle does involve a lot of gadgets and erm I play a lot of games and all that so I leave my electricity going."* (Male) *"I use hair dryers and straighteners but only for a few minutes at a time."* (Female)

Age and gender did not significantly predict knowledge ($R^2 = .02$, F (2,98) = 1.13, $p = .33$), responsibility ($R^2 = .03$, F (2,98) = 1.35, $p = .26$), habit ($R^2 = .01$, F (2,98) = .71, $p = .50$), peers ($R^2 = .01$, F (2,98) = .44, $p = .65$), cool ($R^2 = .00$, F (2,98) = .03, $p = .97$), appliances (R^2 = .00, F (2,98) = .02, p = .98), benefits (R^2 = .05, F (2,98) = 2.70, p = .07), financial costs(R^2 = .05, F (2,98) = 2.36, p = .10), time (R^2 = .05, F (2,98) = 2.73, p = .07), parents (R^2 = .05, F (2,98) = 2.39, p = .10) and information (R^2 = .05, F (2,98) = 2.47, p = .09). Gender differences were found for one barrier, lifestyle, with males rating lifestyle as a significantly stronger barrier to energy-saving than females. Males believe their lifestyles prevent them from saving energy as the appliances they use need to be plugged in all the time, whereas females stated they only use their electrical appliances for short periods of time (see Table 7).

STUDY 4

There were conflicting findings regarding knowledge, with teenagers identifying knowledge as a barrier Study 1 and 2, but not in Study 3. Study 4 aimed to further explore knowledge as a barrier to energy-saving, and clarify these conflicting findings. A ranking task was used to explore if participants were aware of how much energy different electrical devices consume. The researchers were interested in whether teenagers' rankings of how much electricity devices used matched their actual ranking. If participants rank ordered the devices correctly this would demonstrate awareness and knowledge of electrical energy consumption. Evidence of awareness was expected to be shown by a significant correlation between participant and actual ranking.

The task was designed by the researchers. Participants were presented with twelve pictures of different electrical devices. They were asked to rank order the twelve items in terms of the amount of energy each device used in 10 minutes, from 1 (the most energy) to 12 (the least energy).

Participants

100 participants completed the ranking task with an age range of 12 to 15 years. Participants were from four schools within the North East of England and completed the activity at an engagement day at a local university.

Materials

The electrical energy ranking task was a worksheet displaying twelve electrical devices which were chosen based on items mentioned during study 1. It was developed to explore teenagers understanding of what devices they believe use the most and least energy.

Procedure

Participants were informed the study consisted of ranking electrical devices based on how much energy they used. They were instructed to order the items based on how much electricity the item uses in 10 minutes, with 1 being the device that used the most energy to 12 being the least. Participants were presented with the task in small groups and completed it alone. They were given as much time as they needed to complete the task, which was typically 5 - 10 minutes.

Results

Participant rankings of electrical energy consumption per device where analysed in relation to actual consumption to investigate if any relationship or difference existed. Participant mean score per item were calculated and correlated with actual consumption of the 12 devices using a Spearman rank correlation. A significant positive correlation was found (r (12) = .615, p=.033) between participant ranking and actual consumption of each device.

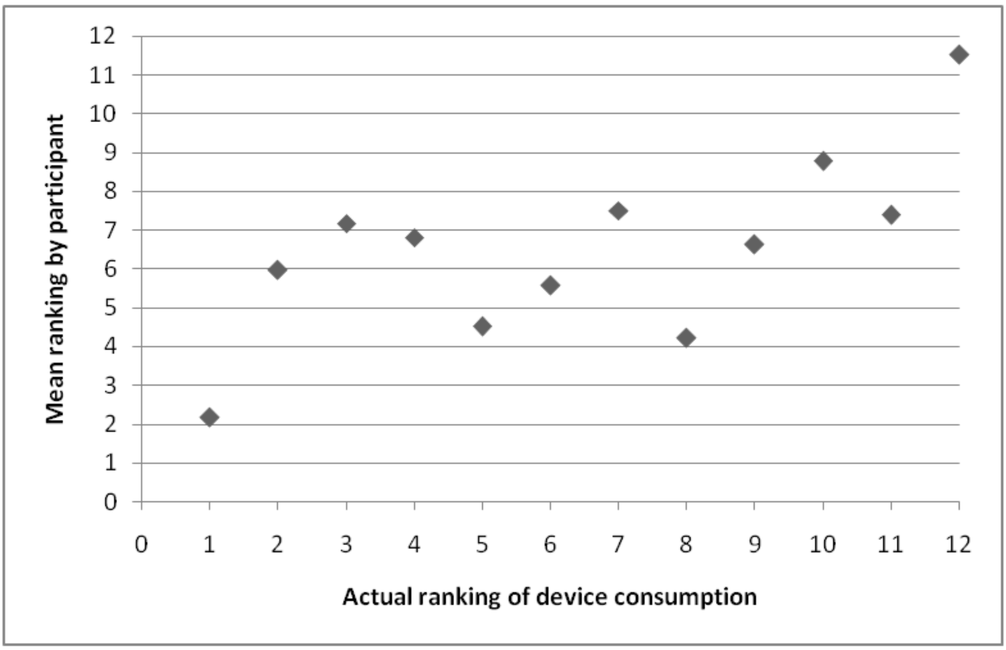

Figure 3. Participant ranking of each electrical device and actual ranking consumption.

This finding indicates there is a relationship between participant rankings of electricity consumed by each device and actual consumption. This provides evidence that participants show awareness and knowledge of how much electrical energy different devices use.

To investigate any difference between participant and actual ranking one sample t-tests were conducted for each item. Nine of the items exhibited significant differences between the actual ranking and participant rankings.

These findings reveal participants are not fully aware or have knowledge of how much electrical energy each device consumes. Table 8 indicates only 2 items (the oven and energy saving bulb) were ranked correctly by the teenagers. Participants appear to perceive personal items using less electricity in comparison to household goods. The energy saving bulb is a bit of an anomaly and this could be associated with the labelling of that particular item. The majority of items displayed a large disparity between participant and actual ranking and therefore has implications for educating people about electrical energy consumption of different devices.

Table 8. Participant, actual and mean ranking of each device including t value

Participant	Rank	Actual	Mean ranking (*SD*)	*t*
Oven	1	Oven	2.17 (2.13)	5.45**
Microwave	2	Kettle	5.96 (2.97)	13.28**
32 TV	3	Hairdryer	7.10 (2.67)	15.26**
Hair straighteners	4	Toaster	6.81 (2.63)	10.60**
Hairdryer	5	Microwave	4.51 (2.68)	-1.80
Toaster	6	Games console 1	5.57 (2.35)	-1.80
Phone charger	7	Hair straighteners	7.43 (2.90)	1.49
Kettle	8	32 TV	4.22 (2.95)	-12.73**
Games console 1	9	Laptop	6.62 (2.62)	-9.00**
Games console 2	10	Phone charger	8.67 (3.05)	-4.31**
Laptop	11	Games console 2	7.38 (2.69)	-13.34**
Energy saving bulb	12	Energy saving bulb	11.50 (1.62)	-3.03*

STUDY 5

This study aimed to explore the barriers to saving electrical energy faced by teenagers in a quantitative way and confirm the barriers developed in the previous studies, using a larger, more representative sample.

Teenagers completed an online survey about electrical energy which included questions about barriers to saving electrical energy. This study reports the findings from the survey and the barrier statements are presented in the results section below.

Participants

286 teenagers, 94 males and 192 females, answered the questionnaire, although not all participants completed the full questionnaire. Participants were aged 13 to 19 (*M*=16.67, SD=1.69). Of the 286 teenagers who completed the questionnaire, 247 teenagers completed the barriers statements. Teenagers were recruited by contacting schools, predominantly in the North East of England.

Materials

An online survey was administrated. The survey was developed by the researchers based on their previous research (Toth et al., 2013). The survey included 36 statements about barriers towards saving electrical energy. These statements were rated on a 5 point likert scale from 1 strongly disagree to 5, strongly agree. The statements are included within the results section.

Procedure

Teenagers completed the survey online and it took approximately 30 minutes to complete.

Table 9. Statements, Cronbach alpha coefficient, mean score and standard deviations for each barrier (* Items reversed scored)

Barrier	Cronbach Alpha Coefficient (α)	Mean (standard deviation)
Lifestyle : *I don't even notice how much electrical energy I'm using, It's too much effort to save electrical energy, I don't do anything to save electrical energy, Nothing I do will make a difference, I don't know how much electrical energy costs, Saving energy would spoil my routine, I am not willing to change my behaviour to save energy, It is a hassle to save energy, I am not sure that I can save electrical energy, I take electrical energy for granted, I limit the amount of electricity I use to save energy*, Saving electrical energy is enjoyable*, Saving electrical energy is important to me*, I am able to save electrical energy**	.74	2.81 (0.57)
Peers: *Nobody else I know saves electrical energy, My friends don't care about saving electrical energy, My friends are aware about saving electrical energy, My friends are concerned about saving electrical energy*	.61	2.47 (0.82)
Detached from the problem: *I don't know what I can do to save electrical energy, I don't believe it's something I personally can do anything about, I don't have much choice in what electrical energy I use, I don't believe it's something I personally need to do anything about, I can make a difference to the problems around electrical energy use*, I am part of the solution to electrical energy use*, I don't believe the problems around electrical energy will affect me, I think the problem about electrical energy is not that bad, I'm not bothered about the problems around electrical energy use, I'm not concerned about the problems around electrical energy use, I am not affected by energy problems*	.81	2.27 (0.66)
Knowledge: *I don't know what the problem about electrical energy is, I don't understand what the problem about electrical energy is, I don't understand the effects of the energy problems*	.84	1.95 (0.90)

Results

Of the 36 barrier statements, the researchers excluded four statements from the analysis due to these statements referring to other people rather than the teenagers themselves (e.g., *My parents/guardians pay our energy bills so I don't think about how much I use).*Of the remaining 32 statements, the statements were organised into four sub-scales, each representing a specific barrier. The four sub-scales (or *barriers*), the statements that comprised them, and the internal reliability of these items (calculated using Cronbach's alpha) are shown in Table 9. Participants mean level of agreement with the statements are also shown.

The barrier which prevents teenagers the most from saving energy was lifestyle. Whereas, the barrier which prevented teenagers from saving energy the least was knowledge.

The researchers were also interested in the relative extent to which gender and age predicted barrier ratings.

In order to do this, multiple regression analyses were carried out separately for each barrier sub-scale, with age and gender both inserted as predictor variables into each model. Age and gender did not significantly predict knowledge (R^2 = .01, F (2,244) = .686, p = .50) or detachment from the problem (R^2 = .02, F (2,244) = 2.18, p = .12).Though age did not predict lifestyle, gender did, β = .21, p=.001, (R^2 = .06, F (2,244) = 7.73, p = *.001*). Examination of the means revealed that females rated lifestyle as a significantly stronger barrier to energy-saving (M = 2.90, SD = 0.55), than males (M = 2.62, SD = 0.58). Similarly, gender was also a significant predictor of peers, β = .31, p<.001, though age was not, R^2 = .09, F (2,244) = 12.67, p <*.001*. Examination of the means revealed that females rated peers as a significantly stronger barrier to energy-saving (M = 2.64, SD =0.67), than males (M = 2.10, SD =0.99).

To summarise, lifestyle was the barrier which prevents teenagers the most from saving electrical energy. In contrast, knowledge was the barrier which prevents teenagers the least from saving electrical energy. Gender differences were found for both the lifestyle and peers barriers, with both barriers rated as a stronger barrier by females than males.

SUMMARY OF BARRIERS

The five studies detailed in this chapter provide valuable insights into the barriers encountered by teenagers when engaging in energy-saving behaviours. A range of methodological approaches, yielding both qualitative and quantitative data, were utilised in a complementary fashion, in order to gain an in-depth and detailed understanding of the barriers. In total, six main barriers preventing teenage energy conservation were identified in the course of our research. The barriers are outlined individually, and in detail, below:

1. Knowledge

In the qualitative data obtained in Study 1 and 2, it was apparent that teenagers did not really understand how much energy they used and how they could save energy, i.e., they lacked the appropriate knowledge. However when asked to rate their knowledge about energy in Study 3 and 5, teenagers felt that they did have a good understanding of energy-related issues. Therefore, an important distinction must be made between what teenagers *think they know* about energy and what they *actually do know*. In our research, it was apparent that teenagers felt that they had a good understanding of energy-related issues because they learnt about them, on an abstract scientific level, at school, but do not understand how this is relevant to them, i.e., their own personal role in energy-related issues. The need for teenagers to be educated in personally relevant knowledge about energy consumption and conservation was further echoed in Study 4, which found concerning discrepancies between teenagers' perceptions of which household devices use the most electrical energy, and which ones actually do.

2. Lifestyle

In the diary and story activities from Study 1, it was clearly evident that patterns of energy consumption were firmly embedded in teenagers' lifestyle and that saving electrical energy would pose an inconvenient threat to this lifestyle; a finding that was confirmed in the subsequent focus groups (Study 1), in the modelling activity (Study 2) and also questionnaire-based studies (Study 3 and 5). During the course of the research, several aspects of teenagers' lifestyles that had been identified as separate barriers to energy conservation in earlier studies –namely habit, time and effort - were combined into the lifestyle barrier, since it was felt that these were all barriers that inconvenienced the teen lifestyle. Study 5 aimed to measure lifestyle in this broad, multi-faceted way, incorporating elements of convenience, habit, time, and effort. The measure developed was found to have high internal reliability, supporting this broad conceptualisation of the lifestyle barrier.

3. Detached from the Problem

A recurring theme throughout our research was that teenagers felt detached from the energy problem and did not feel that the negative consequences of excessive energy consumption would personally affect them. In the qualitative research conducted in Study 1, teenagers described how they felt that the consequences of energy use would happen in the distant future, beyond the scope of their life-time. Feeling detached from the problem was also found to manifest as a lack of feelings of personal responsibility for energy consumption and conservation, and also a sense of hopelessness that they could not personally make a difference, which were both measured in Study 3 and 5. Interestingly, teenagers felt that if they could somehow feel closer to the problem (study 2) then they would feel more inclined to save energy. This barrier may therefore be seen as linked to the knowledge barrier, since both barriers could potentially be overcome by making the energy problem more *personally relevant* to the teen.

4. Financial Costs

Teenagers tend not to be responsible for paying the energy bills at home. This lack of awareness for the financial ramifications of excessive energy use and diminished feelings of responsibility for them was identified as a barrier to saving energy in the focus groups in Study 1, the modelling task in Study 2, and the quantitative questionnaire in Study 3. Interestingly, Study 3 found that teens rated lack of financial responsibility as the most potent barrier to energy-conservation, yet unfortunately, this barrier is difficult to overcome since teens cannot be expected to be financially liable for their energy-consumption. It is likely that the lack of financial responsibility for energy consumption may contribute to the reasons why teenagers feel detached from the energy issue, and future research may benefit from further exploring this link.

5. Peers

Peers have been identified as a key factor influencing adolescent behaviour in a variety of domains (e.g., Garner & Steinberg, 2005), and so it was not surprising that our research found that peers are an important influence on the behaviour of other teenagers with regards to energy consumption and conservation. In Study 1, teenagers discussed that saving energy is not something that is typically done by teenagers and is seen as not "cool" by their peers. Peers were further confirmed as a barrier to teen energy consumption in the larger questionnaire studies (Study 3 and 5). Trying to increase (both actual and perceived) peer support for energy conservation may be an effective strategy for increasing energy-saving behaviours amongst this age group.

6. Parents

The influence of parents can be seen to impact teenagers' views about saving energy as indicated in study 3. While the subsequent studies presented in this chapter did not focus on further understanding this barrier, exploring the role of parents may be a useful direction for future research.

BARRIERS INFORMING BEHAVIOUR CHANGE

Understanding the barriers faced by teenagers when engaging in energy conservation is only the first step towards involving this important population in the solution to the current energy crisis. The next crucial step involves utilising this knowledge to develop effective interventions that overcome these barriers, and foster attitude and behaviour change in this domain. Importantly, adolescence may provide an important window of opportunity for attitude and behaviour change. It is a critical period for psychological, biological and social development, since it is during this time that teens begin to develop the new beliefs, attitudes, values and behaviours that will form the foundations of their stable adult identity (Erikson, 1986; Lloyd, 2002).This flexibility to psychological change that defines typical teenage development may mean that teenagers are particularly receptive to the development of energy-saving attitudes and behaviours.

Development of effective interventions for the reduction of teenage energy consumption should now form a central part of research focus. To date, we have developed one intervention that has been successful in increasing the energy–saving behaviours of teenagers. *Planning to Save the Planet* is an online intervention that aims to reduce teen consumption of electrical energy (Bell, Toth & Little, 2013). It is based on the psychological theory of implementation intentions, which posits that creating specific "If …. Then…" plans detailing when a particular behaviour will be performed, increases the likelihood that the behaviour will occur (Armitage, 2006). The intervention was developed in response to the findings of the five studies outlined previously in the chapter, which had found that teenagers often failed to perform energy-saving actions, not because they didn't see the importance or value of the behaviours, but rather because they were not in the habit of performing them and did not see how these behaviours could fit within their personal lifestyle. As such, the intervention hoped to directly overcome the “lifestyle and habit” barrier to energy-saving that we had identified. It was anticipated that formulating specific plans – or *implementation intentions* - would help teenagers overcome these barriers and find a way of incorporating energy-saving into their everyday life.

Figure 4. Screenshot image of the registration page for the online intervention.

An initial pilot evaluation of the “Planning to Save the Planet” intervention was performed, involving 180 teenagers from North-East England (M = 13.45, SD= 0.57). The results of this evaluation indicate that the intervention was a successful method of increasing energy-saving behaviours for some teenagers, but not others.

More specifically, it was found that formulating precise energy-saving plans can be an effective strategy of increasing the energy-saving behaviour of teenagers who are already motivated to save electricity, and already do so on an irregular basis. For these teens, it is likely that formulating personal and precise energy-saving plans helped them to overcome ‘lifestyle’ barriers that typically prevent them from saving energy. In contrast, teenagers who were not motivated to save electrical energy and did not already do so, were unaffected by the intervention.

Future research should therefore focus on developing methods of persuading teenagers who are not already thinking about engaging in energy-saving behaviour, into doing so. It may be that interventions aimed at overcoming the other barriers discussed in our research, such as peers and financial costs, may be more effective for these unaffected populations.

CONCLUSION

Teenagers are the adults of tomorrow, and are responsible for future policy and decision making. Creating pro-environmental attitudes and behaviours amongst this population now may not only have positive impact on energy issues now, but also a long-standing impact that is also felt by generations to come.

It is important to understand the barriers faced by teenagers to conserve energy. This understanding can lead to the design of interventions for teenagers to save energy. This series of studies utilised a range of methods with teenagers, including quantitative and qualitative methods to explore this area. Six key barriers to teenage energy conservation were highlighted: knowledge, lifestyle, detached from the problem, financial costs, peers and parents. This chapter also details one successful intervention designed to help teenagers save energy. It is suggested that future research builds upon the findings from our study to not only further understand and clarify the barriers identified, but to also develop interventions to overcome them.

ACKNOWLEDGMENTS

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Chapter 7

IMPACTS OF INDEPENDENT RESEARCH AND DEVELOPMENT, FOREIGN TECHNOLOGY AND DOMESTIC TECHNOLOGY TRANSFER-DRIVEN ACTIVITIES ON ENERGY CONSUMPTION

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ABSTRACT

Energy has a significant role to play in human lives. For this reason, the world is taking the responsibility to map out an action plan on improving the infrastructure to obtain the needed energy supply efficiently and to achieve the economic growth target. Energy is significant due to the interdependence of energy and economic development. Energy and economy dynamics present unique challenges to the present and future generations. Outcomes from a diversity of activities need to be deliberated by policy makers of both developing and developed countries in order to evaluate the dynamics of their decisions. Otherwise, energy, which is a priceless exhaustible resource will repeatedly be exhausted and give rise to severe environmental harms, such as air pollution and global warming gases.

Among the indicators that have a major part to play in the consumption of energy is intensity factor. Considering the influence of intensity on energy consumption; its reduction will go a long way in promoting the sustenance of energy supply both locally and internationally. Various activities that will help achieve the phenomenon of intensity reduction are independent research and development, introduction of foreign technology and domestic technology transfer driven activities.

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The objective of this chapter is to focus on these activities and their impacts on the consumption of energy. This chapter aims also to define the role that energy policies can play on these activities.

Keywords: Independent Research & Development, technology transfer, energy policies

INTRODUCTION

The benefits of energy intensity of country's economies as an indicator of sustainable development as indicated by Peck & Chipman (Peck and Chipman, undated) states that "reducing the amount of energy used per unit in the production of goods and services can contribute both to the alleviation of environmental stress and to greater economic and industrial productivity and competitiveness." A chief determining factor of energy intensity is the energy efficiency, apart from the structural change in the economy which is also an important factor. To put a sharp decline in energy intensities, drastic measure should be introduced. Energy related problems have been a complex issue stemming from the days of the 1970 oil crisis. To solve these problems, there is need to have a thorough understanding of the structure in place and dynamics governing the energy situation. Energy consumption has continued to increase as it has always been leading to a continuous growth in oil imports, air pollution. Technological improvements in the various sectors where energy is consumed could drastically cut this trend of energy consumption (PCAST, 1997). Research and Development (R&D) would lead to the improvement of technologies, whereas technology improvements invariably would lead to technology transfer in the various sectors. The study of the Independent Research and Development (IR&D), foreign technology and domestic technology transfer impacts on energy demand and supply is limited in resolving energy related problems. However, studies that contributed in this area include the study of YuhuaTeng, ChorFoon Tang and EuChye Tan, Liu and Dapeng Liang and Ana Pueyo (Teng, 2012, Tang and Tan, 2013, Liu and Liang, 2013, Pueyo, 2013). IR&D, refers to the discovery and creation of new knowledge about scientific and technological topics (anonymous, 2013), in this case energy, for the purpose of uncovering and enabling development of valuable ways of minimizing energy consumption. IR&D is crucial because it can increase the economic efficiency of a country's research activities and this can affect the growth of a country and its supply of energy to its people. With IR&D's discovery and creation of new knowledge to the minimization of energy consumption, this can go a long way in affecting energy policy.

Every country owes its future generation a clean and healthy environment. It becomes imperative to boost, develop and encourage IR&D in the area of energy which leads to economic sustainability. In line with strategic needs to reduce energy intensity, various research programs which lead to innovative integration in the development of new ideas as a solid foundation to the reduction of every nation's energy intensity should be introduced. There is need for recruitment programs where talents are been attracted to work as researchers in the aim of making energy strategic innovations. Recognition of those who have made meaningful contribution should also be noticed with awards.

Indigenous policy innovation that will guide and fund IR&D on energy related matters should be introduced. Just as the Chinese government has encouraged; emphasis should be placed on funding, talent recruitment, and award on science and technology as a fundamental part of innovation (Liu and Liang, 2013).Pulling promising technologies from IR&D stage into the market is crucial to reducing energy consumption while preserving economic growth steadily into the future (ACEEE, undated).

Technology transfer stated by C. Philibert deals with the concept of embracing technology needs assessments, technology information, enabling activities and capacity building (Philibert, 2004). Improved energy technologies can power the world economy and satisfy growing energy needs, especially of the developing world, while stabilizing atmospheric CO2 concentrations in the long run (Philibert, 2003). However, such technologies could be dependent on environmental factors. The local differing conditions could contribute a limitation to where these improved technologies may be deployed. Also, different countries might have different technology policies and modernization programs that have influence on technology transfer. An example of such countries is China (Martinot et al., 1997). Attention is still on international technology transfer to mitigate global environmental problems (Martinot et al., 1997), an aspect of improving energy efficiency. The employed framework for foreign and domestic technology transfer for this study concentrates on technology needs assessments, technology import, operation of the technology and its adaptation to local conditions.

The next section focusses on IR&D programs with the intent of looking at its impact on energy consumption. Section three concentrates on the framework for foreign and domestic technology transfer as it impacts on energy consumption. The fourth section elaborates on how policies can assist in achieving efficient consumption of energy looking at the various activities that can be involved.

IR&D PROGRAMS

IR&D activities are the motor of technological development (Garrone and Grilli, 2010). These activities have in part been directed towards developing energy efficient technology (Henriksson et al., 2012). Lindmark et al., (Lindmark et al., 2011), confirmed this by showing that substantial R&D attention was biased towards energy efficiency measures since the oil crisis during the 1970s. The structure of the R&D spending path mirrors the nature of investment in breakthrough technologies (Bosetti et al., 2009). Examples of R&D investments in the United States are the American Competitiveness Initiative (ACI) and the Advanced Energy Initiative (AEI) launched by the Bush administration. In the 2009 Omnibus Spending Bill of the United States, President Obama made a down-payment for funding of R&D on renewables up by 16%, US$ 800 million for biomass R&D and US$ 400 million for geothermal energy R&D amongst the 2009 Stimulus Package with a strong focus on clean technologies (Witte, undated). The European countries like France and Germany have also upgraded their funding into energy R&D in recent years, with large increases for energy efficiency, renewable energy sources and fusion research (Witte, undated).

An example of country where industry takes major part in energy R&D is Japan. The Japanese Government’s support for R&D expenditures is less than 3% (Watanabe, 1995). Watanabe in one of his studies analyzed the contributing factors to energy reduction in Japan. From his study, 44% of the reduction of unit energy consumption was attributed to the substitution of technology for energy and the remaining contribution was made by R&D

intensity (47.5%) and energy price increase (8.5%) (Watanabe, 1993). More than a decade ago, a research conducted in the U.S(DOE, 1995) quoted a hand-full of successes of energy research development and demonstration (RD&D). There is consensus among economists that R&D has a payback that is higher than many other investments (Worrell et al., 2001).

Max Luke discovered that the United States and Germany have showed about equal declines in per capita energy consumption over the 1980-2000 period (Luke, 2013). This shows the efficacy of energy R&D investments. Examples of successful outcomes of the R&D programmes include the wind and solar technologies in Germany's Energiewande, the nuclear power industry supplying 35% of the world's zero carbon energy and the Shale gas development in the United States to name a few (Luke, 2013).

IR&D Programs to assist the reduction of energy intensity covers a wide range of activities. Energy IR&D programs should focus on development of less environmentally invasive technologies, such as lowering atmospheric emissions and reducing energy consumption, focus on energy-intensive industries, identify challenges that would dramatically improve energy efficiency in all sectors, identify areas that hold potential for improvement in a particular area, identify barriers that prevent improvement in the energy areas (ACEEE, undated). This leads to an advancement in energy efficiency. A number of market failures that impede the diffusion of new, energy-efficient technologies and practices can be addressed through IR&D (ACEEE, undated).

From (Anonymous, 2011), the following are coined to help improve energy IR&D: (1) mastering the complexity; mastering the problem involves defining the problem, i.e., looking at multiple perspectives to shape the problem definition. Failure of IR&D is mostly attributed to lack of its focus; (2) removing the unseen barriers to investment; a combination of policies will be required. First, an analytical framework of various environments affecting energy research should be investigated. This includes political and socio-economic environments. As indicated by the Fourth Framework Programme (FP4, 2001), the objectives of IR&D should be located within and attached to strong and stable, politically determined energy policies. A study conducted by Gromet et al., (Gromet et al., 2012) confirmed that more politically conservative individuals were less in favour of investment in energy-efficient technology than were those who were more politically liberal. This in turn will affect IR&D to ensure more efficient use of energy; (3) creating public-private partnerships that works and (4) finding new sources to fund energy IR&D. There is need for appropriate policies that will govern funds acquisition to carry out laudable and valuable research. Research and development can have various goals, depending on the barriers to be tackled (Worrell et al., 2001) to optimize the consumption of energy. These goals include the reduction of greenhouse gases (GHG) emitted by the energy sector, the reduction of risks to energy security and national security, and the promotion of economic competitiveness (Anadon, 2012). However, the barriers to be tackled to achieving these goals include economic efficiency of the market conditions the consumers face (e.g., energy prices, information availability) (Gillingham et al., 2009) and behavioral changes which is as a result of conscious decision-making on consumer's part (Markowitz and Doppelt, 2009).

There are lots of benefits that can be accrued from energy IR&D, amongst them are insulating economies from the costs associated with price shocks and disruptions in imported energy supplies, leading to enhancement in nation's energy security (Greene et al., 1995), reduction in adverse environmental impacts associated with energy production, delivery and use (Dooley, 1998).

FRAMEWORK ON TECHNOLOGY TRANSFER

Governments and organizations of the present world are faced with social and business responsibility to reduce energy consumption and greenhouse gas emissions (Mckay and Khare, 2004). A key constraint facing developing countries is the difficulty of matching their needs with appropriate technological solutions that reduce GHG emissions (Kathuria, 2002). Technological innovation, a means of improving energy efficiency would play a role to depending less on energy (Watanabe, 1995). This can be either indigenous or foreign technology transfer. Although, some technologies may have opposite effects on different environmental issues as cited by Steenberghen and Lopez (Steenberghen and Lopez, 2008). It is important to assist indigenous technology transfer especially when environmental, economic and social issues are considered. This can be achieved through various policies and regulations like fiscal and tariff regulations on few foreign technologies that have domestic or local substitutes. A strong relationship between suppliers and recipient and the orientation of the recipient's enterprise are two critical factors in determining the extent which indigenous transfers can assist in reducing energy consumption (Kathuria, 2002).

Technology transfer is no doubt a significant component of clean development in general and its governance should be expected to influence the extent to which its potential can be realized (Wang, 2010). Technology transfer has been considered to be based on the know-how, know-what and know-why (Wang, 2010, Lall, 2002). Properties of the know-how, know-what and know-why (Wang, 2010) have been stated by Wang. Sound technology choice is the backbone of any strategy for international technology transfer. Technology transfer generally involves various steps as expressed by Vinish Kathuria. These include assessment of technology needs, technology import, operation of the technology, adapting the technology to local conditions (Kathuria, 2002). For technology transfer process to be realized, the cycle of the various processes stated by Vinish Kathuria need to be completed as depicted in Figure 1.These factors are discussed further below,

Assessment of technology needs. This involves adopting particular lists of sustainable development standards where countries' needs and priorities in terms of energy service and economic improvements are met in accordance with the countries' endowed resources and legislation.

Technology import. This involves not just the transfer of codified engineering knowledge and blueprint (Pueyo et al., 2011) but also the transfer of skills and know-how for operating and maintaining technology hardware to further independent innovation where possible by recipient firms (Bell, 1990, Ockwell et al., 2008).

Operation of the technology. It takes competent hands to be able to put into use the technology. This is where training comes into play. It is of no use if there are technologies deployed and no one is able to put them into rightful use.

Adapting the technology to local conditions. Adapting technology to suit local conditions is important, but practices vary widely. Countries that spend on average more on adaptation have proved to be more effective in technology transfer (Worrell et al., 2001). Most transferred technologies were designed based on the place of its origin. But due to different geographical locations as these technologies are transferred, it becomes imperative to adjust the technology to suit the conditions in which it is going to be operated. Adapting and developing technology to suit the needs is a vital step in successful transfer of technology (Worrell et al., 2001).

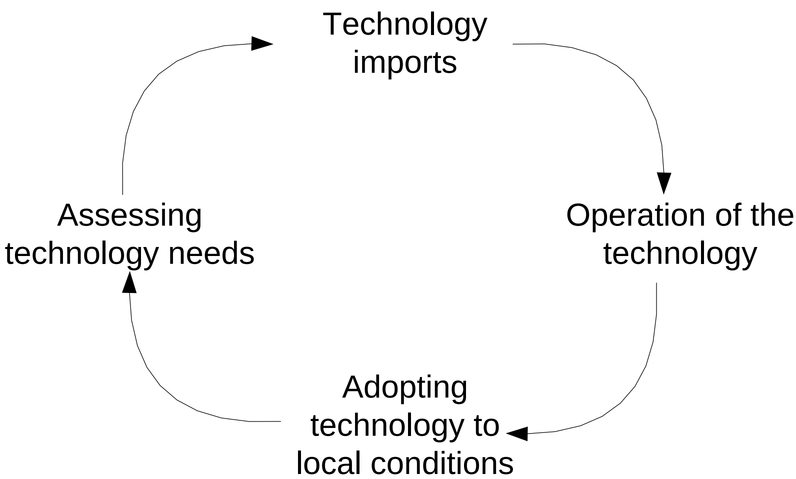

Figure 1. Various cycle steps involved in technology transfer.

Hence, as interpreted by Worrell et al., technology transfer is a process involving the trade and investment in technology, adoption, adaptation, and dissemination of industrial technology, and last but not least, capacity building, as science and technology are strongly related (Worrell et al., 2001).

The lack of political will, including the concerns surrounding intellectual property rights, and the weak capacity of absorption from inadequate institutions and policies constitute the failure to transfer technology. United Nations Development Programme (UNDP), a multilateral institution, however has been at the forefront in supporting the development and diffusion of climate-smart technologies for adaptation globally. Its Climate Change Adaptation programme has incorporated technology transfer in different regions, including twenty three interventions on technology transfer in Africa, sixteen interventions in Asia, two interventions in both Europe and Latin America and five in the Pacific region (Tessa and Kurukulasuriya, 2010).

POLICY INITIATIVES

To put a sharp decline in energy intensities, policies should be introduced. The role of policy is to make possible the best way of using energy resources to meet the needs of the society (Tyler, 2009). ‘Policy’ is defined as having a group of components, varying from wide ‘policy paradigm’ which directs the method to the development of policy in a specific field, to declarations and intents, printed manuscripts and institutional directions and capacity. From the definition, it is debated that, at printed and stated energy policy levels, there is an intention to proceed to a further wide-ranging, resourceful and less carbon-intensive energy sector. Few policy mechanisms are being advanced which go a long way to realizing this

(Tyler, 2009). Energy policies were intended to increase energy supply and replace coal with oil and other new energy carriers before the oil crisis. The early reaction to the oil crisis was 'energy conservation', which concerned the reduction of energy consumption and thus reducing consumption of energy services. More demand-focused energy policies had begun to replace 'conservation' with 'energy efficiency' by the beginning of the 1980s, which involved a development in the efficiency of conversion of energy carriers to energy services, and consequently a decrease in energy usage while retaining similar intensity of consumption of energy services (Marquard, 2006).

Reducing energy consumption to bring about its efficient use would need a strong hold of legislative initiatives to promote IR&D and technology transfer. This calls for efficient policies. IR&D is the fundamental factor in attaining a huge progress in technology (Jamasb et al., 2008). Just as PCAST says 'it is the linchpin of technological advancement' (PCAST, 1997). Technology transfer needs to be incorporated in IR&D strategies, as many (public) environmental sound technologies "remain on the shelves" and are not brought into the market as rapidly as may be expected (Worrell et al., 2001). Sponsoring IR&D projects have led to the validation of technology transfer as one of its benefits, if not the main benefit (Kingsley et al., 1996).

Due to energy efficiency barriers, the apparently beneficial measures are not being implemented (Schleich, 2011). According to Sorrell et al. (Sorrell et al., 2004), these barriers may generally be characterized as "postulated mechanisms that inhibit a decision or behavior that appears to be both energy efficient and economically efficient" as interpreted by Schleich (Schleich, 2011).The recognition of multiple economic and institutional barriers in developing countries that hold back efficient achievement of energy policies advancing sustainable development has been reported by Abdalla (Abdalla, 1994) and interpreted by Pandey (Pandey, 2002). They include

- weak governance structures promoting inefficiency in state-owned industries;
- weak financial institutions;
- trade barriers and
- large underdeveloped markets.

Based on these obstacles, coordinating policies to address these issues is very critical across all sectors (IEA, 2011). Developing effective policy for overcoming these barriers would require better understanding of the nature of the energy efficiency barriers (Schleich, 2011). An understanding of different kinds of barriers and their implications for equity, sustainability and growth is required for effective modeling and prescription of policy measures that meet the demand ends (Pandey, 2002).

A crucial responsibility is played by governments in positioning the cross-sectoral framework for energy efficiency. Investment in energy efficiency and implementation acceleration through national energy efficiency strategies can be stimulated by the governments. Once in place, observing, enforcement and assessment of such approaches are fundamental to pinpointing gaps and accomplishing objectives (IEA, 2011).

There is a growing consensus that intervention by the national governments may be essential to effectively promote energy-efficiency programs (Sovacool, 2009). More importantly, there should be an authorizing body, assigned by the government, to implement energy conservation standards (Al-Ajlan et al., 2006). What seems to be lacking is not the availability of robust public policy mechanisms, but the political and social will to implement them (Sovacool, 2009).

Many countries have created aggressive IR&D programs in a search for new technologies to lower energy demands. Policies to channel energy IR&D in a progressive direction include those specified by Dennis and Larry (Engi and Icerman, 1995).

- Creating an environment where public and private institutions can work together, like the case of Germany.
- Eradicating poor coordination and maintenance of duplicative efforts. Without its eradication, this will hamper the progress of R&D like the case of Italy (IEA, 1992).
- There is need for functional policies to encourage collaborations among public and private R&D organizations.

Policies to channel technology transfer in a progressive direction include those specified by Slavo Radosevic (Radosevic, 1999)

- Reduction of costs and terms of transfer.
- Maximization of the learning effects of technology import.

Various countries have set various energy goals to help achieve energy sustainability. For example, to tackle climate change EU has agreed to reduce greenhouse gas emissions and energy consumption by 20% compared with the 1990 levels as well as to increase by 20% the use of renewable resources. The Chinese government established its 12th Five-Year Plan (FYP) for 2011-2015 on energy and climate goal focussing on 16% reduction in energy intensity, increasing non-fossil energy to 11.4% of total energy use and a 17% reduction in carbon intensity (Lewis, 2011). Europe has a range of policy measures in place including support schemes, standards, and administrative rules to promote renewable energy development (2013) to achieve energy sustainability. However, Europe has a long way to go due to lack of legally binding targets, primarily because member states want to keep control over their national energy policies (Meyer, 2005/2006). The 12th FYP is supported with the country's Renewable Energy Law and Mid-long Term Development Plan for Renewable Energy among others (Ding et al., 2012).

The need for an enabling policy to support the sustenance of the future energy use is critical. This can be made possible by reconciling both the short-term objectives and long-term solutions responsible for energy sustainability.

CONCLUSION

IR&D and technology transfer should be a plan meant for ascertaining economical utilization of energy in all sectors of the economy, including industry, commercial buildings, institutions, households, transport and agriculture. Efficient use of energy is the cheapest and quickest way to mitigate the capital restraints of building new power stations and extend domestic energy supplies. In order to bring about sustainable development, it is essential to further advance and increase energy efficiency. This can be successfully done through energy IR&D and through technology transfer but adequate policies should support them.

In this chapter, activities by which energy consumption could be addressed have been highlighted in the form of energy IR&D and technology transfer for both foreign and indigenous. By examining these activities, we highlighted the benefits of a nation having a dedicated energy IR&D institution with a focus on improving the best approach of minimizing energy consumption. The various cycle steps involved in technology transfer have also been highlighted.

The introduction of energy policies has been to reduce the intensity of energy. Various governments and stakeholders across the globe have its department which responds to various energy challenges that has led to one or more energy policy development. The governments of few countries have policies in place that supports energy research and development and technology transfer. These few governments are found in the developed countries. Since the reduction of energy consumption is a gobal war, it is imperative for joint collaboration beteween developed and developing countries to assist in formulating the right policies to assisting the developing countries in this regard. Before the introduction of demand-side in the energy policy scope, supply-side issues have been on the forefront of most energy policies. A proper analysis and development of IR&D and technology transfer will assist in the development of policies needed for the abatement of energy consumption.

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Chapter 8

THE PROGRESS IN SUSTAINABLE ENERGY IN COLOMBIA

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ABSTRACT

Sustainable energy is important for the development and welfare of the population, and analysis of how the countries use their energy is a key to strengthening productive activities from an environmental protection perspective. This study seeks to determine the progress in sustainable energy in Colombia over the last decade by analysing three features, such as access to energy, energy efficiency and renewable energy. For every feature, this study defines several indicators determining their trends with the primary results, achievements, gaps and barriers within the institutional and policy framework.

The results of this analysis demonstrated that Colombia has achieved significant advances in its access to energy, has recognized the need to increase energy efficiency and has directed actions for the application of renewable energy in specific projects exploiting the significant potential of this energy. The Colombian government has formulated two regulations (Law 691/2001 and Decree 3683/2003) and the PROURE program with Resolution 180919/2010 to implement various measures to promote sustainable energy. However, this country faces several challenges to achieve improved energy use that decreases the environmental impacts while strengthening economic growth and development.

Keywords: Sustainable energy, access to energy, energy efficiency, renewable energy, Colombia

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INTRODUCTION

Energy is an important factor that can aid in the achievement of sustainable development and the reduction of poverty and inequality. Energy affects all aspects of development (social, economic and environmental), including livelihood, access to water, sanitation, agricultural productivity, health, population levels, education, and gender-related issues. None of the Millennium Development Goals (MDGs) can be completed without enhancing the quality, affordability and quantity of energy systems and services in developing countries (UNDP, 2013, Kaygusuz, 2012).

Modern energy services are important to human welfare and to a country's economic development and growth. Access to modern energy is essential for the provision of clean water, sanitation and healthcare and for the provision of reliable and efficient lighting, heating, cooking, mechanical power, and transport and telecommunication services. In 2011, nearly 1.3 billion persons remained without access to electricity, and 2.6 billion still do not have access to clean cooking facilities. However, in recent years, the number of persons without access to electricity has decreased by 50 million globally, and the number without clean cooking facilities has declined by nearly 40 million. These improvements have been primarily in Latin American where 6% of the population does not have access to electricity, and 14% of the population uses traditional biomass for cooking (IEA, 2012).

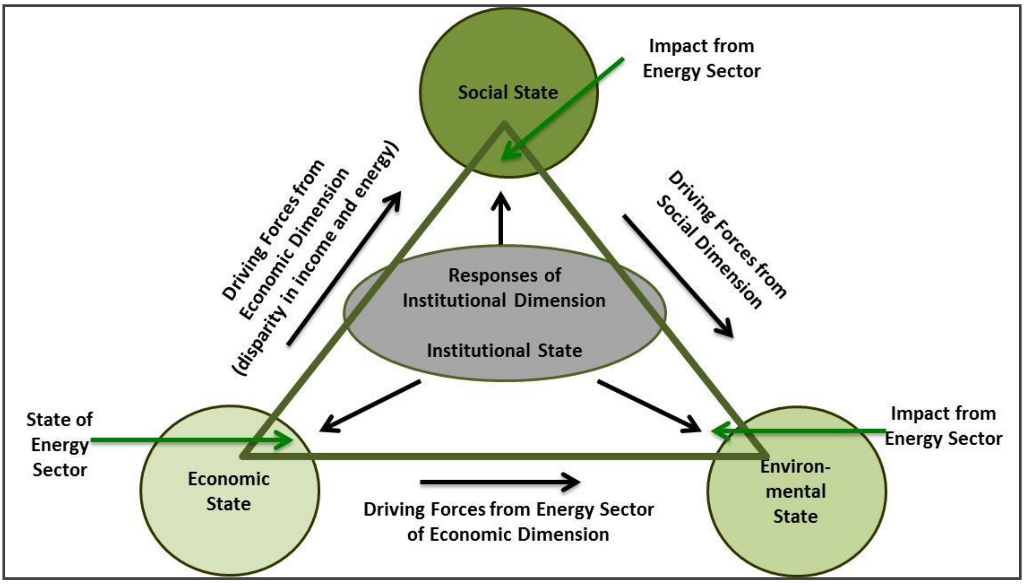
According to the International Energy Agency (IEA) (2012), from the Sustainable Energy for All initiative, to achieve the goal of universal access to electricity and clean cooking facilities by 2030, the investments required are nearly US$1 trillion, which is an average of $49 billion per year (from 2011 to 2030). This requirement is minor compared with the global energy-related infrastructure investment, which is equivalent to approximately 3% of the total.

Both the global gross domestic product (GDP) and energy consumption have shown a substantial growth in the last decades. The global GDP grew by over 100% between 1990 and 2010, with more rapid growth in certain developing countries (WB, 2012). The total final energy consumption grew 23% globally between 1990 and 2005, and developing countries were the fastest growing nations in energy consumption in the world. The consumption of electricity grew 54% during the same period. The energy intensity has decreased in the majority of countries, primarily because energy use has been increasing more slowly than economic activity in most countries. Therefore, the global energy intensity, calculated in terms of the final energy use per unit of gross domestic product (GDP), decreased 26% between 1990 and 2005. The reductions in energy intensity were largest in non-OECD countries due to a combination of structural changes and efficiency improvements (IEA, 2008).

The use of renewable energy has shown progress in certain countries in which the aim of the Sustainable Energy for All (SE4All) Initiative is doubling the share of renewable energy in the global mix. Global investments in these energies increased $211 billion in 2010 with a 32% rate of growth in 2009, and more than half of these investments were in developing countries (Scott, 2012). Renewable energy accounted for more than 25% of the total global generation capacity by the end of 2011 (REN21, 2012).

A sustainable energy economy has as principle of environmental and ecosystem stewardship based on equitable, reliable, renewable, safe, secure, and economically viable energy strategies and solutions that allow for the reduction of energy and carbon intensity while maintaining continued economic growth through innovative energy technologies and an expansion of green jobs.

Sustainable energy sources should be affordable, safe and available in sufficient quantity to enable continued economic and social development while promoting environmental stewardship (NSB, 2009). Figure 1 shows the interrelations between the sustainability dimensions of the energy system.



Source: IAEA, 2003.

Figure 1. Interrelations between the sustainability dimensions of the energy system.

Strategies for sustainable energy should be for both short- and long-term goals, as follows: *i. Short-term strategies*: the design and application of mechanisms for conserving energy, strengthening energy efficiency and developing, demonstrating and applying both existing and new technologies; and *ii. Long-term strategies*: understanding and applying the basic science related to the climate and the carbon cycle, increasing innovative energy technologies, facilitating transfer technologies into the marketplace and decreasing barriers for their application, exploring new materials for better energy storage and conversion, and training the workforce and population in new technologies and strategies on sustainable energy use (IEA, 2012, NSB, 2009).

Studies on sustainable energy have focused primarily on the following topics: a. *Formulation of indicators*: Abdallah et al. (2013) investigated the causal mechanism between indicators for sustainable energy development related to energy consumption from the Tunisian transport sector and determined that, with the goal to improve the energy efficiency in the transport sector, economic growth, environmental degradation, energy and transportation policies should be recognized.

Vera and Langlois (2007) analysed indicators for sustainable energy development that aim to provide an analytical tool for the evaluation the current energy production and use patterns on a national level, determining that indicators are an effective tool for policy makers to evaluate, design and monitor the progress of programs and strategies in the area of energy and can further determine specific areas in which focused measures and policies should be directed. b. *Policies for sustainable energy*: Naimi and Zadeh (2012) showed an overview of the origination and formulation of the sustainable development concept and the related energy policy that examined 40 case studies and determined that new energy policies should consider complex, multi-trajectory, non-linear and dynamic interrelations of energy system components, and the effects of these policies on the energy systems should be estimated before a final policy decision is made. Tsoutsos and Stamboulis (2005) analysed and proposed an alternative approach for the integration of the supply- and demand-side perspectives to deploy renewable energy technologies, suggesting that successful policy should focus on the systemic innovation processes that characterise the development and sustainable diffusion of renewables, which may contribute to the growth of successful applications. c. *Technologies for sustainable energy*: Midilli et al. (2006) investigated the green energy strategies for sustainable development and certain key parameters and requirements for their development, determining that the investment in green energy supply and progress should be encouraged by governments and other authorities for a green energy replacement of fossil fuels to achieve sustainable energy in the future.

Musango and Brent (2011) developed a conceptual framework for an evaluation of energy technology sustainability that included technology development, sustainability and a dynamic systems approach with the goal of understanding the potential effects of a technology and of reducing technology transfer risks to the promotion of sustainable energy technologies at a policy level.

These studies determined the importance of sustainable energy from the formulation of an adequate energy policy to the application of technologies that allow decreased environmental impacts and increase or maintain sustainable development.

Using this background information, this chapter seeks to analysis the progress in sustainable energy in Colombia over the last decade by evaluating three features, such as access to energy, energy efficiency and renewable energy. Studies that determine the trends in sustainable energy in developing countries in a Latin-American context are limited. Hence, this study intends to describe Colombia as a country rich in energy resources that has driven sustainable energy by determining the primary achievements and political strategies.

The remainder of this study is organised as follows: Section 2 presents a review of the energy situation in Colombia. Section 3 explains the primary results and implications for energy access, energy efficiency and renewable energies as key issues of sustainable energy. Section 4 analyses the primary gaps and barriers to achieving sustainable energy in Colombia. Section 5 presents the primary conclusions and policy implications.

THE ENERGY SITUATION IN COLOMBIA

Colombia has significant unrealised potential for sustainable energy gains. The government of this country recognises this potential and has implemented a national energy plan 2010-2030 with objectives, programs and measures to increase the uptake of renewable energy and energy efficiency.

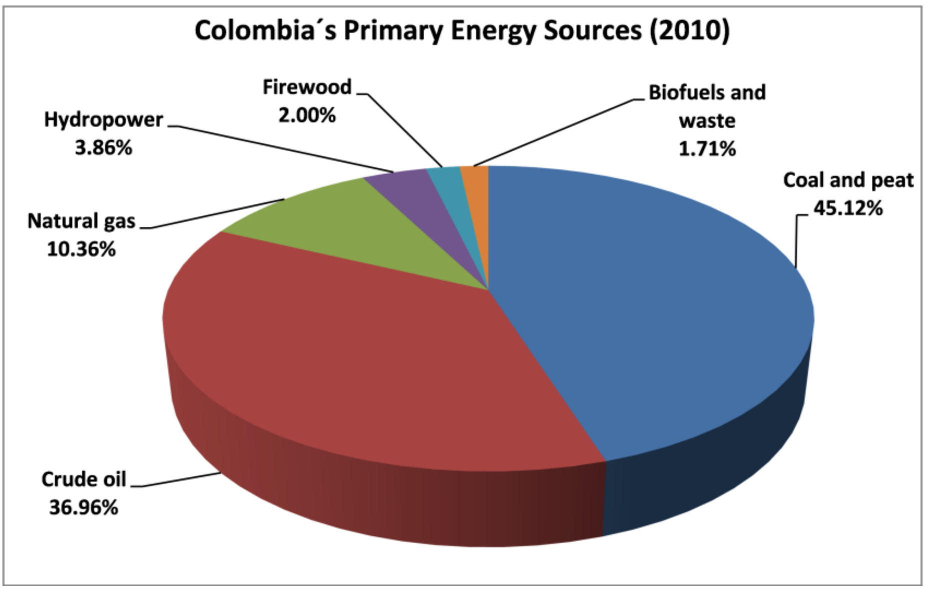
Figure 2 represents Colombia's primary energy mix in 2010 and shows that the primary energy sources are the following: coal (45%), oil (37%) and natural gas (10%). In Colombia, the expected growth rates in renewable energy account for less than 1.6% annually (UPME, 2006a).

Since the 1990s, the Colombian government has modified its role from being a main player, in charge of resources administration, investors and nearly absolute ownership of the electric sector, toward defining a clear separation of the roles between investors and the government, in which the latter is responsible for policy-making, regulating and exercising control, conducting surveillance and performing the electric sector planning, performing a regulatory function for the transmission expansion and indicative for generation expansion (UPME, 2006b). Figure 3 describes the Colombian power sector.

The effective net capacity installed as of December 31, 2011 was 14.42 GW. From the total effective capacity at the end of 2011, the hydraulic plants constituted 64.2%, thermoelectric 31.0%, minor (hydraulic, gas and eolic plant) 4.4% and co-generators 0.4%. Colombia exports electricity to Ecuador and Venezuela, which was represented as 1.294 billion kWh (2011 est.), and imports 8.22 billion kWh (2011 est.) (CIA, 2012).

In 2011, Colombia's GDP was $331.7 billion (current US$). The contribution of the mining and energy sector to the GDP has increased in recent years, with an average over the last decade of 7%, and it has functioned as a stabilizer of internal and external income. The energy sector contributed 22% of income tax in 2009.

Moreover, this sector also contributed 20% of the total government revenue. Colombia has a system of subsidies for the energy consumption of population groups of low-income households (WB, 2012).



Source: UPME, 2010a.

Figure 2. Colombia's primary energy mix in 2010.

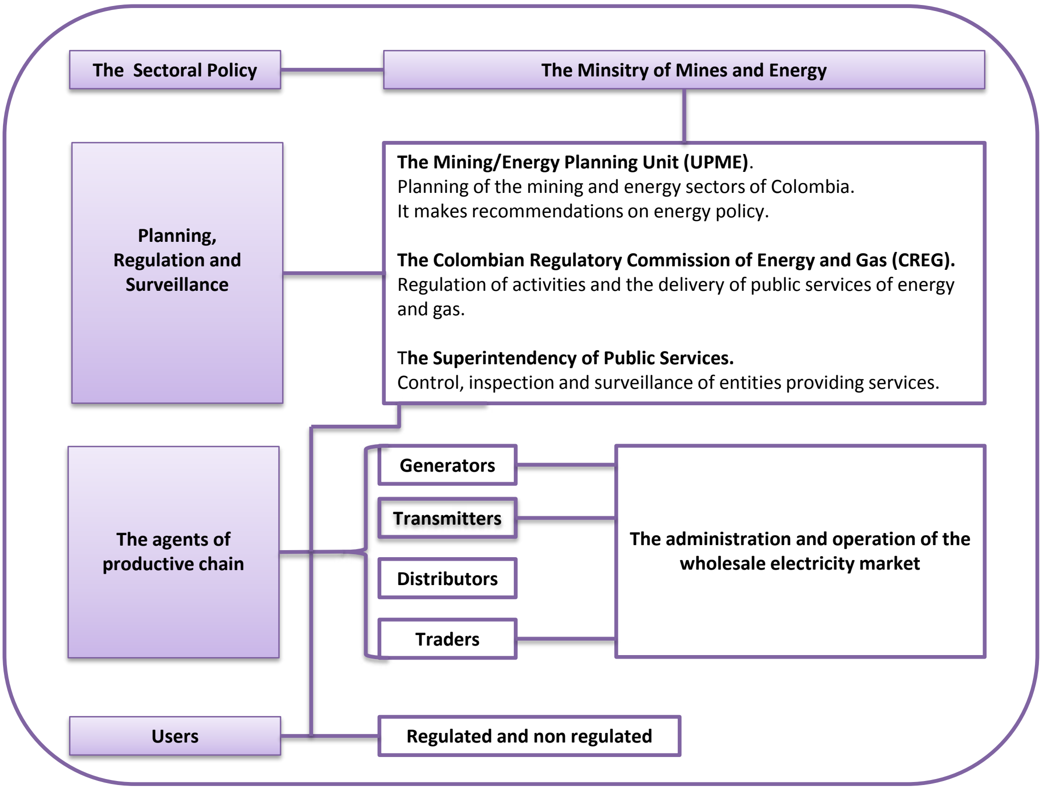
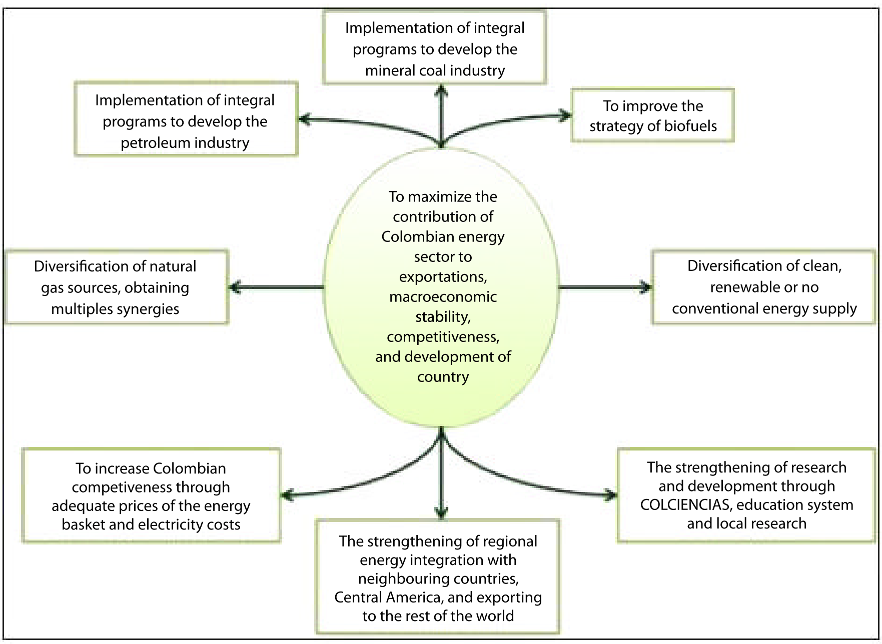


Figure 3. Colombian Power Sector.



Source: UPME, 2010b.

Figure 4. Integration of the energy sector in the National Plan of Development.

RESULTS OF THE PROGRESS OF SUSTAINABLE ENERGY IN COLOMBIA

In this section, the primary results of this study are presented considering the progress of sustainable energy in Colombia based on the following three issues: energy access, energy efficiency and renewable energy.

Energy Access

Colombia has been working on energy access and has developed an indicative plan of electricity coverage expansion that is formulated and reviewed every four years. The last plan was formulated for the period 2010-2014 in which the primary barriers are the acquisition of reliable data for private stakeholders and increased electricity coverage in no-interconnected zones (NIZ), which have generated the formulation of different regulations and incentives to develop new strategies to increase electricity coverage in rural zones with the goal to overcome these barriers.

Physical access to modern cooking appliances is nearly universal in the urban sector, whereas in the rural sector and in NIZ, the coverage is below 70%. In 2010, an estimated 43.0% of households used natural gas, 24.3% used electricity, 23.3% used liquid petroleum gas (LPG), and 7.5% used wood and other sources (1.9%) for cooking. Therefore, most households in Colombia use natural gas for cooking. In this country, tariffs are classified in one of six socio-economic strata, which are used to determine the level of tariffs for electricity and natural gas. In this system, consumers living in areas considered to be poor and consumers using low amounts of electricity receive electricity and natural gas at subsidized tariffs. These cross-subsidies are almost entirely (approximately 98%) financed by consumers living in areas considered to be relatively affluent and in which more electricity is used (UPME, 2010a). Access to electricity is differentiated in the NIZ and the National Interconnected System (NIS) in Colombia. Table 1 shows the primary statistics related to physical access in Colombia.

Table 1. The primary Colombian statistics on access to electricity

Description	NIS	NIZ	Total
Coverage 2009 [%]	95.56%	65.16%	94.90%
Household without service	483,256	78,818	562,074
The estimated coverage 2014 [%]	97.35%	-	97.21%
The estimated coverage 2019 [%]	99.37%	75.49%	-

Source: UPME, 2010c.

The productive sectors (commercial, industrial, and agricultural) in Colombia, localized in urban zones, have universal access to electricity. The total annual demand by sector (in GWh, for 2010) was the following: commercial and public 11,476 GWh, industrial 14,631 GWh, and agricultural 7.24 GWh (UPME, 2010a). Moreover, the productive sector in urban zones is universally connected to the electric grid, and, in several rural zones, the services are accessible for agricultural and industrial activities. Moreover, several industrial sectors have begun to implement projects related to renewable energy sources (RES), energy efficiency and the mechanism of clean development, e.g., biomass in the sugar industry and the palm oil industry, pilot projects to apply RES in rural zones and to improve energy use and decrease CO_2 emissions in energy-intensive industries.

The goals of the Vision Plan 2019 established that Colombia should increase its electricity coverage in the NIS by 99.4% and in the NIZ by 75.49% as a strategy to increase competiveness and development of the country (UPME, 2010c).

These data concur with the advancements and improvements in energy access, especially those in India, Indonesia, Brazil, Thailand, South Africa and Ethiopia. However, in developing Asia and sub-Saharan Africa, the situation is critical, and the worsening trend will persist until approximately 2030, whereas Latin America plans to achieve universal access before 2025 (IEA, 2012, OECD and IEA, 2010).

Energy Efficiency

The Colombian government has promulgated two regulations (Law 691/2001 and Decree 3683/2003) and a program (PROURE) with Resolution 180919/2010 related to the rational use of energy, energy efficiency and non-conventional energy sources. The main objectives of the PROURE program are the following: i. decrease energy intensity, ii. increase and improve energy efficiency in all of the sectors, and iii. promote the use of non-conventional energy sources. These objectives apply to the identification and definition of potential energy-saving goals and participation of non-conventional sources and technologies in the energy basket of the country. The main purposes of this program are to increase energy security according to demand, increase industrial productivity, especially in the energy-intensive sectors, improve the quality of life and decrease greenhouse gas emissions. Moreover, the PROURE program includes sectorial subprograms for industry, households, transport and services (MME, 2010).

In 2010, the total primary energy supply was 1,587,100 TJ. The total GDP (current US$) in the same year was US $ 288,764 million. This value corresponds to US $181,945 of the GDP per TJ in 2010. The trends in GDP and energy consumption show a relative decoupling, although their trends are similar in the Colombian case (UPME, 2010a, WB, 2012).

The industrial sector in Colombia consumed 159,901 TJ in 2010, which represented 33% of the total electricity demand. In 2010, the commercial sector consumed 12,875 TJ and accounted for 42% of the total electricity demand (UPME, 2010a). Based on the PROURE, the industrial sector has the following subprograms: optimization of electricity use as the driving force, optimization of boiler use, efficiency in illumination, energy integral management in industry with an emphasis on cleaner production, cogeneration and auto-generation, rational use and energy efficiency in small and medium enterprises (SMEs), optimization of the combustion process, and optimization of the cold chain. According to Resolution 0186, for 2015, the energy saving goals for the industrial sector are 3.43% for electricity and 0.25% for other energy sources. For commercial and service sectors, the PROURE program determined the following subprograms: diffusion, promotion and application of technologies and good practices in illumination systems, refrigeration and air-conditioning; design, construction, energy reconversion, and efficient and sustainable use of buildings; characterization, indicators management and technical assistance; and updating or technological conversion of public lighting (MME, 2010).

Households consumed 41% of the electricity in Colombia in 2010. This usage equated to a total consumption of 70,747 TJ in that year (UPME, 2010b). The PROURE program established the following sub-programs for this sector: substitution of incandescent light bulbs; energy efficiency in refrigeration equipment, air-conditioning, and other electrical appliances; application of fuel-efficient stoves, especially in rural zones; design, construction and efficient and sustainable use of households; and application of the GLP in the rural sector and marginal zones (MME, 2010).

The Colombian government, through the PROURE program and Resolution 180919/2010, established in Article 1 the goals of energy saving and efficiency for the industrial and transport sectors. Table 2 shows the goals of energy saving and efficiency. The government intends to achieve these goals by the implementation of sub-programs and lines of action with the PROURE program (see Table 3).

Table 2. The goals of energy saving and efficiency

Sector	Goals of energy saving - 2015	
Industrial	Electricity	3.43%
	Other fuels	0.25%
Transport	Other fuels	0.33%

Source: UPME, 2010c.

Table 3. The sub-programs and lines of action for energy efficiency

Sub-program	Lines action
Industrial Sector	
Optimization of electricity use for the driving force	To promote the substitution of motors by high energy efficiency motors
Optimization of combustion process	To promote the advantage of the residual heat generated in the combustion process
Transport Sector	
Technology re-conversion of vehicle fleet	To promote the use of electric and hybrid vehicles in the mass transport system
Modes of transport	To mass the use of train
	To mass clean transportation systems

Source: UPME, 2010c.

In the Latin American context, Colombia has shown strong and steady GDP growth and has achieved decreased energy intensity (20%) in the last 15 years, whereas countries, such as Argentina and Brazil, have increased this indicator (GTZ, 2003 and WEC, 2004).

Renewable Energy

Colombia has directed actions for the application of renewable energy, especially in the identification of individual projects for the NIZ in the last three decades. Colombia, by its geographical position and features, has a significant potential to apply several renewable energies, such as solar, hydric, biomass, geothermic, and ocean energy. The law 697/2001 recognised renewable energy as important to the public interest and national coexistence. Moreover, the PROURE program seeks to promote the use and inclusion of renewable energy in the national energy matrix with diversification, complementarity and security criterions considering the appropriate technologies for the economic, social, productive and environmental conditions of this country.

In Colombia, 63.3% of the electricity is generated by large hydroelectric plants that are not considered to be renewable energy due to their greater environmental impacts. Therefore, the use of utility scale renewable energy generation in Colombia is limited and has been focused especially in the NIZ, despite the significant potential to apply several renewable energies, such as solar, hydric, biomass, geothermic, and ocean energy. There is a certain amount of distributed generation, but it makes up less than one percent of the total generation capacity For example, in 2009, distributed generation was composed of 472 MW of small hydroelectric plants and 18.4 kW of wind energy). Several projects that apply renewable energy in Colombian NIZs have developed under the leadership of the IPSE as a strategy to increase energy access and the use of modern energy (UPME, 2010b). In 2009, 77 MW were installed, which is equivalent to 110.000 m^2 of solar collectors in which the primary use is for heating water in several Colombian cities and other applications in the NIZ (UPME, 2011).

In the NIS, the use of renewable energy sources (RES) is focalized in small hydroelectric plants, in processes using cogeneration with cane bagasse or biomass used primarily by sugar mills and wind generation in which smaller plants of 20 MW could commercialize energy. In the NIZ, the primary RES are photovoltaic systems in isolated applications for telecommunications. Moreover, the IPSE has developed several pilot projects as innovation centres for the application of RES in the NIZ to encourage the use of these energy sources in rural productive activities (e.g., poli-generation in La Guajira, a biomass gasifier in Necocli, smaller hydroelectric plant in La Encarnación, and photovoltaic systems in Isla Fuerte, etc.) (UPME, 2011).

The Colombian government, through the PROURE program and Resolution 180919/2010, established in Article 2 the goals of using renewable energy in the Colombian energy sources (see Table 4). To achieve these goals, the primary lines of action are the following: i. to characterize solar, wind, small waterfalls and geothermic energy potential with the goal of promoting the development of energy solutions; and ii. to develop and implement pilot projects of renewable energy considering technical, economic, market, environmental and social variables.

Table 4. The goals of renewable energy in Colombia

Participation of renewable energy in NIS	
2015	3.5%
2020	6.5%
Participation of renewable energy in NIZ	
2015	20%
2020	30%

Source: UPME, 2010c.

The data of Colombia concur with features of developing countries in which renewable energy sources provide more than half of the total primary energy supply and a higher proportion of electricity than in industrialised countries (REN21, 2012, Scott, 2012).

GAPS AND BARRIERS FOR SUSTAINABLE ENERGY IN COLOMBIA

There is a need to strengthen the institutional framework for sustainable energy in Colombia. The public institutions recognise this need. The Colombian National Energy Plan 2010-2030 calls for the following:

- To achieve better coordination between the many different agencies and institutions involved in this sector with the goal of determining and clarifying roles and coordinating joint actions.
- To achieve better coordination with other ministries to develop sustainable energy policies according to the requirements of the country.
- To institutionally strengthen certain entities, such as UPME and CREG, by defining the primary origin of their resources for funding.
- To define and implement an autonomous institutional framework to promote energy efficiency and renewable energy resources.
- The publication and continuous updating of information on energy technologies and statistics.
- To improve sectorial information systems.

However, in the Colombian National Energy Plan 2010-2030, it is necessary to define specific action plans for the implementation of strategies and measures. Technical and financial assistance may be required.

The Colombian government, through the National Energy Plan 2010-2030, has determined the following challenges for the power sector:

- Expansion of the electric sector: i. to establish a technologies mix to guarantee a reliable supply and decrease the vulnerability of the system, especially climatic and hydrological conditions; ii. to encourage the use of renewable energy in new power plants by modifying the reliability charge; iii. to achieve improvements in energy efficiency in power plants; iv. to improve market regulations.
- Market: i. to achieve an effective price discovery that reflects the scarcity of the resources, the environmental effects and risk; ii. to define a mechanism of efficient contracting.
- Transport and distribution: i. to improve the technical quality in the substations; to define a remuneration mechanism for plans of reduction of losses.
- Grants and contributions: i. to analyse the level of grants and contributions with the goal of allowing access for the entire population and maintaining or increasing the competitiveness of the Colombian industry, ii. to maintain the financing of the Support Found for Rural Electrification (FAER), the Support Found for Non-

Interconnected Zones (FAZNI) and the Found of Social Energy (FOES) to increase access to modern energy in poor and isolated zones in Colombia.

To achieve the goals for sustainable energy, Colombia recognizes that it must strengthen its institutional framework, educate sufficient sustainable energy technicians and engineers, increase awareness among the public through public awareness campaigns and facilitate the provision of a reasonably priced fund for sustainable energy investments in the public and private sectors. However, further work will be required to define and implement measures to achieve these targets. Table 5 shows a summary of the objectives for sustainable energy in Colombia.

Table 5. Objectives for Sustainable Energy in Colombia

Objectives	Situation
Energy access	The electricity coverage has increased especially in the interconnected system whereas in non-interconnected zones the coverage is 70%.
Renewable energies	The government has generated different regulations to motivate the application of renewable energies especially in non-interconnected zones with the aim to increase these energies in 30%.
Energy efficiency	The government has developed PROURE program that seeks the implementation of energy efficiency in all sectors. In the industrial sector the objective is to save 3.43% of electricity and 0.25% of the other fuels.

CONCLUSION

Colombia has made significant advances in its energy access, but in rural and non-interconnected zones, the access to modern energy remains limited, primarily due to cost and geographic conditions, with electricity coverage below 70%. The use of renewable energy in electricity generation is limited (lower than 1%); however, the country formulated several regulations to increase the share of renewables in its electricity generation mix, especially in non-interconnected zones, with an objective to supply 30% by 2020.

In Colombia, the access to modern energy is nearly universal in the urban sector, whereas in rural sectors and in the NIZ, the coverage is below 70%. However, the primary problem with increasing the electricity coverage in the NIZ is the cost of the technologies that generate electricity; an alternative should be RES, which has been led by the IPSE with the development of several innovation centres of RES. Moreover, the Colombian government has promulgated two regulations (Law 691/2001 and Decree 3683/2003) and a program (PROURE) with Resolution 180919/2010 related to the rational use of energy, energy efficiency and non-conventional energy sources with the goal of implementing measures and strategies for increasing the economically and commercially viable energy efficiency and renewable energy technologies that improve the welfare of the population.

The Colombian government has also recognized the need to increase energy efficiency. In the industrial sector, the objective is to save 3.43% of electricity and 0.25% of other fuels. The Colombian government formulated two regulations (Law 691/2001 and Decree 3683/2003) and the PROURE program with Resolution 180919/2010 to implement several measures to promote energy efficiency and conservation, including setting energy efficiency standards, requiring energy audits, remaining informed about changes in technologies, strengthening energy information systems and developing public information, education, and awareness campaigns and programs.

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Chapter 9

ENERGY CONSUMPTION AND SOCIAL INEQUALITY: THE PROBLEM OF FUEL POVERTY

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ABSTRACT

A growing awareness for the problem of fuel poverty can be observed in industrialized countries. Fuel poverty implies, amongst other things, an inability to heat or light the flat sufficiently or having expenses above average for energy provision. It represents an expression of social inequality in the energy system. This chapter approaches the issue of fuel poverty from a European perspective, focusing on Austria in particular. It is being questioned how fuel poverty could be defined, which reasons account for it, and which consequences it implies for those concerned. Questions about measuring fuel poverty are being discussed, and numbers about the extent of fuel poverty in Austria and Europe are presented, also making reference to empirical projects in Austria. A whole section is dedicated to coping strategies of fuel poor households. To close with, possible policies for tackling fuel poverty are being presented, weighing up their respective strengths and weaknesses.

Keywords: Social inequality, fuel poverty, vulnerability, coping strategies

INTRODUCTION

Energy is a basic requirement for social life and social integration and is also tightly linked to social structure and power relations (Rosa et al., 1988). Energy consumption is a manifestation and part of social stratification, and social inequalities often become evident in

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energy practices. Analyses of the social differentiation of energy consumption are crucial because they shed light on patterns of social distribution and ways of appropriating the use of resources. While (unlimited) availability of energy is the norm for some social groups in industrialized countries, other parts of society are faced with the problem of not being able to afford energy in sufficient quantities or having to limit their use of energy services. To give an example: Even in European countries, deaths related to energy causes are not the exception because some people are not in a position to keep sufficiently warm in winter or to protect themselves from heat in summer. In the UK, for example, almost 30,000 people died from cold-related illnesses in 2007/08 (Boardman, 2010).

Although socially less privileged groups in general have a lower consumption of energy, their position on the energy market is feeble, i.e., in most cases they have to spend more on energy than households on a higher income (e.g., due to dunning fees because of delays in the payment of their bills). Moreover, they profit less from a liberalization of the energy market because they change their energy providers less frequently than households on a better income and thus often keep paying higher rates (Summerton, 2004).

What is more, socially less privileged groups are notably more frequently hit by fuel poverty that is to say they are frequently incapable of satisfying basic needs such as heating their homes adequately. These groups of energy consumers are vulnerable to the consequences of insufficient or insecure access to energy. In the face of the complex interplay of rising energy prices, stagnant or decreasing incomes, high levels of unemployment, and the slow rate of redevelopment of residential buildings in terms of improving energy efficiency, the problem of fuel poverty has become increasingly urgent in recent years.

A growing awareness for the problem of fuel poverty can be observed within our society. One indicator for this is the increase in the number of media coverage about people who are unable to heat their homes during winter or struggle to pay their energy bills. What is more, social organizations report that more and more people with energy-related problems are consulting respective advisory centers. Fuel poverty cannot be considered a problem only on a global level anymore but also affects well-off industrialized countries.

Austria is one of the countries which still need to develop a comprehensive understanding of the problem. It can be observed that fuel poverty is increasingly being discussed in public by social organizations who are in touch with those affected by the problem and are trying to find solutions on the one hand, and activists who take up the cause of fighting poverty in all its manifestations on the other. Having said this, it also has to be noted that on a political level, fuel poverty is still not being recognized, and none of the departments assumes responsibility for this issue. Single measures in the course of the implementation of the Third EU Single Energy Market Package, designed to protect vulnerable consumers, have also been taken in Austria, but yet, a comprehensive debate of this issue on the level of society or politics is still pending. A definition of fuel poverty is missing, therefore precise numbers are not available and it remains difficult to reliably estimate the frequency of fuel poverty. Although quantitative empirical reports are still due, there are at least some preliminary qualitative insights about the causes, forms and consequences of fuel poverty in Austria.

This chapter approaches the issue of fuel poverty from a European perspective, focusing on Austria in particular. It is structured in the following way: First, questions are being raised about how fuel poverty could be determined more clearly, which causes may be held accountable for it, and why fuel poverty is not merely a question of poverty. In sequence, different ways in which fuel poverty manifests itself are discussed in a European context. The issue is then presented from the point of view of those concerned, pointing out which coping strategies low-income and/or fuel poor households adopt and which consequences they might entail. Finally, possible political measures for combating fuel poverty are being discussed, elaborating on their respective potentials and limits.

WHAT IS FUEL POVERTY?

Before going into greater detail about the causes of fuel poverty it is necessary to define the terms employed here. On an EU level, for instance, the expressions 'fuel poverty' and 'energy poverty' are sometimes used in a contradictory sense (Thomson & Snell, 2013).

In this chapter, the term 'energy poverty' refers to the fact that 1.4 billion people world-wide do not have access to energy (especially electricity) and that for another billion people, energy is available only in irregular intervals (Sovacool et al., 2012). However, fuel poverty cannot be considered a problem only on a global level anymore as it also affects well-off, industrialized countries. Fuel poverty in industrialized countries implies, amongst other things, an inability to heat or light the flat sufficiently; expenses above average for energy provision; energy inefficient flats, heating systems and household appliances; health hazards caused by bad housing conditions and reduced thermal comfort; debts with energy suppliers; power cuts because of outstanding payments; cutbacks in other areas in order to pay for energy (Brunner et al., 2012).

A combination of factors may be held responsible for fuel poverty, among them: high energy prices, low incomes and low energy efficiency of flats (Boardman, 2010). Besides these main causes, further constituting factors may be identified. Sunderland & Croft (2011) registered that under-occupation of buildings, dependence on rent prices, precarious living conditions and high costs of living may feature among the elements conditioning this situation. A lack of savings, as well as living in rented dwellings might further limit the possibility for improvements in the energy efficiency of the building on part of the inhabitants (Boardman, 2010). What is characteristic for the fuel poverty dilemma is that the causes are less frequently singular, but rather appear to be in interplay with each other. Therefore, fuel poverty resulting from various causes cannot be equaled with poverty in terms of income. While the latter may be effectively combated by financial support, this measure is not sufficient in the case of fuel poverty (Healy, 2004).

People living in poverty because of a low income, on the other hand, cannot automatically also be considered fuel poor; however, fuel poverty does not necessarily occur in combination with a low income. We thus have to assume that there are two groups to start with, including a certain number of people at the intersection of both income and fuel poverty. To quote an example, in 2011, a number of 219,000 Austrians were unable to afford heating their flats adequately. More than half of these people were not considered to be at risk of poverty (Statistik Austria, 2012). At the same time, income poverty and fuel poverty may potentiate each other. Households on a low income might be forced to cut back on their energy consumption; reversely, high energy bills (e.g., conditioned by energy inefficient buildings) may reduce the household budget dramatically (Thomson & Snell, 2013).

All this indicates that fuel poverty cannot only be seen as a topic related to poverty and located within the responsibility of social policy measures. It has to be recognized that it lies at the cross-section of social, environmental, energy and housing policies.

Whether a household may be considered as fuel poor, however, depends on the respective definition. On an EU level, still no unified definition of fuel poverty exists, but it has to be noted that, over the past years, signs of recognition of the issue of fuel poverty could be noticed, accompanied by respective policies intended to tackle the problem (Bouzarovski et al., 2012). Thus, the European Economic and Social Committee made the suggestion to define fuel poverty as “the difficulty or inability to ensure adequate heating in the dwelling and to have access to other essential energy services at a reasonable price” (Santillán Cabeza, 2010, p. 1). Moreover, two European Council Directives declared that especially vulnerable customers should be supported. What exactly the term 'vulnerable customers' implies was left for the member states to define, stressing the importance of securing a high level of consumer protection (European Parliament, 2009). The Council Directives, however, do not contain any indications as to who is likely to be a vulnerable customer, or which possible measures to counter fuel poverty could be taken and integrated into national action plans (Bouzarovski et al., 2012). Therefore, a common definition is still not in sight at the present moment.

On a national level, only Ireland, France and the UK have released official definitions of fuel poverty to date (Thomson & Snell, 2013). While the Irish government defines fuel poverty as “the inability to afford adequate warmth in a home, or the inability to achieve adequate warmth because of the energy inefficiency of the home“ (Office for Social Inclusion, 2007, p. 67), in France, people are considered fuel poor if they face difficulties to ensure energy supplies that satisfy their basic needs, especially if due to a lack of financial resources or bad living conditions (Plan Bâtiment Grenelle, 2009). The most well-known is the British definition, according to which a household may be considered as fuel poor if it needs to spend more than 10 per cent of its income in order to achieve adequate energy services in the home.

In the past years, however, the British definition has been increasingly criticized. On the one hand, the absolute limit of 10 per cent is considered deliberate, and many voices call for exchanging it for a relative measuring of fuel poverty. In the latter, fuel poverty is defined in relation to other households (comparison of the income situation and energy costs). On the other hand, the question about in how far costs of housing should be considered in these calculations is still open to discuss. Furthermore, critical comments suggest that income and energy costs should be considered according to the composition of the household.

Stimulated by ongoing debates about this definition, efforts have been made to find other ways of defining fuel poverty (Moore, 2012). Thus, in 2011, John Hills was invited to reassess the current methods of measuring fuel poverty. A year later, Hills presented an alternative definition of fuel poverty which strives to compensate the flaws of the existing one. According to Hills (2011), fuel poverty arises from an interplay of costs above average and household income below average. His definition therefore consider households as fuel poor if they have required fuel costs above the median level and were they to spend that amount they would be left with a residual income below the official poverty line. In view of the concerns about the current definition, the government intends to adopt the approach being put forward in Hills’ final report. There are plans for developing a new fuel poverty strategy for the UK in 2013, taking the revised definition of fuel poverty as a basis (DECC, 2012).

While the UK already looks back on a long history of engaging with and trying to combat the problem, other countries have only developed a marginal perception of the issue, if at all (EPEE, 2009). Therefore, enormous differences can be observed between the nations of Europe concerning the perception, measurement and control of fuel poverty. It has been estimated that between 50 and 125 million people within the EU are living under conditions of fuel poverty, and these figures are predicted to rise further in the near future. Social and political awareness for this problem, however, is still relatively low or rather, varies considerably (Santillán Cabeza, 2010).

THE EXTENT OF FUEL POVERTY

The first part of this section presents various possibilities for measuring fuel poverty. On the basis of this, figures on fuel poverty in Austria and across Europe are then being discussed.

Measuring Fuel Poverty

Objective and/or subjective indicators may be used for measuring fuel poverty, depending on the respective definition. Objective indicators refer to factors like household income, equipment or energy costs, just to name a few. In contrast to this, subjective indicators register aspects of fuel poverty in terms of individual estimates, bringing the perspective of those concerned to the foreground.

In the British definition of poverty, objective indicators on income and energy costs of the household hold a central position. In the previous section, it has already been touched upon briefly that there is no unified opinion on how to quantify these factors. Thus, when eliciting household income, discussions on whether only the "basic income" (net income of all members of the household, including subsidies) or the "full income", which also considers earnings from housing (e.g., housing benefits, income from rent) should be used as a basis (DECC, 2010). In England, "full income" has been opted for since 1996 in registering those hit by fuel poverty, as it had proved that recurring to the "basic income" identified too many rich households as fuel poor than was actually the case (Boardman, 2010). It also remains a contested issue whether to consider the number of people in the households. The current definition (full income, no conversion according to number of people in the household) mainly prefers households of senior citizens, especially those living on their own (Moore, 2012).

When measuring energy costs, the actual fuel spend might be an adequate source of information. Many households, however, limit their energy consumption for cost reasons, compromising their health as a consequence. Therefore, arguments in favor of calculating the costs that would be required to achieve a room temperature beneficial to health (required fuel spend) are being put forward. In principle, the real energy costs can objectively be gathered by means of energy bills. Also, drawing on the necessary energy costs, which is currently being practiced in the UK, may be considered an objective indicator, as this method does not take into account individual energy necessities of the household members.

In a number of studies on fuel poverty on an EU level, subjective indicators were included, as well, for instance in the “consensual approach” (Healy, 2004). It defines fuel poverty as an inability to afford items that the majority of the general public considers to be basic necessities of life, e.g., having a warm home beneficial to one's own health. Indicators used for measuring fuel poverty refer to the financial situation of the household (energy bills and costs of housing), the building substance (e.g., dampness, mold) and the heating technology in place. They may be divided into subjective estimates of the people interviewed on their own housing situation and income, on the one hand, and objective indicators about the building substance and the financial situation on the other. The key indicator for the identification of fuel poor households according to Healy (2004) is the subjective indicator which captures whether a household can afford keeping its home adequately warm. From this follows that questions on the household income and energy or heating costs do not remain in the foreground anymore. Moreover, temperature limits related to health become obsolete, as the interviewees themselves quote an estimate of what they consider adequate.

Fuel Poverty in Austria

Since there is no official, legal definition of fuel poverty in Austria, also no comprehensive surveys on the extent of fuel poverty have been conducted to date. Based on Healy's (2004) approach, however, the subjective indicator on the affordability of adequate room temperature which is being assessed yearly within the EU might be taken as a point of reference here. In 2011, this indicator revealed that 219,000 Austrians were unable to afford heating their homes sufficiently (Statistik Austria, 2012). Even if this number may not be taken to equal the number of people living in fuel poverty (ideas about what is sufficient may vary), it provides a tentative quantitative insight into the situation in Austria regarding fuel poverty. A project currently ongoing in Austria with the participation of the authors of this text – the "Pilot Project against Fuel Poverty" – is drawing on both objective and subjective indicators for measuring fuel poverty. The project is funded by the Austrian Climate and Energy Fund and being carried out in cooperation with three projects of the welfare organization Caritas. It has the aims of implementing tailor-made measures of energy efficiency against fuel poverty in 400 fuel poor households in Austria and of elaborating a national program against fuel poverty (Brunner et al., 2013). The households are selected within the projects according to the urgency of their situation (e.g., debts with their energy provider, power cuts). The free-of-charge offer by this organization grants households in need individual counseling sessions which directly relate to their lived-in worlds. In the course of this, the living and housing situation of the participants is also being evaluated. Objective indicators consider elements such as the condition of the building and the housing situation of the household. Preliminary data show that more than half of all households included in the study live in buildings dating back to before 1960. At the same time, there is no evidence of redevelopment measures in many of these cases. Accordingly, numerous of the residents in the households under investigation have to live with strains caused by leaky windows and doors. In one third of the households mold was identified, mostly in the bathroom/toilet, but also in other parts of the flat, representing a health hazard. The mold evidenced inside the buildings also clearly supports the conclusion that the dwellings are not energy efficient, ineffectively heated or continuously remain unheated (Healy & Clinch, 2002).

Subjective indicators on fuel poverty in this project include estimates about the room temperature and perceived difficulties in the payment of energy bills. Thus, in about half of the cases, walls and floors are frequently perceived as cold, around one third is unable to maintain the whole living area warm enough to feel comfortable. The number of households which have to worry about being able to pay their energy bills is extremely high (around 85%). Most of the cases examined state to have experienced difficulties in paying their energy bills over the past two years. For one of the three sub-projects under the heading of the Pilot Project against Fuel Poverty, a particular low-threshold approach was chosen, allowing access to people living in severe fuel poverty, i.e., people characterized by multiple burdens, in the Austrian capital Vienna. Examining this subgroup, the situation presents itself even more serious than expected: more than two thirds of these households live with mold in the dwelling, most of them have already received an overdue notice from their energy provider, and more than 10% have experienced a power cut during the past years. Even though the households were not selected by methods of statistical sampling but went to see assistance with a counseling service in energy related problems, one thing may be concluded from this: even in lack of a clear definition of fuel poverty it is evident that fuel poverty represents a problem in Austria which would require more attention than is currently the case. Especially those living in deep fuel poverty are in need of immediate support.

Fuel Poverty in Europe

A recent country comparison by Thomson & Snell (2013) reveals that the situation regarding fuel poverty is even more severe in other EU countries than in Austria. For this study, three indicators were chosen for measuring fuel poverty: the ability to pay for keeping the home adequately warm, arrears on utility bills in the last twelve months, and evidence of a leaking roof, damp walls or rotten windows. This selection is based on the consensual measurement of fuel poverty already mentioned above (Healy & Clinch, 2002).

The majority of the households which are currently unable to afford keeping their house warm could be found in Portugal (35.3%), followed by Bulgaria (31.6%) and Cyprus (30.8%). The EU average here results in 12.1%. In comparison to this, relatively few households (2%) in Luxemburg, Estonia and Sweden state being unable to finance adequate heating for their homes. The fact that particularly countries with a milder climate lead the ranking may be attributed to the low quality of the building substance of houses and flats in those countries.

With respect to arrears with payment of utility bills, lower numbers were registered altogether. The EU average for this indicator lies at 7.8%. The largest number of arrears was registered in Bulgaria (32%), Romania (23%) and Greece (16%); the Netherlands, Luxemburg and the UK quote the smallest numbers with less than 2%. An especially large number of households are confronted with leaking roofs, damp walls or rotten windows; the EU average regarding this objective indicator is 18.1%. Only in four of the member states (Slovakia, Denmark, Sweden and Finland), less than 10% of the households state to be living in such conditions. A particularly high concentration of households with bad housing conditions was evidenced in Hungary (31.2%), Slovenia (30.8%) and Bulgaria (29.1%).

In total, the research carried out by Thomson & Snell (2013) brings to light how widespread fuel poverty is within the EU, especially in the new member states, such as

Bulgaria and Romania. From this perspective, fuel poverty appears to be a problem in countries in the South and East of Europe in particular. According to this data, Austria is concerned to a comparatively low degree. This, however, should not lead to the conclusion that it is not necessary to take measures against fuel poverty.

THE PERSPECTIVE OF THOSE CONCERNED: COPING STRATEGIES AND SCOPE OF ACTION

In the section at hand, the focus lies on the following questions: How do people affected by fuel poverty deal with this situation? Which strategies do they invent in order to satisfy their need for warmth and light? What is their scope of action, given certain conditions of housing and living?

To date, only few studies exist which place those concerned in the center of interest (Boardman, 2010). However, these few papers, together with our own research results allow for reasonable insights in coping strategies and scopes of action of people affected by fuel poverty. In a first step, we are going to discuss the results of one of our own empirical research projects, later on contextualizing them against the backdrop of a number of international studies.

Fuel poverty in Vienna: The NELA Project

The project NELA (German acronym for 'Sustainable Energy Consumption and Lifestyles in Poor and at-Risk-of-Poverty Households'), was realized between 2008 and 2011 and financed by the Austrian Climate and Energy Fund. Its main aim was to investigate energy practices in poor and at-risk-of-poverty households in the Austrian capital Vienna (Brunner et al., 2012). The project was based on the qualitative research paradigm (methodology of Grounded Theory) and strived to analyze energy consumption under limited financial conditions in its various manifestations, underlying motives, driving forces and causes. The perspectives of those concerned and their ways of dealing with the situation in conditions of living and housing which contain elements of fuel poverty to a greater or lesser extent formed the core of the project. In total, 50 qualitative interviews were conducted in poor and at-risk-of-poverty households (plus 10 in high-income households). Additionally, quantitative data (e.g., on the appliances featured) and, to some extent, also data on real energy consumption (evidenced by energy bills) were gathered. The interviews were conducted during summer 2009 and spring 2010 within the dwellings of the interview partners, which at the same time allowed gaining insights into their living and housing conditions. The majority of households are concentrated in certain districts (working class districts and districts with a large share of immigrants). Contact with the interview partners was established through social organizations and NGOs. All interviews were transcribed and analyzed according to hermeneutic methods and computer-based qualitative data analysis.

Some of the results of the NELA project regarding energy burdens and coping strategies shall be summarized here:

Analyzing the interviews, it became evident that energy practices in poor and at-risk-of-poverty households result from the interplay of a number of factors. Living and housing conditions represent a crucial factor here. A large number of households live in deprived conditions, carrying multiple burdens (lack of financial resources, energy-inefficient dwellings, old devices, high energy costs and long-term illnesses, just to name a few). Debts, lack of provisions and economizing as a way of life are the order of the day. Adopting a modest lifestyle in various dimensions often becomes a necessary long-term strategy in order to cope with the situation.

In recent decades, it could be observed in numerous spheres of everyday life that the standards of what is considered normal with reference to energy consumption in our society have gradually increased (e.g., higher room temperatures, more marked hygienic standards, doing the laundry more frequently) (Shove, 2003). Faced with these developments, many of the low-income households included in the study react to burdens they bear with a clear lowering of their living standards, adapting successively to conditions below the level of what would commonly be considered a 'normal' lifestyle. A comparative analysis shows that financially well-situated households do not even think about some of the things that poor households already consider a luxury (e.g., heating all rooms of the house or taking a full bath).

The limited financial resources of most of the interviewees are mirrored in the state of their dwellings. The majority lives in blocks of council flats or similar blocks of flats for rent, the larger part of which date back years in their construction, are badly insulated and have leaking windows and doors. Only a small share of the people lives in thermally improved, energy-efficient flats. Income does not only limit the free choice of dwelling, but is frequently also reflected in household equipment and appliances. The latter are often little energy efficient, old and second-hand appliances are common, and compared with high-income households, the degree of equipment is generally low.

High energy costs or unexpected additional margins of energy suppliers, augmenting the debit of the households concerned, represent another problematic area of living in conditions of poverty. Two thirds of the people interviewed perceive their energy expenses to be a burden. Increasing prices are particularly problematic because they might entail an additional subsequent payment on the annual statement, even if consumption did not augment. Frequently, low-income households display a fragile financial management, leaving them unprepared for high supplementary payments at the receipt of the annual statement. Thus, receiving an invoice for the annual bill represents a disconcerting experience or even a shock for many of the people interviewed. Delayed payments may in consequence lead to power cuts, which further on could initiate a spiral of debts. If financial management and supportive systems fail, disconnections could be the consequence. More than a quarter of the people interviewed reported having been disconnected, sometimes more than once, from power supply due to non-payment of arrears. Frequently, the debts are settled within a few days after disconnection and the services are restored. Sometimes, however, the financial crisis continues, and the household remains cut off from energy services. In the most extreme cases, this situation could even last for several years.

Even though various strategies are being adopted to keep energy costs at a minimum and exploit saving potentials, a lack of feedback systems often renders them a highly insecure tool. In most cases, the annual energy bill remains the only feedback which allows evaluating if the effort of reducing energy consumption has been successful. Moreover, the resulting savings are often made void by rising energy prices.

Within the sample of 50 interviewees, a large number of different coping strategies regarding heating and lighting practices could be identified and divided into strategies for efficiency and strategies for sufficiency, both of which are characterized by low necessity for investment. What was termed efficiency strategies mainly comprises low-cost investments, which allow for increasing the efficiency of the dwelling (e.g., windows) or appliances (e.g., water-saving tops). They also include sealing leaking windows and/or covering them with thick protecting curtains, or installing window blinds, all with the aim of preserving heat (cf. Harrington et al., 2005). All actions geared towards reducing energy consumption through cutbacks and sacrifices can be considered sufficiency strategies. In 21 out of the 50 households, the heating is turned on only in one room of the flat. For one third of the households, the cold part of the year also signifies having to put on various layers of clothing inside the house. Another related strategy for coping with the cold inside the flat is “slipping under the covers”, even at daytime. 31 out of 50 households adopt one or more of these three strategic options aimed at lowering the heating costs and satisfying their energy needs at least to some extent. Similar efficiency and sufficiency strategies could be detected regarding lighting practices.

In the comparison between low-income and high-income households in the sample it showed that the first, to a greater extent than the latter, tend to make financially feasible 'small investments' directed at energy saving. However, the financial resources available clearly limit the scope of action as regards improving energy efficiency of household appliances and equipment of flats, which is why a large number of the interviewees only see meager possibilities of achieving additional savings. Besides financial restrictions, a lack of real-time feedback systems complicates the traceability of the savings gained.

The International Perspective

Studies from other countries mainly concentrate on senior citizens and their energy consumption and comfort practices. The focus here often lies on heating practices. Day & Hitchings (2009) conducted a survey among elderly people in the UK on how they manage their needs for warmth in winter. The results showed that people in low-income households frequently put on additional layers of clothing in order to keep warm. Thermostats were turned down and less money was spent on heating. Some of the people tried to respond to the rising energy prices by trying to save energy. However, besides income, age played a crucial role here, as older people generally appeared more cautious regarding energy consumption, also in better-off households. Wright's (2004) study also highlighted this phenomenon, for example in the practice of leaving bedroom windows open during the night, even in winter, with the argument of having advantages for health (although the contrary is true, from a medical viewpoint). Many of the people interviewed stated that they did not have central heating in their childhood, perceiving the same as a luxury in modern houses. This practice of austerity could definitely be identified as being more pronounced in fuel-poor households: in these cases, the heating was often turned off during the day, or even never turned on in the bedrooms. Instead of turning on or increasing the heating when feeling cold, they put on another pullover or used a blanket to keep warm. Gilbertson et al. (2006) also identified coping strategies in senior citizens, such as a limitation of the living area used in the house or returning to bed in the case of cold. Further strategies to keep warm inside the house included: supplementary gas and electric fires, hot water bottles, blankets (Day & Hitchings, 2009).

“Overall, there was a significant diversity in routines (in heating)“ (Day & Hitchings, 2009, p. 1). Also Radcliffe (2010) found out in his study, conducted among fuel-poor households in Wales, that people adopt a range of behaviors and strategies when confronted with cold weather (cf. Jenkins et al., 2011).

Gibbons & Singler (2008) identified three general types of coping strategies in their research overview:

1. Fuel Use Reduction through Rationing

This practice already became evident in the studies mentioned before, but also featured in some of the others as a central coping strategy. For instance, in a UK study on low-income households 62% stated that they had to limit their heating needs. Some turned off the heating altogether, others only heated the house selectively (e.g., only one room), and a number of people only used the heating intermittently (Harrington et al., 2004; Anderson et al., 2010).

Generally, it could be observed that low-income and fuel-poor households often consume less energy than would be necessary for health reasons (Boardman, 2010). A British study discovered that in almost half of the low-income households, the houses or flats were colder than desired in winter (Anderson et al., 2010). If sufficient energy supplies are not affordable for the people and they have to remain in the cold they take health risks. This particularly affects elderly people and children. Families with children more frequently report difficulties in keeping their flats or houses warm and bearing the corresponding costs (Boardman, 2010; Hernández & Bird, 2010). Living in a cold dwelling may entail health risks (e.g., depression), just as it curtails the quality of life, for example, making it impossible to invite friends (Anderson et al., 2010) and thus reducing the social interaction of the households (Hills, 2011). Medical evidence for a connection between low temperatures and bad health status has already been given, for example, when mold starts to grow in the flat (Heffner & Campbell, 2011). Mold inside the dwelling, on the other hand, correlates significantly with low energy efficiency, old buildings, reported difficulties in paying the energy bills and dissatisfaction with the heating system (Oreszczyn et al., 2006). People living in fuel poverty thus have to recur to health services with considerably higher frequency. Evans et al. (2000) also revealed that in those who are unable to keep their living area warm the majority of the time, the risk of having to seek an outpatient clinic is twice as high. In the most extreme cases, fuel poverty might lead to higher mortality. Thus, a total of 38.203 excess winter deaths per year (within 11 countries in the EU region) have to be attributed to effects of a too low temperature inside the dwelling (Braubach et al., 2011). Insufficient heating and, related to this, humidity can also lead to damages in the building substance, which in turn makes it more difficult for the inhabitants to heat their house or flat adequately (EPEE, 2008).

The health risks related to fuel poverty become particularly evident when comparing the situation before and after a thermal improvement measure. While in adults, only slight physical health improvements could be observed after such measures, significant improvements in the physical health of children became evident. Significant mental effects were recorded both in adults and adolescents (Liddell & Morris, 2010). Measures for increasing energy efficiency could improve quality of life, for example by making more rooms inside the flat available, which is particularly relevant in families with children. More warmth and comfort increase emotional security and diminish stress. Even the simplest improvements in material circumstances could have positive effects, not only on the physical but also on the mental wellbeing (Gilbertson et al. 2006). Energy efficiency measures may even decrease the incidence of anxiety and depression by 50% (Green & Gilbertson, 2008). A study from New Zealand found "that insulating existing houses led to a significantly warmer, drier indoor environment and resulted in improved self-rated health, self-reported wheezing, days off school and work, and self-reported visits to general practitioners as well as a non-significant trend to fewer hospital admissions for respiratory conditions" (Howden-Chapman et al., 2012, p. 139). However, improvements in thermal efficiency do not necessarily lead to the same result of a beneficial increase in the temperature inside the housings. Especially elderly people (in the UK) do not modify their cold temperatures, demonstrating what has been called "thermal resistance" (Critchley et al., 2007), indicating a "generational tendency to economy" (Day & Hitchings, 2009), partly also in more affluent households. Improvements in the efficiency are not automatically connected to a reduction of the heating bill either, as the households tend to compensate savings by increasing the temperature (Oreszczyn et al., 2006). However, such rebound effects may be considered a positive development from a health point of view: thermal efficiency could be seen as a form of medicine (Heffner & Campbell, 2011).

2. Financial Measures, Reducing Expenditure on Other Essential Items, Particularly Food

An American study has shown that poor families tend to spend more on energy in periods of cold weather, but at the same time cut back on their expenses for food in equal amounts. Especially parents reduce their food consumption, which entails certain health risks. This phenomenon, also observed among elderly women in Wales (O'Neill et al., 2006), has been termed the "Heat-or-Eat-Dilemma" (Bhattacharya et al., 2003). Another study from the US targeting low-income families facing disproportionately high energy costs, points out the health hazards that come along with a reduction of food consumption, also for children (Child Health Impact Working Group, 2007; Liddell, 2008). Anderson et al. (2010) report that low-income households actively try to find out about special offers regarding food, comparing prices. Hills (2011) assumes that only the poorest quarter of older households practices the strategy of reducing their spending on alimentation, considering it less frequent than other researchers supposed.

3. Incurring Debt (Arrears or Other Forms of Debt)

Many fuel poor households report difficulties in paying their energy bills. This may lead to stress, anxiety or depression (Green & Gilbertson, 2008). In half of the low-income households in the UK, arrears in payment were registered (Hills, 2011). In an American study, almost 80% of low-income households report difficulties with provision, for example, arrears in payments to energy providers and power cuts (Hernández & Bird, 2010). Another (rather scarce) coping strategy of fuel-poor households is "to disregard the cost of fuel". This, however, leads to debts in the majority of cases or increases already existing debts (Radcliffe, 2010).

The results of both the Austrian NELA project and of international studies clearly show that low-income and fuel poor households are characterized by a number of energy burdens and related coping strategies. The main causes of fuel poverty are interrelated in most cases, which means that apart from a low income and economic straits, those concerned often live in energy inefficient buildings or flats equipped with energy inefficient appliances and are particularly affected by rises in energy prices. A frequent coping strategy here is to limit energy consumption, even at the expense of their own health. Mostly, however, we witness a combination of coping strategies characteristic of the households in question, e.g., efficiency and sufficiency strategies.

The factors that render households vulnerable but, at the same time, are beyond reach of their influence, could mainly be found in an inefficient structure of the building, the heating technology and larger household appliances. Different studies quoted here reveal that these households have great difficulties in tapping their full efficiency potential due to the cladding of the building, the heating technology and the household equipment. Smaller and cost-neutral efficiency potentials are often already being exploited to a large part (for example, using energy saving bulbs). For further measures, however, the financial resources and their agency are often insufficient, even if demands for greater efficiency in the building exist.

Starting from this situation, questions arise about the kind of measures that could be taken in order to fight fuel poverty. The discussion in the last part of the chapter is going to focus on that.

POLICIES FOR TACKLING FUEL POVERTY

A range of studies on coping strategies have shown that there is a multitude of factors which have an influence on how people deal with their situation of living and housing. They also pointed out how widely ways of handling it vary (e.g., according to severity of fuel poverty, differing grades of being affected by it in connection with adherence to social groups, but also agency of the people concerned). It has been mentioned already that fuel poverty in most cases has to be attributed to a batch of causes. It has also become clear that many fuel-poor households carry multiple burdens which might even aggravate each other. In response to these conditions, policy measures targeting fuel poverty should try to simultaneously take a range of various actions in order to do justice to the multiple causes and pressures. This, however, only rarely turns reality.

To date, policies specifically addressing fuel poverty on an EU level have been limited (Thomson & Snell, 2013) and there is insufficient institutional capacity to deal with fuel poverty at multiple levels of governance (Bouzarovski et al., 2012). It should be noted that this does not only hold true for the EU as a whole, but also for individual member states. In many countries, fuel poverty has not been recognized as a problem yet and consequently, few political measures are being taken to address the causes behind it. However, even with a lack of recognition of the issue of fuel poverty, measures for aiding particularly vulnerable consumers exist (e.g., with income subsidies).

Generally, three main policies for tackling fuel poverty may be identified, in accordance with the three major causes: income support measures, measures to impact on energy prices, and measures aimed at improving the energy efficiency of housing. Complementing this, mechanisms for consumer protection (e.g., the protection against disconnections in winter) or measures raising awareness and addressing behavioral patterns may be mentioned here, e.g., the promotion of energy literacy to expand the knowledge base regarding energy conservation efforts at home (Hernández & Bird, 2010).

Low incomes represent one of the main causes of fuel poverty. Therefore, one strategy against it consists in income support measures: In less than half of the EU member states, economic support mechanisms intended to help certain categories of consumers exist (Grevisse & Brynart, 2011). Examples that could be quoted here include winter fuel payments in the UK or a heating subsidy in Austria, which is a means-tested benefit provided on a regional level and funded publicly. These measures are used for short term curative assistance which may directly reach all low-income households or those estimated fuel poor (for instance, elderly people). The hitch of income-oriented measures is that they are not ring-fenced. Thus, lowering energy consumption or investing in energy efficiency may not be necessarily expected as a logical consequence. Often, the group of people eligible for these benefits is so loosely defined that those actually suffering from fuel poverty only benefit from these income support mechanisms to a certain share. Boardman (2010) demonstrates that winter fuel payment in the UK is only 19% effective as a fuel poverty alleviation program. Less than 25% of the annual expenditure on fuel poverty is received by the fuel poor, with the remainder being received by people receiving means-tested benefits or those who are identified as vulnerable despite not living in fuel poverty according to the government definition. Very often these days, the subsidies are being granted globally and at the same rate to all eligible parties, without consulting efficiency data on the dwelling. Moreover, winter fuel payments and other heating benefits do not fully cover rising energy prices.

One possible, exemplary measure for countering rising energy prices are social tariffs. They lower energy expenses of the household by limiting energy prices for a certain target group. In various European countries, social tariffs exist for those in need, also in a few provinces of Austria. In order to become eligible, income is generally the only criterion. Housing standards are largely ignored here (Sunderland & Croft, 2011).

A number of authors assume that through measures aimed at improving the energy efficiency of housing, all three dimensions of fuel poverty could be addressed (Thomson & Snell, 2013). “For fuel poverty programmes to be effective, energy efficiency measures must be prioritized“ (Sunderland & Croft 2011, p. 466). Financial benefits for energy efficiency are destined to enable households to maintain a certain comfort, if not even raise it, while at the same time spending less energy and thus escaping fuel poverty. Following this idea, energy efficiency programs could solve the issue in a preventive way. There is one problem, however, that often interferes here: support for efficiency measures granted to low-income households often does not yield the desired effect as the necessary share to be paid by the households themselves is impossible for them to finance without assistance (Hills, 2011). Consequently, funds related to energy efficiency measures often turn into middle and upper class subsidies (Raho, 2012). In Austria, for instance, there are no efficiency subsidies directed at low-income households. Although energy efficiency programs represent a powerful tool in the fight against fuel poverty, it should be kept in mind that energy efficiency measures alone cannot save those trying to cope with cold weather through extreme sufficiency strategies (Radcliffe, 2010).

Effective policies for tackling fuel poverty should consider that fuel poverty creates different risks for different groups of people (Hirsch et al., 2011) and that there is a range of responses to fuel poverty and energy inefficiency by different tenants. Measures for tackling fuel poverty should therefore be target group-specific. Taking into account the variety of contexts and scopes of action may increase the efficiency of measures. The example of income support measures showed that exact targeting of fuel poor households is crucial in order to use resources in a focused way. Groups living in deep fuel poverty, for instance, would have to be addressed specifically (Radcliffe, 2010). The sub-project "neighborhood parents", which forms part of the Austrian Pilot Project against Fuel Poverty already mentioned before (Brunner et al., 2013), is trying to achieve this by specifically targeting structurally disadvantaged residential areas. In most of these areas, pre-WWII residential buildings dominate. It therefore starts from one of the roots of the problem of fuel poverty, which is, inefficient flats. Following the principle of capacity building, the residents of the buildings in question receive training on the topics of energy, housing and community life, subsequently passing on the recently gained knowledge as multipliers (so-called ‘neighborhood parents’) in the course of home visits in their communities. By doing so, they assume a bridging function between households in difficult situations regarding energy and housing, and professional service centers and offers. On the one hand, this initiative strives to make a contribution to the fight against fuel poverty, promoting health and the improvement of housing conditions. On the other hand, the target of the project is to strengthen the competences of the residents and support their empowerment. What is especially relevant for the target group here is the low-threshold, outreach approach in different mother tongues, avoiding social stigma. The neighborhood parents are familiar with the lived-in world of those affected and act as neighbors rather than professionals. This follows experiences from already existing energy counseling services which consider trust in the counselor a crucial element for the success of the intervention (Darby, 1999). Experiences to date have shown that this low-threshold approach seems to achieve high accuracy in the identification and targeting of those in deep fuel poverty. It contributes to promoting energy literacy of the fuel poor and, by doing so, also makes a contribution to energy related behavior change.

Talking about policies, it is crucial to highlight the necessity of tackling fuel poverty as a multidimensional and cross-sectoral phenomenon (Bouzarovski et al., 2012). In the introduction, we already stressed that fuel poverty has to be located at the contested crossroads of different areas of politics, which is also why collaboration across ministries would urgently be called for. Energy efficiency should not be seen as a policy approach solely driven by energy ministries with the aim of managing energy usage in a society, but rather as a complementary policy approach achieving policy goals of a range of other ministries (e.g., environment, health, social affairs) (Ryan & Campbell, 2012). To date, this is not the case in Austria.

The question here does not only concern energy savings, but touches upon a wider impact on the conscience about “non-energy co-benefits“ of energy efficiency programs (e.g., higher property values, local job creation, improved health, reduced emissions) (Heffner & Campbell, 2011). If this was being considered, also the costs of such programs would appear in a different light. What is important with all of these measures (e.g., in the case of carbon mitigation policies) is to understand the distributional consequences, as they may have adverse effects on those with low incomes: “Attention must be paid to any national level policies that are likely to increase energy bills, as without appropriate protection in place these are likely to hit the poorest households the hardest, potentially pushing more households into fuel poverty” (Thomson & Snell, 2013, p. 571).

Conclusion

In the first paragraphs of this chapter, we tried to sketch out the relation between energy consumption and social inequality. The problem of fuel poverty served to illustrate the ways in which people belonging to lower social classes deal with energy in the household and to demonstrate which difficulties rising energy prices, energy inefficient dwellings and appliances, as well as low incomes entail. Although energy consumption varies widely, also among the fuel poor, the latter are on average lower energy users and therefore also less responsible for carbon emissions. At the same time, however, they often have to pay higher prices because they profit less from the liberalized energy market than the better-off (Boardman, 2010), which in turn may be held responsible for higher emissions. The fuel poor seem to live low-carbon lifestyles (Jenkins et al., 2011). This should be rewarded with appropriate policies.

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Chapter 10

E4 IMPACTS OF ENERGY EFFICIENCY IN THE BUILDING SECTOR: A GLOBAL AND LOCAL PERSPECTIVE

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ABSTRACT

Since there is a strong interest on the promotion of energy efficiency through renovation investments in buildings, it is of public interest the monitoring of its impact on Energy, Economy, Environment and Employment (E4) systems. The purpose of this chapter is to provide an integrated analysis of the most representative renovation energy saving measures in the building sector (residential, private services and public services) regarding energy consumption, global and local economic indicators, global and local environmental impacts and employment creation. The methododology followed combines a top-down approach relying on Input-Output (I-O) analysis with a bottom-up approach based on different financial appraisal tools through the use of Multicriteria Decision Analysis (MCDA). A case study based on the characterization of the building stock of a Portuguese urban area is provided in order to assess how these energy efficiency renovation measures perform either from the producer’s or from the policy decision authorities’ stances.

Keywords: Energy efficiency, Building renovation measures, E4 systems

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INTRODUCTION

The building sector is responsible for 40% and 30% of total energy consumption in the European Union (EU) and Portugal, respectively, offering a great reduction potential for energy consumption, CO_2 emissions and energy dependence (Directive 2010/31 EU). In this framework, the Energy Efficiency Plan (Communication 109/2011 EC) is focused on the instruments aimed at promoting the renovation in public and private buildings and thus improving the energy performance of the components and appliances used in them. In Portugal, the National Energy Strategy (NES 2020) also accounts for the approval of a National Energy Efficiency Action Plan (Ministerial Order 20/2013) in its energy efficiency guidelines. The enhancement of energy efficiency is currently believed to be the cheapest, fastest and most environmental friendly way to meet a significant portion of the worlds' energy needs, reducing the necessity for investing in energy supply. Therefore, regardless of the development of fuel prices, countries need to be on track of energy efficiency policies more thoroughly in the long-term. In general, mandatory and regulatory measures are the most cost-effective ways of increasing the energy efficiency of the building sector on a long-term basis. Although this is especially true for new buildings this is not the case for existing buildings (about 70% of the building stock in Portugal was built before 1991). On the other hand, the topic of energy efficiency renovation in buildings has not been thoroughly explored in scientific literature until now.

In this framework, energy efficiency renovation in existing buildings refers to the interventions aimed at improving their energy efficiency, contributing to the minimization of the environmental footprint, reducing the energy bills of households, corporations and public institutions, implying a reduced need for subsidies for energy consumption, facilitating the achievement of EU's 2020 targets, increasing the value of buildings, contributing for job creation and re-launching the construction sector, avoiding the continuous degradation of the building stock and the occurrence of accidents.

The current economic climate is ideal for starting such projects: real interest rates are at record low levels while, unfortunately, unemployment has risen in a fast pace. Hence, investment costs are low and there are ample available labour resources. Studies suggest that harvesting the investment opportunities provided by energy efficiency renovations in the existing building stock can stimulate economic activity, create jobs and bring benefits to Gross Domestic Product - GDP (some preliminary results were provided by Oliveira et al., 2013a; Oliveira and Antunes, 2013). These benefits stem from increased economic activity in both the primary affected sectors and through the indirect and induced impacts on secondary sectors.

In this context, the aim of this chapter is to provide a holistic approach which allows assessing the current energy performance and possible renovation measures for the existing building stock. The building stock of the urban area of Coimbra, a medium sized city located in the central region of Portugal, will be used for illustrating the integration of different methodological approaches through the use of MCDA tools. This chapter is organized as follows: section 2 briefly reviews the latest literature on the subject; section 3 describes the methodological framework used herein; section 4 presents the implementation of the methodology in a Portuguese urban context with some illustrative results, and, finally, section 5 highlights some conclusions and presents future work developments.

REVIEW OF PREVIOUS STUDIES

The strong interest on the promotion of energy efficiency may be ascertained in recent studies with specific focuses on energy renovation actions in the building sector. In the framework of building certification, Freitas et al. (2011) have suggested technical solutions for building renovation duly quantified in terms of costs, energy and economic savings. Other similar studies have already been presented by Burton (2001) and Pfafferott et al. (2004), focusing on the type of buildings being renovated, without leaving behind the construction of new buildings.

The project "OFFICE", funded by EU, subject to the theme of building renovation, aimed at increasing energy performance and the quality of indoor environment. In this project some buildings were monitored as case studies and defined as renovation sets.

Further information might be found in a more recent study based on the conclusions of this Project, which has simulated and quantified several renovation solutions (Holmes and Hacker, 2006).

Rysanek and Choudhary (2013) describe a methodology for analysis and optimization of renovation decisions using dynamic building energy models, consisting of a combined engineering-economic assessment of building energy systems.

In the scope of I-O models combined with life cycle assessment (LCA), Cellura et al. (2013) present an energy and environmental extended model to assess the energy and environmental benefits arising from the Italian policy of tax deduction for energy renovation actions in buildings.

Also with the use of the I-O approach Oliveira et al. (2013a) provide a consistent estimate for depicting the significant contribution of energy saving measures in the building sector (residential, private services and public services) in net employment generation in Portugal. Markaki et al. (2013) exploit the use of I-O analysis for estimating the direct, indirect and induced macroeconomic effects associated with the implementation of selected energy conservation measures, including the promotion of renewable energy technologies.

Oliveira and Antunes (2013) report some preliminary results on the analysis of the main impacts due to the implementation of four specific energy efficiency renovation measures in several types of buildings on direct and indirect job creation, the overall employment and GDP. A systemic methodology has been proposed by introducing a bottom-up approach in a previous version of a top-down Multiobjective Linear Programming (MOLP) I-O model with interval coefficients (Oliveira and Antunes, 2011, 2012; Oliveira et al. 2013b) that allows the assessment of avoided energy consumption and CO_2 emissions associated with the renovation measures.

Asadi et al. (2012a) employ a simulation-based multiobjective optimization scheme (a combination of TRNSYS, GenOpt and a Tchebycheff optimization technique) to optimize renovation costs, energy savings and thermal comfort of a residential building.

Asadi et al. (2012b) also present a multiobjective optimization model to assist stakeholders in the definition of intervention measures aimed at minimizing the energy use in a building in a cost effective manner, while satisfying the occupant needs and requirements.

In the next section the methodological framework used herein, that combines some of the methodologies previously reported, will be provided.

THE METHODOLOGICAL FRAMEWORK

The development of the methodology proposed involves four different stages (see Figure 1): i) a top-down approach through the use of I-O multipliers to obtain the employment generation potentials and the income impacts on the economic system; ii) a bottom-up approach by means of financial impact assessment tools; iii) the characterization of the existing building stock that allows obtaining avoided CO_2 emissions and the reduction of energy consumption; iv) a methodological framework based on MCDA to facilitate the integrated analysis of the different energy efficiency renovation measures.

This chapter is focused on buildings from the residential and private and public services, considering buildings constructed within the range of 1946 to 1990. Four key categories have been identified as important to be integrated into a renovation project: window frame and single glazed window replacement, and roof and wall insulation.

The methodology starts with the selection of the different alternatives that are next scrutinised with the purpose of choosing the representative criteria. These will be then used to obtain the performance of each alternative against each criterion.

Top-Down Approach

I-O analysis allows calculating employment and income (value added) multipliers, taking into account the differences in technology between industries and their linkages. Multipliers measure total change throughout the economy from a one unit change for a given sector.

In this context, direct effects represent impacts generated from a change in spending patterns resulting from an expenditure taken in a renovation project; indirect effects (Type I multipliers) include impacts generated in the supply chain and supporting industries of an industry directly impacted; and induced effects (Type II multipliers) are those originated by the re-spending of income resulting from both direct and indirect effects.

Employment and income multipliers are different. While the first represent for every employee hired in the energy renovation activities the additional individuals employed because of indirect and induced effects. The last represent the additional revenue generated due to indirect and induced effects for every €1 million of sales in the energy renovation activities.

In order to obtain the multipliers associated with the implementation of energy efficiency renovation investments in the buildings sector it was first necessary to use an I-O symmetrical product by product table for total flows (Oliveira and Antuntes, 2013; Oliveira et al., 2013b). Subsequently, the total investment costs associated with the implementation of the renovation investments considered were first disaggregated to account for the economic sectors directly engaged with each renovation investment (for further details see Oliveira et al., 2013a).

Moreover, we assumed that the impact on employment regarding these interventions is expected to occur within the country. Figure 2 depicts the sectoral distribution of the investment for each of the interventions herein tackled, which was based on several experts' opinions (academics and practitioners in the field of energy efficiency).

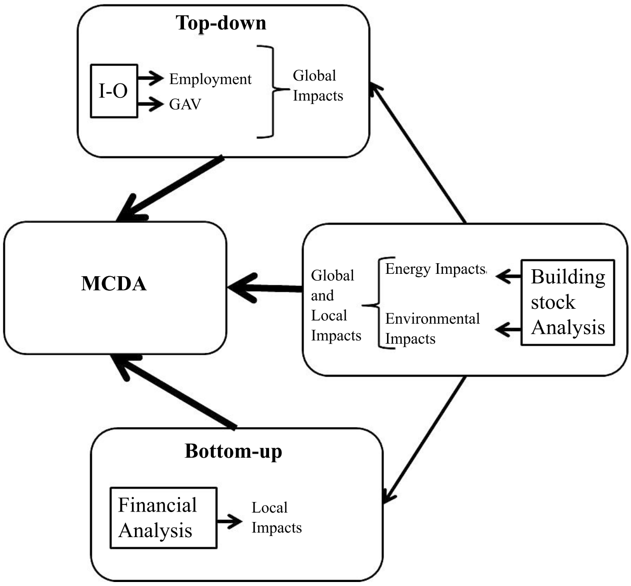


Figure 1. Block diagram of the methodological framework.

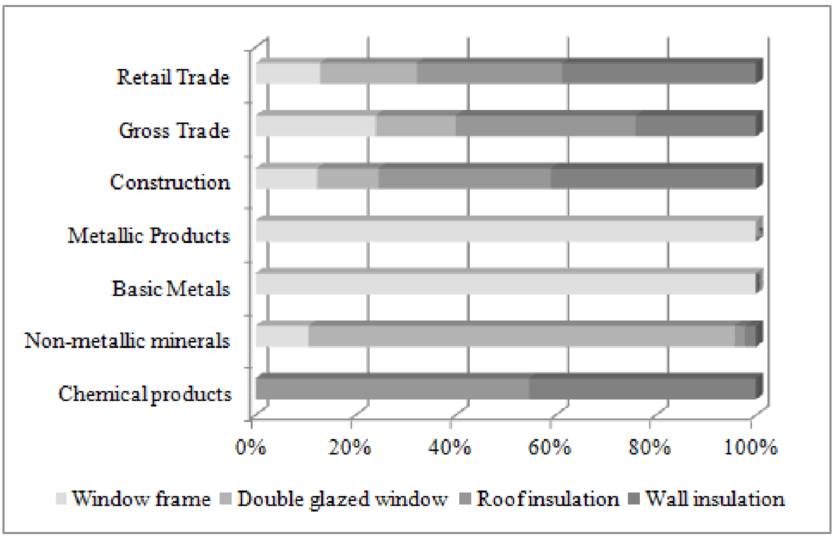


Figure 2. Sectoral distribution of each renovation investment.

Figure 3 illustrates the overall effects (direct, indirect and induced) of each energy efficiency measure that might be conducted in each building sector (private, public and residential) to Gross Value Added (GVA) and Full Time Employment (FTE), according to the useful floor area obtained from the characterization of the existing building stock. The energy efficiency renovation options with the highest impacts on both employment and GVA are obtained with the replacement of single glazed windows with or without frame replacement in the private and public sectors. In the residential sector (with buildings with 2 and 4 facades) the highest impacts on these indicators are obtained with the interventions on the opaque facades.

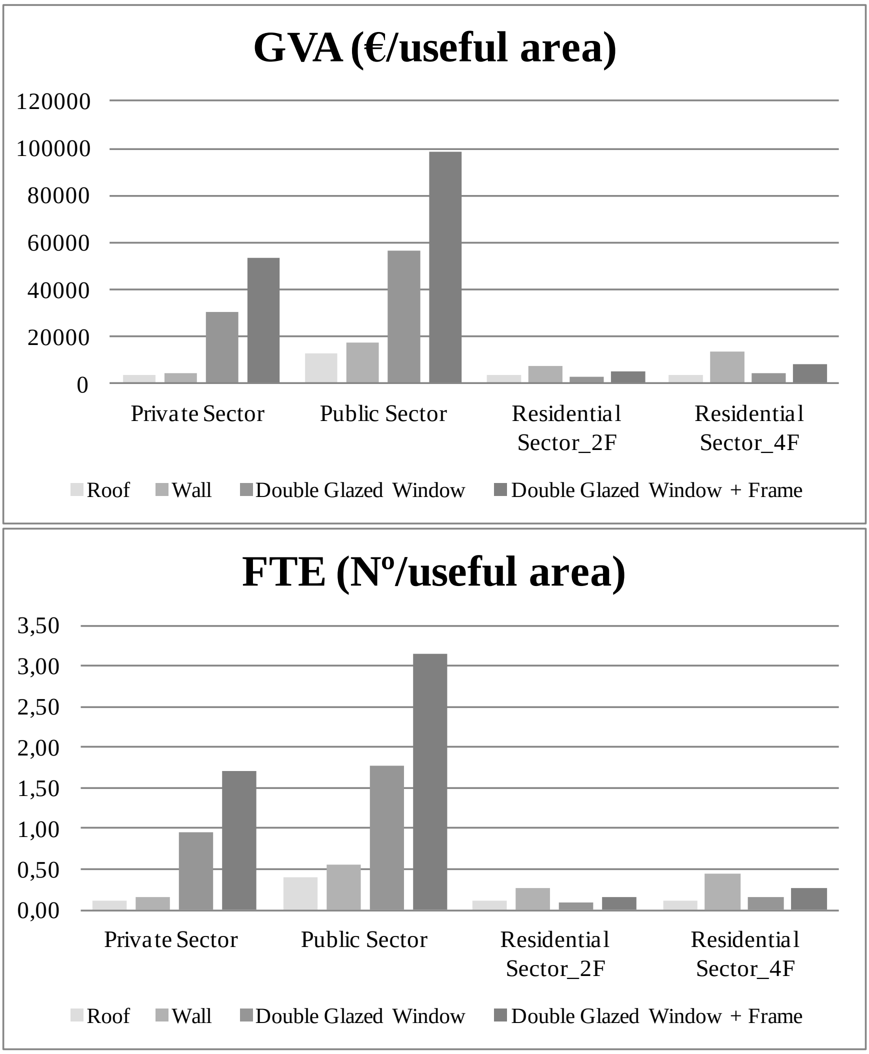


Figure 3. Some global economic indicators.

Bottom-Up Approach

The economic viability of an energy renovation project may be assessed by applying the following financial techniques:

- Net Present Value (NPV) - defined as the total present value of a time series of cash flows. It is a well-known method for the appraisal of long-term energy projects and it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met. NPV is often used to assess the feasibility of energy projects by an investor standpoint.
- Payback period - refers to the period of time required for the return on an investment to "repay" the sum of the original investment. It intuitively measures how long a project takes to "pay for itself"; shorter payback periods being obviously preferable

to longer payback periods to investors. In this context, the concept of payback period is extended to account for the energy payback period, i.e., the period of time over which the energy savings of a project equal the amount of energy expended since project inception.

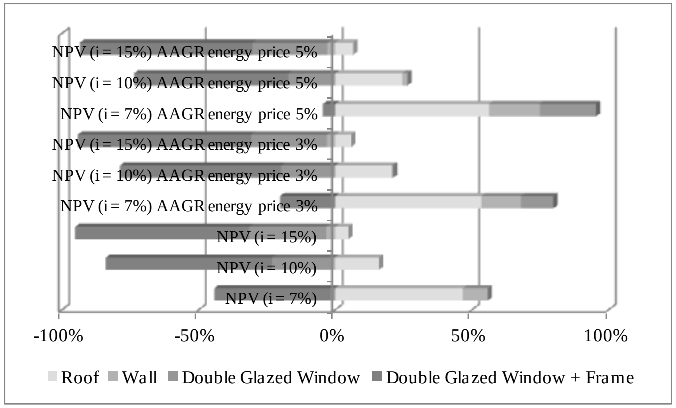
Since the assumptions of discount rates for energy projects is not worldwide consensual, we perform the analysis in the 7% to 15% range to reflect issues such as technological or market risks (see Figure 4). We also consider two different annual average growth rates (AAGR) for energy prices, between 3% and 5%, respectively (see Figure 4 and Figure 5).

After performing the analysis of the impact of different discount rates on the NPV of each alternative, it is possible to conclude that the most attractive investment options are those referring to roof and wall insulation (with the highest NPV values and the lowest payback periods). The investment on the replacement of single glazed windows is only appealing from the investor's point of view with the lowest discount rate (assuming low risk) and with higher energy prices (with this assumption the opportunity cost of the investment becomes lower). For illustrative purposes we provide the evolution of the accumulated cash flows in the public sector during the foreseen useful life for different investment types (see Figure 6) with an AAGR of 5% for energy prices, becoming once more evident the attractiveness for the investment options on roof and wall insulation.

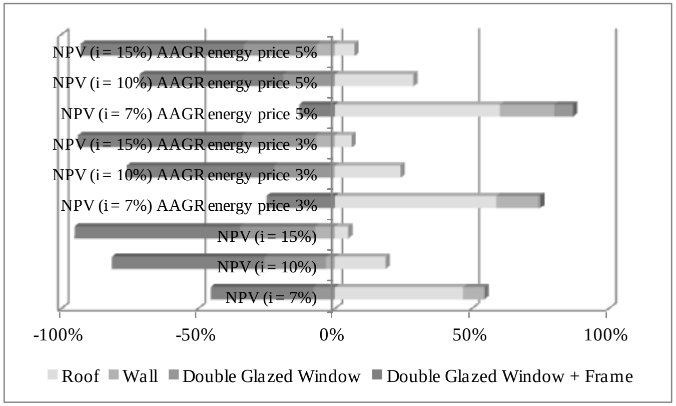
Building Stock Characterization

In Portugal, the first regulation related to energy performance and thermal comfort of buildings was endorsed in 1990 and required that new buildings and great renovations of existing buildings implemented measures to improve building energy performance. In the sequence of the previous European Directive on the energy performance of buildings (Directive 2002/91/EC) that was addressed to the Member States, a package of new regulations was enforced in Portugal during 2006 and is currently binding.

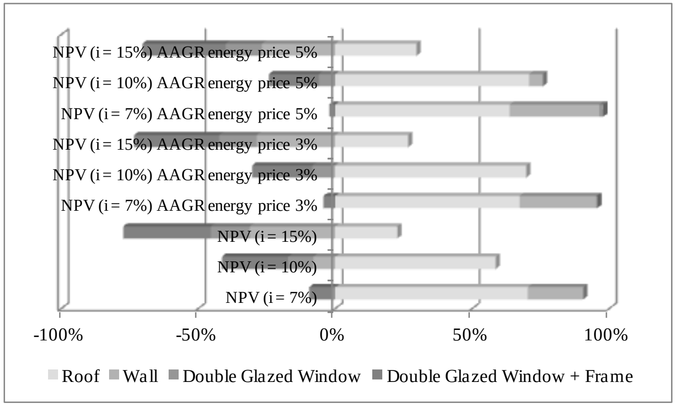
In the building sector, the Portuguese legislation includes regulations regarding the energy and indoor air quality performance in buildings through the National System of Energy Certification and Indoor Air Quality in Buildings (SCE) (Decree-law 78/2006), according to the requirements and statements contained in the Regulation of Building Comfort of Energy Systems (RSECE) (Decree-law 79/2006), and according to the Regulation of the Characteristics of Thermal Behaviour of Buildings (RCCTE) (Decree-law 80/2006). This new legislation package is stricter than the previous one and is either applicable to the new or older buildings needing greater rehabilitation interventions. Therefore, the major potential for energy efficiency improvements exists in buildings, which have been constructed before 1990, when the first thermal insulation regulation was enacted. These buildings represent 71% of the existing building stock and 20% of this percentage has been constructed before 1945. The characterization of the building stock for the illustration of this analysis was based on the methodology developed by Coelho (2013) and Coelho et al. (2013). With this portrayal it was possible to obtain data regarding CO_2 emission reduction and energy savings according to the energy consumption mix (Electricity, Natural Gas – NG, Liquefied Petroleum Gas – LPG and Biomass) of the different building types (see Figure 7 and Figure 8).



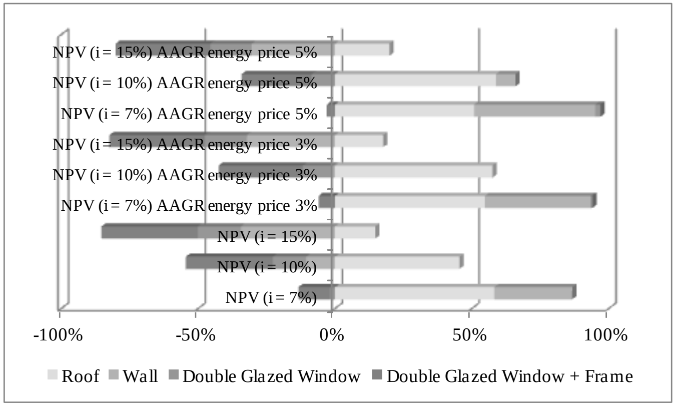
a) Private Services - Buildings with 4 floors, 2 facades and 2/3 of glazed area



b) Public Services - Buildings with 3 floors, 4 facades and 1/2 of glazed area

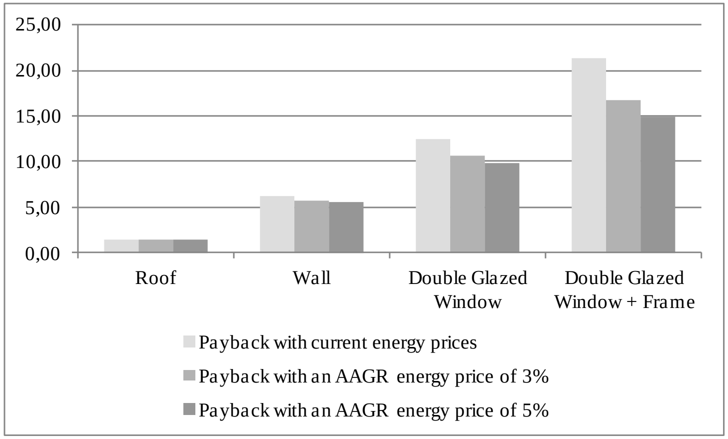


c) Residential - Buildings with 2 floors, 2 facades

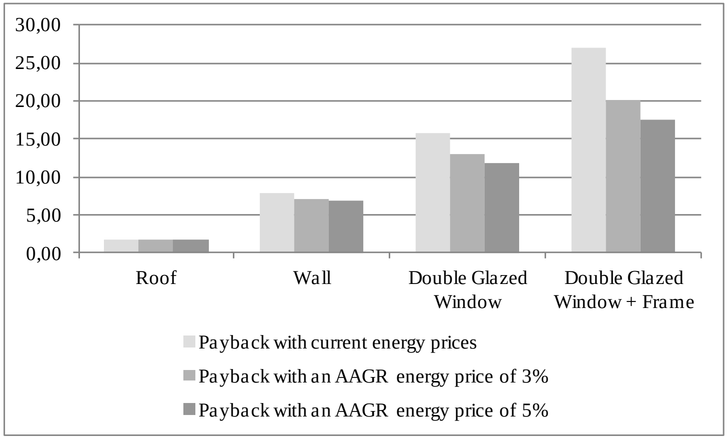


d) Residential - Buildings with 2 floors, 4 facades

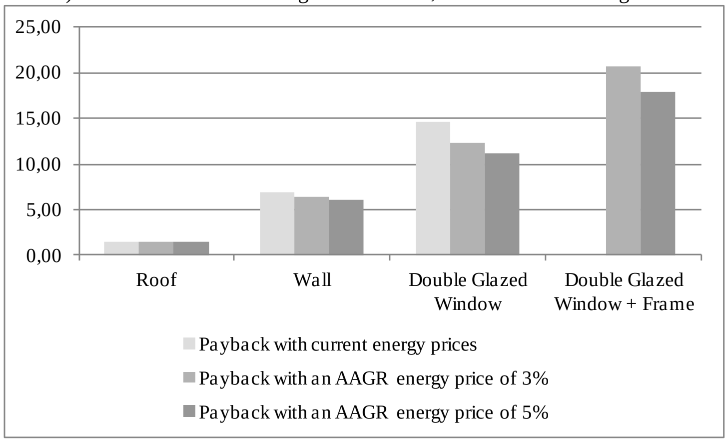
Figure 4. NPV with different discount rates for each renovation investment option.



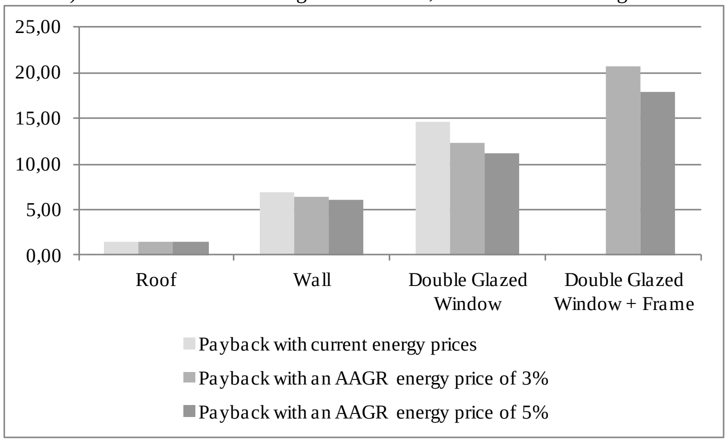
a) Private Services - Buildings with 4 floors, 2 facades and 2/3 of glazed area



b) Public Services - Buildings with 3 floors, 4 facades and 1/2 of glazed area



c) Residential - Buildings with 2 floors, 2 facades



d) Residential - Buildings with 2 floors, 4 facades

Figure 5. Payback period with different energy prices.

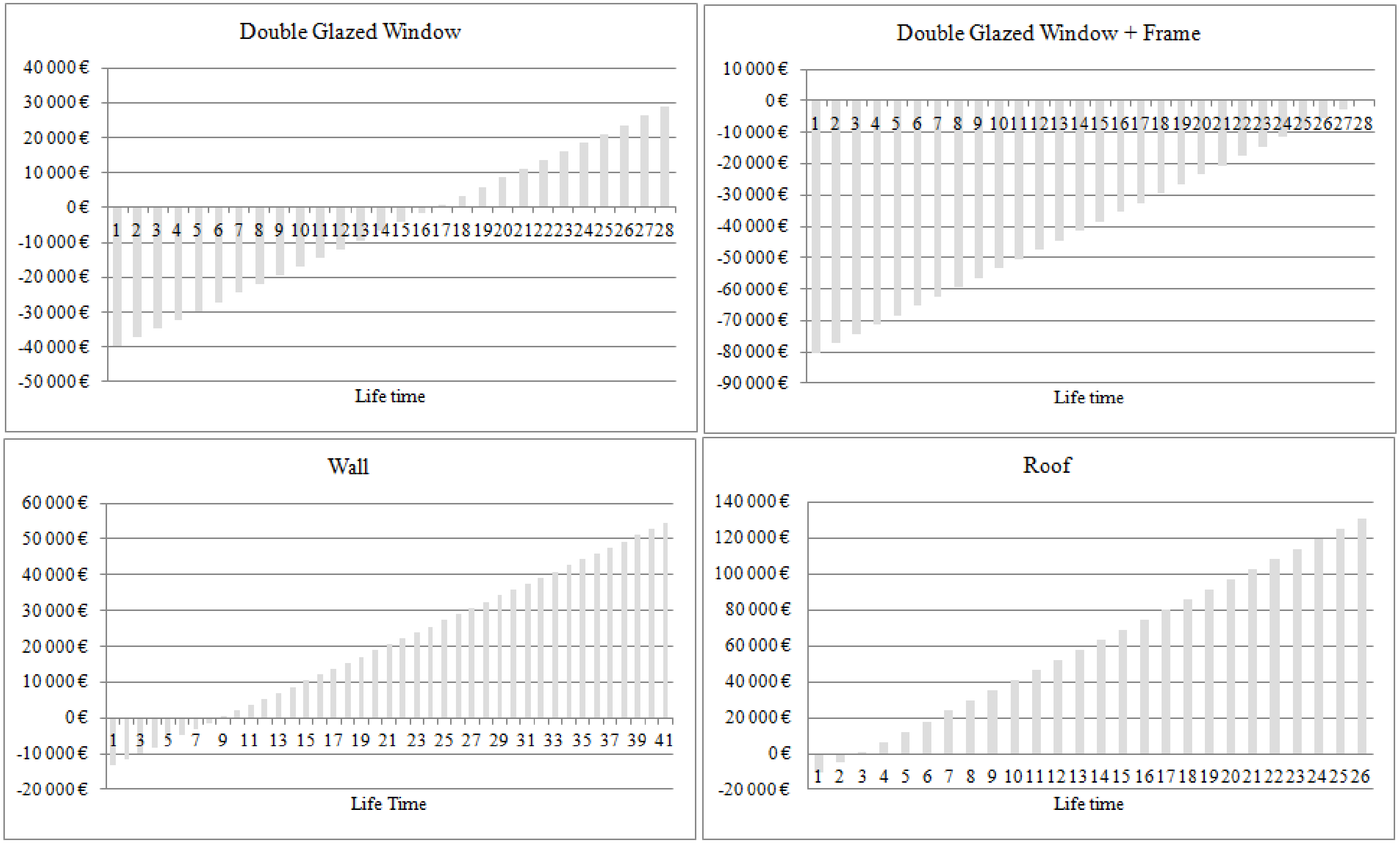


Figure 6. Accumulated cash flows in public services.

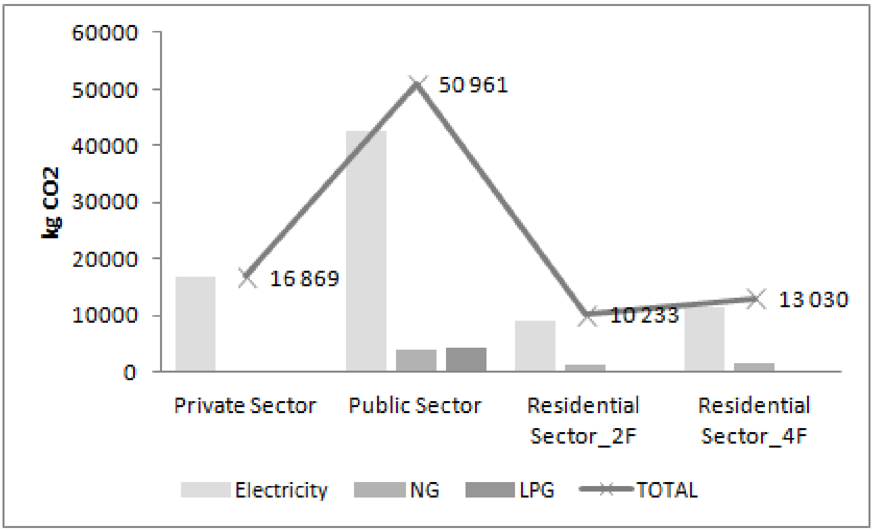


Figure 7. CO_2 emissions reduction considering the energy consumption mix.

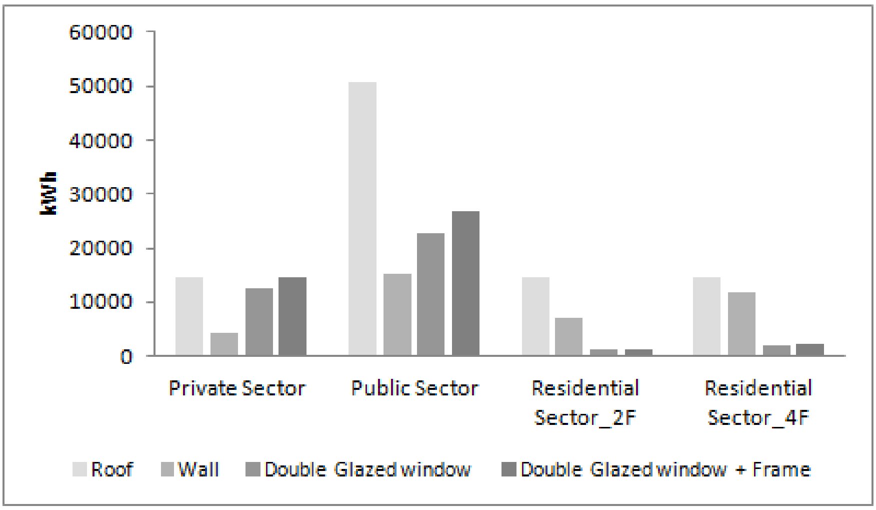


Figure 8. Energy savings for each energy efficiency investment option.

MCDA Methodological Framework

MCDA tools are able to deal with complex processes inherently involving multiple issues, multiple and conflicting evaluation criteria, offering the opportunity to deal with mixed sets of data either quantitative or qualitative. The appropriate use of this kind of methods can also contribute to ensure that public values are reflected in the assessment of the energy efficiency measures, incorporating the perspectives of different stakeholders involved in the problematic situation.

The MCDA model used considers the eight criteria presented in Table 1. Criteria are classified into economic, technological, environmental and social groups. Criteria with well-established quantitative scales are expressed in quantitative units. Qualitative criteria are expressed in a four point scale.

Table 1. Criteria identification

Criterion	Performance measure	Score type	Optimization Criterion
Investment costs	€	Quantitative	Minimize
NPV	€	Quantitative	Maximize
Energy saving	kWh/year	Quantitative	Maximize
Employment	Nº FTE	Quantitative	Maximize
Technology maturity	Four-point scale	Qualitative	Maximize
CO_2 reduction	kg/year.	Quantitative	Maximize
GVA	€	Quantitative	Maximize
Social acceptability	Four-point scale	Qualitative	Maximize

Economic Criteria

Investment costs - include all costs regarding the renovation options herein considered.

NPV - is used to assess the feasibility of an energy project by an investor.

GVA - refers to the capacity of the energy renovation project of promoting local/regional/national economic income.

Technological Criteria

Energy savings - refers to the total annual energy consumption avoided with the energy efficiency measures implementation.

Technology maturity - measures the degree of maturity of the technology and refers to how widespread the technology is at both national and international levels. It is a qualitative criterion and can take the following values from1 to 4 (Coelho et al., 2013): (1) technologies that are only tested in laboratory; (2) technologies that are only performed in pilot plants, where the demonstrative goal is linked to the experimental one, referring to the operating and technical conditions; (3) technologies that could be still improved; and (4) consolidated technologies, which are close to reaching the theoretical limits of efficiency.

Environmental Criteria

CO_2 reduction – measures the amount of equivalent CO_2 emissions avoided as a result of energy efficient actions or as a result of energy production from renewable energy systems and it is measured in kg of CO_2 equivalent per year.

Social Criteria

Employment – evaluates the energy efficiency renovation investments by taking into account their impacts on direct, indirect and induced employment, with local and/or national implications.

Social acceptability – expresses the index of acceptance by the local population regarding the realization of the projects under review or the implementation of energy efficient measures. Social acceptance is expressed as a qualitative criterion. The following four-point qualitative scale was applied (Coelho et al., 2013): (1) the majority of inhabitants are against the implementation of any renovation project or any action; (2) weak acceptance by the inhabitants; (3) the majority of inhabitants accept the proposed measures, provided there are no negative externalities for them; (4) the majority of inhabitants are favourably disposed towards the proposed measures.

The Electre Tri method was selected to provide decision support. Electre Tri is devoted to the sorting (or classification) problem, which consists in assigning each alternative $a_i \in A=\{a_1,\ldots,a_m\}$, evaluated according to n criteria, $g_1,\ldots,g_n$, to one of a set of pre-defined ordered categories (classes of merit) $C=\{C^1,\ldots,C^h\}$, where C^1, C^h are the worst and the best category, respectively. Each category C^l, l=1,…, h, is limited by two reference profiles (upper bound and lower bound), defined for each criterion g_j, j=1,…,n. The assignment of each action $a_i \in A$ to a category C^l is done by comparing its value in each criterion to the performances of the reference actions.

The procedure assigns each action a_i to the highest category such that its lower bound is outranked by a_i. The outranking relation is verified by comparing a credibility index with a cutting level. Also, a set of indifference (q_j), preference (p_j) and optional veto (v_j) thresholds for each criterion and reference profile is defined. For further details about The Electre Tri method see Mousseau and Dias (2002).

In the experiments presented in this chapter the software package IRIS 2.0 was used (Dias and Mousseau, 2003). IRIS implements a methodology based on the Electre Tri method, accepting uncertainty in the input parameters.

IMPLEMENTATION OF THE METHODOLOGY IN A PORTUGUESE URBAN CONTEXT

According to the different energy efficiency renovation options herein analysed, 16 actions were considered to be evaluated. The data elements gathered from the characterization of the building stock of a Portuguese urban set (see the previous section) were used for assessing the performance of the actions according to the different criteria, as well as for the reference profiles and associated thresholds.

Actions should be assigned to four categories of merit: (C^1) Very Poor; (C^2) Poor, (C^3) Fair; (C^4) Good and (C^5) Very Good, according to the multiple evaluation criteria. The set of profiles and thresholds for the actions selected is presented in Table 3. Indifference and preference thresholds were fixed as percentages of the value ranges in each category, 1% and 10%, respectively. The veto threshold was not applied in this case study.

Both the data concerning the alternatives to be evaluated and the technical parameters required by the method (reference profiles, thresholds, and criterion weights) were supplied to the IRIS software. The cutting level (λ), which determines the exigency of the classification, was constrained to the interval [0.51, 0.67], corresponding to a simple majority and a two-thirds majority requirement, respectively.

Some illustrative results are presented in Figure 9, using different shades of grey to indicate the range of possible assignments for each action, i.e., the categories the action can be assigned to without violating constraint bounds and assignment examples. The assignment recommended by IRIS software based on the inferred combination of parameter values is represented by the cell with a darker shade of grey.

In some situations, there are some intermediate categories an action cannot be assigned to, as for instance the third action in Figure 9, which is indicated in black. This means there is no combination of the values of the cutting level and the criterion weights that allow the classification of this action in category C^2.

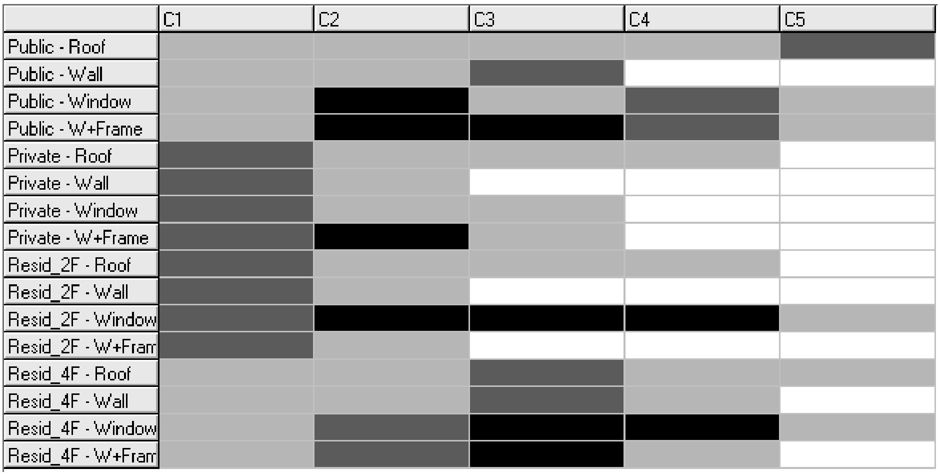
Figure 9 a) presents the results obtained with the IRIS software, where all the criteria are scrutinized and non-dominant, i.e., $k_j \in [0.01; 0.49]$. In this situation only roof interventions on the public sector are classified in the best category (C^5). On the other hand, only the replacement of single glazed windows with or without frames in the public sector are classified in the second best category (C^4) with one half of the energy efficiency renovation actions being classified in the worst category (C^1).

Figure 9 b) illustrates the results reached according to the preferences expressed by the investor. The explicit consideration of the investor’s preferences, by assigning higher weights to “Investment costs”, “NPV”, “Energy savings” and “Technology maturity”, imposing them as the most important criteria, leads to the classification of all actions in the three worst categories. In fact, the best classification possible for the energy renovation actions herein assessed is “fair”. This is the result of the bad performance of these actions regarding the “Investment cost” and “NPV” criteria (see also Figure 4).

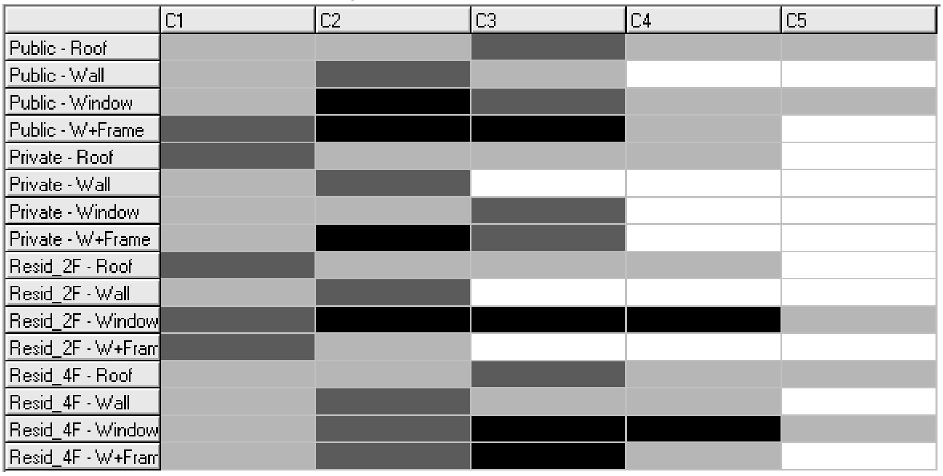
It is worth noting that the best options available from the investor’s point of view should be on roof interventions and single glazed windows replacement on public buildings, on single glazed windows replacement with or without frame replacement on private service buildings and, finally, on roof insulation on the residential buildings with four facades. However, the results herein obtained suggest that from the investors’ point of view there are not enough incentives to implement these kinds of energy renovation actions, particularly if we add to this kind of decisions the current economic situation.

When assigning the preferences expressed by political authorities (see Figure 9 c)), i.e., considering “Employment”, “GVA”, and “Social acceptability” as the most important criteria, the majority of the energy renovation actions are classified in the two worst categories. Nevertheless, in this situation, single glazed windows replacement with or without frame replacement on public buildings are classified in the second best category.

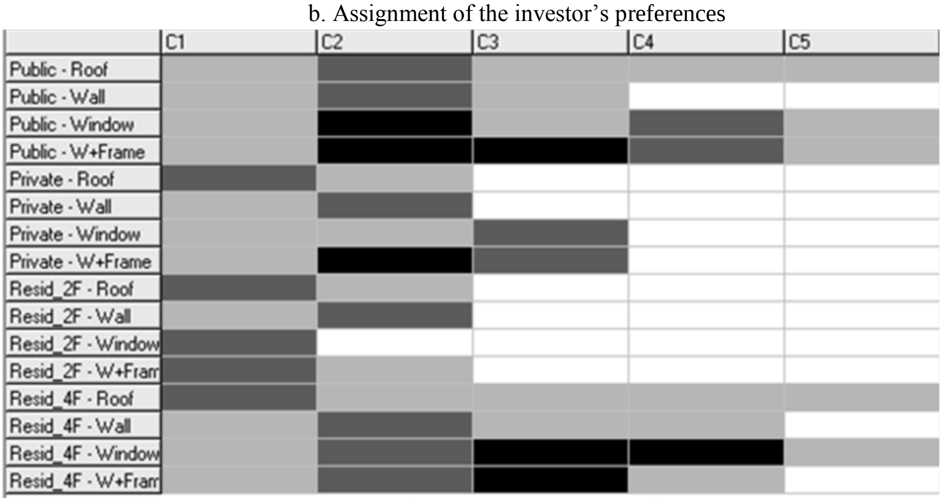
The same might be concluded in the next worst category for private service buildings. This is due to the performance of these actions according to the potential income generation - GVA (see Figure 3).



a. kj ϵ[0.01;0.49] and λ ϵ [0.51;0.67]

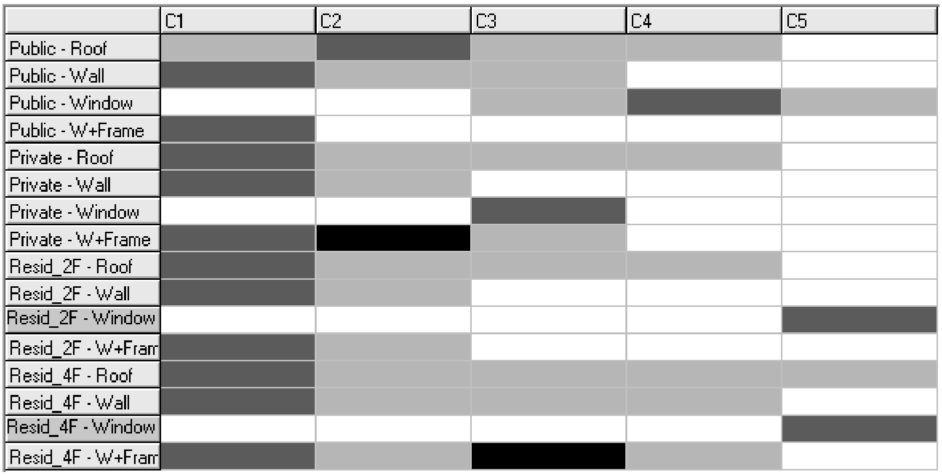


b. Assignment of the investor's preferences



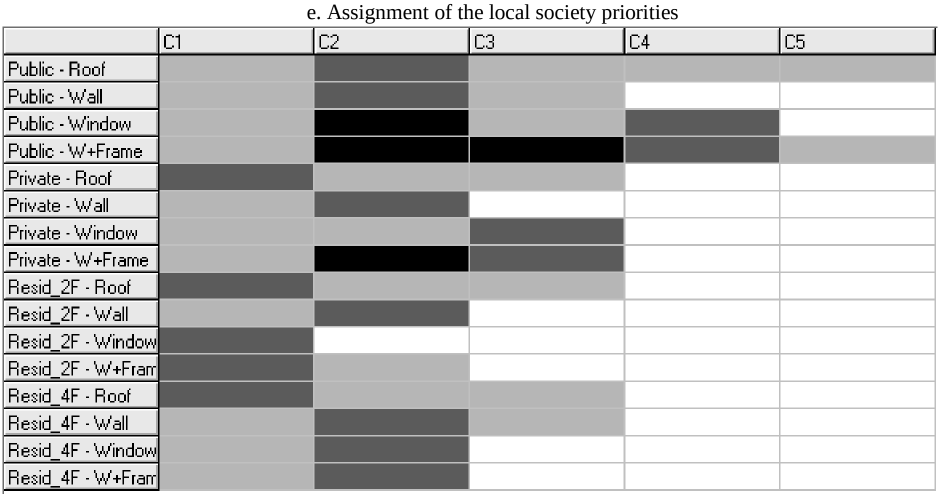
c. Assignment of the political authority's preferences

Figure 9. (Continued).



d. Imposing a minimum classification to window glazing replacement in residential buildings with 2 facades

e. Assignment of the local society priorities



f. Assignment of the local society priorities and GAV

Figure 9. Results obtained with different assumptions.

The results depicted in Figure 9 d) were obtained considering that the actions regarding single glazed window replacement of residential buildings (with two or four facades) should be at least classified as “Good” (C^4) (identified by a darker grey shadow of their label). The imposition copes with the priorities given by the National Energy Efficiency Action Plan, although no incentives were defined. The introduction of this assignment example "drags" all the other actions to the worst category, while these actions are limited to the best category (C^5). The proposed classification leads IRIS to assign a higher weight to the "Investment costs" and “Technology maturity” criteria, thus benefiting the actions regarding single glazed window replacement that have a better performance against these criteria and penalizing the remaining actions that have a bad performance in these criteria.

When considering local society priorities (see Figure 9 e)), i.e., by assigning “Energy savings” and “CO_2 emissions reduction” with the highest weights, only 2 actions are classified and limited to the worst category and the majority of the actions have a “positive” classification. These results highlight the trade-off between the environmental and economic criteria – either locally or globally. However, when including the “GVA” criterion with a higher weight, the results proposed by IRIS are quite different (see Figure 9 f)). The majority of actions become classified in the two worst categories and only 2 actions related to single glazed window replacement (with or without frame replacement) are classified as “Good”. This reinforces the previous conclusion.

The MCDA assessment can continue by adding new information or reviewing/changing the information already included. If other indicators are obtained with both bottom-up and top-down approaches they can easily be included in the MCDA framework, since actions are compared in absolute terms (against reference profiles) and not in comparison with other actions.

CONCLUSION

This chapter reinforces the fact that energy savings obtained through the renovation of the existing building stock is one of the most effective options available to reduce CO_2 emissions and potentially leading to improvements in energy security levels by reducing energy imports. Nevertheless, although it may seem a particularly good time for pursuing such kind of energy renovations measures and there is extensive evidence that undertaking energy efficient renovations at current energy prices generally pay for themselves, this is not straight forward. In fact, the energy renovation actions herein considered from the investors’ point of view are not very attractive indicating the need of further incentives for achieving the Portuguese and EU 2020 energy efficiency targets.

It is also worth noting that besides the benefits these energy efficiency renovation actions may convey, they will also help generate the much needed spur to the economy at a time of economic underperformance and spare capacity. In this context, this Chapter highlights the trade-offs between the investors’ point of view and the global economic performance of the measures tackled, particularly in the buildings of public and private services (see Figure 3), where single glazed window replacement with or without frame replacement achieve the highest global economic scores, even with the lowest scores obtained with NPV and the payback period (see Figure 4 and Figure 5).

On the other hand, by reducing energy consumption and increasing the quality of indoor climate when renovating, co-benefits may be reached such as reduced expenditure on government subsidies, and improved health due to a lesser amount of air pollution and a better indoor climate, both of which also leading to fewer hospitalizations and improved worker productivity. Future work is currently under way in order to encompass other energy efficiency measures and other different building types.

ACKNOWLEDGMENTS

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