Modelling of energy demand drivers of the service sector in IMAGE[1]

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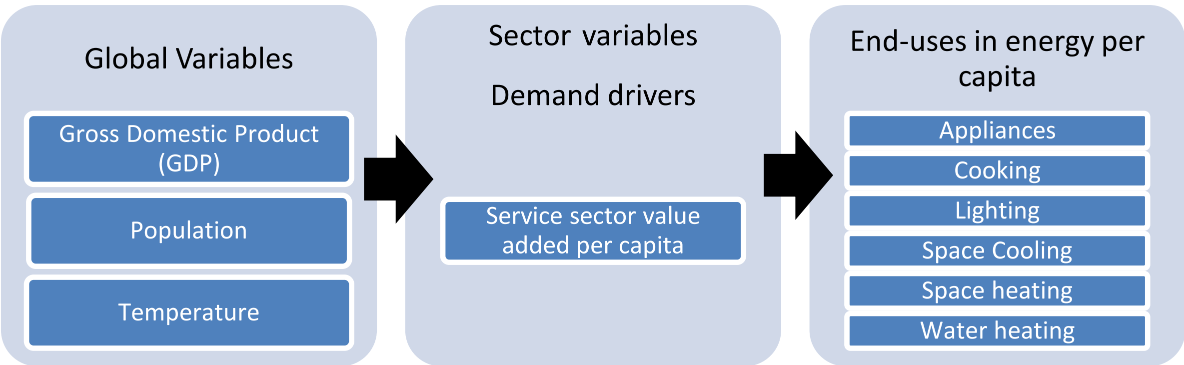
The service sector, also referred to as the commercial and public service sector, or the tertiary sector, has grown rapidly in the last decades, which has resulted in an increase of final energy consumption by 37% between 1990 and 2005. In 2005 the final energy consumption was 27 EJ, and the associated CO_2 emissions, including indirect emissions from electricity, amounted to 2.6 GT CO_2. 73% of the service sector final energy demand is consumed in the OECD; however energy use has grown faster in Non-OECD countries recently (IEA, 2008).

The growth of service sector final energy consumption is mainly due to an increase in electricity use, which has grown by 73% between 1990 and 2005. The use of electricity driven devices such as lighting, air conditioning and electric appliances have become more important in the last years. The service sector energy mix varies significantly amongst countries. Natural gas and electricity are the dominant energy carriers in most OECD countries, while China and South Africa use a significant amount of coal, and India relies mainly on both coal and biomass (IEA, 2008).

The service sector comprises a wide range of activities, including trade, finance, real estate, public administration, health, food and lodging, education and commercial activities[2]. These activities serve different purposes and therefore require different technologies. This is reflected in their heterogeneous demand for energy end-uses. The heterogeneity of the service sector in activity and end-uses makes analyzing the development of its energy consumption and CO_2 emissions a challenging task, and requires detailed disaggregated data. As the service sector energy demand is growing, with increasing emissions affecting climate change, it has become more important to understand what drives the sector's energy demand.

Within the ADVANCE project a detailed service sector model has been developed, containing a representation of service sector energy demand drivers and its end-use structure. The main drivers of service sector energy demand have been identified based on analysis of regional service sector end-use demand data. The sectors' behavior in terms of structural change of end-uses, energy intensity and technology change can be represented, by modelling energy end-uses. Figure 1 shows the proposed demand drivers and the disaggregation of the sector by end-uses used in the model.

Figure 1: Data, end-uses and demand drivers for the service sector model



[1] This section is part of ongoing research planned to be submitted to a peer reviewed journal.
[2] As classified by the International Standard Industrial Classification ISIC two-digit level rev. 4.0 – 33, 36-39, 45-96, 99 excluding class 8422 (UNSD, 2008).

The research was carried within the Integrated Model to Assess the Global Environment (IMAGE) and The IMage Energy Regional Model (TIMER). IMAGE is an ecological-environmental model framework, developed by PBL Netherlands Environmental Assessment Agency, which simulates the environmental consequences of human activities worldwide. To represent global energy supply and demand, an energy-system simulation model, TIMER, has been integrated into the IMAGE model. TIMER simulates trends in energy use and efficiency, and is used to analyze long-term energy demand and supply scenarios in the context of sustainable development challenges (Stehfest et al. 2014, Van Vuuren et al., 2014).

Modelling method: Relating service sector energy demand to drivers

A literature research for service sector energy demand data was conducted collecting data from several countries (Brazil, China, South Africa, United Kingdom, United States of America, and Canada). The different datasets were difficult to compare due to incompatible timeframes and varying definitions of the end-uses. The IEA provided service sector data for 25 regions per end-use and energy carrier in 2011 (IEA,2013). Even though this data does not have a time dimension, it contains consistent and detailed data covering regions from all continents, originating from a reliable source.

Based on the IEA data, relations between scenario drivers and service sectors energy end-use have been formulated. Figure A.1.1 in the appendix shows the amount of useful energy demand per capita for each region's level of SVA, for Appliances, Lighting and Cooking. Figure A.1.2 shows the amount of useful energy demand per capita per degree-day for each region's level of service sector value added (SVA) for the end-uses Space Cooling, Space Heating and Water Heating, that depend on temperature differences[3]. The cooling degree days (CDD) and heating degree days (HDD) we based on Isaac et al. (2009). The regional SVA per capita values were calculated as follows:

Eq. (1): Regional SVA per capita

$$SVApc_{region,t} = \frac{GDP_{region,t} \times \% \; of \; GDP_{region,t}}{Population_{region,t}}$$

- Where:
  - SVApc = Services Value Added per capita
  - GDP = Gross Domestic Product (OECD,2012)
  - % of GDP = Share of the Services Sector of the total GDP (OECD,2012)
  - Population = Total inhabitants (OECD, 2012)

It can be seen that countries with a higher SVA per capita use more useful energy (UE) demand per capita for each end-use while countries with low SVA per capita use less energy, confirming the suitability of SVA per capita as a driver of service sector energy use. Moreover, for each end-use useful energy grows fast initially and then levels off, suggesting an s-type relation between the two.

Three logistic growth functions were compared to the historical regional end-use demand data. Of the three functions the Gompertz function (eq. 2) is used to represent this behavior in TIMER, as it had the best fit and the Gompertz function has also been used in the TIMER residential sector (Daioglou et al. 2012). In the appendix A.2 the outcome of the regression analysis can be found. Based on the analysis, the new TIMER service model was designed where the y of the Gompertz function refers to UE per capita for Appliances, Lighting and Cooking and UE per capita per degree-day for Space Heating, Space Cooling and Water Heating. The x for each end use refers to SVA per capita. The parameter a, b, c and e can be found in appendix A.2.

[3] The final energy data was converted to Useful Energy, using the global conversion efficiencies for each energy carrier based on Daioglou et al. (2012).

Eq. (2): Gompertz function

$$y(x) = ae^{-be^{-cx}}$$

where:

- a = asymptote, sets the carrying capacity
- b = displacement along the x axis, positive number
- c = growth rate
- *e* = Euler's number

Distributing across energy carriers

Appliances, Lighting and Space cooling are generally speaking fueled by electricity, which results in a straightforward conversion to Final Energy. Cooking, Space heating and Water heating can be fueled by different energy carriers, which involve different conversion efficiencies. For these functions the conversion to Final Energy depends on the shares of each energy carriers. The energy carrier market shares vary among regions, depending on fuel prices and availability, and also on technological preferences (e.g., in some regions electrical water heaters are more common that gas water boilers). In TIMER the multinomial logit function (MNL) is used to determine the market share of the different energy carriers based on their relative fuel prices in a set of competing energy carriers and taking fuel-specific conversion efficiencies into account (eq. 3)

Eq. (3): Multinomial Logit

$$MS_{R,EU,EC} = \frac{e^{-\lambda c_{R,EC}}}{\sum_{EC} e^{-\lambda c_{R,EC}}} \qquad (2)$$

Where:

- MS = Market Share
- R = TIMER region
- EU = Energy End-use
- EC = Secondary Energy Carrier
- λ = Logit factor, substitution sensitivity to fuel costs
- c = Fuel costs

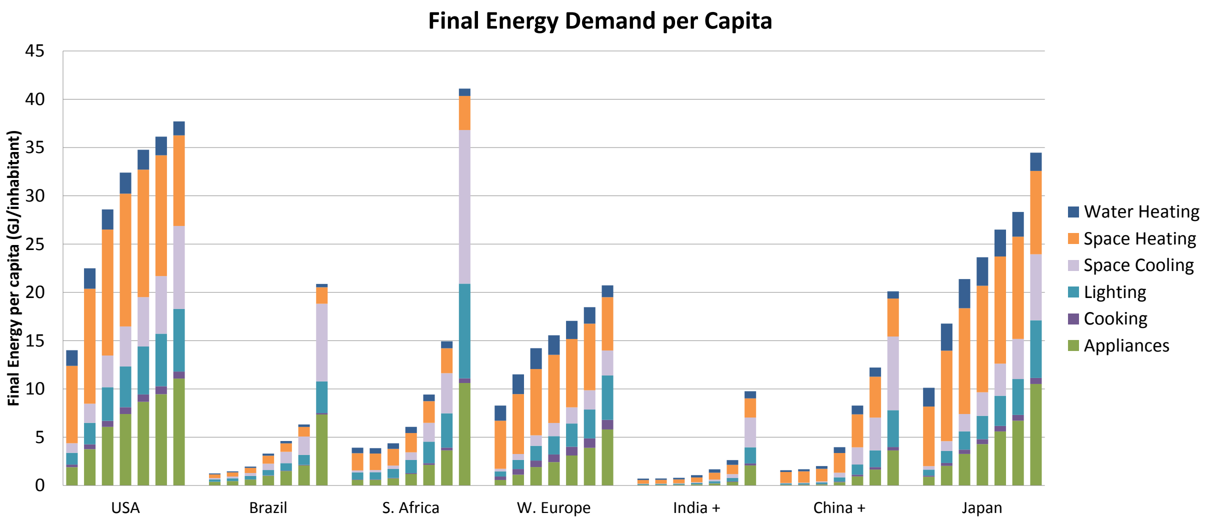
The fuel costs are endogenously calculated in the TIMER supply module taking direct production costs and energy cost into consideration.

The IMAGE model runs from 1970, providing the opportunity to calibrate the model to historic energy use. First the fuel shares of cooking, space heating and water heating were approximated to those of the IEA data in 2011 by introducing premium factors (PF) to the fuel cost of the MNL function. PFs are a 'perceived cost' added to the fuel cost per end-use and per region so the model can reflect the historic fuel share tendencies of the region, depending on its fuel and technology availability. Premium factors describe the non-monetary considerations (environmental policies, infrastructure or the lack of it, ease of access and use of the energy carrier, quality of energy carrier, etc.), which determine fuel choices (Stehfest et al., 2014). Then between 1971 and 2012 the service sector total fuel shares were calibrated to the historical data collected by the IEA Energy Balances (IEA, 2014a, IEA 2014b). The objective of this model calibration is to approximate the final energy fuel shares to the actual fuel shares of each region within an error margin of ± 15%.

Baseline final energy demand

The new service sector model results are tested using SSP2[4] scenario assumptions. In SSP2 GDP per capita, which is related to SVA following eq. 1, is assumed to increase until 2100 in all regions as GDP grows at a higher rate than population. Therefore, energy use per capita continues to increase throughout the century as can be seen in Figure 2. Figure 3 shows the projected development of final energy demand by end-use. The results are presented for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100, and for seven TIMER regions. These regions were chosen for their importance in world economy and their varied temperatures.

Figure 2: Final energy demand per capita. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, disaggregated by end-uses for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100.



Globally, space heating is responsible for the largest share of service sector energy use. Per region, however, this depends on regional climate characteristics (HDD). This is the reason why in Brazil, a very warm country with low HDD, space heating takes up a relatively small share. Furthermore, it can be seen that space cooling share starts to increase rapidly after a certain SVA per capita level, i.e. China, where Space Cooling has a very small share until after 2020, and in 2050 it has a share comparable to that of Space Heating. Cooking for all regions and time takes up the smallest share.

It is worth noting that among regions with similar SVA per capita there are significant differences in the final energy demand. This is evident when comparing Japan to the USA and Europe, or Brazil to India and China. This is mainly because of differences in the fuel mix, and thus the efficiency of meeting the useful energy, but also due to a different end-use structure. The structure of end-uses in the service sector has a region specific energy matrix that will depend on the availability of the energy carrier, its cost, and the technological preference of the region.

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[4] SSP2 is the middle of the road scenario. It depicts a future where the development trends do not shift markedly towards any direction, and are consistent with the historic growth patterns. Environmental systems keep degrading; meanwhile, technology improves without major breakthroughs. Fossil fuel dependency declines gradually, but no policy framework boosts the use of renewable sources or sets limits to the use of unconventional fossil resources. Population growth is moderate and it levels off by the second half of the century (O'Neill et al., 2015).

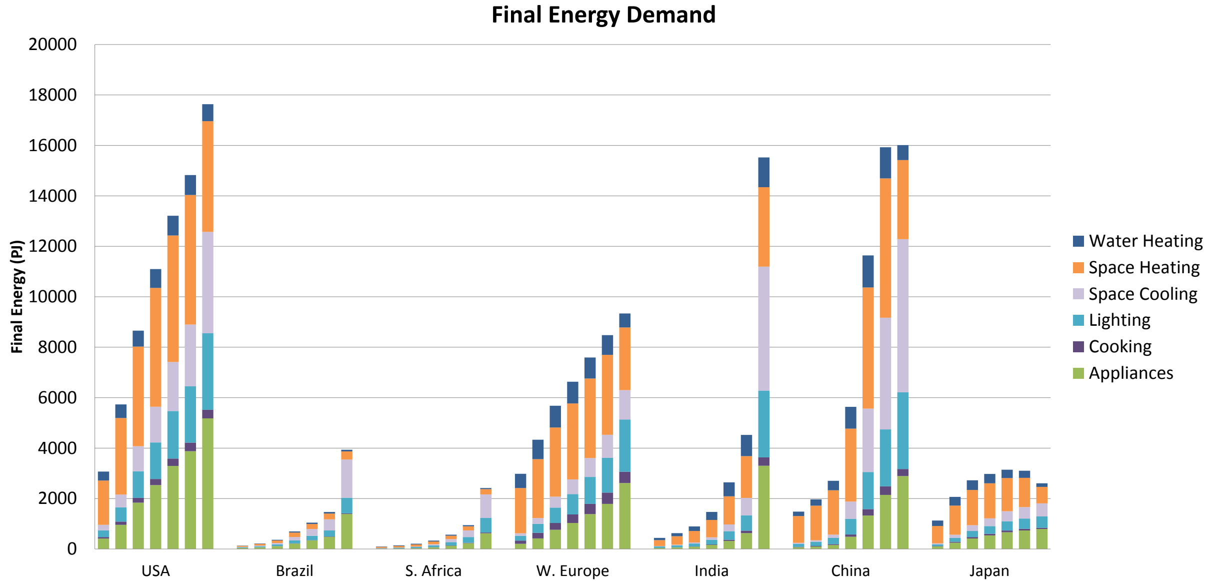

Figure 3: Final energy demand. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, disaggregated by end-uses for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100.

Figure 4 shows the share of each of the secondary energy carriers involved in the service sector. The new model projects a tendency towards electrification in the service sector. This is due to: a) the increasing share of Appliances (from 15,8% in 2010 to 25,1% in 2100, global), Lighting (11.3% to 16.4%) and Space Cooling (9.2% to 32,6%) in the sector's structure, with the latter becoming the more important energy end-use of the service sector by the end of the century, and, b) the price increase of fossil fuels, which makes the MNL function of the model to choose less expensive and more efficient energy carriers, such as electricity.

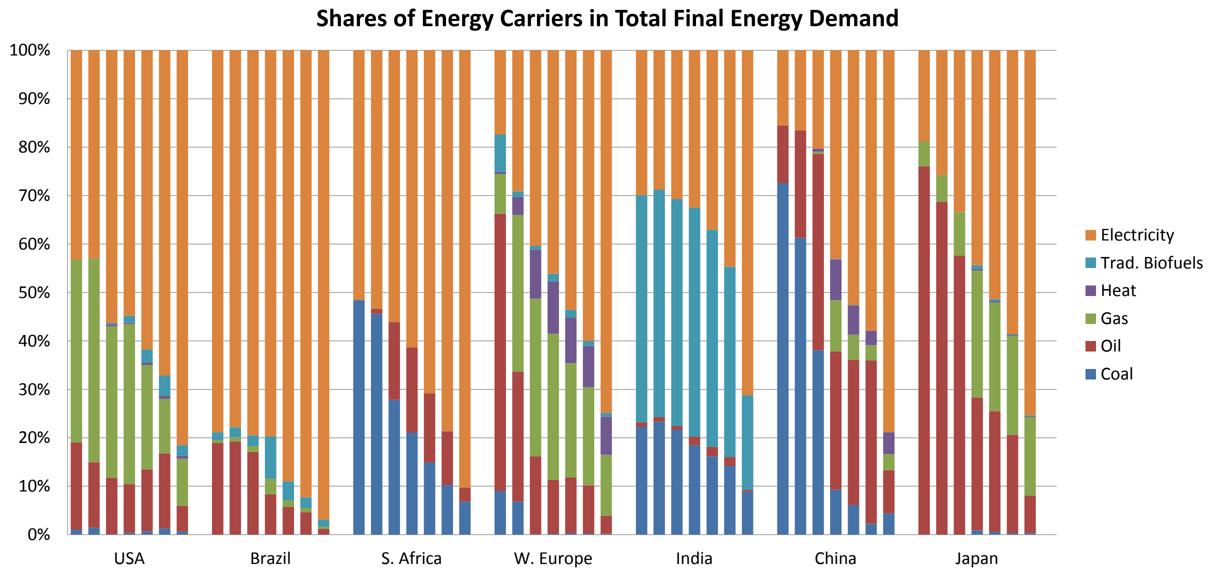

Figure 4: Market shares of the different energy carriers. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100.

Discussion and Conclusion

The service sector model was developed based under the assumption that regions follow the same development in service sector energy end-use in relation to SVA per capita, corrected for climate conditions. This assumption had to be made as comparable data was only available for 2011. It could be argued however that each region has a different service sector activity structure, therefore different paths of development.

Further research could be improved by a) developing different functions for different groups of regions depending on their level of service sector development, b) compile more information of the service sector by region, such as:

1. Floor area – This would allow a better modeling of the upper limits of functions as space heating, space cooling and lighting and efficiency improvements.
2. Number of employees – This model was constructed by linking SVApc to UE per inhabitant. If the SVA increases but less people work in the sector this could lead to decreasing demand of for example space heating demand, which currently is not taken in to account.
3. Building stock – In order to improve the potential and barriers to efficiency improvements in the service sector the building stock can be helpful. In addition information on energy efficiency measures in building codes and regulations can be included.
4. Share of the different activities – The service sector consists of many different activities: from hospitals to schools, office buildings to casinos, IT buildings, shopping malls and supermarkets, hotels and restaurants, that all differ in demand of energy requiring uses.

The previous model included factors to represent two types of energy efficiency improvement: autonomous energy efficiency improvement (AEEI) and price-induced energy efficiency improvement (PIEEI). While saturation of useful energy demand is implicit in the Gompertz function, where after a certain level of SVA per capita UE demand growth decreases following the assumption that countries get more efficient as their SVA grows, AEEI, in the form of for example boilers getting more efficient, and PIEEI are not accounted for. Over time or in reaction to changing fuel prices in the current model no switching to efficient conversion technology takes place. Research shows that several barriers for the service sector to improve its efficiency can be found in many of its sub-sectors. As described by Schleich, J., & Gruber, E. (2008), the energy cost share in this sector is in most cases very low (3% share in total turnover), in contrast with energy-intensive industries for example. This leads to a certain unattractiveness of the energy efficiency investments, mainly due to for example: a) considerable uncertainty on the amount of energy savings, therefore return of investment, due to a lack of energy use measurement, b) hidden costs (time and resources) for information gathering about the different energy efficiency measures, or technologies, or c) the investor/user dilemma, when companies work on rented spaces, and neither the landlord nor the tenant possess a real incentive to invest in energy efficiency, as no matter who invests, they will not be able to fully appropriate the benefits. Therefore energy saving, or cost saving energy-related projects have low chance in competing with core-business cost-saving projects in the service sector. Literature has also shown that energy efficiency improvement in the service sector is achieved when it is induced by new policies, e.g. with new building codes, lighting efficiency and energy-efficient appliances regulations, which can even imply getting more efficient cooking, space and water heating, and cooling technologies (Schleich, J., & Gruber, E., 2008). Thus, it is recommended to improve the model by modeling a policy-induced energy efficiency improvement.

An example of this can be found in the modelling of lighting. Lighting requirements for working spaces are established in lumens per square meter or lux. According to the European standard, BS EN 12464-1:2011, office spaces require a minimum of 300 to 500 lux, depending on the task to perform. Similar work place lighting standards can be found in several regions. Lighting fixtures, e.g. fluorescent lamps, output a certain amount of lumens per watt of input; this is often called the conversion efficacy, to differentiate it from the conversion efficiency. The so-called high-efficiency lamps possess a high conversion efficacy, i.e. a high amount of lumens per watt. In order to get a better bottom-up approach for the service sector’s energy demand model, it is recommended to understand the shares of the different lighting fixtures in the service sector.

Conclusions

Service sector useful end-use energy demand and SVA have been found to relate a high correlation. There are still opportunities of improvement by adding other variables to the equation, e.g. floor space or employees of the sector. Nevertheless, this model brings a good starting point in terms of reliability for more complex additions.

Modelling service sector energy end-use of each region gives better insight of structural change. The new model gives a more detailed overview of the demand behavior per region. This model can be used to get more input for explaining the reason why a certain region has a higher share of electricity, or any other fuel for that matter. Space heating and space cooling use differences can be explained through differences in the heating and cooling degree-days. Energy carrier shares can be often explained through the end-use structure or by regional energy prices and fuel and technological availability, but information about the latter is not always available.

This model shows that, as long as the service sector maintains its growth, its final energy demand will increase globally. When looking at specific end-uses, it is clear that space heating loses the lead in end-use share to space cooling and appliances. A major shift into the use of electricity is also evident. Although fuel prices play a role in the energy carrier mix, since the energy costs of the service sector do not represent a major part of the sector’s cost, their importance is not significant. Therefore, in order to mitigate CO_2 emissions it is necessary to instate efficiency policies. In that way, space heating and space cooling requirements can be reduced significantly. Also, the required energy to cover appliances and lighting requirements would be substantially diminished.

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A.1 Useful energy per capita compared to service sector value added per capita for the various end-uses.

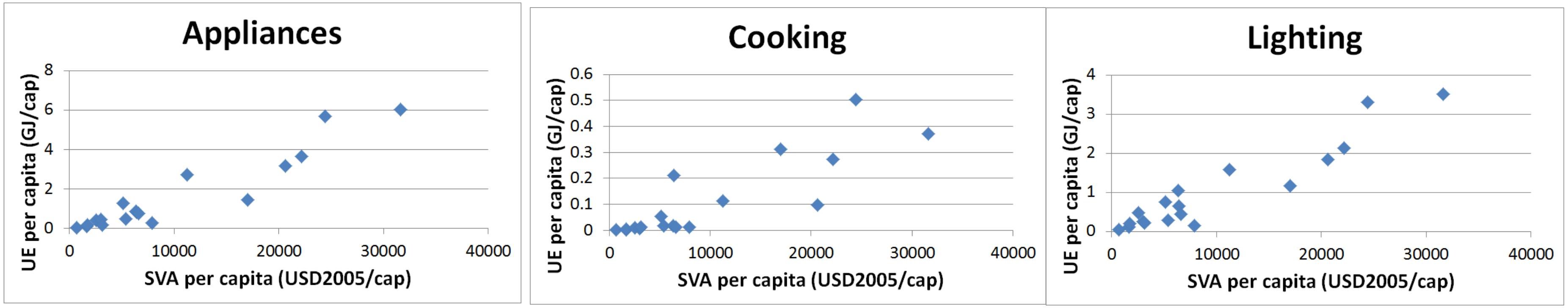

Figure A.1.1 Use of energy compared to the country's SVA in 2011, for each of the energy end-uses

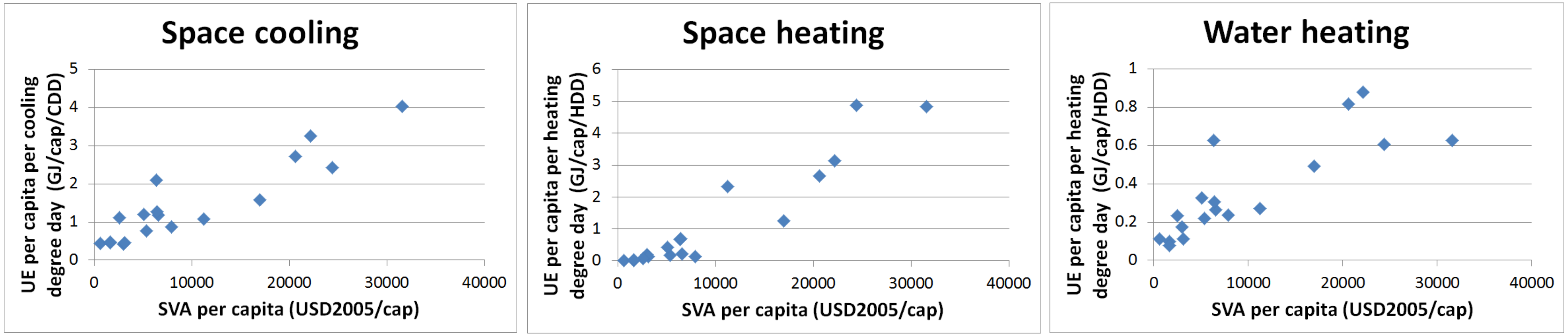

Figure A.1.2 Use of energy per degree-day compared to the country's SVA in 2011, for each of the energy end-uses

A.2 Parameterization Gompertz function Service sector model

Gompertz	a	b	c	R^2
Appliances	12.36	4.073	0.057	0.904
Cooking	0.484	4.352	0.101	0.738
Lighting	7.401	3.626	0.051	0.901
Space Cooling	7.487	4.683	0.079	0.906
Space Heating	4	2.206	0.079	0.817
Water Heating	0.755	2.119	0.129	0.738

Gompertz function parameters used for each end-use equation, and their respective R squared from the regression analysis.