Exploring the energy demand of the service sector and its role in global emissions

An Energy Science Master Thesis

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Summary

The service sector has grown rapidly in the last decades, resulting in a significant increase of its energy consumption and subsequently greenhouse gas emissions. Therefore, it has become utterly important to understand what drives the sector's energy demand. For this purpose, this study takes a look at the regional development of each of the energy end-uses of the service sector: appliances, cooking, lighting, space cooling, space heating and water heating.

In order to understand the energy demand trend of the service sector and its projection into the future, a global service sector model has been developed, within the IMAGE/TIMER model environment by linking the energy use of each of the end-uses to the sector’s value added (SVA). This model aims to facilitate the analysis of the energy demand behavior of the service sector by region, by end-use and by energy carrier and its relation to its main energy demand drivers: SVA, population and temperature.

In the end, this model should be used to assess the efficacy of different energy policies for the sector in terms of greenhouse gases mitigation.

Acknowledgements

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1. Introduction

The service sector, also referred to as the commercial and public service sector, or the tertiary sector, has grown rapidly in the last decades, resulting on an increase of final energy consumption of 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 (See Figure 1.1). 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).

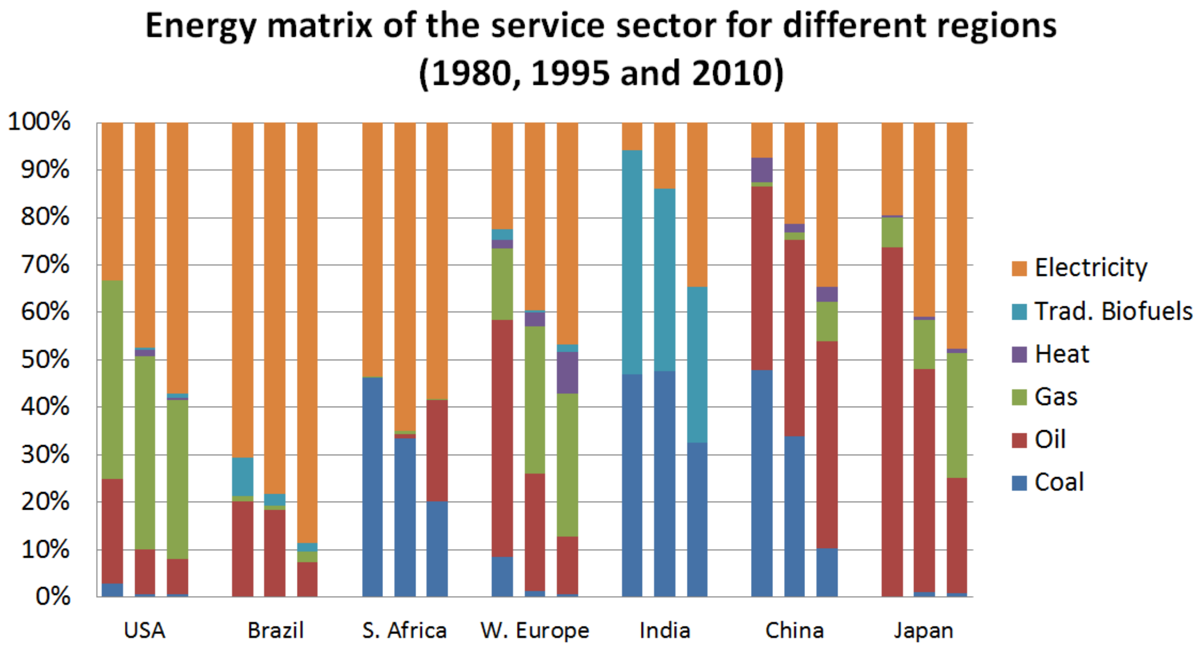

Figure 1.1 Services energy use by energy commodity (IEA, 2008)

The service sector comprises a wide range of activities, including trade, finance, real estate, public administration, health, food and lodging, education and commercial activities[1]. These activities serve different purposes and therefore require different technologies. This is reflected in their heterogenic 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. The aim of this study is to identify the main drivers of service

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[1] 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).

sector energy demand, by taking a closer look at the regional service sector end-use demand. This can provide insights into forecasting possible future scenarios of energy consumption of this sector.

Specifically this research will address the following research question:

What are long-term trends in future energy demand of the service sector?

To answer the main question, the following sub questions will be addressed.

1. Can strong relations between drivers and end-uses be found in existing data to produce a reliable model?
2. Can differences in service sector energy use between regions be explained?
3. How do different global economic trends, depicted in the three main Shared Socioeconomic Pathways (SSPs), influence the energy demand of the service sector?
4. What impact does the incorporation of service sector end uses in the TIMER model have on the scenarios of CO_2 emissions?

This 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, (Van Vuuren et al., 2014).

The service sector energy use is determined in the demand component of the TIMER model. In this module, final energy demand is simulated as a function of changes in population, economic activity and energy intensity of the sector. Equation 1 depicts the function through which energy demand is calculated in TIMER, for sector S (service sector in this case), for each region R, energy form F (heat or electricity) (Van Vuuren et al., 2014).

Equation 1 *Aggregated energy demand*

$$SE_{R,S,F} = \frac{POP_{R}(t) * \frac{ACT}{POP}_{R,S}(t) * SC_{R,S,F}(t) * AEEI_{R,S,F}(t) * PIEEI_{R,S,F}(t)}{\sum_{EC} \eta_{R,S,C(t)} * MS_{R,S,C(t)}}$$

Where:

- SE = final energy;
- POP = represents population;
- ACT/POP = sectorial activity per capita;
- SC = factor of intra-sectorial structural change;
- AEEI = autonomous energy efficiency improvement;
- PIEEI = price-induced energy efficiency improvement.
- η = end-use efficiency of energy carriers used in, for example, boilers and stoves;
- MS = share of each energy carrier.

There are three new and important concepts in this equation. The SC factor represents the changes in the mix of activities of the sector as a function of development and time. These changes may influence the energy intensity of the sector. For example, using more trains instead of private cars as means of transport would decrease the energy intensity of the transport sector. AEEI is a factor used to account for technological improvement. It represents the fact that in time, technologies become more energy efficient. PIEEI is a multiplier used to depict the effect that increasing fuel prices in the efficiency investment behavior of the users (Stehfest et al., 2014). As we see, in this aggregated form of energy demand model structural change is represented by a growth dependent factor, and underlying processes of the shifts in the activity mix are not explicitly represented.

This brings up an improvement opportunity in the TIMER model: to develop a detailed service sector model that will depict a better representation of its end-use structure and allow a better understanding of what drives its energy demand and structural change in terms of end-uses and energy intensity. This is the knowledge gap that this research will study, in order to depict the future trends of energy demand in the service sector.

This representation involves a deeper understanding of the sectors' behavior in terms of the energy intensity of each of the end uses. Possessing this degree of detail in the services sector model would improve the representation of the role of structural change and technological efficiency. Figure 1.3 shows the proposed disaggregation of the sector by end-uses and the demand drivers to be used in the model.

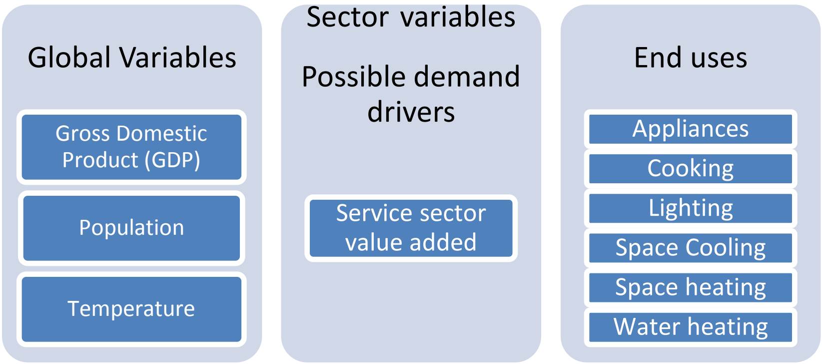

Figure 1.2 Data, end-uses and demand drivers for the service sector model

As we can see in the figure above, we have divided the energy demand of the sector on 6 standard end-uses. In this research the development of the service sector energy demand was analyzed by each end use, identifying their main drivers, and the analysis is used to improve the representation of future service sector energy consumption within the IMAGE model, which brings us to our research question:

It is important to mention that this research is part of a major effort for improving the TIMER model by reformulating the energy demand in order to better represent specific energy functions, or end-uses, of the different sectors. For example, the residential sector, in which the energy demand is now calculated in a more detailed manner by representing different end uses, and differentiating between urban and rural households, as well as income groups (Daioglou et al., 2012); or the heavy industry sector, where cement and steel demands are now calculated in detail, depending on specific technologic and industrial energy efficiency (Boskaljon, 2010). Similar examples of improvement can be found in the transport (Girod et al., 2012) and non-energy sectors (Daioglou et al., 2014).

In this paper, chapter 2 describes the methodology for creating the service sector model. In the same section the scenarios used in the study are qualitatively described. Chapter 3 summarizes the main results found by running the standalone service sector model and the results of the scenario analysis. In chapter 4 the methodology and results are discussed, focusing on the uncertainty of the model and how to interpret its results, including suggestions for future research and improvement. Concluding with section 5, where the research questions will be answered.

2. Methodology

The purpose of this chapter is to explain how the model was created and how it was used to address the research question described in chapter 1. It will be divided in three subchapters: energy demand data and drivers; model coding and calibration; scenario simulations. In the first subchapter, the energy demand and drivers data that was used to build the model is described and the method to find the relation between them is shown. Also, the method used to establish relations between the drivers and the energy demand is explained. The coding process of the model and the method used to calibrate the model to the historic data of the service sector's energy demand of each region is explained in subchapter 2.2. Finally, in the subchapter 2.3 the method for simulating different scenarios is described.

2.1. Relating service sector energy demand to drivers

A literature research for service sector energy demand data was conducted as prior to the work of this thesis started. Data from several countries (Brazil, China, South Africa, United Kingdom, United States of America, and Canada) was gathered, but the different datasets were difficult compare due to an incompatibility of timeframes between each other and a varying definition of the end-uses. The IEA provided service sector data for 25 regions per end use and energy carrier in 2011 (L. Cozzi, personal communication, 21 November 2013). Even though this data does not have a time dimension, it contains consistent and detailed data with high global coverage, originating from a reliable source. Therefore, the outcome of the literature research was to use the mentioned dataset, which cannot be showed in this document due to confidentiality motives, as the basis of the model. The IEA dataset shows the final energy demand of the service sector, disaggregated in the 25 IEA regions, 6 energy end uses (appliances, cooking, lighting, space cooling, space heating and water heating) and 7 secondary energy carriers (coal, oil, gas, electricity, heat, bioenergy and other renewables) for the year 2011, in millions of tons of oil-equivalent.

To build a model that is compatible with the current TIMER model the next step was to translate the useful energy data from IEA regions to TIMER regions. Table 2.1 shows how this translation was done.

IEA Regions	TIMER Regions	Differences
CAN	1 – CAN	-
US	2 – USA	-
MEX	3 – MEX	-
CHILE + OLAM	4 – RCAM + 6 – RSAM	-
BRAZIL	5 – BRA	-
NAFR	7 – NAF	-
OAFR	8 – WAF + 9 – EAF + 26 – RSAF	-
SAFR	10 – SAF	-
OE5 + EUG4 + EU17 + EU7 + OETE	11 – WEU + 12 – CEU + 13 – TUR + 14 – UKR	Israel
RUS + CASP	15 – STAN + 16 – RUS	-
ME	17 – ME	Israel
INDIA	18 – INDIA	-
KOR	19 - KOR	DPR of Korea
CHINA + ODA	20 – CHN + 25 – RSAS	DPR of Korea, Papua New Guinea, Rest of Oceania, East Timor
ASEAN9	21 – SEAS	East Timor
INDO	22 – INDO	Papua New Guinea
JPN	23 – JAP	-
AUSNZ	24 – OCE	Rest of Oceania

Table 2.1 Summary of the translation between IEA Regions and TIMER Regions and their differences.

It is an assumption of the present research that service sector energy demand is related to the service sector value added (SVA) and population of a region. Certain energy functions could grow more with growing SVA, which then would be a form of structural change in the sector. For space heating, water heating and space cooling it is expected that climate conditions play an important role. To research whether this is the case the next step is to find relations between the useful energy demand and drivers, such as the sector's value added (SVA), population and temperature in terms of heating degree days (HDD) and cooling degree days (CDD) as presented in Figure 2.1. Equation 2 shows how the SVA per capita is calculated.

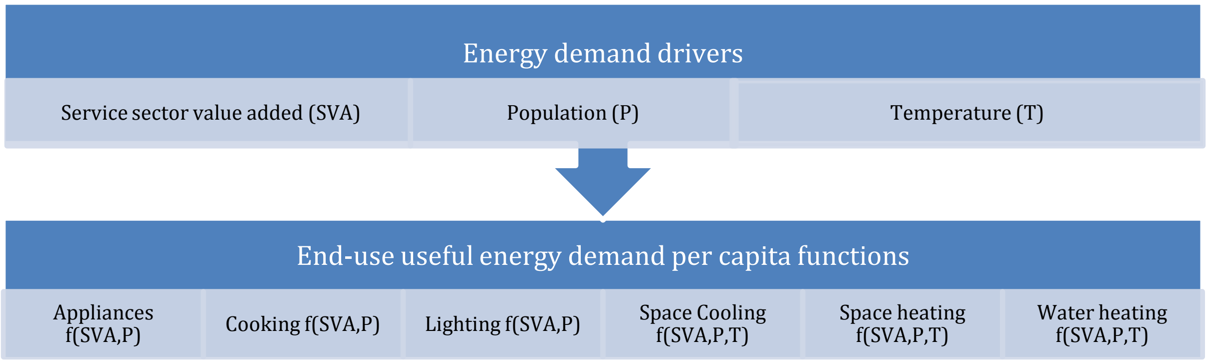

Figure 2.1 Relation between drivers and useful energy functions.

Equation 2

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

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)

To analyze whether a relations can be found between the SVA and the energy demand, first the energy demand needs to be known in terms of use, i.e. Useful Energy (UE). For this purpose, the final energy data was converted to (UE), using the global conversion efficiencies for each energy carrier and end-use shown in Table 2.2, following Equation 3:

Equation 3

$$UE_{(EU,EC)} = FE_{(EU,EC)} * \eta_{(EU,EC)}$$

Where:

- UE = Useful Energy
- FE = Final Energy
- η = End use conversion efficiency
- EU = Energy End Use
- EC = Energy Carrier

	Solid	Liquid	Gas	Hydrogen	Modern Biofuels	Secondary Heat	Traditional Biofuels	Electricity
Heating (space and water	0.6	0.67	0.67	0.4	0.67	1	0.19	1
Cooking	0.15	0.503	0.604	-	0.334	-	0.14	0.713

Table 2.2 End use conversion efficiencies for the different end uses and fuels, gathered from Residential model.

Figures 2.2-4 show the amount of useful energy demand per capita ($UE_{region,2011}/population_{region,2011}$) for each region’s level of SVA, for Appliances, Lighting and Space Cooling. And for the end-uses that depend on temperature differences, as Cooking, Space Heating and Water Heating, Figures 2.5-7 show the amount of useful energy demand per capita per degree-day ($UE_{region,2011}/population_{region,2011}/dd_{region,2011}$) for each region’s level of SVA.

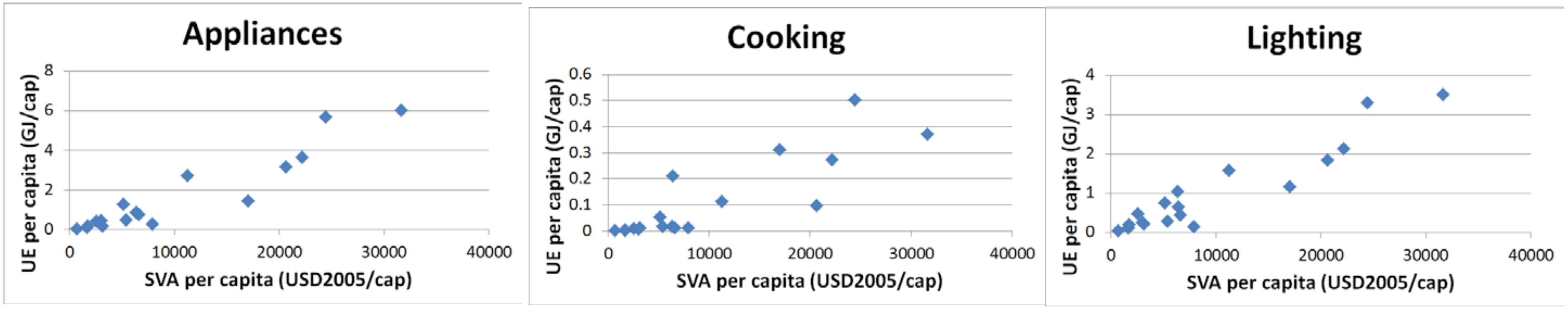

Figure 2.1, 2.2 & 2.3 Use of energy compared to the country's SVA in 2011, for each of the energy end-uses

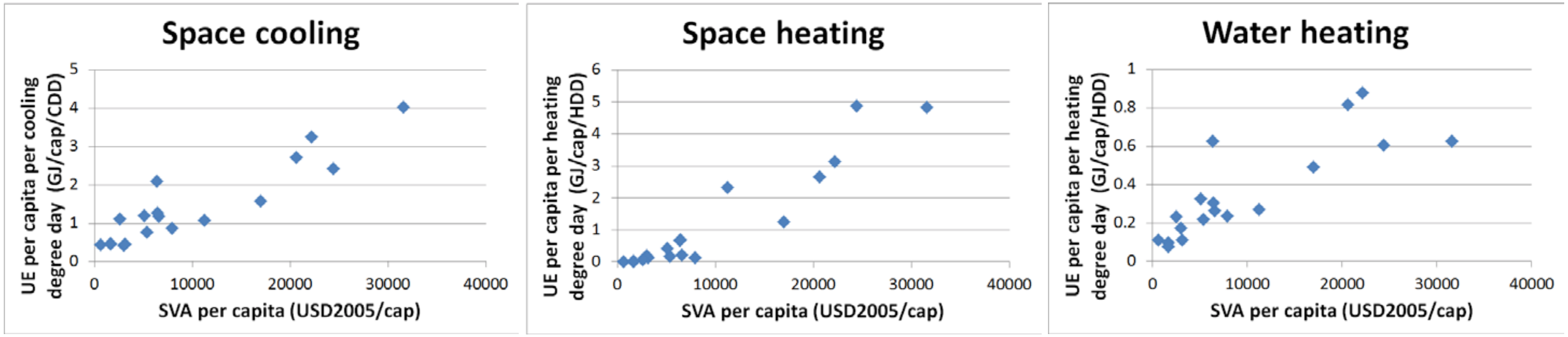

Figure 2.4, 2.5 & 2.6 Use of energy per degree-day compared to the country's SVA in 2011, for each of the energy end-uses

In these graphs, it can be noticed that countries with a higher SVA per capita present higher UE demand per capita and countries with low SVA per capita use less energy, suggesting that there is a relation between the energy demand of the sector and its economic activity. From a visual analysis we assume that this relation is shaped as a sigmoid S curve of growth.

To be able to build a model that calculates the projections of energy demand in time the following assumption had to be made: the growth curve fitted by regression analysis for the 2011 data will be used to model the end-use energy demand per region in time. This assumption implies that all regions will follow the same paths of end-use energy demand growth formulated for the relations found on 2011 data. This is a very rough assumption but had to be made due to limited data availability.

Three different sigmoid functions were used for the regression analysis: Gompertz function, Generalized Logistic function and the third one is a hybrid between the previous two. Part of the literature research for this thesis was to understand how these functions and their different parameters work. Equations 4-6 show each function's equation and a brief description of each of their parameters.

Equation 4

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

Gompertz function, where:

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

Equation 5

$$y(x) = a(1 + e^{(b-cvx)})^{-1/v}$$

Generalized Logistic function, where:

- a = asymptote, sets the carrying capacity
- b = parameter that allows the x point where y = a/2, to be varied
- c = growth rate
- v = parameter introduced as a power law so it can define asymmetric curves
- *e* = Euler's number

Equation 6

$$y(x) = a(1 + e^{(-cvx)})^{-1/v}$$

Hybrid function, where:

- a, c, v, e have the same definition as in Equation 5

For each of end use a regression analysis with all the three equations was performed. For this purpose, the SPSS Statistics software was used. All functions showed a good fit with the data, indicated by the R^2in Tables 2.3-5, along with the parameters.

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

Table 2.3 Gompertz function parameters used for each end-use equation, and their respective R squared from the regression analysis.

GLF	a	b	c	V	R^2
Appliances	6.1	591.95	0.117	196.292	0.923
Cooking	0.452	0.883	0.401	0.322	0.738
Lighting	7.381	-4.599	18.683	0.003	0.901
Space Cooling	5.022	17	0.135	5.102	0.920
Space Heating	4	10.017	0.065	5.538	0.839
Water Heating	0.749	-0.696	0.709	0.199	0.738

Table 2.4 General logistic function parameters used for each end-use equation and their respective R squared from the regression analysis.

Hybrid	a	c	v	R^2
Appliances	10.674	0.403	0.181	0.904
Cooking	0.466	0.679	0.172	0.738
Lighting	6.31	0.33	0.204	0.901
Space Cooling	6.967	0.598	0.158	0.906
Space Heating	4	0.277	0.329	0.821
Water Heating	0.745	0.428	0.349	0.738

Table 2.5 Hybrid function parameters used for each end-use equation, and their respective R squared from the regression analysis.

2.2. Building the model and calibration

The modeling of the service sector end-uses consists of three main parts: 1) modeling the useful energy of each end-use as related to its drivers, 2) relating the useful energy demand to secondary energy prices to model the final energy demand per energy carrier per end-use, and 3) calibrating the model to historical data.

With the purpose of avoiding conflicts in the TIMER/IMAGE environment, the new service sector energy demand model was constructed as a standalone model at first. The detailed methodology of how to get a standalone model started and running is documented in Appendix A.

As there was no clear winner between the three tested functions, Gompertz, GLF and Hybrid the model was built containing all three, using the parameters stated in Tables 2.4, 2.5 and 2.6. The following lines set an example of coding of the different functions for Appliances.

Gompertz (R2 of 0.904):

```
Appli_EnUse_pc [R,1] = 12.36 * EXP(-4.073 * EXP (-0.057 * SVApc [R] / 1000)), R = 1 to 26;

Appli_EnUse_pc [27,1] = LSUM(R = 1 to 26, Appli_EnUse_pc [R,1]);

Appli_EnUse [R,1] = Appli_EnUse_pc [R,1] * POP [R], R = 1 to 27;
```

GLF (R2 of 0.923)

```
Appli_EnUse_pc [R,2] = 6.1/((1 + EXP(591.948 - 0.117 * 196.292 * SVApc [R] / 1000)) ** (1/196.292)), R = 1 to 26;

Appli_EnUse_pc [27,2] = LSUM(R = 1 to 26, Appli_EnUse_pc [R,2]);

Appli_EnUse [R,2] = Appli_EnUse_pc [R,2] * POP [R], R = 1 to 27;
```

Hybrid (R2 of 0.904)

```
Appli_EnUse_pc [R,3] = 10.674/((1 + EXP(0 - 0.403 * 0.181 * SVApc [R] / 1000)) ** (1/0.181)), R = 1 to 26;

Appli_EnUse_pc [27,3] = LSUM(R = 1 to 26, Appli_EnUse_pc [R,3]);

Appli_EnUse [R,3] = Appli_EnUse_pc [R,3] * POP [R], R = 1 to 27;
```

In the code above, Appli_EnUse_pc[R,F] is the Useful Energy per capita of Appliances while is Appli_EnUse[R,F] is the total Useful Energy for Appliances; R represents the region and F is the type of function. This code is similar for all six end-uses. The only difference is the multiplication by degree-days in the temperature dependent end-uses, in order to get the total Useful Energy.

Appliances, Lighting and Space cooling are generally speaking, only 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 of course involve different conversion efficiencies. This makes the conversion to Final Energy not so straightforward, and therefore the shares of each energy carrier are required. 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. To be constituent with the rest of the model we apply the MNL method to calculate the fuel market shares for each of the three end-uses. This function is based on the following equation:

Equation 6

$$MS_{R,EU,EC} = e^{-\lambda c_{R,EC}} \Big/ \sum_{EC} e^{-\lambda c_{R,EC}}$$

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 and carbon taxes into consideration. Thus, they can link the model to the rest of the TIMER model. Nonetheless, as stated before, we built a standalone model, working separately from TIMER. So, for now, this fuel costs are imported as exogenous data.

To calculate the final energy demand (FE) per end-use and energy carrier, the useful energy demand was coupled to the market share in the code as follows:

Equation 7

$$FE_{R,EU,EC,F} = UE_{R,EU,F}\left(\frac{MarketShare_{R,EU,EC}}{\eta_{R,EU,EC}}\right)$$

Where:

- R = TIMER region
- EU = Energy End Use
- EC = Secondary Energy Carrier
- F = type of function (Gompertz, GLF, Hybrid)
- η = End Use conversion efficiency

The final energy is calculated by multiplying the total UE for each end-use by the market share of each energy carrier divided by its respective conversion efficiency. It is important to mention that an improvement rate has been considered for the conversion efficiencies of each fuel, based on the improvement rate established in the Residential sector.

In order to have a reliable model, it needs to be able to reproduce the historical data. For this purpose, a model calibration process was needed, in which different factors are used to reflect historical service sector energy demand trends by fuel and by region. This historical data was collected from the IEA Energy Balances from 1971 to 2012; part of the work for this thesis was to update the historic files with the data recently released by the IEA, for the 2011-2012 periods. This data does not differentiate between end-uses, but is region, sector and energy carrier specific.

First the fuel shares of cooking, space heating and water heating were approximated to those of the IEA data in 2011 shown in Table 2.1, 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). A limitation to the calibration process is that the fuel shares of each end-use are only known for 2011.

Therefore, the second part of the calibration consists on using this new set of premium factors as a base for calibrating the total fuel shares from 1971 to 2012. In this second part, model is calibrated by visually comparing the total fuel shares calculated, aggregated by end-use, to the historic data from the IEA; and setting new premium factors until comparable shares can be seen. 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%. This process was done by visually comparing the plotted FE results of the model until 2012 with a graph showing the historic data. Figure 2.7 shows how these two graphs looked before the calibration process.

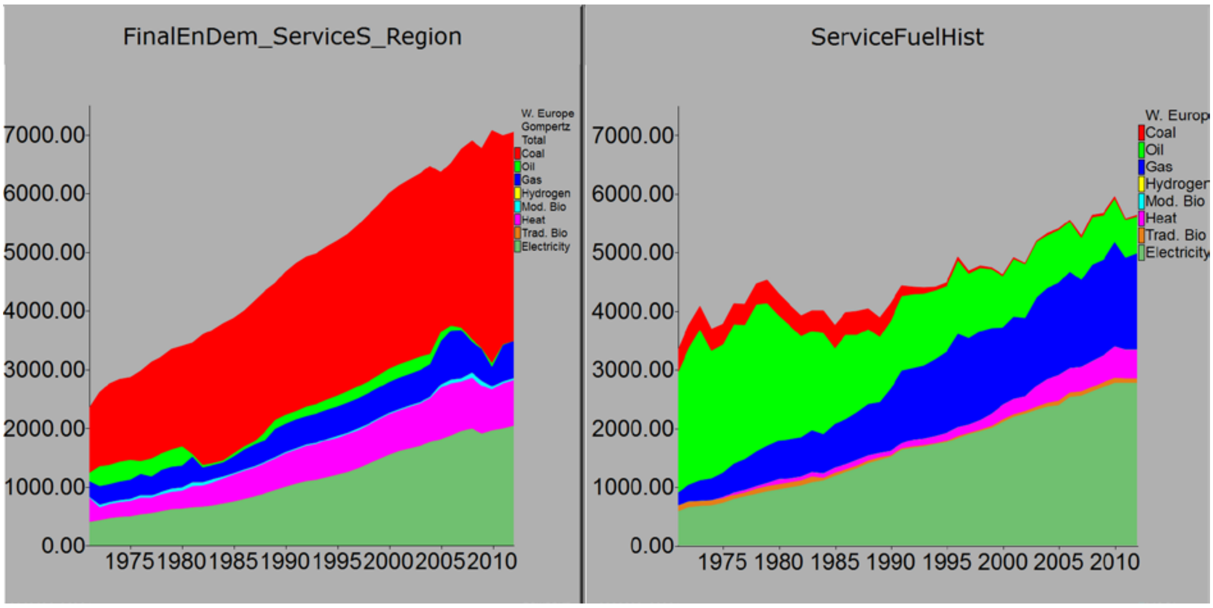

Figure 2.7 Visual comparison of model results by energy carrier before calibration (left) and historic data of the service sector energy demand by energy carrier (right), for Western Europe, using a Gompertz function.

In the graphs above, an example of how the calibration method to match each region’s service sector fuel preference is shown. After 1990, Western Europe’s service sector covers approximately 90% of its energy demand with electricity, oil and gas; a small share of coal, traditional biofuels and heat covers the rest. The premium factors are set to make the shares resulting from the model similar to the historical, in that way capturing regional preferences. Figure 2.8 shows how the graphs look after the calibration process.

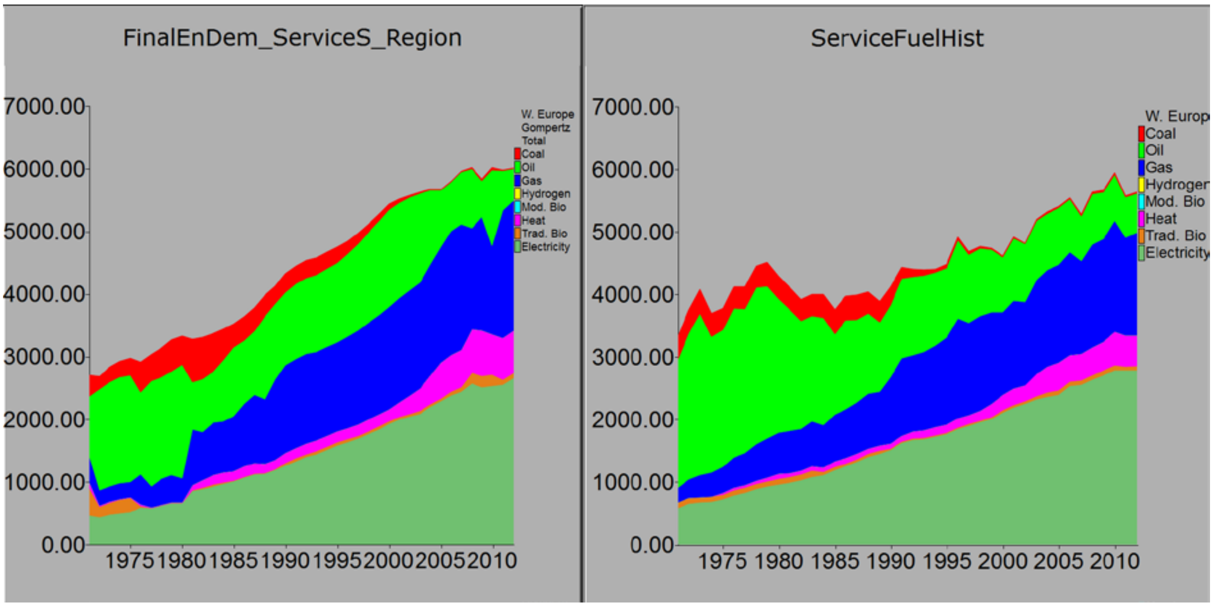

Figure 2.8 Visual comparison of model results by energy carrier after calibration (left) and historic data of the service sector energy demand by energy carrier (right), for Western Europe, using a Gompertz function.

It is important to mention that in order to perform the calibration, bundled regions (see Table 2.3) had to be disaggregated to change their premium factors individually. In those cases, the first part of the calibration (matching the fuel shares to those from 2011 data) was no longer possible, so the entire calibration process was done in total fuel shares, regardless of end-use, through the visual method in the visual manner described above.

The model captures fuel share per region but due to time constraints, it could not be fully calibrated to match historic data trends in terms of total final energy demand. One of the missing steps towards completing the calibration is, for example, the fine-tuning of historic conversion efficiency per region. This and other further improvements of the calibration process will be pointed out in the Discussion chapter.

Not having a fully calibrated model results in an error between the final energy demand calculated by the model between 1971 and 2012 and the historic demand for the same time period. The way the error is calculated is shown in Equation 8. In Figure 2.9, the error in calibration is shown from 1991 to 2011. This 20 year time period was chosen because it will shape the trend line of future energy demand.

Equation 8

$$Calibration\ Error_R = \frac{(FE_R - Historic\ demand_R)}{Historic\ demand_R}$$

Where:

- R = TIMER region
- FE = Final energy demand from 1971 to 2012
- Historic demand = IEA data on the service sector energy use (IEA Energy Balance 2012, TIMER data)

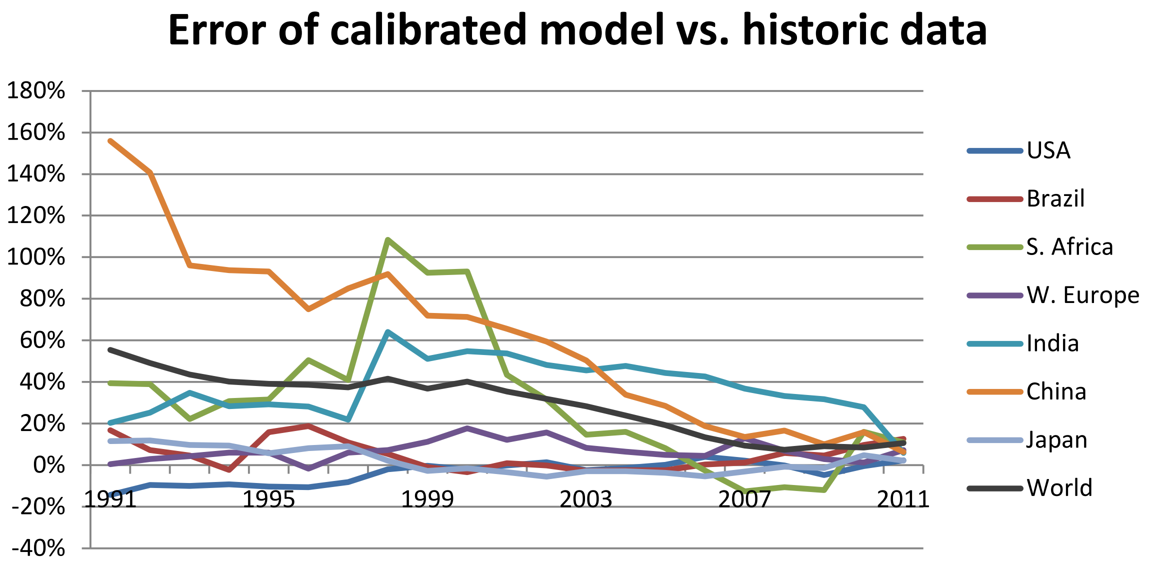

Figure 2.9 Percentage errors between calibrated model and historic data for seven representative TIMER regions and global average from 1991 to 2011.

To evaluate the different functions described in Chapter 2, the differences between each of the functions were analyzed per region by observing the to the historic trend line, in terms on starting and ending demand levels for the time period, and comparing steepness of the curves. These observations are summarized in Table 2.6.

Regions	Best-fit curve	1971-1990 observations	1991-2011 observations
1 – CAN	Gompertz	Low start point and steeper curve	Good end point and flatter curve
2 – USA	Gompertz	Low start point and steeper curve	Good end point and steeper curve
3 – MEX	GLF	High start point, good steepness	Good end point, good steepness
4 – RCAM	GLF	High start point, good steepness	High end point, ending too steep
5 – BRA	GLF	High start point, flatter curve	Good end point and steeper curve
6 – RSAM	Gompertz	High start point, flatter curve	Low end point, good steepness
7 – NAF	Gompertz	High start point, good steepness	High end point, ending too steep
8 – WAF	Gompertz	High start point, steeper curve	High end point, fails to follow trend
9 – EAF	GLF	Good start point, good steepness	Low end point, flatter curve
10 – SAF	Gompertz	High start point, steeper curve	High end point, ending too steep
11 – WEU	Gompertz	Low start point and steeper curve	High end point, good steepness
12 – CEU	Gompertz	Low start point, flatter curve	Good end point, good steepness
13 – TUR	Gompertz	High start point, steeper curve	High end point, good steepness
14 – UKR	Gompertz	Good start point, fails to follow trend*	Low end point, good steepness
15 – STAN	Gompertz	Low start point, flatter curve	Low end point, fails to follow trend*
16 – RUS	GLF	Good start point, fails to follow trend*	High end point, fails to follow trend*
17 – ME	GLF	High start point, good steepness	High end point, ending too steep
18 – INDIA	Gompertz	High start point, steeper curve	Good end point, good steepness
19 - KOR	Gompertz	High start point, good steepness	High end point, ending too steep
20 – CHN	GLF	High start point, good steepness	Good end point, flatter but ends well
21 – SEAS	Gompertz	High start point, steeper curve	Good end point, flatter curve
22 – INDO	Gompertz	High start point, good steepness	Good end point, flatter curve
23 – JAP	Gompertz	High start point, flatter curve	Good end point, good steepness
24 – OCE	Gompertz	Good start point, good steepness	Good end point, good steepness
25 – RSAS	Gompertz	High start point, steeper curve	High end point, ending too steep
26 – RSAF	Gompertz	High start point, good steepness	Good end point, good steepness

Table 2.6 Observed best-fit model function compared to historic trend line. Observations are based on the model compared to the historic trend line. * Fails to follow trend because historic data is unreliable.

Table 2.6 shows that the Gompertz function fits best in a majority of the TIMER regions. Therefore, this function will be used to calculate the results in the next chapter. It also shows that for regions that have high SVA per capita values, e.g. Canada, USA, W. Europe, the model depicts a steeper curve than the one shaped by historic trend. This can be due to a number of reasons, but mainly because their curves start in an advanced section of the Sigmoid function, where the steepness is high, and they start to flatten out after 2012. The exact opposite reason could be applied to regions with low SVA per capita, where the model depicts a flatter, higher curve than the one shaped by historic data: their curves start on the first stage of the sigmoid, almost flat, and then the curve gains steepness really fast until it reaches the asymptote level.

Finally, a way to calculate the total CO2 emissions associated with the energy use and project future service sector CO2 emissions was required in the model's code. In order to include the CO_2 emission calculations, emission factors had to be added as input data. Also an input data file was added with the share between light liquid fuels (LLF) and heavy liquid fuels (HLF) in the service sector. This is because TIMER calculates the emissions based on 5 different energy carriers: solid fuels, heavy liquid fuels, light liquid fuels, gas and biofuels. Therefore, the final energy demand of oil had to be divided between heavy oil and light oil by using Equations9 and 10, shown below. Equation 11 shows how the service sector CO_2 emissions are calculated.

Equations 9 & 10

$$FE_{R,HLF} = (1 - LLFfraction_R) * FE_{R,Oil}$$

$$FE_{R,LLF} = (LLFfraction_R) * FE_{R,Oil}$$

Where:

- R = TIMER region
- LLFfraction = % share of light liquid fuels of total liquid fuels.

Equation 11

$$CO_2\ emissions = \sum_{R} \sum_{EC} FE_{R,EC} \times EMFCO_{2_{R,EC}}$$

Where:

- R = TIMER region
- EC = Energy Carrier
- $EMFCO_2$ = Emission factor of each energy carrier

2.3. Testing the model by scenario simulation

The model built relates service sector energy use and CO2 emissions to global population, SVA, HDD, CDD and fuel prices. The projections of fuel prices are an output of the TIMER energy supply model, and CDD/HDD data is collected from (Isaac, 2009). To test the model dynamics and compare different service sector projections, different population and SVA pathways running to 2100, as defined in the Shared Socioeconomic Pathways (SSPs), are used as input to the model. Below a brief description of what each of these SSPs represents:

- SSP1, also called Sustainability – Taking the green road, features a commitment toward a sustainable development. In this future scenario, human activity is moving towards a greener and more inclusive world. Technological improvement and policy framework restructure lead to a reduced overall energy demand and makes renewable energy more attractive. There is a relatively low population due to a demographic transition, accelerated by investments in education (O'Neill et al., 2015).
- SSP2 is the middle of the road and in this study is the baseline 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).
- SSP3 is also known as Regional rivalry – A rocky road, and it is themed around a story of separation within regions, disrupting the trends of globalization. Policy framework shifts toward regional security issues in terms of energy and agricultural resources, including trade barriers. Therefore, economic development is slow. Environmental and sustainable development concerns are low priority worldwide. Population growth is very low in industrialized countries and high in developing countries. Resource intensity grows alongside with fossil fuel dependency (O'Neill et al., 2015).

For the purpose of this study, only fuel prices, SVA per capita and regional population will be varied according to the SSP scenarios. SVA per capita and population are depicted in Figures 2.9 to 2.22 to facilitate the analysis of Final Energy and CO_2 emissions results.

It is important to mention at this point that, although the model is global, we will present the results for only seven TIMER regions. These regions were chosen for their importance in world economy and their varied temperatures, and they are: USA, Brazil, South Africa, Western Europe, India+, China+ and Japan.

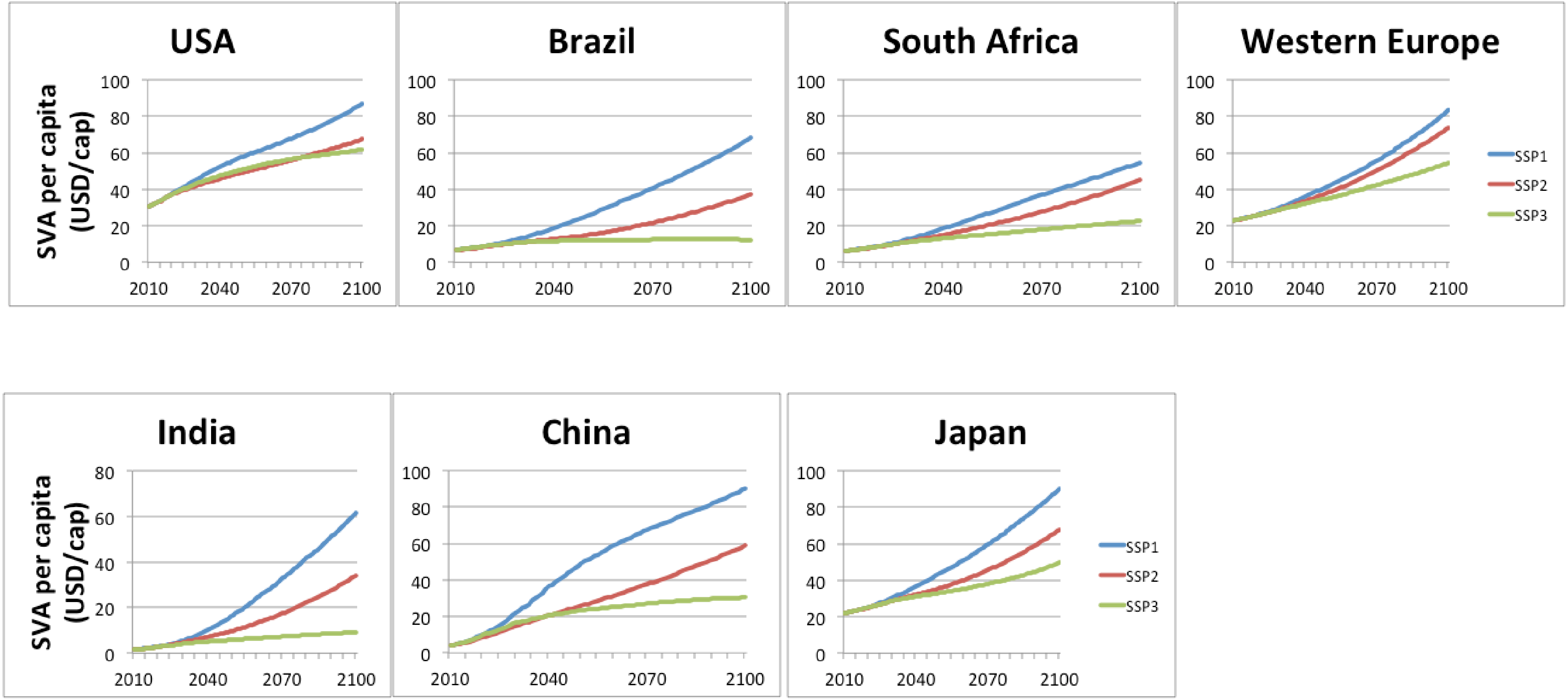

Figure 2.10-16 Service Value Added per capita curves for each of the seven regions for the three different SSPs, from 2010 to 2100. Data gathered from TIMER.

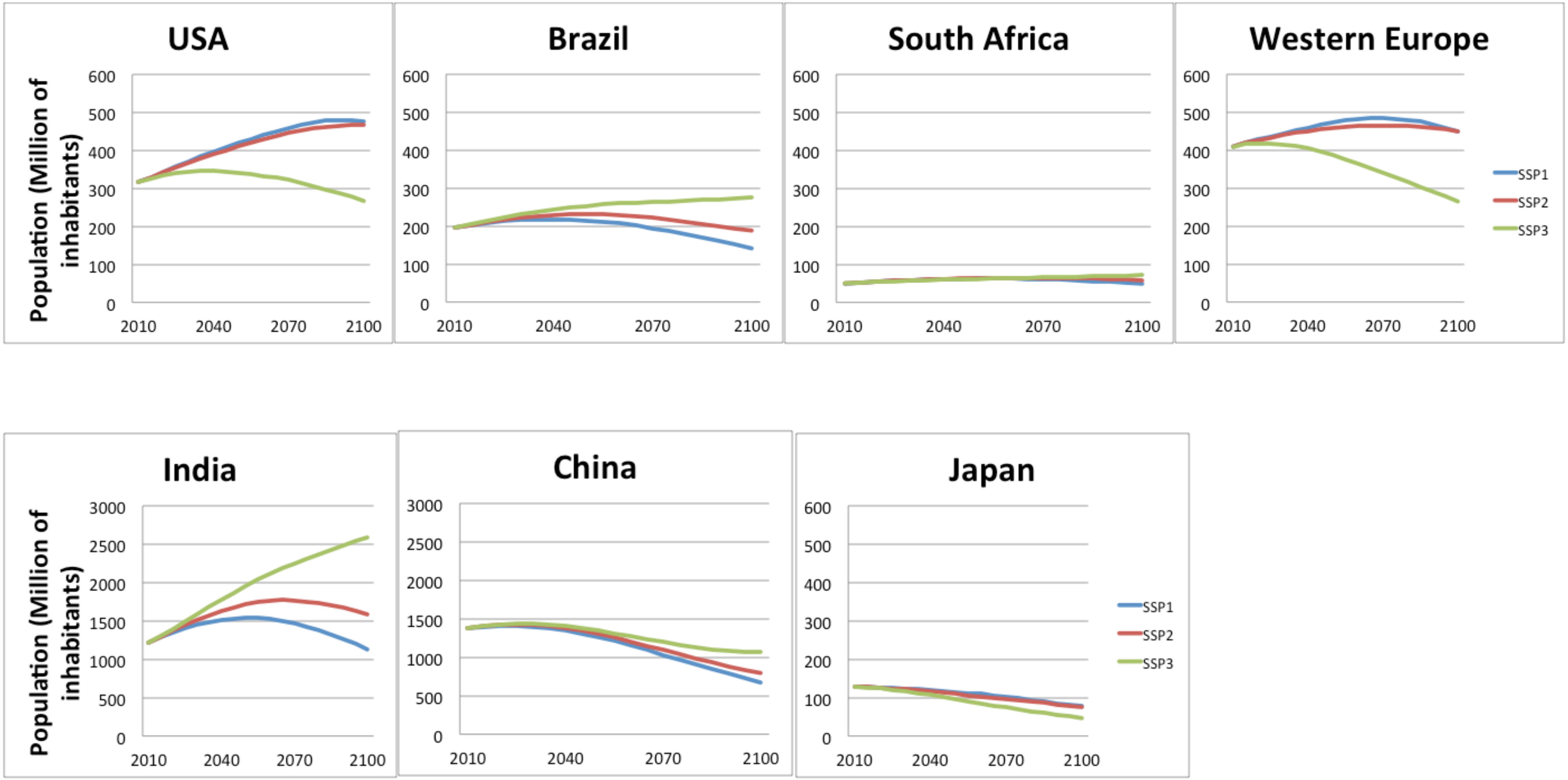

Figure 2.17-23 Population curves for each of the seven regions for the three different SSPs, from 2010 to 2100. Data gathered from TIMER.

As shown in the graphs above, in all of the seven regions SSP1 presents the higher growth in SVA per capita; meaning that even though SSP1 is not a story of economic growth, there is a shift in the economy towards the service sector. In developed regions like USA and Western Europe, where SSP1 depicts a slow decline in population, this is more noticeable. While in the developing countries, where SSP1 presents a much steeper decline in population, this doubles the effect on SVA per capita growth.

It is interesting to see how in SSP3 the opposite happens. The shift towards services goes to a halt, as regions start to concern about their own economic growth with a disrupted globalization that involves more trade barriers. In this SSP, regions start shifting back towards industrialization. SSP3 also shows a higher curve in population in developing countries compared to the other scenarios, while in developed countries there is a steep decline.

As expected SSP2 presents the business as usual scenario, following the historic trend without any major shift. Finally, the third variable, energy price is shown for the three scenarios in Figure 2.23.

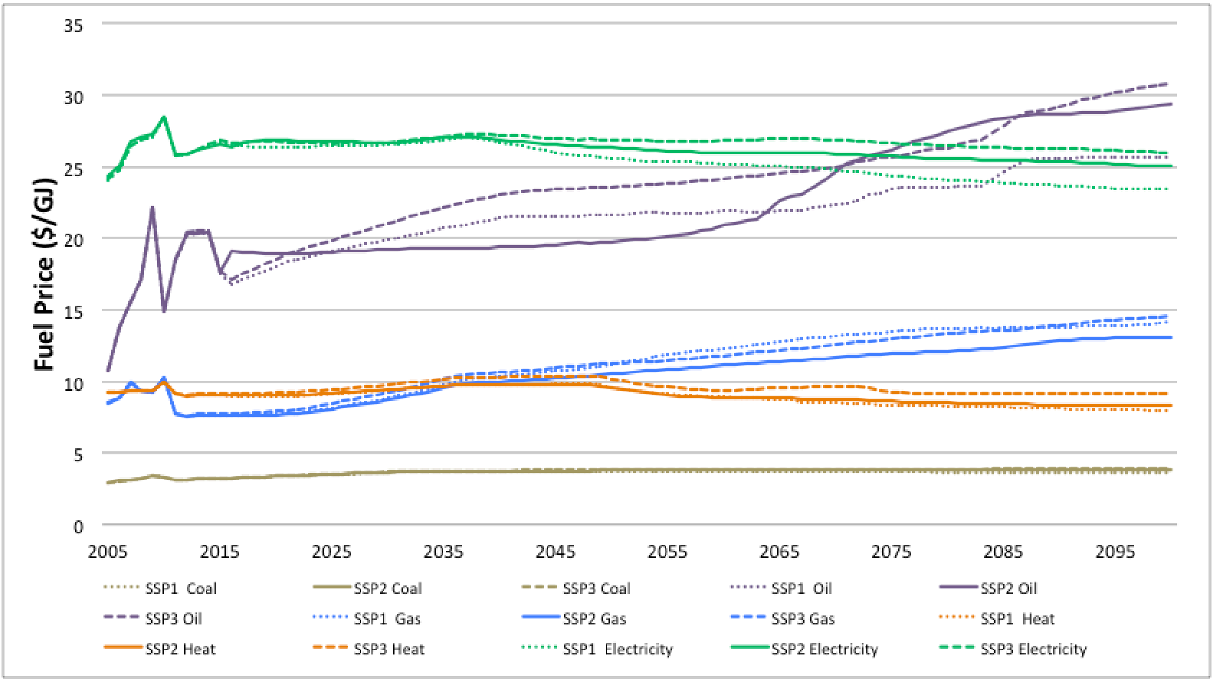

Figure 2.24 World average energy prices for the different energy carriers in each of the three different SSPs. Data calculated endogenously in the TIMER model.

3. Results

In this chapter the most relevant results of the model are shown and explained. Differences in energy demand and its structure among regions is shown first, based on the SSP2, which is the baseline scenario. After that the difference in energy demand by running the three main SSP scenarios is analyzed. And finally a comparison between the CO_2 emissions calculated by the model and those being calculated by the original TIMER model are shown.

Although emission factors vary between regions and this variation is taken into account, the variation is not large, and therefore the CO_2 emissions results and comparison are presented at the global level.

3.1. Baseline final energy demand

In the SSP2 scenario SVA per capita increases until 2100 in all regions as their SVA grows in a higher rate than population. Therefore, both energy use and energy use per capita increase overall although not every end-use behaves the same way, as a result of the different functions modeled. Figure 3.1 shows the evolution of the final energy demand per capita, and Figure 3.2 shows the evolution of final energy demand by end-use for the seven regions. In this sub-chapter all graphs will present results for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100.

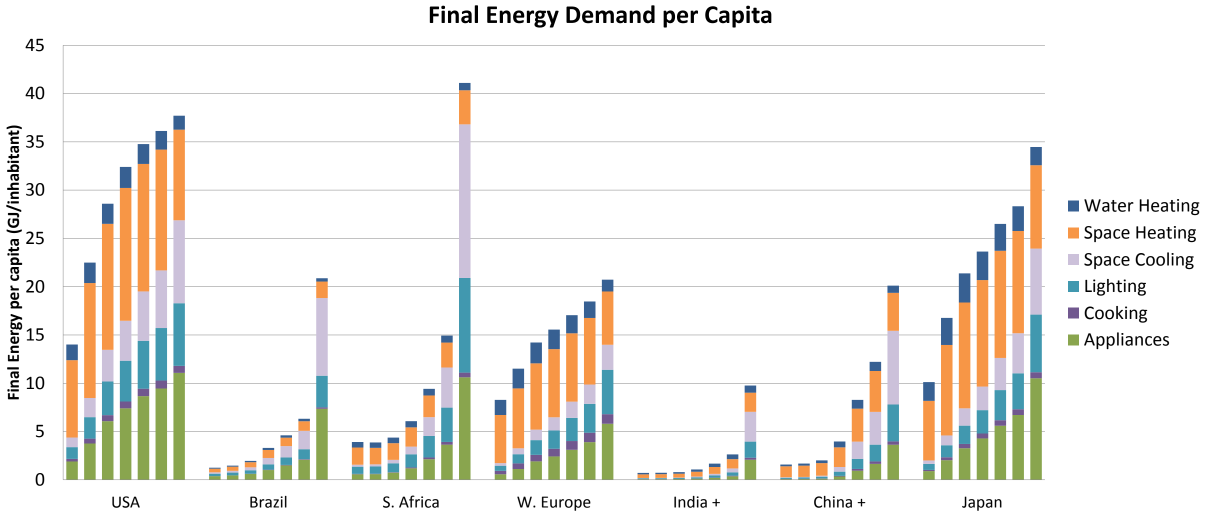

Figure 3.1 Final energy demand per capita. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, disaggregated by end-uses for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100.

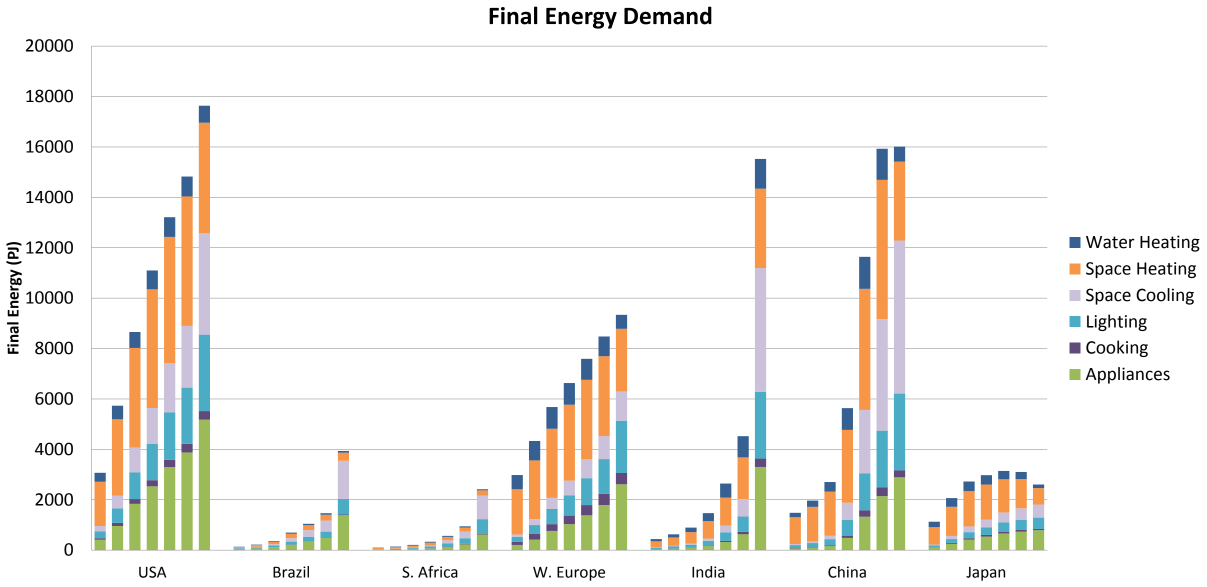

Figure 3.2 Final energy demand. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, disaggregated by end-uses for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100. .

In the figures above, it can be seen that USA is projected to have the largest final energy demand both in absolute and per capita. Globally, space heating has the biggest share among the end uses, per region. It is important to note that this depends on regional climate characteristics (HDD). This is the reason why in Brazil, a very warm country, with low HDD, Space Heating is not the most important energy end-use of the service sector. Furthermore, it can be seen that Space Cooling starts getting increasing shares 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 always has the lowest share.

It is worth noting that among regions with similar SVA per capita (which would have similar useful energy demand according to our formulation), there are large 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. Figure 3.3 shows the share of each of the secondary energy carriers involved in the service sector.

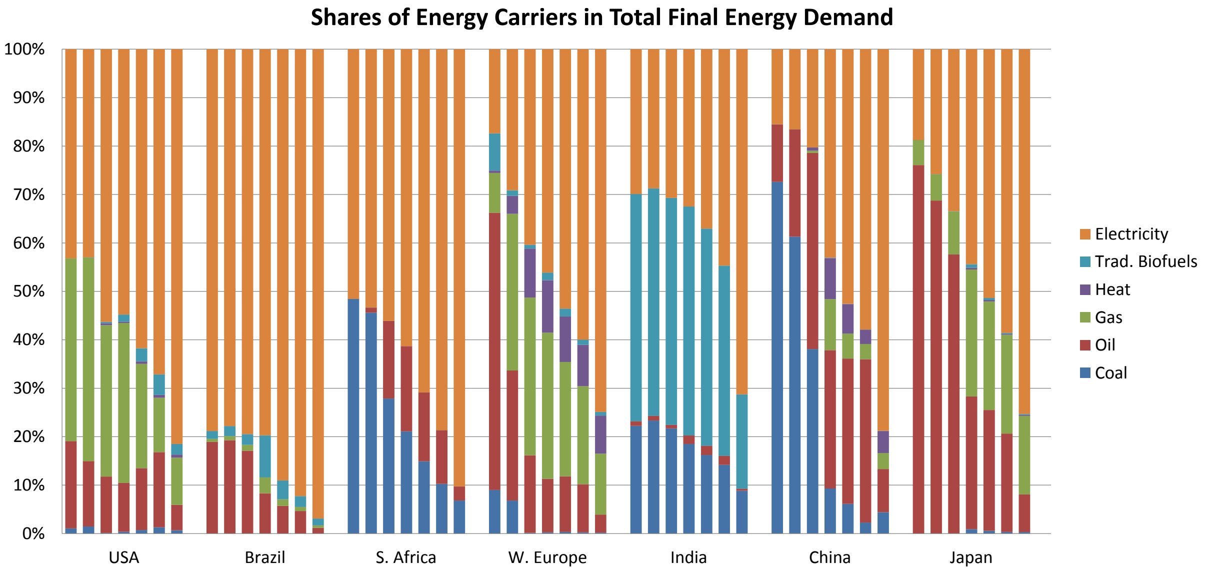

Figure 3.3 Market shares of the different energy carriers. Model results for USA, Brazil, South Africa, Western Europe, India, China and Japan, for the years 1975, 1990, 2005, 2020, 2035, 2050 and 2100. .

The figure above shows that there is 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. It is worth noticing that as electricity gains share in the energy matrix, all fossil fuels will slowly decrease its shares in the service sector matrix in all of these regions.

3.2. SSP Scenario analysis

In this sub-chapter the results of the three different SSP scenarios runs are presented. As the differences between SSPs only start to take major effect after 2030 (see Figure 2.9 to 2.22), the following graphs compare two time periods: 2035 and 2100. Figures 3.4 to 3.17, on next pages, show the FE demand disaggregated by end-uses, and the energy carrier market shares, for each of the seven regions, under the three different SSP scenarios.

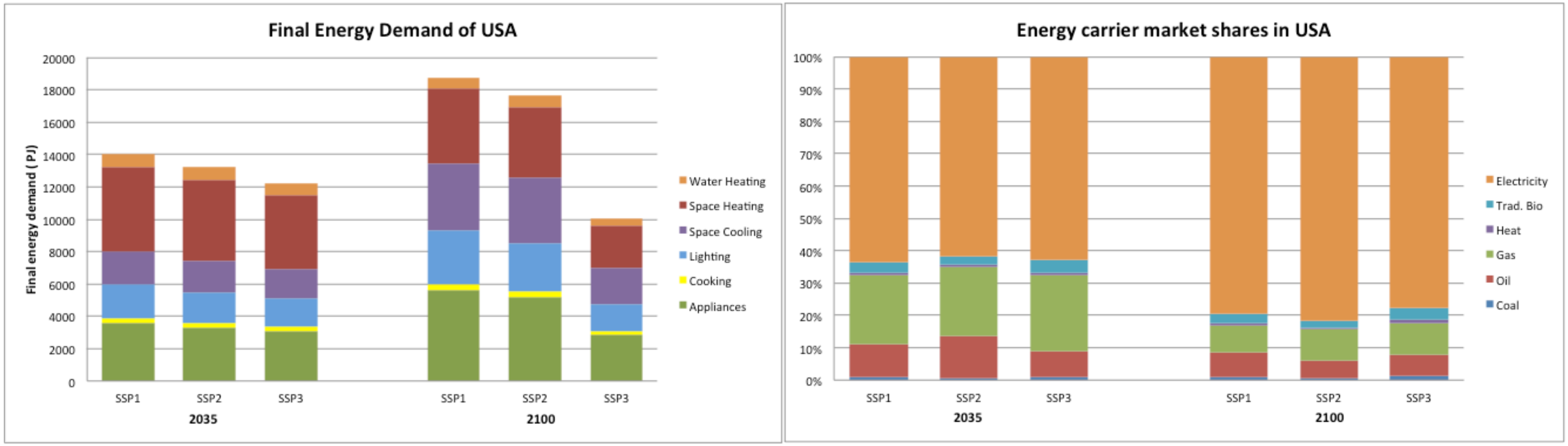

Figure 3.4&5 Final energy demand disaggregated by end-uses and energy carrier market shares of USA. Model results for each SSP in the years 2035 and 2100.

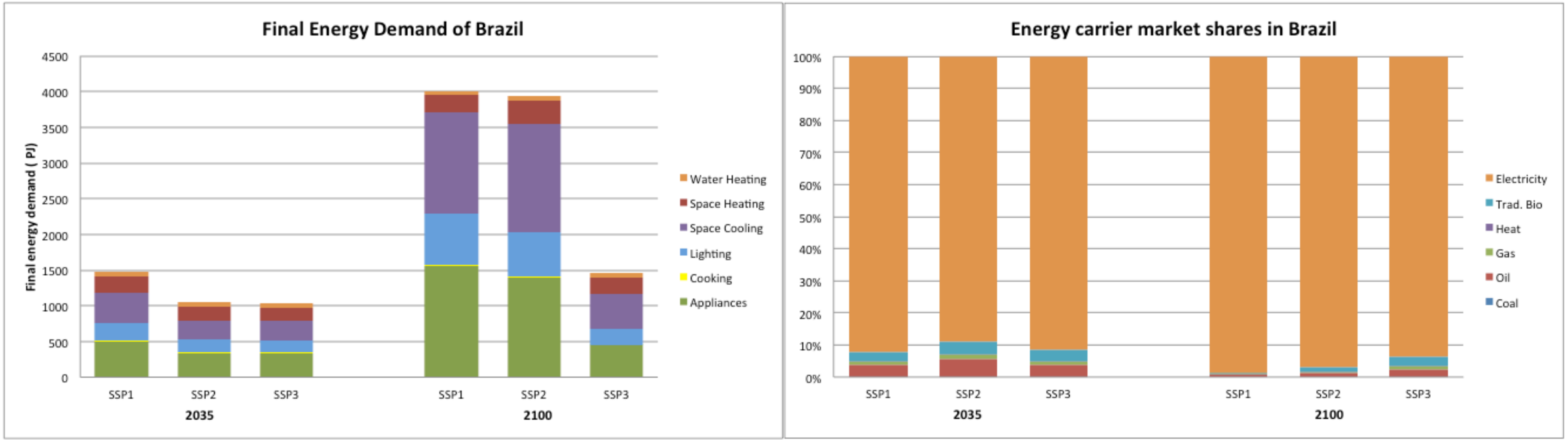

Figure 3.6&7 Final energy demand disaggregated by end-uses and energy carrier market shares of Brazil. Model results for each SSP in the years 2035 and 2100.

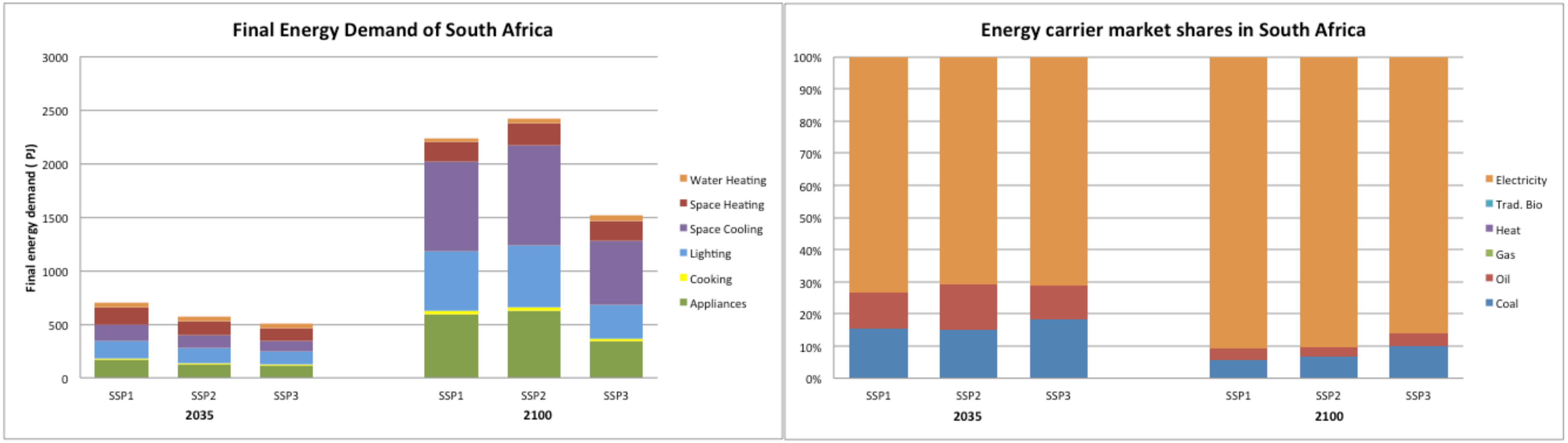

Figure 3.8&9 Final energy demand disaggregated by end-uses and energy carrier market shares of South Africa. Model results for each SSP in the years 2035 and 2100.

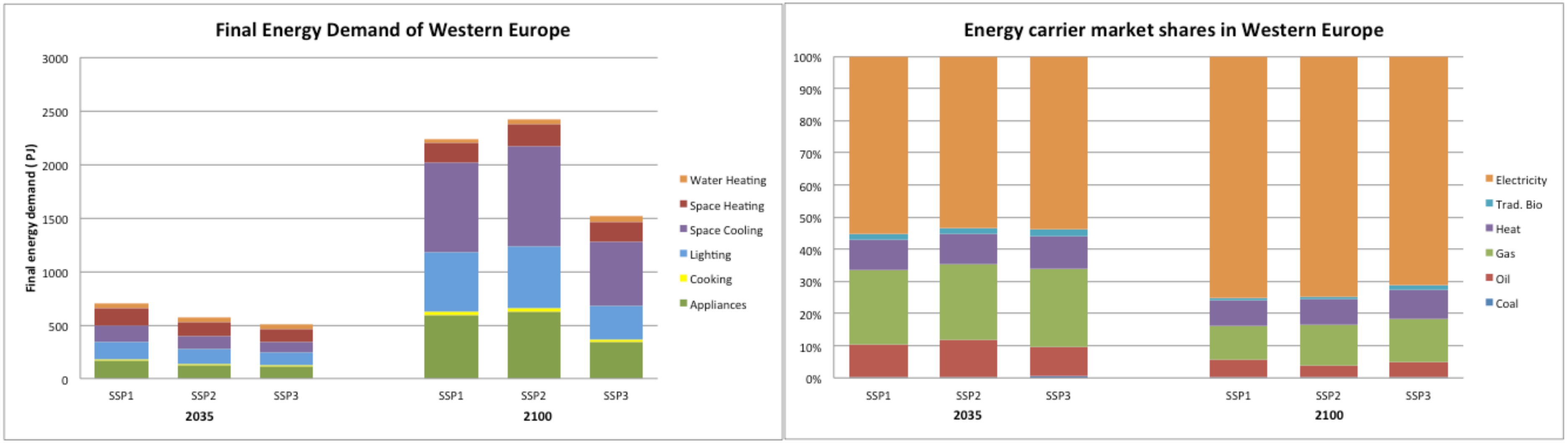

Figure 3.10&11 Final energy demand disaggregated by end-uses and energy carrier market shares of West Europe. Model results for each SSP in the years 2035 and 2100.

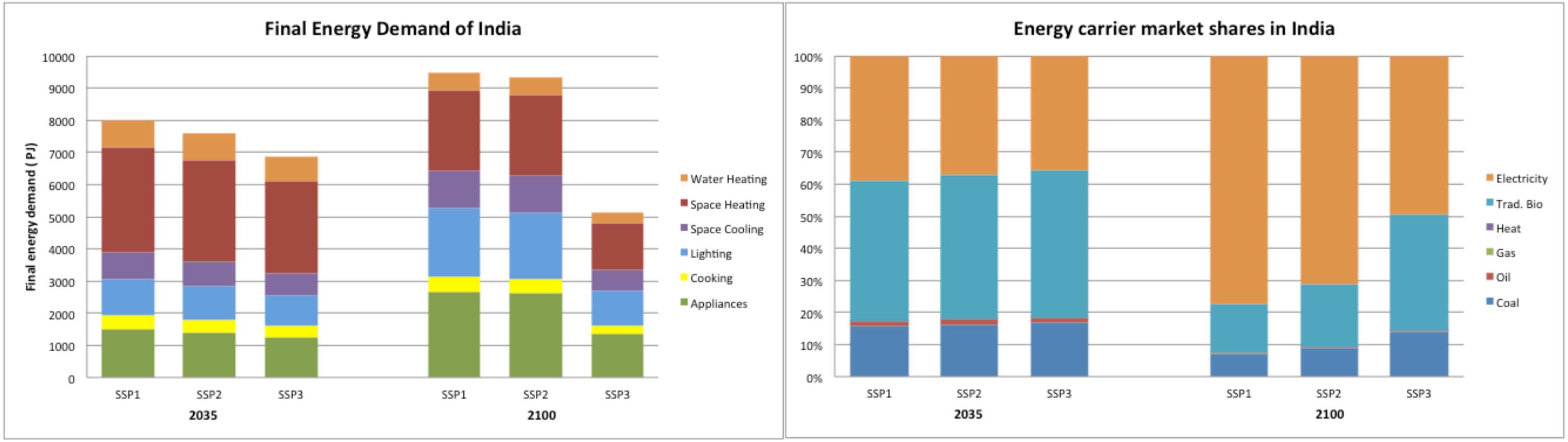

Figure 3.12&13 Final energy demand disaggregated by end-uses and energy carrier market shares of India. Model results for each SSP in the years 2035 and 2100.

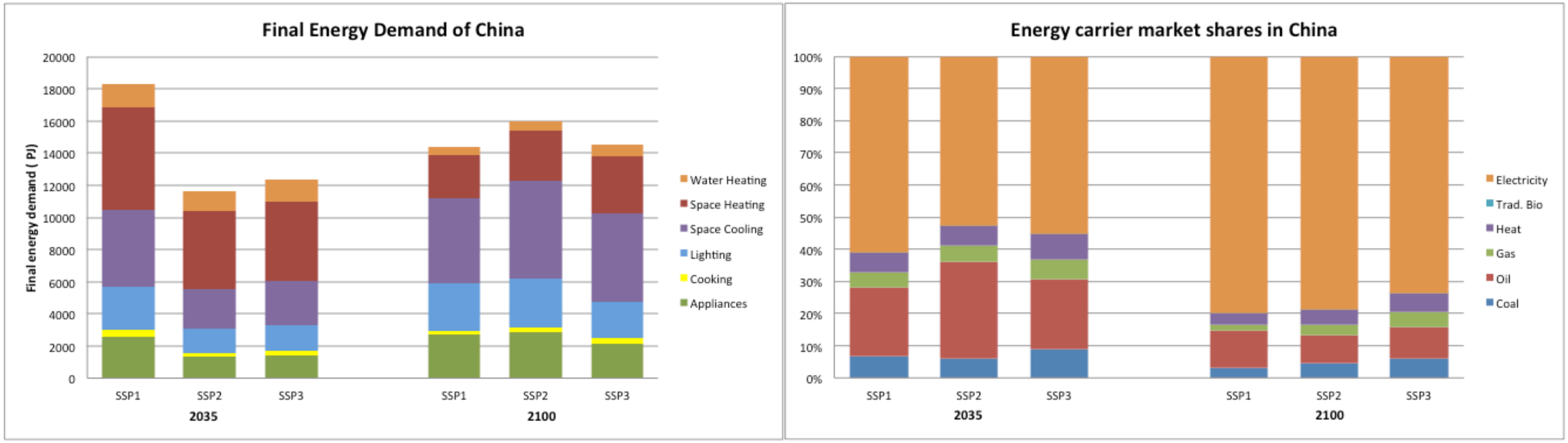

Figure 3.14&15 Final energy demand disaggregated by end-uses and energy carrier market shares of China. Model results for each SSP in the years 2035 and 2100.

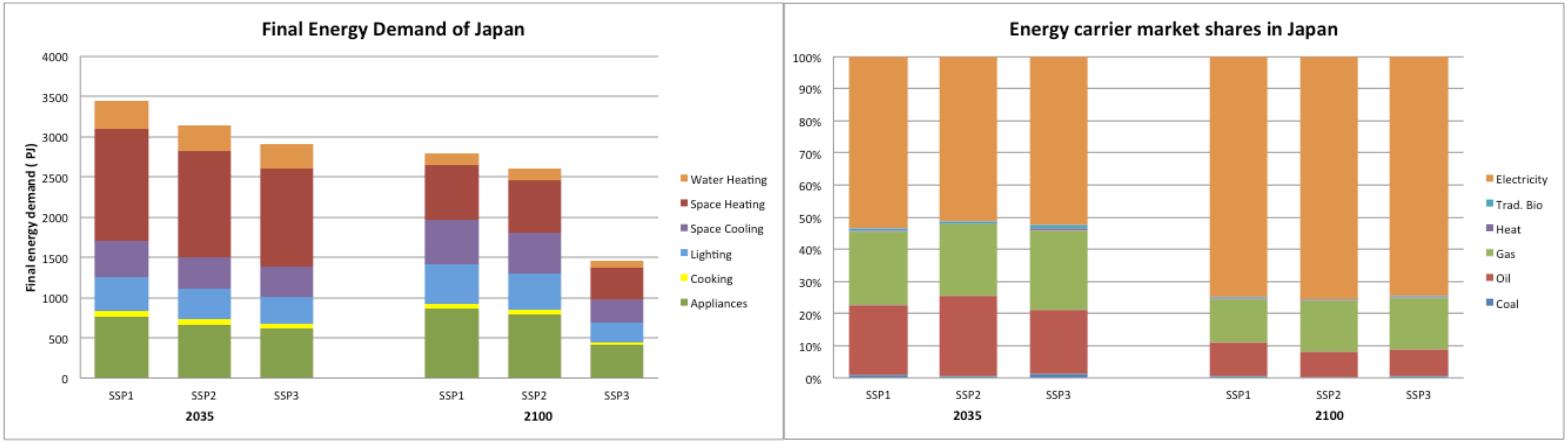

Figure 3.16&17 Final energy demand disaggregated by end-uses and energy carrier market shares of Japan. Model results for each SSP in the years 2035 and 2100.

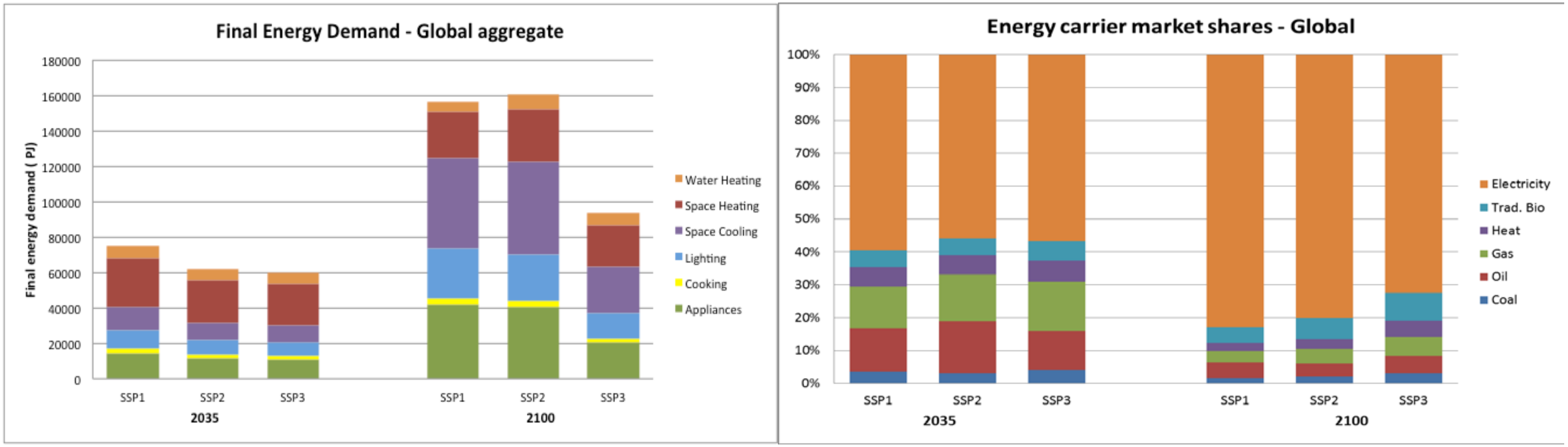

Figure 3.18&19 Global final energy demand disaggregated by end-uses and energy carrier market shares. Model results for each SSP in the years 2035 and 2100.

It is clear by observing the graphs above, that for the seven regions analyzed in this study and even for the global aggregate of the 26 TIMER regions, SSP 3 presents a lower energy demand in the service sector by the end of the century. This was an expected result, as the SSP3 storyline involves the lowest growth of SVA per capita, as shown in Figures 2.9 to 2.22. Furthermore, in some cases the Sustainability scenario, SSP1 presents lower energy demand than the baseline. This discrepancy with the storyline of the SSPs is mainly due to the shift of the economy towards the service sector, represented by SSP1's larger investments in health and education and the lack of modeling some other effects of the scenario story like the shift towards renewable energy (by altering the premium factors) or a more energy saving society (by altering the asymptote parameters in the demand functions). In Figure 3.18, we can see that globally, the service sector will demand less energy in SSP1 than in SSP2 towards 2100, but SSP3 presents a less developed sector which will demand about 56% of the amount calculated for the baseline scenario.

In terms of energy carrier preference, SSP1 results show a major shift towards electricity, while SSP3 presents the complete opposite. This outcome is mainly caused by the different energy prices of each scenario (see Figure 2.23), where SSP1 involves a lower price of electricity and a controlled price on fossil fuels, while SSP3, with its impeded trade structure, involves higher prices on all energy carriers compared to the other two scenarios.

3.3. Emission comparison

The final results of the model are the CO_2 emissions calculated for each of the SSPs, and its comparison with the emissions calculated in the existing TIMER model, as shown in Figure 3.19 below.

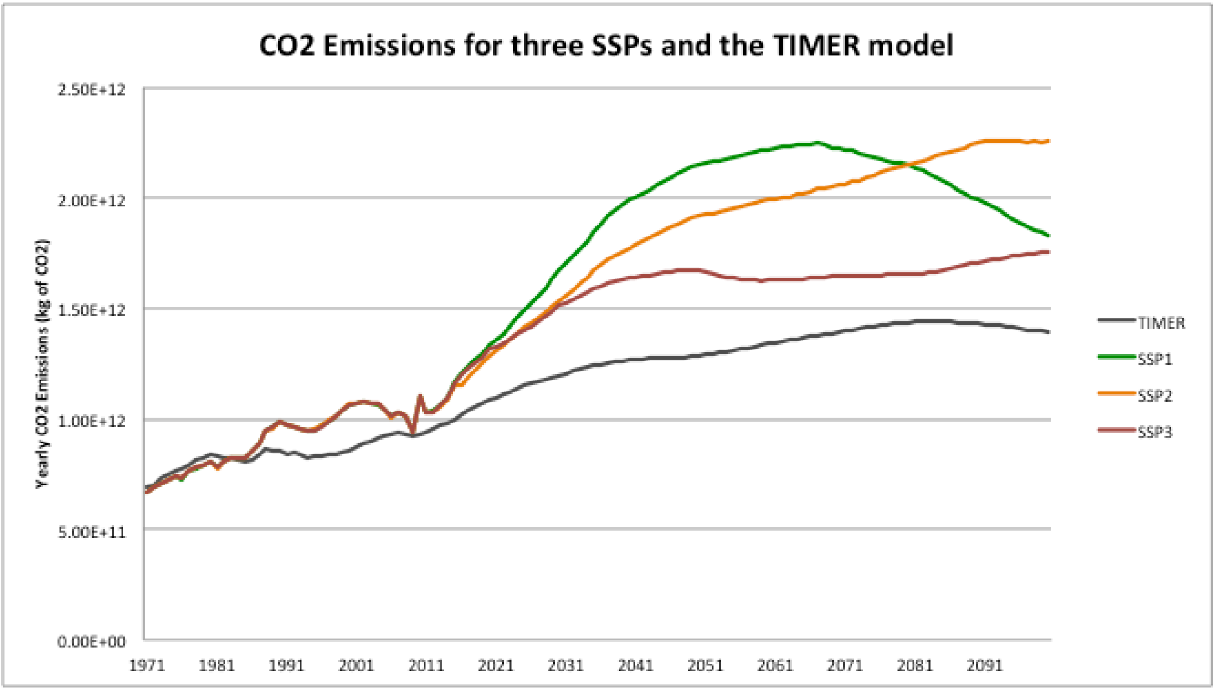

Figure 3.19 Global CO_2 emissions calculated for the three SSPs compared to CO_2 emissions calculated on TIMER model for the service sector.

As seen in the graph above, the CO_2 emissions calculated by the model are higher by those calculated by the TIMER model for the baseline scenario. This is due to mainly four reasons: a) there are other factors that should be included in the scenario design to have a better representation of the SSP storylines, e.g. varying premium factors or, in other words, model the preference for renewable or cleaner energy sources, b) TIMER model has an ever increasing energy efficiency in terms of AEEI, this effect will be discussed more thoroughly in the Discussion chapter, and most importantly c) this model gives a better representation of the behavior of the energy demand of the sector by end-use, i.e. tells a more detailed story than the previous aggregated model.

Figure 3.19 also shows that, as expected from the outcome of previous results, in SSP3 the service sector releases the lowest amount of CO_2 emissions when compared to the other two scenarios. Nonetheless, SSP1 shows a better trend of decreasing the yearly emissions after the second half of the century. While the baseline scenario has a similar trend as the previous model.

It is also important to notice that historic emissions are very similar, with a 20% error at the most. The error is mainly caused by not performing a more thorough calibration process. Nonetheless, the similarity shows that the model, with a proper calibration process and, maybe a disaggregation of functions for certain special regions that follow different trends of development can reproduce historic results.

4. Discussion

The purpose of this chapter is to describe the limitations of the research and the reliability of the developed model. The assumptions made during the development of the model are thoroughly reviewed and recommendations for further research will be described.

This model was developed based under the assumption that the growth curve fitted by regression analysis for the *UE=f(SVA)* relations of each end-use in 2011, can be then used to calculate the UE demand for different levels of SVA per capita, for all the different 26 regions. This implies that, although each region has its own SVApc growth rate, the way it relates to the use of energy is the same across regions. It could be argued by the fact that each region has a different service sector activity structure, therefore different paths of development. In the Introduction chapter, the different activities included in the service sector structure were described: from hospitals to schools, office buildings to casinos, IT buildings, shopping malls and supermarkets, hotels and restaurants, and the list goes on, and they all have different requirements of energy end-uses per unit of SVA. This makes the service sector a difficult sector to model under a "one fits all" function, due to its own heterogeneity. It is therefore recommended for further improvement of the model and its analysis, to a) develop different functions for different groups of regions depending on their level of service sector development, i.e. developed regions, developing regions and underdeveloped regions, and/or, b) gather reliable and compatible regional energy demand data of the service sector divided by end-uses for a critical amount of regions and time periods, large enough to represent each of the development levels and their development path, and c) 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, a unit that, although is consistent throughout the model, it is not a good unit to understand the demand development of the sector in a bottom-up matter. Knowing the amount of energy use per employee per end-use would give a much deeper comprehension of the energy demand behavior.
3. Building stock – In order to improve the modeling of efficiency improvements in the service sector, building stock can be helpful, as new buildings tend to be more energy efficient; particularly in regions where energy efficiency measures are included in building codes and regulations.
4. Share of the different activity types in value added and building stock – This information would help improving the model as described in point a). Possessing a better insight of the service sector structure will help understand how the energy demand relates to the value added.

In the Introduction chapter we also described how the previous TIMER service sector model was constructed (see Equation 1). 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), which have not been included in this model, at least not explicitly.

AEEI is implicit in the model’s sigmoid functions. The Gompertz function and the Generalized Logistic function S-shaped curves involve that, after a certain level of SVApc, UE demand growth decreases. This based on the assumption that countries get more efficient as their SVA grows. This works on the same way that AEEI does on the previous model, reducing the UE/SVA ratio as SVA grows. The difference is that in the first stage of sigmoid functions, the growth rate actually increases. This translates to regions with low SVApc in 2011 (the majority of regions when compared them to USA, Canada or Europe) to peak their growth rate as they reach a certain level of SVApc during the 21st century. This effect contributes to the difference in emission levels between the model and the previous TIMER model. In the TIMER model, all regions will decrease their UE demand growth rate as SVA grows, while in this model most of the region will keep increasing their growth rate until a certain SVApc is reached.

PIEEI has not been modeled, as the price of fuel does not represent a reason for switching towards more efficient conversion technology. 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, 2008). Thus, it is recommended to improve the model by modeling a policy-induced energy efficiency improvement.

Another issue encountered during the research was regarding the units used to model the useful energy for 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.

IEA Energy Balances have historically shown inconsistencies as they get updated. Each year, with every update their historic energy demand data changes. This is why for the TIMER model historic data is updated based on a growth factor based on 2005 IEA energy demand. This results in discrepancies between the IEA 2011 end-use dataset that was used for the construction of the model and the historic data files that are used in TIMER to calibrate the model. For example, regions started installing space or water heating from renewable sources, or installed gas grid after 2005 are not accounted for in the TIMER historic data. This brings difficulties to the calibration of the model.

Furthermore, it is recommended to consider two extra variables that should be altered in order to represent better the storylines of the SSPs in the scenario runs: premium factors and conversion efficiencies. For example, in the Sustainability SSP, premium factors for fossil fuels should be higher to represent the policies that might have been implemented to divest from the use of fossil fuels; and, conversion efficiencies should represent not only the investment in technological development but also the shift towards building efficiency policies across regions. It is recommended that these variables are included in the design of the scenarios for a better representation of these possible futures.

5. Conclusions

In this chapter, analysis of the results and discussion chapter is used to answer the research questions. We will start by answering the four sub-questions and concluding with the main question in order to avoid repetition.

1. **Can strong relations between drivers and end-uses be found in existing data to produce a reliable model?**

   Yes. This study has shown that, using a regression analysis, a link between useful end-use energy demand and the sector's activity driver, SVA, can be found through different sigmoid functions with a relatively high correlation (shown as R^2 in Tables 2.1 to 2.3). As discussed in the previous chapter, 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.

2. **Can differences in service sector energy use between regions be explained?**

   The model shows the end-use structure of each region. This gives better insight of what goes on in each region's service sector. It 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. Nevertheless, although we have shown the differences in the energy end-use matrix of the service sector for seven of the 26 TIMER regions, the differences of the end-use structure cannot be thoroughly explained, mainly due to lack of information on the sector's structure by type of activity. If structure data was available, e.g. building stock of each type of activity of the sector, it would be a very valuable input to the analysis of the energy demand results.

3. **How do different global economic trends, depicted in the three main Shared Socioeconomic Pathways (SSPs), influence the energy demand of the service sector?**

   As seen in Chapter 3.2, the different SSPs can strongly influence the way the energy demand of the service sector, in terms of final energy demand and its different end-uses, and also in terms of the market shares of the energy carriers. As seen in Figures 3.18 & 3.19, SSP3 shows the lowest global energy demand for the sector towards the end of the century, while SSP1 involves a major preference shift into the use of electricity.

4. **What impact does the incorporation of service sector end uses in the TIMER model have on the scenarios of CO2 emissions?**

   The impact of this bottom-up approach in the Service model could increase the CO_2 emissions level for the three different SSPs assessed in this research. Nevertheless, this may be due to the lack of inclusion of other variables that improve the modeling of the SSP storylines, i.e. varying premium factors and technological (conversion) efficiency, and preference of cleaner and renewable energy sources.

What are long-term trends in future energy demand of the service sector?

This study has shown 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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Appendix A. Manual: Creating a standalone model in TIMER

This manual explains the basic steps to create a standalone model in the TIMER environment, as there are global constants and variables that need to be defined for every model. Also, it is a purpose of this document to create a structured order for those definitions and for model construction (using different files for the different modules).

Method

1. Create the header of the model

   The header of the model should consist of four basic components (can have more, but not less):

   a. Title: Title of the model
   b. Description: Brief description of the model and its purpose
   c. Basic methodology: Briefly described the methodology used in this model and the assumptions in which it is based. This, of course, should be written as the model is being created, whenever an assumption is made; and the method when the model is finished.
   d. Author(s), date and literature: Write down who the author, the date it has been created (end date) and the literature where the model is documented supported.

   The header code should look like this:

```
! ****************************************************************************************!
! Title of the model                                                                       !
! Description                                                                              !
! Purpose                                                                                  !
!                                                                                          !
! Basic methodology                                                                        !
!                                                                                          !
! AUTHOR : John Smith                                                                      !
! DATE: Mmm YYYY                                                                           !
! LITERATURE:                                                                              !
! ****************************************************************************************!
```

2. Time definitions

   After creating the header, the next step is to define the time variables. For this we use the following standard code (copy and paste onto the model):

```
!========== Time definition =====================================

T.MIN    = 1971.0;
T.MAX    = 2100.0;

T.STEP   = 1.0;
T.SAMPLE  = 1.0;
T.METHOD  = RK2;
```

3. Declaration of constants and counters

   Include the 'Global constants' module into your model. This method will import all the global constants and counters from TIMER into your model

   a. Copy (do not cut it) and paste the file "...\TIMER_2013\GLOBAL\Gl_cnst2.m" in the folder where you are creating your model.
   b. Then include it into your model by adding the following line in the code, right after the time definition:

```
!============== Definition of Constants==========================
#INCLUDE gl_cnst2.m                    ! Global constants
```

   An alternative method is to open gl_cnst2.m file instead of copying it and only copying the constants and counters that you will need for your model.

4. Declaration of Inputs

   The next step is to define which will be the data inputs for your model, but first the start of the 'Main Module' must be written in the code. Copy and paste the following:

```
MODULE MAIN;
BEGIN
```

   After having decided which inputs are needed for the model, e.g. GDP per capita, population, etc., the correspondent data files must be copied into the folder where the model is being created. It is recommended to create a new folder called "data" inside the model's folder This files can be found in "..\TIMER_2013\ENERGY\ENDATREG\scen\global\". Remember, copying does not mean cutting or moving the files.

   Then the data is imported to the model by coding the following lines (example for population):

```
! ******* DECLARATION OF INPUTS *******
REAL
Pop[NRC](t)                = FILE("Data/Pop.scn");
```

5. Declaration of variables

   After the data inputs have been declared, the declaration of the variables to be used in the 'main module' have to be defined. This step is model-specific, but in order to maintain the structure it should always be preceded by the following lines:

```
! ******* DECLARATION OF VARIABLES *******
REAL
```

6. Inclusion of modules (Model structure)

   This step is basic for creating a well-organized model. This method will explain how this kind of structure is created.

This method is very similar to the one seen on Step 3 above, the only difference is that now the *.m files (modules) to be included in the model, have to be created before hand.

As an example, the Service Sector energy demand model is explained:

The Service Sector model calculates the energy demand of each of its end uses: Appliances, Cooking, Lighting, Water Heating, Space Heating and Space Cooling. Each of this end uses have their own set of equations. In order to maintain a well organized structure, each of the end-uses models is created in a different *.m file in the same folder where the main module Services.m, is located: Appliances.m, Cooking.m, and so on. After this files have been created (there is no need to put any code in them for now), we can include them in the model using the #INCLUDE command:

```
! ******* INCLUDE MODULES *******
#INCLUDE Appliances.m
#INCLUDE Cooking.m
…
```

This will include all the coding of the different files into the main model. It is important to note that in the module files there is no need to state the BEGIN or END of the code, as this is stated in the main module.

7. Last step of the creation of the main module is the coding of the equations. Just as the variables, this part is model-specific. Remember to end each equation with a semicolon (;) and to state the end of the module after all the equations have been coded (END;)

Extra steps for running the model

In order to run the newly created code, first we need to convert it into a model file. In order to do this properly there are a few extra steps.

1. Create a compiler
    a. Open a new text pad and paste this code:

```
if exist ModelName.mdl del ModelName.mdl
if exist ModelName.c del ModelName.c
del *.obj

set MUSEROBJS=timerlp.obj
set OWNLIBS="%M_PATH%\lib\vc\util.lib"
path matlab\bin\win32;%path%

m2c -woff 5,8 -e error.txt ModelName.m
rem m2c -woff 5,8  -fullwarn -sbuwarning -rte fout.txt -e error.txt ModelName.m
mmake ModelName.mdl
```

    b. Replace “ModelName” in the code with the actual model name
    c. Save the code as a windows batch file in the same folder where the model is. Go to ‘Save As…’ option in the ‘File’ menu, and write “Compile.bat” as the File name.

2. Copy and paste the files required
    a. To the '..\TIMER_2013\' folder and copy the following files: vc100.pdb, util.h and timerlp.c
    b. Paste them in the same folder where the model is.
3. Run the compiler
   Execute the Compile.bat file and, if the coding of equations and variables is correct, a ModelName.mdl file is created in the folder. This file is ready to view in TUSS.