A quantitative analysis of current and future electricity demand patterns in Europe

Master thesis Energy Science

Abstract
The future power system may undergo significant changes in order to mitigate climate change. In order to balance future power supply and demand, it is important to obtain more insights into the effect of changes in both the magnitude and shape of future electricity demand. In this master thesis, potential future changes to the electricity demand pattern of the Netherlands, Spain and Sweden are investigated by disaggregating the current patterns into sectors and end use service patterns. Subsequently, potential changes to future demand patterns are quantified and modelled up to 2050 in 7 future demand scenarios. The results for the current demand patterns show a distribution of national demand patterns into sectors which is dominated by the industry, residential and service sectors in all countries. The future demand scenarios indicate an increase of peak demand and demand fluctuation due to electrification of heat demand and transport. Minimum demand may be reduced significantly because of a growth in decentralized PV generation. These results indicate that generation, transmission and back up capacity need to increase whereas base load will decrease. Increased efficiency of electric equipment, demand side management (DSM) and electricity storage could compensate for this. If indeed emission targets are to be fulfilled through considerable boosts of electric heating and transport and renewables, it is possible that equal efforts will be needed for efficiency gains, DSM and electricity storage.

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1 Introduction

The European Union, on its quest for decarbonisation, has set the objective to reduce greenhouse gas emissions by its member states in 2050 with 80-95% relative to 1990 levels. This target is established in order to limit global warming to 2 °C compared to pre-industrial levels. In reaching this target, electricity will play a pivotal role. Both electricity supply and demand are expected to undergo radical changes. On the supply side, a 93-99% reduction in greenhouse gas emissions needs to be achieved (European Commission, 2011a). Such a reduction requires a transition to a mix of low-carbon supply technologies (European Climate Foundation, 2010). Because supply and demand need to be balanced, the composition of future power supply is influenced by future electricity demand patterns (Delarue et al., 2011; Hostick et al., 2012). In order to accurately allocate investments and research efforts, it is important to forecast electricity demand patterns on the long term (Hyndman & Fan, 2008).

Forecasting of future electricity demand is complicated by developments which are also induced by decarbonisation efforts. First of all, an increase of energy efficiency and savings will decrease electricity demand. Furthermore, fuel switching to electricity, for example by electrification of transport, will increase electricity demand (European Commission, 2011a). It is clear that the emission target makes long term forecasting of future electricity demand patterns in the EU both important and complicated. Therefore, it is a very relevant research topic.

In order to forecast (electricity) demand patterns, it is necessary to study the current demand pattern first. By establishing the current demand pattern, a starting point is created on which changes to the future demand pattern can be applied. This approach is used, among others, by Pout et al. (2008), Hostick et al. (2012) and Iwai et al. (2014). Changes in the demand patterns do not only occur on national level, but also on the level of sectors and End Use Services[1] (EUSs) within those sectors (Schade et al., 2009). The national demand patterns of countries within the EU are continuously measured on an hourly basis (ENTSO-E, 2014). Demand patterns on sector and EUS level are not measured and they are therefore a relevant subject for research.

Existing research on current demand patterns of sectors and EUSs is limited. Studies that focus on demand patterns on sector level are often restricted to the residential and service sectors, for example in Iwai et al. (2014) and Van Vliet et al. (2011). This is also the case in most of the research into EUS patterns, for example in Zimmermann (2009) and Placet et al. (2010). A more comprehensive analysis is performed in Hostick et al. (2012) for the USA. This study is limited to a disaggregation of the national demand pattern into sectors. A comparable analysis is performed for the United Kingdom by Pout et al. (2008). In this study, sector demand patterns are also further disaggregated into patterns of EUSs. However, the analysis of sectors other than the residential and service sectors is incomprehensive and the analysis of EUS demand patterns is limited to residential and commercial buildings. Both the studies by Pout et al. (2008) and Hostick et al. (2012) provide methods to disaggregate national demand patterns. However, the methods in these studies are designed to utilize country specific data sources which do not necessarily apply to other countries.

Existing research on forecasting of demand patterns is relatively more extensive. In several studies, demand patterns are forecasted on the long term to assess pathways to more sustainable electricity generation for the European Union and the USA. However, these studies are primarily focused on future electricity supply. The modelling of future demand patterns is usually performed in two main scenarios representing the limits of possible future demand patterns. Examples of this type of analysis are found in European Climate Foundation (2010), Pfluger et al. (2011) and Hostick et al. (2012). Many factors are included in those models, such as energy efficiency improvement or electrification of cooling and heating. However, little attention is paid to the impact of individual

[1] End use services are final applications for electricity, such as lighting, heating, etc.

factors. There are a number of studies that focus on individual factors. Examples of this are found in Van Vliet et al. (2011) and Iwai et al. (2014). A comprehensive analysis is found in Pout et al. (2008), in which the long term impacts of 7 individual factors on future demand patterns in the UK is highlighted in several scenarios.

The current knowledge base on forecasting of demand patterns shows significant gaps. First of all, little research is done on current demand patterns, particularly not on sector and EUS demand patterns of other sectors than the residential and service sectors. Secondly, the only comprehensive analysis found in Europe is performed for the UK (Pout et al., 2008). Additionally, the forecasting of demand patterns shows a knowledge gap in the analysis of individual factors on future demand patterns.

These gaps are addressed in two parts. In the first part of this thesis, an overview of current demand patterns is created by disaggregating national demand patterns into patterns of sectors and EUSs. The purpose of this is twofold:

1. To obtain insight in how current demand on national, sector and EUS level;
2. To obtain a starting point (base year) for modelling future changes of demand patterns. By disaggregating the national pattern, changes can also be applied and observed on sector and EUS level.

Since existing research on this topic is limited, no universal methodological framework for such an analysis is found in literature. Therefore, methodological insights are also obtained from this analysis. In the second part of this thesis, the impact of 4 major factors on long term future demand patterns is modelled and the resulting impact on power system requirements is analysed. All analyses are performed for countries within Europe, specifically the Netherlands, Spain and Sweden. This allows for a comparison of current and forecasted demand patterns between countries, which is not found in existing literature. The analysis is carried out by addressing two research questions:

1. *How is the national electricity demand pattern within Europe disaggregated in demand patterns of sectors and end use services?*

2. *To what extent do major factors influence the development of national demand patterns across Europe until 2050 and consequently the power system requirements?*

From a societal point of view, the results of this study are relevant for 2 reasons. First, the fulfilment of emission targets is (indirectly) supported. The forecasted demand patterns can be used to improve future supply models, which are used to direct investments and research efforts. Second, the results of this study indicate potential for demand response or storage strategies, which lower future cost of electricity (Hand et al., 2012).

From a scientific point of view, the results of this study are relevant for 4 reasons. First, the scientific knowledge base of current electricity demand patterns is expanded. Second, methodological insights are gained (primarily) on the disaggregation of national demand patterns into demand patterns of sectors and EUSs. Third, the impact of individual factors on electricity demand is further explored. Fourth, the first comparison of current and future demand patterns is made between countries.

This report has the following structure. First of all, the main methodology is laid out. Subsequently, more detailed approaches to address both research questions are described in chapters 3 and 4. Finally, the results (chapter 5), discussion (chapter 6) and conclusion (chapter 7) are presented.

2 Main methodology

In this chapter, the methodology used to address both research questions is laid out. Since the analysis is carried out using a significant number of different approaches and data sources, this chapter only discusses the main methodological steps. This is done in order to maintain a clear overview of the methodology. In chapter 3, more detailed methods and data used to disaggregate current electricity demand patterns are explained and the disaggregation process is evaluated (focus on research question 1). Chapter 4 covers more detailed methods and data descriptions for the generation of future demand patterns (focus on research question 2). Wherever appropriate, additional information is provided in appendices. All analyses are performed using Microsoft Excel.

In the next sections, the research deliverables and the boundaries of the analysis are defined first. Next, the main research structure is laid out and main methods are explained. Lastly, data collection is discussed.

2.1 Research deliverables

To address the research questions posed in the introduction, four deliverables are defined:

1. An overview of current demand patterns on national, sector and End Use Service (EUS) level
2. An evaluation of the uncertainties in the analysis of current demand patterns
3. Future demand patterns according to 7 scenarios
4. An analysis of the effects of the future demand scenarios on power system requirements

2.2 Boundaries

In this thesis, the analysis is performed for three countries located in different regions within Europe. These regions represent different climatological zones which allows for analysis of current and forecasted demand patterns in the context of different climate conditions. The regions (countries) are: a Western European country (the Netherlands), a Nordic country (Sweden) and a Mediterranean country (Spain).

The electricity demand patterns in this analysis are laid out in hourly time steps over a period of 1 year, i.e. 8760 values of hourly demand. This resolution is also used in various studies such as Boßmann et al. (2012) and Hostick et al. (2012). However, some studies make use of half-hourly time steps such as Hyndman & Fan (2008) and Pout et al. (2008). For this thesis, the hourly time step is chosen because it matches the resolution of some important data sources, notably the ENTSO-E data which is used to create demand patterns on a national level (ENTSO-E, 2014).

To enable the modelling of future demand patterns, a base year is created as a starting point. This year is set to 2013 for all countries. The time horizon of the analysis is set to 2050. This point in time is chosen because it is an important checkpoint for environmental measurements and predictions. For example, the European Commission considers 2050 a key year in which climate targets need to be met (European Commission, 2011).

Due to a lack of comprehensive data, a number of parameters that are incorporated in the scenario analysis are only quantified for one or two points in the future. In some cases, only a prediction of 2050 is used; the development of these parameters in intermediate years is not clear. In these instances, exponential growth of these parameters is assumed. Since this assumption heavily affects the results of intermediate years, the results of the analysis are only shown for 2013 and 2050.

In the scenario analysis, the impact on future demand of three factors is modelled on an hourly scale. These factors are: the electrification of heat and transport and the onsite generation of photovoltaic (PV) electricity. The impact of additional factors included in the scenario analysis is reflected only in changes of annual demand on a national, sector or EUS level.

2.3 Research structure and main methods

The research structure depicting the steps used to address both research questions (RQs) presented in figure 2.1. References to sections in chapters 3 and 4 which include more detailed methods are included in the figure. For both RQs, two primary research steps are carried out, which are subdivided in several secondary steps. In the next subsections, all primary and secondary steps are explained and their role in the analysis is clarified.

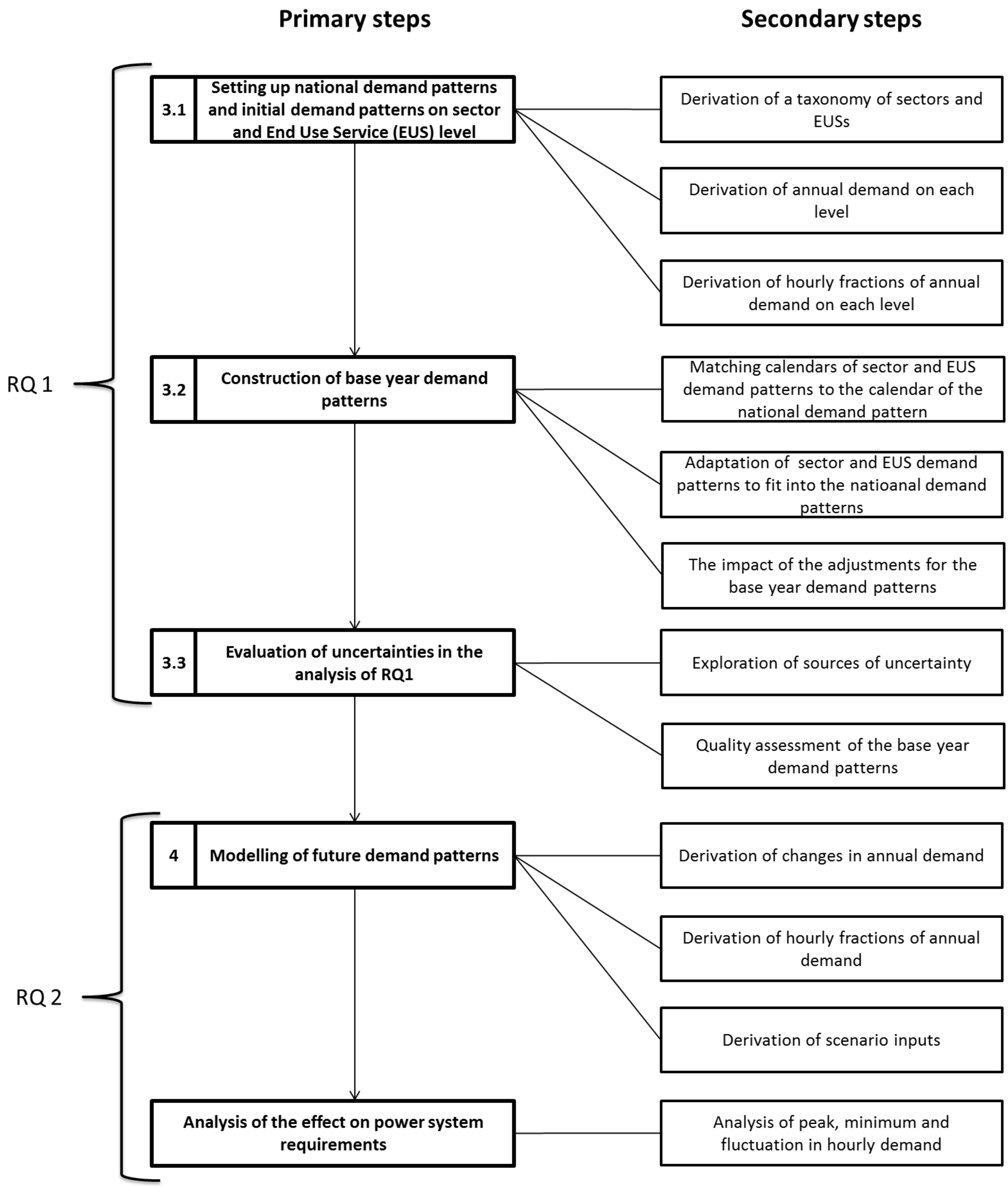

Figure 2.1: main research structure including corresponding section numbers in chapters 3 and 4

2.3.1 Primary steps

The first research question is addressed in three primary steps. First, demand patterns on a national and initial demand patterns on sector and EUS level are set up using a bottom up approach. The resulting aggregated demand patterns on sector level do not match the patterns on a national level. On EUS level, aggregated demand patterns do not match the corresponding sector level patterns. This is caused by two reasons:

1. The demand patterns are derived from sources which contain demand data of different periods;
2. The type of data and the means by which the data is collected varies.

In a disaggregation of the national demand pattern, aggregated sector and EUS demand patterns should match the national demand pattern. Also, a problem exists for the analysis of research question 2, since it is desirable to analyse to what extent a change on EUS or sector level affects the sector and national demand patterns.

In the next step of the analysis, this issue is addressed. This is done by adopting an approach by Pout et al. (2008), in which demand patterns on sector level are adjusted to fit into national demand patterns and the EUS demand patterns are adjusted to fit into the adjusted sector demand patterns. The resulting 'base year' demand patterns (representing 2013) form deliverable 1.

In the third step of the analysis, the uncertainties in the analysis of current demand patterns are evaluated (deliverable 2). This is done because:

1. The type and quality of the applied data varies considerably;
2. Most of the approaches used to create this overview of current demand patterns are not previously applied or they have not been combined in this fashion before.

The second research question is addressed in the two succeeding steps. First, the impact of 4 major factors on future demand patterns is modelled according to 7 scenarios (deliverable 3). Second, the effect of the scenarios on the power system requirements is analysed (deliverable 4).

2.3.2 Secondary steps

2.3.2.1 Setting up national demand patterns and initial demand patterns on a national, sector and EUS level

First, a taxonomy of sectors and EUSs is derived in order to establish in which sectors and EUSs the national demand pattern is disaggregated. National demand is disaggregated in 6 sectors. Two sectors (the residential and service sectors) are further disaggregated into 15 and 9 categories of EUSs, respectively. For the 4 remaining sectors, no data is found from which EUS patterns can be created.

Second, national demand patterns and initial demand patterns are set up for each sector and EUS. As indicated earlier, each of these patterns consist of hourly demand values that cover a 1 year period. The hourly demand values are calculated according to:

$$Hourly\ demand = Annual\ demand \cdot Hourly\ fraction\ of\ annual\ demand$$

With hourly and annual demand expressed in MWh.

To establish the demand patterns, annual demand (i.e. the 'magnitude' of a demand pattern) and hourly fractions of annual demand (i.e. the 'shape' of a demand pattern) are determined on a national level and for all categories of sectors and EUSs. The derivation of the sector and EUS categories and the data and approaches used to derive the shape and magnitude of the demand patterns are presented in section 3.1.

2.3.2.2 Construction of base year demand patterns

The base year patterns are constructed in two steps:

1. The demand patterns on sector and EUS level are adjusted to match the calendar of the national demand pattern;
2. The demand patterns on sector level are adjusted to fit into national demand patterns and the EUS demand patterns are adjusted to fit into the adjusted sector demand patterns.

As a result of the two steps, the shape and volume of the adjusted demand patterns on sector and EUS level has changed with respect to the initial situation. The national demand pattern is not affected. The extent of the changes on sector and EUS level is analysed.

A detailed description of the adjustment procedure and an analysis of the impacts in provided in section 3.2.

2.3.2.3 Evaluation of uncertainties

The uncertainties of the analysis for research question 1 are evaluated in two steps:

1. The sources of uncertainty are explored. Due to a lack of time, this evaluation is limited to a qualitative analysis of uncertainties resulting from the data used in RQ 1. Uncertainties with regard to the method are not investigated. Also, no sensitivities are explored for this part of the analysis.
2. Based on the explored uncertainties, the quality of the demand patterns created for the base year is assessed.

A detailed description of these steps is provided in section 3.3.

2.3.2.4 Modelling of future demand patterns according to 7 scenarios

For the analysis of research question 2, 7 scenarios of future demand development are set up. Each scenario covers the development of a set of factors that influence future electricity demand. This set of factors is modelled using both a collective and an individual approach. This is explained in the first subsection. In the second subsection, the 2 modelling approaches are discussed. The final subsection introduces the 7 scenarios.

Collective and individual modelling of factors

A large number of factors can affect future electricity demand, such as the penetration of new technologies or population growth. In appendix A, an overview is presented of factors that are cited in several studies on future electricity demand. Due to the large number of factors, it is not possible to model the effect of each factor on future demand patterns individually. In addition, there are numerous interactions between the factors that make modelling more complex. For example, the impact of an increase in energy efficiency is conditional to policy and technology developments (Boßmann et al., 2012). To simplify the modelling approach, the impact of a set of factors is collectively modelled.

The collective modelling of factors is performed by adopting scenarios of existing modelling studies. These scenarios include development of a set of factors which is reflected in a single figure of annual demand change. From the scenario results, annual demand change is derived on national, sector and/or EUS level. The advantage of this approach is that a large number of factors can be incorporated in a relatively simple modelling exercise. However, there are two limitations:

1. The effect of a single factor on the electricity demand pattern cannot be distinguished;
2. Only changes in annual demand on national, sector or EUS level can be derived. As mentioned above, this can result in a change of the shape of the demand pattern on a sector and national level. However, it is likely that the shape of the demand patterns will undergo additional changes, which are not taken into account in this approach.

In addition to the collective modelling of a set of factors, 4 major factors are modelled individually. The impact of each of these individual factors is highlighted in a 'single parameter' scenario. The following factors are selected for individual analysis:

- Increase of energy efficiency
- Electrification of (space and water) heating
- Electrification of passenger cars
- Increase in onsite generation of photovoltaic (PV) electricity

These factors are selected because a potentially significant impact of these factors is frequently cited in literature. Furthermore, scenario inputs for these individual factors can also be derived from the data sources which are used for the collective analysis of factors. This way, scenarios are created that correspond to the same set of underlying assumptions.

There are 2 main limitations in this approach:

1. The impact of the individual factors is only modelled in the residential and service sectors.
2. The electrification of heating and passenger cars is only modelled in a 'worst case' situation, which excludes 'smart' solutions that could counteract negative effects (such as higher peak demand) of these factors on the national demand pattern. However, the 'worst case' situation does show the potential for application of smart solutions.

Modelling approaches

To model the impact of factors on hourly demand values for 2050, changes are applied to the base year demand patterns, resulting in forecasted demand patterns of 2050. The following approaches are used to change the base year demand patterns:

1. Annual demand of the base year on national, sector and/or EUS level is changed. Because sector and EUS demand is aggregated, different levels of change between sectors or EUSs also change the shape of the national and sector demand patterns. The shape on EUS level remains unchanged. This approach is used for modelling of both the collective factors and the individual impact of energy efficiency.
2. A new electricity demand pattern is added on EUS level, also resulting in changes on sector and national level. This approach is used for modelling of the electrification of heating and transport and the increase in onsite generation of PV electricity. Similar to the analysis of current demand patterns, hourly fractions of annual demand and annual demand are derived for these demand patterns.

Similar approaches are used in Pout et al. (2008).

For these approaches, two parameters have to be derived:

- Changes in annual demand resulting from the impact of both the collectively and individually modelled factors;
- Annual fractions of hourly demand for future demand patterns of electric heating, transport and onsite PV generation.

A description of the derivation of these parameters is described in sections 4.1 and 4.2.

Introduction of scenarios
The modelling of future demand patterns on national, sector and EUS level is performed for 7 scenarios. The scenarios are:

1. Business as Usual ('BAU')
2. Increase of energy efficiency ('Efficiency')
3. Electrification of heat demand ('Heat')
4. Electrification of passenger cars ('Transport')
5. Onsite generation of PV ('Onsite')
6. 4 °C global temperature increase ('4DS')
7. 2 °C global temperature increase ('2DS')

A Business As Usual (BAU) scenario is first created as a baseline for comparing other scenarios. The inputs of this scenario are based on an existing modelling study, in which likely mutual development of the 4 individual factors and a set of additional factors are featured. In scenario 2 through 5, the impact of each of the 4 individually modelled factors is amplified in variations of the BAU scenario. These scenarios are coded 'single parameter scenarios' in the remainder of this study. These scenarios also function as a sensitivity analysis. In scenarios 6 and 7, inputs from another existing modelling study are adopted. These inputs reflect likely mutual development of the 4 individual factors and a collectively modelled set of additional factors, in 2 global warming scenarios. These scenarios reflect a situation of 4 °C and 2 °C global temperature increase compared to pre-industrial levels. These scenarios are coded 'combined parameter scenarios' in the remainder of this study.

The scenario inputs are established in section 4.3.

2.3.2.5 Analysis of the effect on power system requirements
In this part of the analysis, the effects of the forecasted national demand patterns on the requirements for the supply side of the power system are analysed. The effects are considered for the following system parameters:

- The required generation capacity
- The required transmission capacity
- The base load volume
- The required load following and peaking power capacity

These parameters are primarily observed from a technical perspective, e.g. a change in the amount of generation capacity that that is required. Changes in these parameters obviously have economic consequences. For example, higher requirements for peaking power capacity increase the cost of electricity (Eurelectric, 2009). In this analysis, the extent of economic effects is not quantified.

To evaluate the effect of the demand patterns on these parameters, three indicators are calculated for the national demand patterns in each scenario:

- *Peak demand* – Indicator for required generation and transmission capacity.
- *Minimum demand* – Indicator for base load
- *Mean Absolute Step Change (MASC)* – Depicts the fluctuation in demand as an indicator for required load following and peaking power capacity

The MASC is calculated by:

$$MASC = \frac{1}{8759} \cdot \left((a_2 - a_1) + (a_3 - a_2) + \cdots + (a_{8760} - a_{8759}) \right)$$

In which the 8760 hourly demand values (in MWh) of a demand pattern are the input. Each demand value is denoted by $a_{(\#\ demand\ value)}$.

It is important to note that these indicators do not directly relate to the volume of the base load and the generation, transmission, load following and peaking power capacities that are required. This is caused by the fact that the demand patterns are analysed at an hourly time scale. Demand patterns on alternate time scales likely show different outcomes for these indicators.

2.4 Data collection

The data for this thesis is collected from scientific literature, publicly accessible databases and reports from private and public research institutes. Additional data is acquired from research institutes and companies. For confidentiality reasons, company names and names of contact persons are coded. In the analysis of research question 1, several anomalies are encountered in the data. Remarks about these anomalies and solutions to deal with them are listed in appendix B.

3 Disaggregation of national demand patterns

In this chapter, additional methods and data descriptions for the analysis of research question 1 are presented. In figure 3.1, an overview is given of the structure of this chapter, including corresponding section numbers. Whenever appropriate, additional information is provided in appendices.

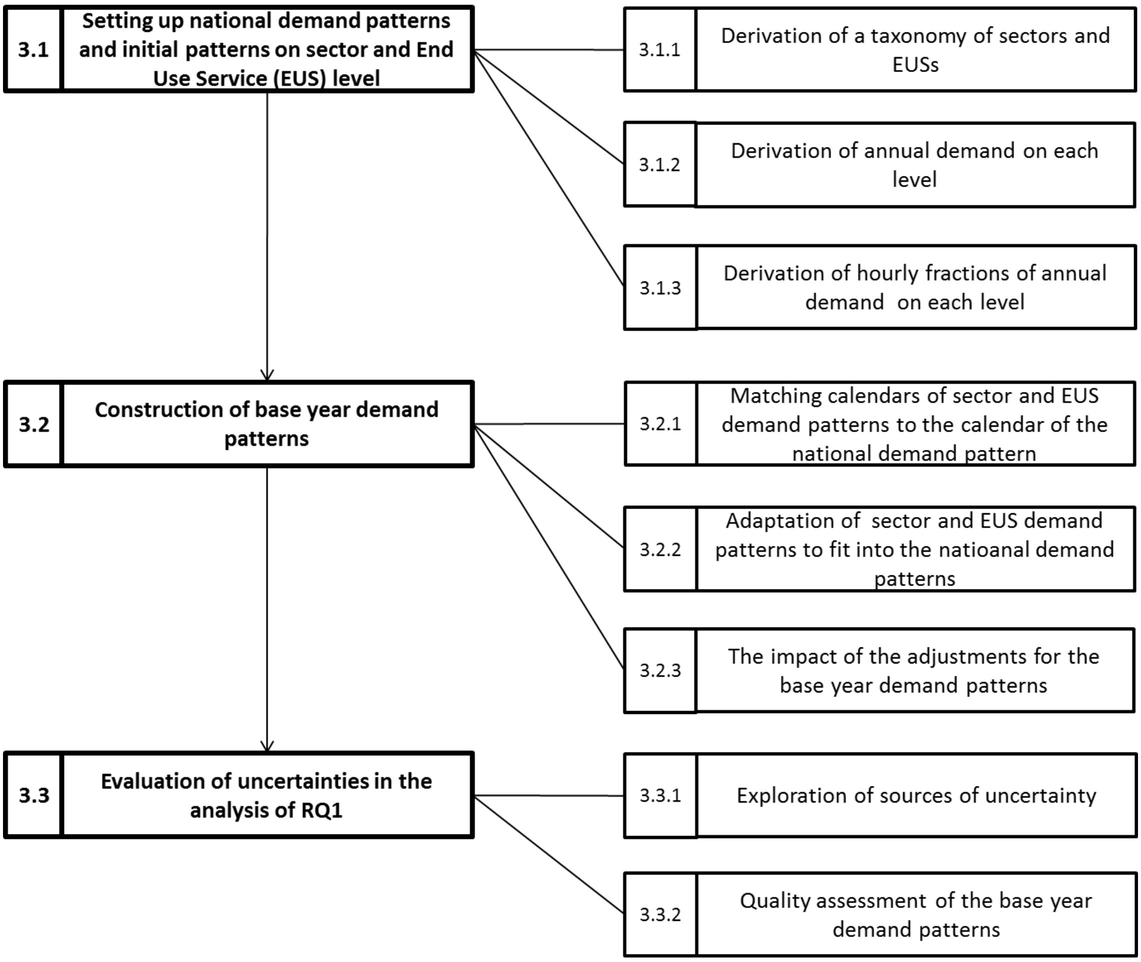

Figure 3.1: structure of chapter 3 with corresponding section numbers

3.1 Setting up national and initial sector and EUS demand patterns

As described in chapter 2, the following formula is used to set up the national demand pattern and initial sector and EUS demand patterns:

$$Hourly\ demand = Annual\ demand \cdot Hourly\ fraction\ of\ annual\ demand$$

Where *Annual demand* represents the 'volume' and *Hourly fraction of annual demand* represents the 'shape' of a demand pattern. Both hourly and annual demands are expressed in MWh.

In this thesis, *demand* is defined as the power absorbed from the electricity network by a nation, sector or end use service in a specified period (e.g. hourly or annual). It excludes losses on the electricity transmission network.

In the data sources used for this study, other terms are also used that, in some instances, comply with this definition. These terms are:

1. Final consumption
2. Consumption
3. Deliveries
4. Load

In these instances, the terms are interchangeable with demand. However, these terms are not interchangeable in general. Whenever terms other than demand are used in this thesis to indicate a quantity of electricity (e.g. in definitions), it is indicated whether this is interchangeable with demand.

In the next subsections, the following elements are derived:

1. **A taxonomy of sectors and EUSs** - to establish the categories of sectors and EUSs for which demand patterns are set up. This taxonomy is identical for each country.
2. **National annual demand and initial annual demand on sector and EUS level** - i.e. the 'magnitude' of the demand patterns.
3. **National hourly fractions of annual demand and initial hourly fractions of annual demand on sector and EUS level** - i.e. the 'shape' of the demand patterns.

For some of these elements, multiple data sources are available. The following criteria are used to make a selection:

- Representativeness
- Accuracy (i.e. is the data realistic?)
- Novelty (i.e. in what year is the data collected?)
- Completeness (i.e. is the dataset of sufficient size for a complete analysis?)

3.1.1 Derivation of a taxonomy of sectors and EUSs

3.1.1.1 The taxonomy of sectors

In this section, the taxonomy of sectors is set up. Since the aggregated demand pattern of the sectors should match the national demand pattern, the taxonomy depends on the data source that is used for the shape of national demand pattern. This data is retrieved from the European Network of Transmission System Operators for Electricity (ENTSO-E). It consists of hourly 'load' values, which the ENTSO-E defines as:

(1) Load on a power system is referred to as the hourly average active power absorbed by all installations connected to the transmission network or to the distribution network;

(2) *Load is the power consumed by the network including (+) the network losses but excluding (-) the consumption for pumped storage and excluding (-) the consumption of generating auxiliaries*[2] (ENTSO-E, 2010).

These definitions of load do not comply with the definition of demand used in this study, since network losses are excluded. In the context of this data source, hourly load is therefore not interchangeable with hourly demand. However, the definition of demand does apply to the load minus distribution losses, which is equal to the 'power consumed by the network'. When it is assumed that distribution losses make up a fixed percentage of the load, the shape of the national demand pattern (and of the aggregated sector pattern) depends solely on the power consumed by (entities on) the network. These entities on the network can be categorized using the following definition:

(3) *Final electricity consumption is the electricity which reaches the consumer's door. It is the sum of final energy consumption in industry, transport, households, services, agriculture and it excludes consumption of the energy sector itself and network losses* (Eurostat, 2012)[3].

In this definition, final consumption is interchangeable with demand. Based on definition 2 and 3, the consumption of entities on the network can be divided into two main categories:

1. Consumption of final consumers
2. Consumption by the energy sector itself, minus consumption for pumped storage and generation auxiliaries. This represents, for example, electricity consumption in coal mining and refineries.

The two main consumption categories are divided in 6 sectors which form the sector taxonomy for this study. Consumption of final consumers is divided among the 5 sectors described in the Eurostat definition:

- Industry
- Transport
- Residential (households)
- Service
- Agriculture

Consumption by the energy sector itself, minus consumption for pumped storage and generation auxiliaries, is represented in 1 sector, which is henceforth referred to as 'Energy'.

A summary of the derivation of these categories is depicted in figure 3.2.

[2] A generation auxiliary is, for example, a main transformer at a power station (ENTSO-E, 2010).
[3] This definition originally describes final energy. However, this definition also applies to final electricity.

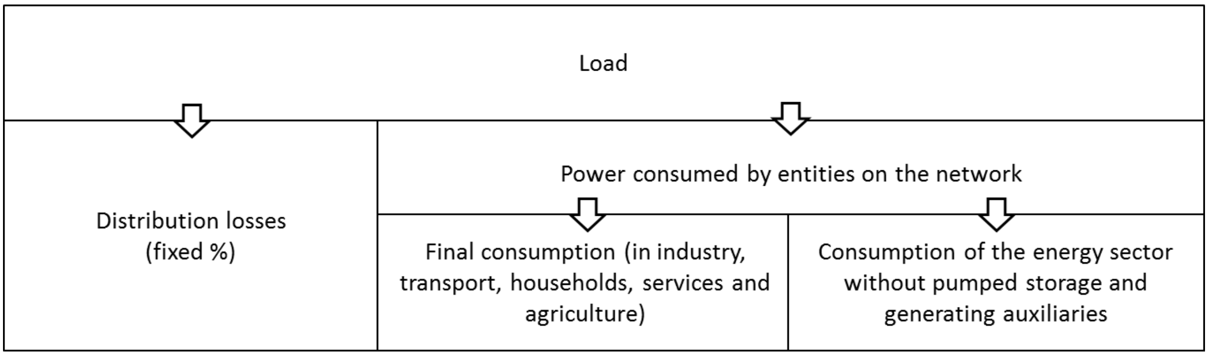

Figure 3.2: Graphical representation of the components of the ENTSO-E data

The main consumption categories could be divided in other ways. For example, a three sector division as described in Fisher (1939) could also be applied. However, the taxonomy currently applied is more convenient for this analysis, since it is also commonly used in energy statistics (Segers, 2010). Additionally, a division in smaller subsectors of the current selection of sector could be applied. In particular, the service, industry and energy sectors could be subdivided in multiple subsectors (United Nations, 2008). However, such a division would also significantly expand the size of the analysis.

3.1.1.2 The taxonomy of end use services

In this section, the taxonomy of EUS is presented. Because of lacking data, patterns of end use service are only constructed for the residential and services sectors. This also causes the taxonomy of EUSs to be based solely on the data from which the shapes of the EUS demand patterns are derived. Table 3.1 lists the EUS taxonomies for both sectors.

Some expected EUS categories are missing, for example air conditioning in the residential sector. This is caused by the fact that the taxonomy of EUSs in the residential sector is primarily based on Swedish data, a country where demand for air conditioning is small because of relatively low temperatures (Bessec & Fouquau, 2008).

Table 3.1: EUS taxonomy for the residential and service sectors (see also comments below)

Residential sector, based on Zimmermann (2009) and IDAE (for the category 'Standby'; 2011b)	Service sector, based on Pout et al. (2008)
Lighting	Lifts
Cold appliances	Cooling
Cooking	Computing and consumer electronics
Dishwashing	Other
Washing	Catering
Drying	Cold Appliances
Audio/visual appliances	Water heating*****
Gaming*	Space heating
Computers	Lighting
Ventilation	
Space heating	
Water heating	
Other	
Not known**,***	
Standby****	

* Due to a lack of annual demand data, this demand pattern is only constructed for Sweden.

** The category ‘other’ is formed by multiple known EUSs which have relatively small demand. The category ‘not known’ is formed by demand on EUS level which is measured, but cannot be assigned to a specific EUS.
*** Due to a lack of annual demand data, this demand pattern is not constructed for Spain
**** Due to a lack of annual demand data, this demand pattern is only constructed for Spain.
***** Due to a lack of annual demand data, this demand pattern is not constructed for Sweden

3.1.2 Derivation of annual demand on national, sector and EUS level

3.1.2.1 Annual demand on national level
The annual demand on national level is obtained from the energy statistics database of Eurostat (2014a). Other sources could also be used, such as the ENTSO-E (2014) or databases of national energy statistic bureaus in the Netherlands, Spain and Sweden. However, annual demand data is preferably obtained from one data source, since databases may use different definitions and calculation methods which may lead to statistical differences as described in Segers (2010).

This source is selected for two reasons:
1. Annual demand of the Netherlands, Spain and Sweden is included in the database;
2. It contains additional annual demand values for sectors. As a result, annual sector demand data is also collected under the same definitions and calculation methods.

The Eurostat database uses the terms consumption and final consumption, which match the definition of demand used in this thesis. National annual demand is derived from the database as the sum of final energy consumption (including consumption of the industry, transport, residential, agriculture and service sectors) and consumption in the energy sector (minus consumption of generating auxiliaries and pumped storage).

The use of this database has the disadvantage that consumption figures of 2013 are not yet available. The demand data of a previous year could be used instead. However, the level of annual demand varies between years, for example because of temperature differences (Hekkenberg et al., 2009) or changed economic activity (Declercq et al., 2011). Therefore, the annual demand of the base year represents what it should have been in 2013, according to the latest trend in demand. The resulting annual demand figures are presented in table 3.2. The extrapolation of demand to 2013 is described in appendix C.

Table 3.2: national annual demand in 2013 derived from Eurostat (2014a)

Country	The Netherlands	Spain	Sweden
National consumption [GWh]	114079	257715	129424

3.1.2.2 Initial annual demand on sector level
In this section, the derivation of initial annual demand on sector level is described. Because of the adjustments applied for creation of the base year, the distribution of annual sector demand is altered. The altered annual demand values are utilized in part 2 of this thesis.

The annual demand data on sector level is obtained from the energy statistics database of Eurostat (2014a). Alternatively, databases of national energy statistic bureaus could also be used. As with annual demand on national level, the annual demand of sectors in the base year represents what it should have been in 2013, according to the latest trend in demand. For this, the extrapolation approach is again (see also appendix C). The resulting annual demand of sectors is presented as % of national demand (table 3.3).

Table 3.3: the initial distribution of sectors in national consumption (Eurostat, 2014a)

Sector/ Country	The Netherlands	Spain	Sweden
Industry	32%	27%	41%
Transport	1.5%	1.3%	1.9%
Residential	22%	32%	29%
Agriculture	6.9%	1.7%	0.95%
Services	33%	35%	24%
Energy	4.8%	2.6%	2.6%

3.1.2.3 Initial annual demand on EUS level

In this section, the derivation of initial annual demand on sector level is described. Because of the adjustments applied for creation of the base year, the distribution of annual EUS demand is altered. The altered annual demand values are utilized in part 2 of this thesis.

Annual demand of EUS is not available in the Eurostat database. Instead, country specific data sources are used. These sources may use different definitions and calculation methods which may lead to statistical differences as in Segers (2010). Since it is not clear what underlying methods and definitions are used, no corrections are performed.

The resulting annual demands of EUSs are presented as % of annual sector demands (tables 3.4 and 3.5). Since the data is collected in different years (see tables), it is assumed that these distributions represent the trend level of 2013. The categories of EUS found in the data did not always comply with the taxonomy of EUS. To match the distribution used in this research, some categories are aggregated or split up. These adaptations are listed in appendix D.

Table 3.4: the initial distribution of EUSs in annual demand of the residential sector

EUS/country & source	The Netherlands (ECN, 2014a); based on data of 2013.	Spain (IDAE, 2011a, 2011b); based on data of 2009.	Sweden (based on the dataset of Zimmermann (2009); provided by contact person 2; based on data of 2007.
Lighting	13%	12%	3.5%
Cold appliances	14%	23%	3.8%
Cooking	7.2%	14%	1.7%
Dishwashing	5.2%	3.7%	0.89%
Washing	5.2%	7.3%	0.70%
Drying	7.2%	2.1%	0.64%
Audio/visual appliances	15%	7.5%	1.8%
Gaming	-	-	0.64%
Computers	6.2%	4.6%	1.7%
Ventilation	7.2%	2.3%	1.0%
Space heating	7.2%	7.4%	66%
Water heating	5.2%	7.5%	11%
Other	1.0%	2.2%	2.0%
Not known	5.2%	-	4.6%
Standby	-	6.6%	-

Table 3.5: the initial distribution of EUSs in annual demand of the service sector

EUS/country,	The Netherlands	Spain (Fleiter et al.,	Sweden

	(AgentschapNL, n.d.; Menkveld et al., 2010); based on data of 2008.	2010); based on data of 2007.	(Energimyndigheten, 2010); based on data of 2009.
Lifts	0.67%	2.3%	0.41%
Cooling	6.3%	34%	18%
Computing and consumer electronics	5.0%	4.5%	1.5%
Other	17%	13%	4.7%
Catering	8.6%	2.5%	3.8%
Cold Appliances	16%	6.4%	26%
Water heating	4.5%	8.6%	-
Space heating	11%	6.7%	5.6%
Lighting	32%	21%	40%

In the Swedish residential sector, annual electricity demand is dominated by space heating. The share of space heating is in the service is remarkably lower. Fuel for space heating in this sector is mostly provided by district heating (Energimyndigheten, 2010; Sæle et al., 2010).

3.1.3 Derivation of hourly fractions of annual demand

3.1.3.1 Hourly fractions of annual demand on national level

The data used for the establishment of hourly fractions of annual demand on national level is derived from the ENTSO-E database of hourly load values. The hourly fractions of annual demand are calculated according to:

$$Hourly\ fraction\ of\ annual\ demand = \frac{Hourly\ load\ value}{Sum\ of\ all\ hourly\ load\ values\ in\ a\ year}$$

In which all parameters are expressed in MWh.

Alternatively, the necessary data could be obtained from national Transmission System Operators (TSOs) of the Netherlands, Spain and Sweden. This would make little difference, since the ENTSO-E data is composed of data provided by national TSOs (ENTSO-E, 2010). Additionally, use of the ENTSO-E data allows for a comparison between countries based on the same set of underlying assumptions.

Daily load patterns vary considerably between years in terms of both the level of hourly load and the amount of fluctuation in load between hours. These changes between years can be caused by variations in temperature and holidays that are scheduled irregularly, which in turn affect the behaviour of electricity consumers and the demand pattern (Hekkenberg et al. 2009; Declercq et al. 2011; Pardo et al. 2002). Therefore, the most 'average' year is selected for the national demand pattern. Load values of 5 different years are considered for this: 2009 – 2013 for the Netherlands and Spain and 2010 – 2013 for Sweden (data before 2010 is not available for Sweden).
The selection of an average year is performed on the basis of the average fluctuation of the load values, an important parameter in power supply management (European Climate Foundation, 2010).There are several indicators that could be used to describe this, such as the Standard Deviation (SD) and the Mean Absolute Deviation (MAD)[4] of the hourly load values. However, both these indicators are measures of variation around the mean and do not describe the fluctuation between

[4] For definitions/formulas of these indicators, see TU Eindhoven (not dated).

separate values (TU Eindhoven, not dated). Instead, the Mean Absolute Step Change (MASC) was selected, which displays fluctuation between load values most accurately.

The MASC is calculated by:

$$MASC = \frac{1}{8759} \cdot \left((a_2 - a_1) + (a_3 - a_2) + \cdots + (a_{8760} - a_{8759})\right)$$

In which the 8760 hourly load values (in MWh) of a year are the input. Each demand value is denoted by $a_{(\#\ demand\ value)}$. The final selection is made by selecting the year of which the MASC is closest to the 5 year average of the MASC values. Table 3.6 lists the resulting years and the corresponding MASC values.

Table 3.6: Selected years on which the national demand pattern is based, corresponding MASC of hourly load values, average and range. Derived from ENTSO-E (2014)

Country	**Year on which the national pattern is based**	MASC value in the selected year [MWh]	5 year MASC average [MWh]	MASC value range [MWh]
The Netherlands	**2012**	496.1	499.2	480.9 - 510.7
Spain	**2010**	1257	1249	1146 - 1464
Sweden	**2013**	415.0	417.8*	414.2 - 421.3

*** The average MASC of multiple years is based on the MASC of 4 years for Sweden since only data from 2010 onwards was available with ENTSO-E.**

The analysis of the Spanish MASC values indicates a downward sloping trend in the yearly demand fluctuation. This may be the result of increased sensitivity to electricity prices as a result of the liberalization in the Spanish electricity market. No evidence was found to support this theory. Nevertheless, this issue may be a reason to select a later base year for Spain. This issue is not further pursued, since it is outside the scope of this study.

A number of anomalies is found in the ENTSO-E data during the analysis. Remarks about these anomalies and solutions to deal with these them are presented in appendix B.

3.1.3.2 Hourly fractions of annual demand on sector level

In this section, the hourly fractions (of annual demand) on sector level are established for each country. Since sector demand is not measured, the hourly fractions are based on data of representative consumers within the sectors. The data of these representative consumers is obtained from various sources and in different formats. Three types of data are used:

1. **Standardized demand profiles of small consumers**. Small consumers are defined here as households and small businesses of which electricity demand is not measured hourly, but two-monthly or yearly (ACM, n.d.; European Commission, 2011c; REE, 2014). The standardized demand profiles are used to allocate annual electricity demand over the year. This enables suppliers to accurately invoice small consumers (Eurostat, 2013).
2. **Direct measurements of small consumers.** These are demand measurements (resolution hourly or less) of household or small business, which are collected for scientific or energy management purposes.
3. **Direct measurements of large consumers**. These are demand measurements (resolution hourly or less) of large consumers. Large consumers are businesses for which the electricity tariff varies throughout the day (Nuon, 2014). They are found in all sectors except for the residential sector.

Additional data is provided from the Energy Centre of the Netherlands (ECN) by Contact Person 1, from which hourly fractions could be derived per sector for the Netherlands. Since other sources provided newer and more elaborate hourly fractions, this dataset is not used to set up initial sector demand patterns.

The resolution of all data types is either hourly or less. Data with a resolution which is less than an hour is converted to an hourly resolution by aggregation. Standardized demand profiles consist of fractions of annual demand, so they directly translate to the desired data format. However, there are different types of demand profiles for different types of consumers within a sector (EDSN, 2014; REE, 2014). To obtain single hourly fractions for the sector out of the hourly fractions of multiple profiles, the following formula is used:

$$HFAD_{Sector} = Weight_A \cdot HFAD_{\ A} + Weight_B \cdot HFAD_{\ B} + \ldots \cdot \ldots + Weight_N \cdot HFAD_{\ N}$$

Where:
$HFAD_{Sector}$ = Hourly fraction of annual demand in the sector;
$Weight_A$ = Weight of profile A within the sector;
$HFAD_{\ A}$ = Hourly fraction of annual demand of profile A;
and $A, B, \ldots, N$ are the different profiles within a sector.

The distribution of weights is based on the distribution of annual demand between the different profiles. Alternatively, this could be based on the distribution of small consumers between the profiles. Such a distribution would be less realistic.

Direct measurements are converted to hourly fractions of annual demand according to:

$$Hourly\ fraction\ of\ annual\ demand = \frac{Hourly\ demand\ value}{Sum\ of\ all\ hourly\ demand\ values\ in\ a\ year}$$

In which hourly demand values are expressed in MWh.

In some datasets, the direct measurements do not represent an entire sector directly, but subsectors within a sector. For each of these subsectors, separate hourly fractions of annual demand are set up. To obtain single hourly fractions for a sector out of the hourly fractions of multiple subsectors, the following formula is used:

$$HFAD_{Sector} = Weight_A \cdot HFAD_{\ A} + Weight_B \cdot HFAD_{\ B} + \ldots \cdot \ldots + Weight_N \cdot HFAD_{\ N}$$

Where:
$HFAD_{Sector}$ = Hourly fraction of annual demand in the sector;
$Weight_A$ = Weight of subsector A within the sector;
$HFAD_{\ A}$ = Hourly fraction of annual demand of subsector A;
and $A, B, \ldots, N$ are the different subsectors within a sector.

The distribution of weights is preferably based on the distribution of annual demand between the different subsectors. When this data is not available, the distribution of weights is based on the distribution of consumers between the subsectors.

In some datasets, the direct measurements represent a subsector within a subsector, i.e. 'sub-subsectors'. For example, the industry sector includes the subsector 'Manufacture of basic iron and steel', which in turn includes the subsector 'production of granular iron and iron powder'. For this data, the hourly fractions of sub-subsectors need to be aggregated to hourly fractions of single subsectors, which, in turn, can be converted to hourly fractions on sector level. The previous formula cannot be applied for this aggregation, because data to determine the weights of the sub-subsectors in the subsectors is lacking. Therefore, hourly fractions at sub-sub level are averaged to obtain the hourly fractions of subsectors.

In the next subsections, the data used for the creation of hourly fractions is described per sector and country. Most sector patterns are constructed by means of country specific data. However, hourly fractions of the agricultural sector in Spain and the agricultural and the service sector in Sweden could not be derived because country specific data is lacking. The patterns of these sectors are either assumed to be constant (both agricultural patterns) or created by adopting an hourly fraction pattern from the Netherlands (the Swedish service sector pattern).

The Netherlands: residential and service sector

For the Dutch residential sector and service sectors, several data sources were considered:

- Standardized demand profiles of small consumers (both sectors) obtained from Energie Data Services Nederland (EDSN) (2014). The profiles are established from sampling data of consumers and allocation data (EDSN, 2014). It is not clear how or by which party the sampling or allocation is done. The resolution of this data is quarter-hourly (EDSN, 2012)
- Direct measurements of small consumers (both sectors) obtained from various consultancy and regional network companies. The resolution of this data is varies, but is hourly or less.
- Direct measurements of large consumers (service sector) obtained from Network Company 1. The resolution of this data is quarter-hourly.

To convert the demand data to a single sector pattern, the following abovementioned approaches are used:

- Quarter-hourly data is aggregated to hourly data
- Single hourly fractions for each sector are calculated out of hourly fractions on profile level using profile weights

EDSN distinguishes 10 different types of consumers with different profiles. Three of these profiles exist in the residential sector and seven of these profiles exist in the service sector (EDSN, 2012). To obtain single hourly fractions for the sectors from this data, the distribution of the profiles within the residential and service sectors is derived. This is described in appendix E.

The standardized demand profiles obtained from EDSN are selected to form the Dutch residential pattern. The direct measurements of small consumers are dismissed, because this dataset is not large enough to form an annual pattern. In addition, this set only contains data of a few households and is therefore considered to be less representative for the sector than the EDSN data.

The standardized demand profiles obtained from EDSN are also selected to represent the sector. The direct measurements of small consumers are again dismissed, because this dataset is not large enough to form an annual pattern. In addition, the direct measurements of small consumers are only obtained for a few companies within this sector. Since the service sector has a significant number of subsectors[5], this data is considered not to be representative for the sector. For this same reason, direct measurement data of large consumers is also dismissed. However, the service sector does contain large consumers. Including large consumers would make the resulting sector pattern more representative. This approach is not included, because this would also require a significant amount of additional data. Furthermore, it is not known how demand is distributed between small and large customers in the various sectors.

[5] For an overview, see United Nations (2008).

Spain: residential and service sectors
The Spanish residential and service sector fraction patterns are set up in the same fashion as the Netherlands. For this country, standard user profiles are obtained from the national TSO Red Eléctrica de España (REE, 2014). This is the only dataset available for these sectors. The resolution of this data is hourly and only 4 different profiles exist in Spain.

To convert the demand data to a single sector pattern, the following abovementioned approaches are used:

- Quarter-hourly data is aggregated to hourly data
- Single hourly fractions for each sector are calculated out of hourly fractions on profile level using profile weights

A description of the profiles and the distribution of different profile weights are discussed in appendix F. This distribution is used to convert the different profiles into hourly fractions. This is the only data source available to establish annual fractions of demand for these sectors.

Similar to the Netherlands, the service sector in Spain does not consist solely of small users that could be assigned to standard profiles. Again, the REE based profile of small business consumers is assumed to represent the entire service sector since data of large consumers is not found. Based on the distribution of consumption between the different types of connections found in CNE (2013), it can be deducted that the small businesses represent approximately 65% of total service sector consumption.

Sweden: residential sector
The Swedish hourly fractions are based on a very extensive dataset of the Swedish Energy Agency (Energimyndigheten), retrieved from Contact Person 2. The data is presented in the report by Zimmermann (2009). This is the only dataset found for this sector. It contains direct measurements of 400 households, both on household level and the level of EUS within these households. The households were monitored in the period 2005 - 2008. The resolution of the dataset is adjustable and set on hourly for this analysis. For this study, only measurements obtained in 2007 are used, since data collected in this period provided the most complete and novel hourly fractions of annual demand for this sector. The Swedish residential sector data is divided into several 'subsectors', by sorting the measurements according to the number of residents in a household (varying from 1 to 5 or more).

To convert the demand data to single hourly fractions of the residential sector, the following approaches are used:

- Demand data is converted to hourly fractions
- Single hourly fractions for each sector are calculated out of hourly fractions on subsector level using subsector weights

Using demographic statistics, the distribution of different residential subsector weights is determined (appendix G). This distribution is used to convert the different hourly fractions of subsectors to a single pattern of hourly fractions for the entire sector.

Sweden: service sector
No data is found that could be used to accurately set up hourly fractions of hourly demand for the Swedish service sector. This sector that represents a relatively high share in annual national consumption (24% in 2012 (Eurostat, 2014a)). Because of this, the hourly fraction that is used greatly affects the shape of all adjusted base year patterns on sector and EUS level.

At this point, the choice is made to adopt the hourly fractions of the Dutch service sector. Adopting the pattern from the Netherlands is preferred over Spain, because the national demand patterns of the Netherlands and Sweden are relatively similar (see also section 5.1). Alternatively, constant hourly fractions could be assumed for this sector. However, it is likely that such a pattern would be more unrealistic than the Dutch pattern.

The industry, transport and energy sectors of the Netherlands, Spain and Sweden
To establish hourly fractions of hourly demand for the industry, transport and energy sectors in the Netherlands, 2 main data sources are available:

- Direct measurements of large consumers, obtained from Contact Person 3 at Network Company 1. The resolution of this data is quarter-hourly. This dataset contains demand data of 2013 from 119 large consumers from different sub-subsectors within the industry, transport and energy subsectors. Appendix H lists the number of representative consumers used per subsector.
- Direct measurements of large consumers (only industry) obtained from various consultancy and regional network companies. The resolution of this data is varies, but is hourly or less.

The data from Network Company 1 is by far the most comprehensive, representative and complete. Therefore, this dataset is used for the hourly fractions of the industry, transport and energy sectors of the Netherlands. No hourly demand data of industry, transport and energy sectors is found for Spain and Sweden. Therefore, the Dutch data is also used to establish hourly fraction for the industry transport and energy sectors in these countries.

To convert the demand data to single sector patterns, 4 of the abovementioned approaches are used:

- Quarter-hourly demand data is aggregated to hourly data
- Demand data is converted to hourly fractions
- Hourly fractions at sub-sub level are averaged to obtain the hourly fractions of subsectors.
- Single hourly fractions for each sector are calculated out of hourly fractions on subsector level using subsector weights

The distribution of the different subsector weights is derived from Eurostat energy statistics in appendix H. This distribution varies significantly between the countries, resulting in distinct sector demand patterns for each country.

The Netherlands: agricultural sector
For the hourly fractions of the Dutch agricultural sector, direct measurements of large consumers obtained from Network Company 1 are also used. The resolution of this data is also quarter-hourly. This dataset contains demand data of 2013 from 24 large consumers from different sub-subsectors within the agricultural subsectors.

To convert the demand data to a single sector pattern, the following abovementioned approaches are again used:

- Quarter-hourly demand data is aggregated to hourly data
- Demand data is converted to hourly fractions
- Hourly fractions at sub-sub level are averaged to obtain the hourly fractions of subsectors.
- Single hourly fractions for each sector are calculated out of hourly fractions on subsector level using subsector weights

A distribution of subsector weights for this sector is not available in energy statistics. Instead, a distribution based on the number of firms within agricultural subsectors is obtained from CBS (2014a). An overview of subsectors and weights assigned to the subsectors and calculation steps is described in appendix I.

The agricultural sector of Spain and Sweden
No data was found that could be used to represent the hourly fractions of the agricultural sectors of Spain and Sweden. Dutch demand data could not be adopted for this sector, since a distribution of weights between agricultural subsectors could not be established for these countries. The Dutch hourly fractions of the sector can also not simply be adopted (this approach is used for the Swedish service sector), since the electricity demand pattern in this sector may be greatly affected by local environmental conditions and the different types of agricultural subsectors that exist in the three countries. Because the total contribution in the base year of demand by the agricultural sectors in Spain and Sweden is reasonably small (1-2%) the demand of this sector has little effect on the shape of the national demand patterns (Eurostat, 2014a). Therefore, the hourly fractions are assumed to be constant, i.e. each hourly fraction is equal to $(1/8760)$.

3.1.3.3 Hourly fractions of annual demand on EUS level
In this section, the hourly fractions of annual demand are derived on EUS level for the residential and service sectors. The analysis on EUS level is limited to these sectors due to a lack of data for the other sectors. Additionally, data from which hourly fractions of EUSs can be derived in the residential and service sectors is very limited. Two types of data are used:

1. **Direct measurements of households.** These are demand measurements (resolution hourly or less) of households, which are collected for scientific or energy management purposes.
2. **Graphical representations of demand patterns.** These are found in (scientific) research (resolution hourly or less) and set up for scientific or policy purposes. These representations cover the period of 1 day.

The resolution of all data types is hourly. The formulas to convert direct measurements to hourly fractions of annual demand are described in section 3.1.3.3 for the conversion of demand data to hourly fractions of sectors. These formulas also apply to data on EUS level. The graphical representations of demand patterns are digitized to hourly demand values (of 1 day) by means of digitizing software. Next, these digits are converted to hourly fractions of annual demand according to:

$$Hourly\ fraction\ of\ annual\ demand = \frac{Hourly\ demand\ value}{(Sum\ of\ all\ hourly\ demand\ values\ on\ a\ day \cdot 365)}$$

In which hourly demand values are expressed in MWh. The hourly fractions of 1 day are copied to other days within the year to create a complete pattern of hourly fractions of annual demand.

In the next 2 subsections, the data used is described per sector.

EUSs in the residential sector of the Netherlands, Spain and Sweden
Two data sources are used to set up hourly fractions on EUS level in the residential sector:

- Direct measurements of households, in an extensive dataset of the Swedish Energy Agency (Energimyndigheten), retrieved from Contact Person 2. This dataset is also used to establish the hourly fractions on residential sector level for Sweden. For a more elaborate description of this dataset, see section 3.1.3.2.
- A graphical representation of the demand pattern on a typical day of the EUS category ‘standby’ in Spain, found in IDAE (2011b).

Both data sources have an hourly resolution.

Comprehensive EUS demand data on hourly level could not be found for the Netherlands and Spain. Therefore, the Swedish data is also used to establish hourly fractions of annual demand for these countries.

Again, the Swedish data is divided into several 'subsectors', by sorting the measurements according to the number of residents in a household (varying from 1 to 5 or more).

To convert the demand data to single EUS hourly fractions, the following approaches are used:
For the Swedish data:

- Demand data is converted to hourly fractions
- Single hourly fractions for each sector are calculated out of hourly fractions on subsector level using subsector weights

For the Spanish data:

- The graphical representation is converted to hourly fractions

Using demographic statistics, the distribution of different residential subsector weights is determined for each country (see appendix J). This distribution is used to convert the different hourly fractions of subsectors to a single pattern of hourly fractions for the entire sector.

EUSs in the service sector of the Netherlands, Spain and Sweden
One data source is used to set up hourly fractions on EUS level in the service sector. This data is comprised of graphical representations of daily demand patterns in the report by Pout et al. (2008). A total of 13 different end use demand patterns are described in the report. Four categories had such a small impact that no demand pattern could be interpreted from the graphs. Therefore, only 9 EUS categories are extracted from this report. Four daily patterns are distinguished for each EUS, one for each quarter within a year. The figures are based on a combination of modelled and monitored data from the United Kingdom and the USA (California; only cooling demand). It is unknown in which year consumption was monitored (Pout et al., 2008).

All the graphical representations are converted to hourly fractions of annual demand. The specific daily fractions are copied to the days in the associated quarter of the year, in order to create a complete pattern of hourly fractions of annual demand.

3.2 Construction of base year demand patterns

This section contains the following elements:

3. The demand patterns on sector and EUS level are adjusted to match the calendar of the national demand pattern
4. The demand patterns on sector level are adjusted to fit into national demand patterns and the EUS demand patterns are adjusted to fit into the adjusted sector demand patterns.
5. The impact of the adjustments applied to form the base year is analysed.

3.2.1 Matching calendars of sector and EUS demand patterns to the calendar of the national demand pattern

From the data sources described in section 3.1 demand patterns are set up on national, sector and EUS level. All of these patterns follow a specific calendar, depending on the year from which the hourly fractions of annual demand (i.e. the shape of a demand pattern) originates. For the national demand patterns of the Netherlands and Spain this means that although the patterns represent 2013, the calendars still match 2012 and 2010, respectively. The calendar of the Swedish national demand pattern does represent 2013.

The influence of the calendar on an electricity demand pattern is significant. This influence is visible between different hours within a day, different days within a week (particularly weekends) and holidays (Hyndman & Fan, 2008). In order to distinguish these effects, each daily national demand pattern of is labelled as either a weekday or weekend day pattern. Weekend days include national holidays. Regional holidays were neglected, influence on these days is assumed to be much smaller. An overview of national holidays per country is listed in appendix K.

Because of limited availability of data and the data selection criteria, most of the demand patterns on sector and EUS level do not represent the same calendar as the national demand pattern. These patterns are adapted to fit into the calendar of the national demand pattern for each country. All necessary adaptations are shown in appendix K.

The national demand patterns are registered in Central European Time (CET; ENTSO-E, 2010). In addition, the transition to Daylight Saving Time (DST) is incorporated in the data. A significant effect on the shape of the load pattern is visible when the time registration is switched from winter to summer time and vice versa (ENTSO-E, 2014). The demand patterns of sectors and EUSs are converted to the CET with DST format.

In part two of the research, the forecasted demand patterns are not adapted to future calendars. Such a procedure would be exhaustive and is outside the scope of this analysis.

3.2.2 Adaptation of sector and EUS demand patterns to fit into the national demand pattern

In this section, adjustments are done to the sector and EUS demand patterns to fit into the national demand pattern. This is done according to the following formulas:

$$\begin{aligned} &Adjusted\ hourly\ sector\ demand \\ &\qquad = Initial\ hourly\ sector\ demand \cdot \left(\frac{Hourly\ national\ demand}{Hourly\ aggregated\ initial\ sector\ demand}\right) \end{aligned}$$

$$\text{Adjusted hourly EUS demand} = \text{Initial hourly EUS demand} \cdot \left(\frac{\text{Adjusted hourly sector demand}}{\text{Hourly aggregated initial EUS demand}}\right)$$

In which all parameters are expressed in MWh.

The factor $Hourly\ national\ demand / Hourly\ aggregated\ sector\ demand$ is different for each of the 8760 hours in the base year. This also holds for the factor $Adjusted\ hourly\ sector\ demand / Hourly\ aggregated\ EUS\ demand$. As a result, the shape and volume of the adjusted demand patterns has changed with respect to the initial situation. This extent of these changes is discussed in section 3.3.2. The adjustment process is visualized in figures 3. 3 and 3.4 for the aggregated sector demand patterns on January 1st in the Netherlands.

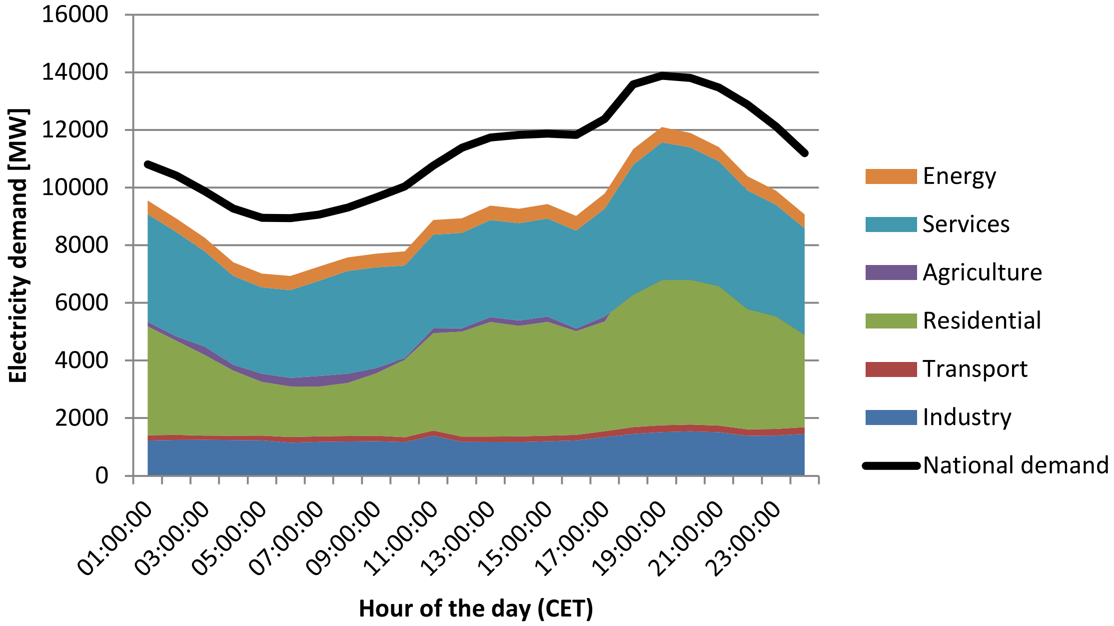

Figure 3.3: the aggregated sector demand patterns on January 1st before base year adjustments

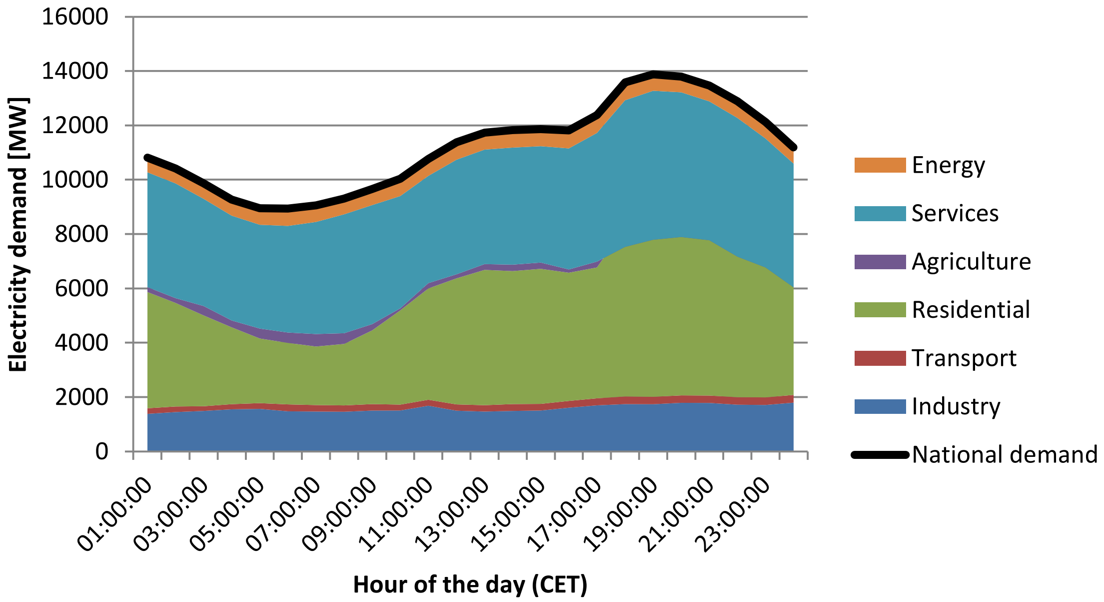

Figure 3.4: the aggregated sector demand patterns on January 1st after base year adjustments

3.2.3 The impact of the adjustments for the base year demand patterns

The impact of the adjustments for the base year demand patterns is analysed in two aspects:

1. The impact of the hourly demand values on sector and EUS level
2. The impact of annual demand on sector and EUS level

3.2.3.1 Impact on hourly demand values

To analyse the impact on hourly demand values, the relative change between the initial and base year demand values is determined. This relative change varies for each hour, it varies on sector and EUS level and it varies between countries. Each hourly relative change is calculated by:

$$Hourly\ relative\ change\ (sector) = \frac{Hourly\ aggregated\ initial\ sector\ demand}{Hourly\ aggregated\ adjusted\ sector\ demand} \cdot 100\%$$

$$Hourly\ relative\ change\ (EUS) = \frac{Hourly\ aggregated\ initial\ EUS\ demand}{Hourly\ aggregated\ adjusted\ EUS\ demand} \cdot 100\%$$

In which all demand parameters are expressed in MWh.

To describe the relatively change of all 8760 hourly demand values on sector and EUS level per country, the range and the Mean Absolute Deviation (MAD)[6] are used. A large range and high MAD values indicate that the impact on the initial hourly demand values is large. This indicates that the initial demand patterns on sector or EUS did not fit well into the national demand patterns. The ranges and MAD values of the hourly relative changes on sector and EUS level (distinguished per sector) are presented in tables 3.7 through 3.9.

Table 3.7: the range and the MAD of hourly relative change on sector level

Country	Range of hourly relative change	MAD of hourly relative change
The Netherlands	-41.6% **<–>** +49.0%	13.8%
Spain	-44.9% **<–>** +90.4%	13.6%
Sweden	-77.8% **<–>** +74.2%	14.2%

It is remarkable that the MAD are almost equal for all countries, since data from the Netherlands is extensively used to create sector patterns for Spain and Sweden. The range indicates that the deviation of the aggregated sector demand pattern in the Netherlands is smallest. However, the range is determined by outliers, so this is not a well-founded deduction.

Table 3.8: the range and the MAD of hourly relative change on EUS level in the residential sector

Country	Range of hourly relative change	MAD of hourly relative change
The Netherlands	-81.9% **<–>** +211%	22.7%
Spain	-88.4% **<–>** +194%	29.8%
Sweden	-74.4% **<–>** +104%	14.7%

Table 3.9: the range and the MAD of hourly relative change on EUS level in the service sector

Country	Range of hourly relative change	MAD of hourly relative change
The Netherlands	-61.6% **<–>** +207%	34.0%

[6] For a description of the MAD and the formula, see (TU Eindhoven, not dated).

Spain	-73.2% **<–>** +354%	44.1%
Sweden	-89.2% **<–>** +207%	40.5%

The ranges in deviation and the in MAD values show considerable variation between the aggregated EUS demand patterns and the adjusted sector demand patterns. The higher MAD values in the service sector indicate a consistently worse fit of EUS patterns in the service sector patterns compared to the residential sector. This is probably a result of the use of data from the United Kingdom and of the fact that this data contains less comprehensive patterns. Additionally, the inaccuracy of the service sector demand patterns may be a cause for deviations. The relatively good fit of the residential sector EUS patterns in Sweden is caused by the fact that both the sector and EUS patterns are based on the same dataset. The relatively low MAD value of EUS demand patterns in the service sector of the Netherlands may be caused by the fact that the UK and the Netherlands have a relatively similar climate.

3.2.3.2 Impact on annual demand

Because of the adjustments for the base year, the distribution of national annual demand between sectors and the distribution of sector annual demand between EUS is changed. The new distributions and the relative changes (in %) with respect to the initial distributions are shown in tables 3.10 through 3.12.

Table 3.10: distribution of different sectors in national annual demand after base year adjustments and the relative change from the initial distribution

Sector	The Netherlands		Spain		Sweden	
	Base year share in the Netherlands	Relative change from initial share	Base year share in Spain	Relative change from initial share	Base year share in Sweden	Relative change from initial share
Industry	32%	+0.58%	27%	-1.2%	40%	-2.8%
Transport	1.6%	+3.2%	1.3%	+3.1%	1.9%	+2.7%
Residential	22%	+3.2%	32%	+1.5%	30%	+4.0%
Agriculture	5.3%	-23%	1.7%	+4.1%	1.0%	+2.6%
Services	33%	+1.7%	35%	-0.8%	24%	-0.12%
Energy	4.9%	+1.3%	2.6%	+0.075%	2.6%	-2.1%

The relatively large change in annual demand of the Dutch agricultural sector is caused by the fact that this sector also has negative demand, i.e. generates electricity. This electricity is mainly produced by onsite CHPs of greenhouses[7]. Because of the adjustments for the base year this negative demand is amplified, which causes the adjusted annual demand of the sector to decrease.

Table 3.11: distribution of different EUSs in adjusted residential sector annual demand after base year adjustments and the relative change from the initial distribution

End use service	The Netherlands		Spain		Sweden	
	Base year share in the Dutch residential sector	Relative change from initial share	Base year share in the Spanish residential sector	Relative change from initial share	Base year share in the Swedish residential sector	Relative change from initial share
Lighting	13.2%	-1.6%	12%	-0.026%	3.7%	+5.2%

[7] This is observed in the Network Company 1 data of the agricultural sector.

Cold appliances	15.2%	+5.5%	25%	+9.1%	3.9%	+1.8%
Cooking	6.8%	-5.4%	12%	-18%	1.7%	+4.2%
Dishwashing	5.0%	-3.7%	3.7%	-2.3%	0.95%	+6.1%
Washing	4.8%	-6.9%	6.0%	-18%	0.73%	+3.6%
Drying	6.4%	-12%	2.0%	-4.4%	0.66%	+2.9%
Audio/visual appliances	15.8%	+2.2%	7.9%	+4.4%	1.9%	+3.8%
Gaming	-	-	-	-	0.68%	+4.9%
Computers	6.3%	+1.8%	4.8%	+3.6%	1.6%	-2.4%
Ventilation	7.5%	+4.1%	2.5%	+7.4%	1.0%	+2.3%
Heating	7.4%	+2.6%	7.9%	+7.0%	65%	-0.77%
Water heating	5.2%	+0.038%	7.5%	+0.41%	11%	-0.90%
Other	1.1%	+2.8%	2.1%	-3.5%	2.0%	-2.4%
Not known	5.4%	+5.1%	-	-	4.7%	+3.5%
Standby	-	-	7.4%	+12%	-	-

Table 3.12: base year distribution of different EUSs in adjusted service sector consumption after modification and the relative change from the initial distribution (table 3.6)

End use service	The Netherlands		Spain		Sweden	
	Base year share in the Dutch residential sector	Relative change from initial share	Base year share in the Spanish residential sector	Relative change from initial share	Base year share in the Swedish residential sector	Relative change from initial share
Lifts	0.63%	-6.7%	2.3%	+3.2%	0.39%	-5.0%
Cooling	6.4%	+0.066%	24%	-29%	14%	-25%
Computing and consumer electronics	4.5%	-9.8%	4.6%	+1.9%	1.4%	-7.8%
Other	19%	+15%	18%	+34%	6.0%	26%
Catering	7.6%	-11%	2.6%	+4.0%	3.6%	-7.0%
Cold Appliances	18%	+14%	8.5%	+33%	32%	25%
Water heating	4.3%	-3.5%	9.8%	+13%	-	-
Heating	12%	+7.2%	8.4%	+25%	6.6%	17%
Lighting	28%	-12%	22%	+2.1%	37%	-8.9%

The relative change of EUS annual demand shares with respect to initial annual demand shares is relatively small for the EUSs in the Swedish residential sector. This is caused by the fact that both the Swedish sector demand pattern and EUS demand patterns are based on the same dataset. The relative changes from initial shares are highest in the service sector. This may be a result of the fact that these patterns are derived from a less comprehensive dataset based on UK data.

3.3 Evaluation of uncertainties in the analysis of research question 1

In this section, the uncertainties which are found in the analysis of RQ 1 are evaluated. This forms deliverable 2 of this thesis. The evaluation is performed in two steps, which are presented in the next subsections:

1. The sources of uncertainty are explored;
2. The quality of the demand patterns in the base year is assessed.

3.3.1 Exploration of sources for uncertainty

The uncertainties in the data used for the analysis of RQ 1 originate in the two types of input parameters:

1. Annual demand (i.e. the 'magnitude' of a demand pattern)
2. Hourly fractions of annual demand (i.e. the 'shape' of a demand pattern)

In the next subsections, the sources of uncertainty are explored per type of input parameter and per level (national, sector or EUS). This exploration is done by reviewing how well the different data sources comply with the 4 selection criteria used to select the data:

- Representativeness
- Accuracy (i.e. is the data realistic?)
- Novelty (i.e. in what year is the data collected?)
- Completeness (i.e. is the dataset of sufficient size for a complete analysis?)

3.3.1.1 Uncertainties in annual demand

On national and sector level

There are few uncertainties on national and sector level because all data is obtained from Eurostat. The representativeness and accuracy of this data is high, since the data matches the definition of demand and the taxonomy of sectors used in this research. Additionally, this data source is complete in the sense that it provides data for all three countries. A small remark can be made about the novelty of the data: the database did not yet contain data of 2013.

On EUS level

In contrast to national and sector data, the annual data of EUS does not match the established taxonomy. A number of assumptions is made to correct for this, which increases uncertainty with regard to representativeness and accuracy. Furthermore, only data of single years is considered which originates from multiple sources. This is not consistent with the approach on national and sector level and increases uncertainty with regard to accuracy and completeness. Finally, the novelty of the data creates uncertainty since the data is collected in different years

3.3.1.2 Uncertainties in hourly fractions of annual demand

On national level

All hourly fractions on national level are derived from the database of the ENTSO-E. This data is constructed with direct measurements of hourly national demand. Therefore, uncertainty with regard to representativeness and accuracy is relatively low, although the manner of data assembly varies per country (ENTSO-E, 2010). Completeness and novelty do not form sources for uncertainty on this level, since the data of all three countries is included in one source and this data is updated regularly (ENTSO-E, 2014).

On sector level

The representativeness and completeness of the data form important sources for uncertainty on this level. First of all, a lot of data for Spain and Sweden for is lacking. For some sectors, data of the Netherlands is used. Other sectors are assumed to have constant hourly fractions of annual demand. This is a major cause of uncertainty, since local circumstances may cause the demand patterns to differ considerably. A second source of uncertainty with regard to representativeness is created by the fact that all the data used on this level does not reflect demand of a sector, but demand of a sample of consumers within a sector. Since the sectors contain various subsectors with their own characteristic demand patterns, the sample has to be representative of all consumers in all subsectors. This is a particular concern in the industry and service sectors, since those sectors contain a relatively large number of subsectors[8].

The accuracy of the data is in some instances also a cause for uncertainty. This is the case for data sources which contain standardized demand profiles, for which sample is used to create them. However, the accuracy of the underlying data is not clear. All other data sources contain direct electricity demand measurements, which are in all cases considered to be relatively accurate. The novelty of the data is also a cause for uncertainty because a number of data sources is relatively outdated. For example, the data used for the Swedish residential sector originates in 2007.

On EUS level
The sources of uncertainty on EUS level are largely comparable to the sources for on sector level. Due to lacking data, data of Sweden and the UK is used to create hourly fractions on this level for each country. This is again a major cause for uncertainty in the sense of representatives and completeness. Part of this data is relatively outdated, compared to data on other levels. Of some data, the period in which the data originates is not known.

The accuracy of the data is also a cause for uncertainty, since it is not clear how part of the data is collected or processed. Furthermore, this data had to be interpreted from graphs. Additional uncertainty is caused by incompleteness of the data. In some cases, the data did only represent hourly fractions of single days, instead of a whole year.

3.3.2 Quality assessment of the base year demand patterns

In this section, the quality of the base year demand patterns is assessed. For this assessment, three variables are defined which influence the quality of the base year demand patterns:

- The quality of the input data used to establish annual demand ('Annual demand')
- The quality of the input data used to establish hourly fractions of annual demand ('Hourly fractions')
- The extent of the adjustments that are applied to the initial patterns to complete the disaggregation ('Adjustments')

To analyse these variables with regard to the demand patterns of the base year, a number of indicators is used (table 3.13). For each indicator, a nominal score is used to express the strength of that particular indicator within a demand pattern. The scoring of these indicators for the base year demand patterns is presented for each country in table 3.14. The scores for the EUS demand patterns are assigned per sector.

Table 3.13: Indicators to assess to the quality of demand patterns and the classification of scores per indicator

Variable	Indicator	Low quality ('Low')	Medium quality ('Medium')	High quality ('High')
Annual demand	Type of data ('type')	Data from country specific sources	N/A	Eurostat
	Year of most recent data in source ('year')	Newer is preferred		

[8] For an overview, see United Nations (2008).

Hourly fractions	Format of hourly demand data ('format')	Graphs (not digital)/assumed to be constant	Demand data/standardized demand profiles of representative consumers	National load data
	Country of data origin ('origin')	Data of own country is preferred		
	Year of most recent data in source ('year')	Newer is preferred		
Adjustments	MAD value of hourly relative changes ('MAD')	Lower is preferred		

Table 3.14: Scoring of indicators for the demand patterns of the base year per country

Pattern level/sector	Variable	Indicator	The Netherlands	Spain	Sweden
National	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	High	High	High
		Origin	High	High	High
		Year	2013	2013	2013
	Adjustments	MAD	N/A	N/A	N/A
Sector – Industry	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	The Netherlands	The Netherlands	The Netherlands
		Year	2013	2013	2013
	Adjustments	MAD	13.8%	13.6%	14.2%
Sector – Transport	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	The Netherlands	The Netherlands	The Netherlands
		Year	2013	2013	2013
	Adjustments	MAD	13.8%	13.6%	14.2%
Sector – Residential	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	The Netherlands	Spain	Sweden
		Year	2013	2014	2007
	Adjustments	MAD	13.8%	13.6%	14.2%
Sector – Agriculture	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Low	Low
		Origin	The Netherlands	N/A	N/A
		Year	2013	N/A	N/A
	Adjustments	MAD	13.8%	13.6%	14.2%

Sector – Service	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	The Netherlands	Spain	The Netherlands
		Year	2013/2014	2014	2013/2014
	Adjustments	MAD	13.8%	13.6%	14.2%
Sector – energy	Annual demand	Type	High	High	High
		Year	2012	2012	2012
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	The Netherlands	The Netherlands	The Netherlands
		Year	2013	2013	2013
	Adjustments	MAD	13.8%	13.6%	14.2%
EUSs – Residential sector	Annual demand	Type	Low	Low	Low
		Year	2013	2009	2007
	Hourly fractions	Format	Medium	Medium	Medium
		Origin	Sweden	Sweden	Sweden
		Year	2007	2007	2007
	Adjustments	MAD	22.7%	29.8%	14.7%
EUSs – Service sector	Annual demand	Type	Low	Low	Low
		Year	2008	2007	2009
	Hourly fractions	Format	Low	Low	Low
		Origin	United Kingdom	United Kingdom	United Kingdom
		Year	N/A	N/A	N/A
	Adjustments	MAD	34.0%	44.1%	40.5%

Because the quality is dependent on multiple indicators, it is difficult to make an overall assessment of the quality of demand patterns. However, some general observations can be made:

- The quality of the national demand patterns is consistently high.
- On sector level, the quality corresponds to a more medium level and also varies between countries and sectors. The sector demand patterns of the Netherlands show on average the highest scores.
- The quality of demand patterns on EUS is consistently low, except for the EUS demand patterns of the residential sector in Sweden.

4 Modelling of future demand patterns

In this chapter, methods are described for the calculation of future demand patterns in the established scenarios. The methods are used to create future demand patterns are determined for 2050. The structure of this chapter is depicted in figure 4.1.

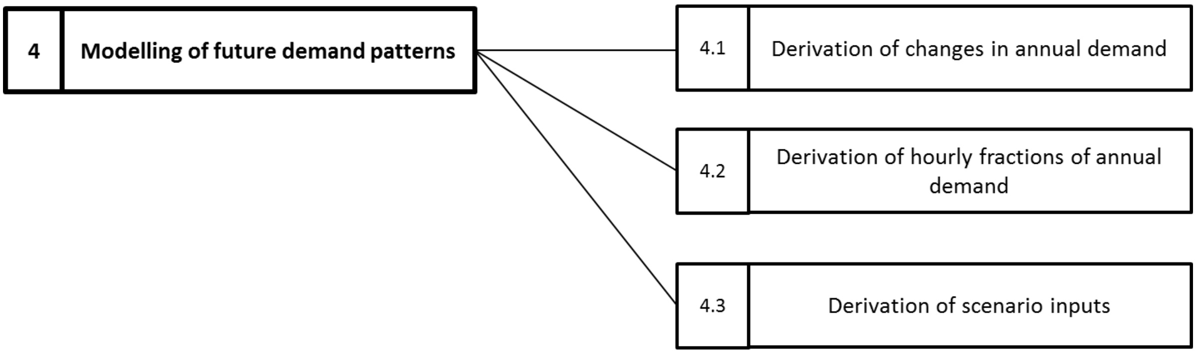

Figure 4.1: the structure of chapter 4

In order to model future demand patterns, the base year demand patterns are used as a starting point. For future years, hourly national demand is set up as the sum of hourly sector demands; hourly sector demand in the residential and service sectors is set up as the sum of hourly EUS demands in those sectors. This is depicted in the following formula:

$$\begin{aligned} & \textit{Hourly national demand} \\ & = \textit{Sum of hourly industry, transport, agriculture and energy sector demands} \\ & + \textit{Sum of hourly EUS demands in the residential and service sectors} \end{aligned}$$

In which all hourly demand values are expressed in MWh.

To model the impact of factors on hourly demand values for 2050, changes are applied to the base year demand patterns, resulting in forecasted demand patterns of 2050. The following approaches are used to change the base year demand patterns:

1. Annual demand of the base year on national, sector and/or EUS level is changed. This approach is used for modelling of both the collective factors and the individual impact of energy efficiency.
2. A new electricity demand pattern is added on EUS level. This approach is used for modelling of the electrification of heating and transport and the increase in onsite generation of PV electricity. Similar to the analysis of current demand patterns, hourly fractions of annual demand and annual demand are derived for these demand patterns.

The 7 scenarios all contain both a set factors which is modelled collectively and the 2 or more of the 4 individually modelled factors. However, impact of the 4 individually modelled factors is also included in the set of factors that is modelled collectively. As a result, the impact of these factors on annual demand is modelled twice. To avoid double counting, annual demand which is allocated to an individual factor is subtracted from the annual demand of the sector for which the individual factor is modelled.
Two main variables are derived for the scenarios:

1. **Annual demand change** for both the collectively modelled set of factors and the individually modelled factors (section 4.1);
2. **Hourly fractions of annual demand in 2050** for electric heating, transport and onsite generation of PV.

In the first two subsections, the two approaches are discussed. In the third subsection, inputs for the 7 scenarios are established.

4.1 Derivation of changes in annual demand

In section, the following approaches are explained:

- Annual demand change by a collectively modelled set of factors;
- Annual demand change by energy efficiency;
- Annual demand change by electric heating and transport and onsite generation.

4.1.1 Annual demand change by a collectively modelled set of factors

To model the impact of a set of factors on annual demand on national, sector and EUS level in 2050, annual growth factors are used. In none of the scenarios, annual growth on national, sector and EUS level is derived from a single comprehensive source. As a result, the sum of calculated annual demand in 2050 on EUS level exceeds or falls short of the corresponding sectorial annual demand; aggregated growth on sector level exceeds or falls short of national annual demand. Annual demand in 2050 is therefore derived in two steps, initial and final, described below.

Initial annual demand on national, sector and EUS level is calculated according to:

$$Initial\ annual\ demand\ = Annual\ demand\ in\ 2013 \cdot GF_{2014} \cdot GF_{2015} \cdot \ldots \cdot GF_{2049} \cdot GF_{2050}$$

Where:

- GF_{2014} is annual Growth Factor in 2014;
- Demand parameters are expressed in MWh.

These growth factors are derived from predicted annual demand figures in existing modelling studies. These figures are either listed digitally or depicted in graphs. In the latter case, the figures are interpreted using digitizing software. Growth factors are calculated out of the predicted annual demand figures according to:

$$Annual\ growth\ factor\ in\ years\ X\ to\ Y = \left(\frac{Predicted\ annual\ demand\ in\ year\ X}{Predicted\ annual\ demand\ in\ year\ Y}\right)^{\left(\frac{1}{y-x}\right)}$$

In which all demand parameters are expressed in MWh.

Final annual demand in 2050 is calculated by scaling aggregated sector demand to national demand and aggregated EUS demand to sector demand. This is done according to the following formulas:

$$Final\ annual\ national\ demand\ = Initial\ annual\ national\ demand$$

$$Final\ annual\ sector\ demand\ = Initial\ annual\ sector\ demand \cdot \left(\frac{Final\ annual\ national\ demand}{Aggregated\ initial\ annual\ sector\ demands}\right)$$

$$Final\ annual\ EUS\ demand\ in\ sector\ X = Initial\ annual\ EUS\ demand \cdot \left(\frac{Final\ annual\ sector\ demand\ in\ sector\ X}{Aggregated\ initial\ annual\ EUS\ demands}\right)$$

Where:

- All parameters are expressed in MWh;
- ‘Aggregated demands’ means the sum of annual demand of all sectors/EUSs;
- Sector X is either the residential or service sector.

An additional complication of the fact that annual growth on national, sector and EUS level could not be derived from a single source is that the different sources contain different assumptions. In order to harmonize the assumptions, national growth in each scenario is derived from one source.

4.1.2 Annual demand change by energy efficiency

In this section, the method for modelling the impact of increased efficiency on annual demand on EUS level in the residential and service sectors in 2050 is explained. This method is applied to the ‘Efficiency’ and ‘2DS’ scenarios. In these scenarios, the impact of increased efficiency in 2050 is limited to EUS level in the residential and service sectors. As a result, demand patterns on sector and national level are indirectly affected.

The data used for this modelling approach is taken from Schade et al. (2009), in which ambitious additional efficiency improvements of electric equipment between 2020 and 2050 are described for 10 categories of EUSs in a low demand scenario (‘400 ppm’). This is compared to a reference scenario in which current, much more modest, efficiency trends are continued. The data is expressed in percentages of annual efficiency improvement. The data is presented in table 4.1.

Table 4.1: Annual efficiency improvements between 2020 and 2050, adopted from Schade et al. (2009)

	‘Reference’ scenario	‘400 ppm’ scenario
Hot water	0.80%	1.30%
Cooking	0.70%	1.50%
Lighting	1.00%	5.50%
Refrigerators	0.70%	3.20%
Freezers	0.80%	4.10%
Washing machines	0.80%	5.00%
Dishwashers	0.80%	3.30%
TV	0.50%	2.90%
Others	-2.20%	-1.00%
AC	0.50%	3.00%

Unfortunately, the data of Schade et al. (2009) is limited to 10 different categories of EUSs. The amount and the type of categories do not correspond to the taxonomy of EUSs used in this research. To compensate for this, a number of categories listed in Schade et al. (2009) is assumed to represent the efficiency the missing EUS categories. This is presented in Appendix L.

By assuming that the ‘reference’ levels of efficiency improvement represent the levels of efficiency improvement in the BAU scenario for all countries, new levels of annual demand can be calculated for each EUS in the Efficiency and 2DS scenarios. In order to isolate the effect of efficiency increase in the Efficiency scenario, the new annual demands on EUS level are not scaled to sector level. In the 2DS scenario, the effect of these efficiency improvements is also taken in account in the change of sector annual demand. Therefore, the annual demands on EUS level in the 2DS scenario are scaled to sector level. The annual demand in 2050 per EUs category is calculated by:

$$'Efficiency'\ annual\ demand\ in\ 2050\ = \\ 'BAU'\ annual\ demand\ in\ 2050 \cdot (Annual\ efficiency\ improvement\ factor)^{\wedge 30}$$

In which all demand parameters are expressed in MWh.

The annual efficiency improvement factors are calculated per EUS category by:

$$Annual\ efficiency\ improvement\ factor = \frac{100\% - additional\ efficiency\ improvement\ 400\ PPM\ scenario}{100\% - additional\ efficiency\ improvement\ reference\ scenario}$$

In addition, a decrease in space heating because of additional insulation is included. This improvement is determined per country and based on the difference in predicted space heating demand figures between the reference and 400 ppm scenarios in Schade et al. (2009). The total efficiency improvement of space heating between 2013 and 2050 is listed in table 4.2.

Table 4.2: Total efficiency improvement for space heating (including effect of isolation) based on Schade et al. (2009)

Sector	The Netherlands	Spain	Sweden
Residential	47%	47%	47%
Service	33%	48%	60%

Additional efficiency improvement of PV and Electric vehicle technology is not incorporated in this analysis.

4.1.3 Annual demand change by electrification of heat and transport and onsite generation of PV

Electrification of heating

Annual demand for electric heating in 2050 is calculated for each country according to the following formulas:

$$Annual\ demand\ for\ electric\ heating\ in\ 2050 = Final\ heat\ demand\ in\ 2050 \cdot Share\ of\ final\ heat\ demand\ fuelled\ by\ electricity\ in\ 2050$$

$$Final\ heat\ demand\ in\ 2050 = Heat\ demand\ of\ 2008 \cdot GFHD_{2008-2050}$$

In which:

- *Annual demand for electric heating* and *final heat demand* are expressed in MWh;
- *Final heat demand* is the final heat demand for space and water heating.
- $GFHD_{2008-2050}$ is the growth factor of heat demand between 2008 and 2050.

The final heat demand for space and water heating in 2008 is presented in table 4.3.

Table 4.3: final heat demand for space and water heating (based on Enerdata (2014)) in MWh

Country	Residential sector	Service sector
The Netherlands	101777619	66109572
Spain	141551056	31760367
Sweden	65448988	25035901

The growth factor of final heat demand between 2008 and 2050 and the 2050 share of heating fuelled by electricity are different for each scenario in which electric heating is modelled ('Heat', '4DS' and '2DS'). The sources from which they are derived are described in section 4.3.

Electrification of transport

For this factor, only passenger cars in the residential sector are considered, which are charged at home. In the context of this research, electric vehicles include Battery powered Electric Vehicles (BEV) and Plugin Hybrid Electric Vehicles (PHEV). The annual final electricity demand for EV charging is calculated for 2050 according to:

$$Annual\ demand\ for\ EV\ charging = Amount\ of\ electric\ vehicles\ in\ use \cdot Electricity\ demand\ per\ car\ per\ day\ in\ 2050 \cdot 365$$

In which *Annual demand for EV charging* and *Electricity demand per car per day* are expressed in MWh

The amount of electric vehicles in use in 2050 is calculated according to:

$$Amount\ of\ electric\ vehicles\ in\ use\ in\ 2050 = Amount\ of\ electric\ vehicles\ in\ use\ in\ 2012 \cdot GFEV_{2012-2050}$$

In which $GFEV_{2012-2050}$ is the growth factor of electric vehicles in use between 2012 and 2050.

The amount of electric vehicles in use is (only PHEV and BPEV) is derived from IEA (2013), presented in table 4.4.

Table 4.4: 2012 stock and share in passenger car fleet of electric vehicles (Eurostat, 2014c; IEA, 2013)

Country	2012 stock of electric passenger cars (PHEV and BPEV)
The Netherlands	6750
Spain	787
Sweden	1285

* The size of the 2012 total stock of passenger vehicles of the Netherlands and Sweden is determined using growth factors from European Commission (2013).

Electricity demand per car per day in 2050 is constant in each scenario and determined by:

$$Electricity\ demand\ per\ car\ per\ day = average\ driving\ distance \cdot electricity\ demand\ per\ km$$

The current average km demand for electric vehicles is set on 38 km per car per day in all three countries. This includes all days and excludes holidays other long trips (Van Vliet et al., 2011). According to IEA (2012), this demand remains unchanged in the future, which is also assumed for this analysis.

Future electricity demand per km is derived from Van Vliet et al. (2011). This report lists the electricity demand per kilometre of different types of EVs (PHEV and BEV) in 2010, 2015 and 'the future' (assumed to be 2050). Since the distribution of EV models is not known, average electricity demand per EV per day is determined by averaging the different demand figures. The resulting demand per car per day is calculated to be 0.00395 MWh. This figure is assumed to represent the average daily demand for the all types of EV passenger vehicles.

The growth factor of electric vehicles in use between 2012 and 2050 is different for each scenario (all scenarios contain electric transport). The sources from which this is derived are described in section 4.3.

Onsite generation of PV
The demand pattern for onsite generation of PV is modelled by creating an additional pattern that represents the hourly generated amount of electricity in the residential and service sectors in 2050. Since electricity is generated with this technology, this demand is negative. This analysis concerns onsite (decentralized) electricity generation, which takes place beyond the boundaries of the electricity network (i.e. 'beyond the consumer's door' in Eurostat terminology) and is not part of the energy sector.

The annual generation (=negative annual demand) by PV is calculated for each year according to:

$$\begin{aligned} &Annual\ generation\ by\ PV\ in\ sector\ X \\ &\quad = Annual\ national\ electricity\ generation\ by\ PV\ in\ 2050 \\ &\quad \cdot Share\ of\ PV\ capacity\ in\ sector\ X \end{aligned}$$

And

$$\begin{aligned} &Annual\ national\ electricity\ generation\ by\ PV\ in\ 2050 \\ &\quad = Annual\ national\ electricity\ generation\ by\ PV\ in\ 2012 \cdot GFPV_{2012-2050} \end{aligned}$$

In which:
- $GFPV_{2012-2050}$ is the growth factor of electricity generation by PV between 2012 and 2050.
- All electricity generation parameters are expressed in MWh.

The annual national electricity generation by PV in 2012 is presented in table 4.5.

Table 4.5: solar collector area, primary electricity production and net (rated) maximum capacity in 2012 per country (Eurostat, 2014a)

	Electricity generation [MWh] in 2012
The Netherlands	253889
Spain	8192778
Sweden	18889

Next, it has to be determined how much of this generated electricity is done onsite (decentralized) in the residential and service sectors. This is derived from statistics describing the current capacity per sector (table 4.6). The distribution of capacity and annual electricity generation is assumed to be equal. Information on future development of this distribution is not known. Without further data, it is assumed that the distribution of PV generation per sector does not change. However, this parameter is a great source of uncertainty for this analysis.

Table 4.6: share of PV capacity in the residential and service sectors for the Netherlands (CBS, 2013b)**, Spain and Sweden (EPIA, 2014)**

Sector	The Netherlands (2012)	Spain (2013)	Sweden (2013)
Residential	70%	1.9%	40%
Service	12%	7.3%	60%

* No distinction is made in Spain and Sweden between the industry, transport, energy and service sectors (commonly named 'commercial'). It is assumed that half of the 'commercial' capacity can be attributed to the service sector in these countries.

The growth factor of electricity generation by PV between 2012 and 2050 is different for each scenario (all scenarios contain generation of PV). The sources from which this is derived are described in section 4.3.

4.2 Derivation of hourly fractions of annual demand

In this section, hourly fractions of annual demand are derived for:

- Electrification of heating;
- Electrification of transport;
- Onsite generation of PV.

4.2.1 Electrification of heating

The electrification of heat demand in the residential and service sectors is modelled by creating for each sector a demand pattern for 2050 that includes both electric space and water heating. This approach is applied in scenarios ‘Heat’, ‘4DS’ and ‘2DS’. Water heating and space heating are combined in a single pattern because annual demand predictions on future electricity demand for electric heating do not distinguish between space and water heating. In the next subsections, hourly fractions of annual demand and annual demand are derived for these demand patterns.

Due to a lack of data, current electricity demand data is used to derive the shape of the future electric heating demand patterns. This is assumed to represent the ‘worst case’ situation for future electric heating. The shape of the electric heating demand pattern in the residential sector is based on the initial demand patterns of space heating and water heating established in section 3.1.3.3. These patterns are created out of Swedish household demand data of 2007 provided by Contact Person 2. This results in a relatively accurate representation of the electric heating demand pattern for Sweden. The demand patterns for Spain and the Netherlands are less representative.

The hourly fractions of future electric heating in the service sector are based on the initial demand patterns of space heating and water heating established in section 3.1.3.3. These patterns are based on hourly data from the UK by Pout et al. (2008) of which no period of measurement is provided. It is difficult to assess the validity of this data for the Netherlands, Spain and Sweden.

To create a single fraction demand pattern from the 2 EUS demand patterns of space and water heating, the following formula is used:

$$\begin{aligned} &Hourly\ fraction\ of\ electric\ heating \\ &\quad = Final\ Share_{SH}\ 2050 \cdot hourly\ fraction\ of\ space\ heating + Final\ Share_{WH} \\ &\quad \cdot hourly\ fraction\ of\ water\ heating \end{aligned}$$

In which:

- $Final\ Share_{SH}$ = final share of space heating in electricity demand for electric heating in 2050;
- $Final\ Share_{WH}$ = final share of water heating in electricity demand for electric heating in 2050.

This distribution in the electric heating demand pattern between space and water is likely to change in the future because of better insulation which decreases demand for space heating, but not for water heating. This is taken into account, using the following formulas to determine the final share of space and water heating in 2050:

$$Initial\ share\ 2050 = Share\ of\ 2013 \cdot (1 - Efficiency\ improvement\ 2013 - 2050)$$

This is scaled according to:

$$Final\ share\ 2050 = \left(\frac{1}{(Initial\ share\ 2050_{RS} + Initial\ share\ 2050_{SS})}\right) \cdot Initial\ share\ 2050$$

In which:

- RS = Residential sector;
- SS = Service sector.

The efficiency improvements of space heating (including isolation) and water heating between 2013 and 2050 are derived from demand predictions and efficiency improvements in Schade et al. (2009). For this, an approach is used which is similar to the derivation of annual demand change described in section 4.1. This resulting efficiency improvement is presented in table 4.5.

The distribution of electricity demand between space and water heating in 2013 is set up using heat demand figures of 2008 from the Enerdata database (Enerdata, 2014) and heat demand growth figures derived from Pardo et al. (2012). The resulting distribution of electricity demand between space heating and water heating in 2013 and 2050 is presented in table 4.6.

Table 4.7: Efficiency improvement for space and water heating between 2013 and 2050 for 2050 (based on data from (Schade et al., 2009))

	The Netherlands	Spain	Sweden
Space heating (residential sector)	53%	53%	53%
Water heating (residential sector)	14%	14%	14%
Space heating (service sector)	67%	52%	40%
Water heating (service sector)	14%	14%	14%

Table 4.8: distribution of electricity demand for heating between space heating and water heating per country in 2013 (based on data from Enerdata (2014) and Pardo et al. (2012)) and calculated distribution for 2050 (based on data from (Schade et al., 2009))

Country	End use	Residential sector 2013	Service sector 2013	Residential sector 2050	Service sector 2050
The Netherlands	Space heating	82%	97%	72%	93%
	Water heating	18%	3.0%	28%	7.4%
Spain	Space heating	69%	91%	55%	85%
	Water heating	31%	9.2%	45%	15%
Sweden	Space heating	87%	94%	79%	91%
	Water heating	13%	6.3%	21%	8.8%

4.2.2 Electrification of transport

Electrification of transport is modelled by adding electricity demand patterns for charging of electric vehicles (EVs) on EUS to the residential sector in 2050. This factor is modelled in all scenarios. The ‘worst case’ situation for this factor is represented by ‘uncoordinated’ charging as described in Van Vliet et al. (2011) and Weiller (2011).

The hourly fractions of annual demand in 2050 are derived from the ‘home charging’ pattern in Weiller (2011), displayed in figure 4.2. This pattern is assumed to apply to each country and to apply for each day of the year.

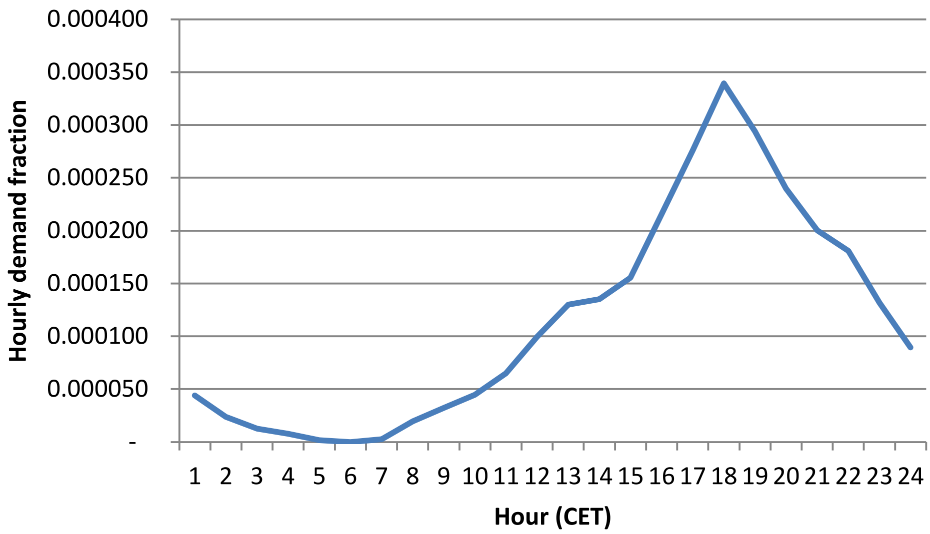

Figure 4.2: shape of the daily demand pattern of uncoordinated EV charging, adopted from Weiller (2011)

4.2.3 Onsite generation of PV

In this section, hourly fractions of annual demand and annual demand are derived for the demand pattern of PV in 2050.

The yield of a PV collector is primarily dependent on Global Horizontal Irradiation (GHI). A number of other factors (e.g. temperature, spectral distribution of sunlight level) also have influence on the hourly yield (Pfluger et al., 2011). Taking all these factors into account is outside the scope of this analysis. For the purpose of this research, it is assumed that PV generation is distributed solely according to the hourly GHI.

The hourly fractions are derived from GHI data from the Netherlands, Spain and Sweden. The hourly GHI is derived for each country from data from multiple locations (table 4.6). The more locations are included, the better the representativeness of the pattern.

Table 4.9: GHI data: number of locations and source per country

Country	Number of Locations	Source
The Netherlands	33	KNMI (2014)
Spain	Approximately 10	SODA (2014)
Sweden	6	SMHI (2014)

4.3 Derivation of scenario inputs

In this section, the scenario inputs for annual demand changes between 2013 and 2050 in the 7 demand scenarios are described. The scenarios all contain both a set factors which is modelled collectively and 2 or more of the 4 individually modelled factors.

The majority of the annual demand change inputs are derived from a combination of inputs and outcomes from 3 previously established scenarios. The first scenario is the reference scenario described in the report 'EU energy, transport and GHG emissions trends to 2050' by European Commission (2013), henceforth named 'EU-REF'. The second scenario is the reference scenario described in the report 'ADAM Adaptation and Mitigation Strategies: Supporting European Climate Policy' by Schade et al. (2009), henceforth named 'ADAM-REF'. The third scenario is the '400 ppm' scenario also described in the 'ADAM' study by Schade et al. (2009), henceforth named 'ADAM-400'.

These three modelling studies include:

- Predictions of annual demand on national, sector and EUS level
- Specific changes in annual demand for of the individually modelled factors

Most changes in annual demand are derived from the abovementioned scenarios. However, additional country specific annual demand predictions on sector and EUS level are derived from smaller, country specific modelling studies. These are described in Appendix M.

In the next subsection (4.3.1), the 3 adopted scenarios are described. In subsection 4.3.2, it is specified for the 7 demand scenarios of this study which inputs are used from which adopted scenario.

4.3.1 Description of the adopted scenarios

EU-REF

This scenario is part of a modelling project directed by the European Commission to assess low-carbon pathways in Europe. It describes development under current policies of national, sector and EUS demand. Specific growth figures of electric transport and PV generation are also included. There is no growth of electric heating specified in this scenario. From Ecofys (2013) can be derived that no significant growth of heat pumps is to be expected with current policies in Spain and Sweden. This is also the case in the Netherlands, according to (PBL, 2014). Therefore, it is assumed that there is no significant increase in electric heating in this scenario. In this source, no changes in degree days are modelled. Therefore, the effect of climate change on the demand pattern is not taken into account. For a complete description of this scenario, see European Commission (2013).

ADAM-REF

This scenario is part of a modelling project directed by the Fraunhofer Institute to assess low-carbon pathways in Europe. It describes development under current policies of national, sector and EUS demand. Growth figures of electric transport, electric heating and PV generation are also included. In this scenario, global average temperature increases with 4 degrees Celsius in 2050 compared to pre-industrial levels. In contrast to the Reference Scenario in European Commission (2013), this scenario includes changes in degree days and the resulting effect on electricity demand parameters. For a complete description of this scenario, see Schade et al. (2009).

ADAM-400

This scenario is also part of the modelling project directed by the Fraunhofer Institute. It describes development under new policies of national, sector and EUS demand. Specific growth figures of electric transport, electric heating and PV generation are also included, in addition to increases in energy efficiency of EUSs. In this scenario, global average temperature increases with 2 degrees

Celsius in 2050 compared to pre-industrial levels. This scenario includes changes in degree days and the resulting effect on electricity demand. For a complete description of this scenario, see Schade et al. (2009).

Although current policies in both the ADAM-REF and EU-REF scenarios are continued, significant differences in outcomes are seen. This is a result of different underlying assumptions and input figures (i.e. 'playing field') in both modelling studies, also related to the novelty of the studies. The 7 demand scenarios in this study are created in such a way that they rely on only the assumptions of 1 of the 3 main scenarios.

4.3.2 Sources of scenario inputs

In this section, the sources of scenario inputs for annual demand changes are presented. These inputs are adopted from the abovementioned scenarios EU-REF, ADAM-REF and ADAM-400. In table 4.10, sources for annual demand change for the collectively modelled factors are described. The resulting annual demand changes per scenario between 2013 and 2050 on national, sector and EUS level are described in appendix M.

Table 4.10: sources of annual demand change due to collectively modelled factors:

Scenario:	Adopted scenario
BAU	EU-REF
Efficiency	EU-REF
Heating	EU-REF
Transport	EU-REF
Onsite	EU-REF
4DS	ADAM-REF
2DS	ADAM-400

In table 4.11, sources for annual demand change for the individually modelled factors are described.

Table 4.11: sources of variable annual demand change due to individually modelled factors

Individual factor: Scenario:	Efficiency	Electric heating	Electric transport	Onsite generation of PV
BAU	-	-	EU-REF	EU-REF
Efficiency	ADAM-400	-	EU-REF	EU-REF
Heating	-	ADAM-400	EU-REF	EU-REF
Transport	-	-	ADAM-400	EU-REF
Onsite	-	-	EU-REF	ADAM-400
4DS	-	ADAM-REF	ADAM-REF	ADAM-REF
2DS	ADAM-400	ADAM-400	ADAM-400	ADAM-400

5 Results

In this chapter, the results of the analyses are presented. The following results are included:

1. Current demand patterns representing 2013 (Research deliverable 1) in section 5.1;
2. Future demand patterns representing 2050 (Research deliverable 3) in section 5.2;
3. Effect on power system requirements (Research deliverable 4) in section 5.3.

All current and future demand patterns are shown for two separate days (not holidays), a Wednesday in summer and a Wednesday in winter. This spread is chosen to show differences in electricity demand for space heating, an important EUS category in both current and future demand patterns. The dates of the Wednesdays are selected to be closest to 21 June and 21 December. This is done to be able to observe the effect of daylight duration. On June 21, there is a maximum duration of daylight. This negatively affects the demand for lighting, a prominent EUS category. In addition, electricity generation by PV is at its highest in this period. On December 21, there is minimum duration of daylight, which positively affects the demand for lighting. In contrast, electricity generation by PV is low in this period.

Since the calendars of the demand patterns vary between countries, different dates are shown:

- For the Netherlands: 20 June and 19 December.
- For Spain: 23 June and 22 December.
- For Sweden: 19 June and 18 December.

5.1 Current demand patterns

In this section, the current demand patterns are reviewed in the form of:

- A comparison of national demand patterns between the Netherlands Spain and Sweden;
- An overview of aggregated sector patterns per country;
- An overview of aggregated EUS patterns for the residential and service sectors. In order to keep the results compact, this overview is limited to the EUS demand patterns in the residential of Sweden and the EUS demand patterns in the service sector of the Netherlands. Both these sectors in these particular countries are selected, because the EUS demand patterns achieved the best match to the corresponding sector demand pattern (see also section 3.2.3).

5.1.1 National demand patterns

Figure 5.1 shows the demand patterns on national level for the Netherlands, Spain and Sweden on a summer and winter day. The demand patterns of the Netherlands and Sweden have roughly the same shape and are relatively flat compared to the Spanish demand pattern. The Spanish demand patterns show a morning peak in summer and an additional evening peak in winter. The morning peak is the result of a peak in activity before midday. In Spain, activity is usually concentrated before midday because of the high afternoon temperatures.

It should be noted that Sweden has a relatively small population compared to the Netherlands (9.6 versus 16.8 million). Hence, Sweden has a relatively high electricity consumption per capita (Eurostat, 2014b). This is probably caused by a relatively high share of electric heating in the residential sector, a relatively large industry sector and low cost of electricity due to a large share of renewables (Campillo et al., 2012; European Commission, 2011b).

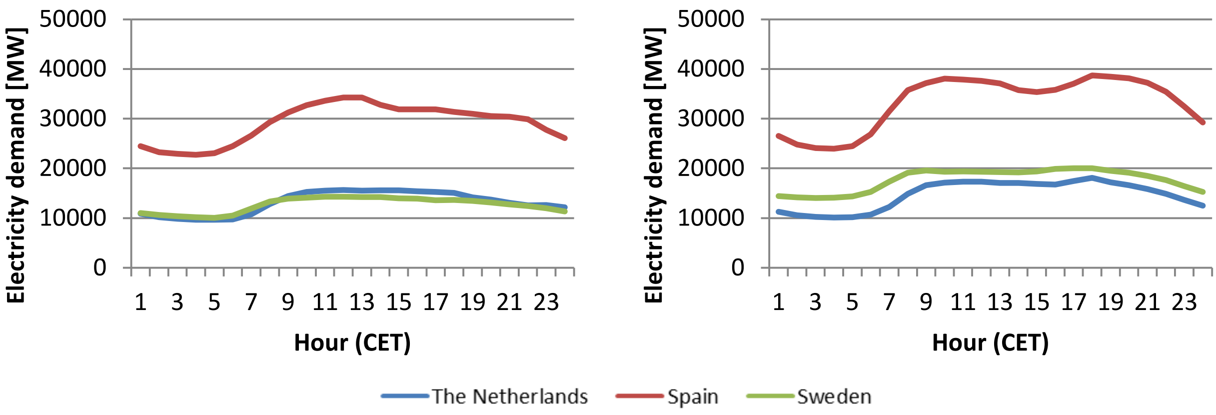

Figure 5.1: current national demand patterns of the three countries on a summer day (left) and a winter day (right)

5.1.2 Sector demand patterns

Figures 5.2 through 5.4 show the daily demand patterns of different sectors within the Netherlands, Spain and Sweden on a summer and winter day.

The largest impact on national demand in each country is generally caused by the industry, residential and service sectors. In summertime, the industry and service sectors in each country show a daytime peak between roughly 6 a.m. and 7 p.m., which is consistent with office hours. For the service sector, this is also valid in wintertime. However, industry sector activity is different on this winter day. In Spain industrial electricity demand is relatively low on this day. This may be caused by a strong seasonal influence on industrial activity, but also by the fact that this day (22 December) is close to the Christmas holiday period. In Sweden, the industry sector shows an evening peak on the winter day. This is probably related to the limited daylight period on this day.

All residential sector demand patterns show a morning and evening peaks, consistent with people going to work and people returning home from work. In Spain, this peak extends to a relatively late hour compared to the Netherlands and Spain. This is also likely to be related to the fact that Spanish daily activity is influenced by the warmer climate.

The transport and energy sectors show in all countries a less influential and mostly constant demand pattern. This is also the case for the agricultural sector in Spain and Sweden, but not in the Netherlands. The Dutch agricultural sector shows a large difference between summer and winter. This is caused by onsite power generation of Combined Heat and Power (CHP), installed with greenhouse horticulture. In summer, power is generated is minimal since little heat is required for horticulture in that period. However, in winter times, more heat is required. As a result, onsite CHPs are generating a significant amount of electricity. This causes the net power demand by the agricultural sector to be much lower on winter days.

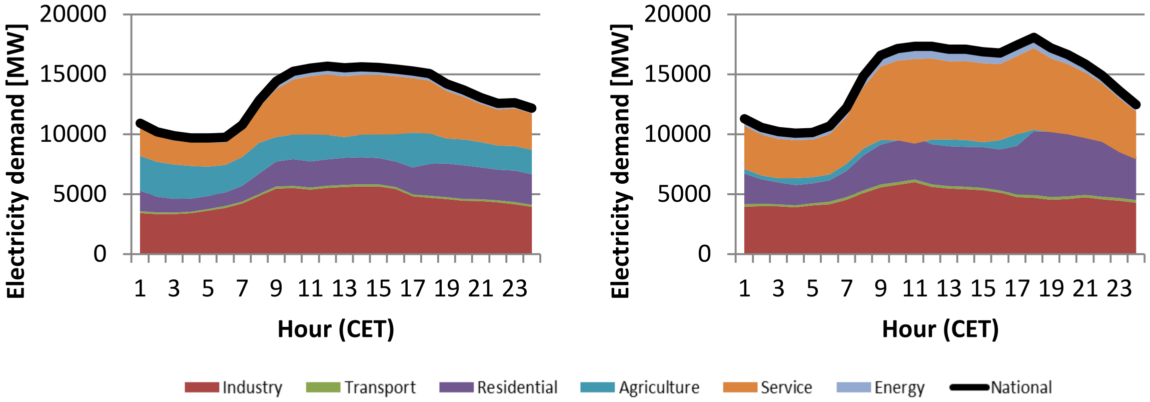

Figure 5.2: current aggregated sector and national demand patterns of the Netherlands on a summer day (left) and a winter day (right)

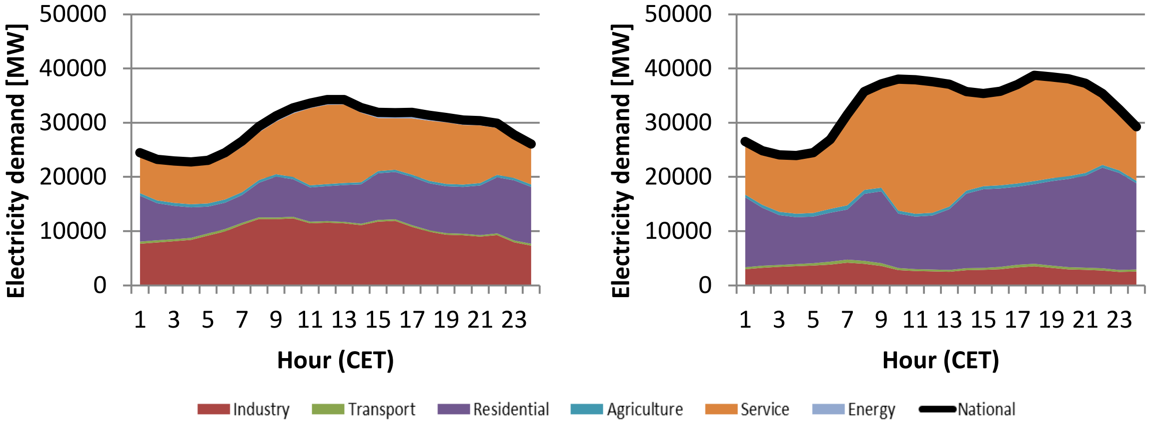

Figure 5.3: current aggregated sector and national demand patterns of Spain on a summer day (left) and a winter day (right)

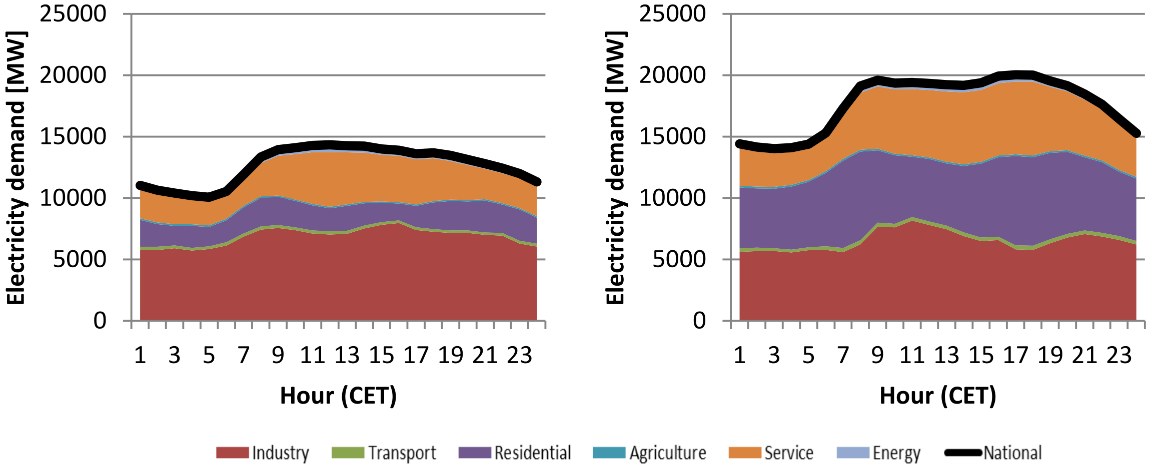

Figure 5.4: current aggregated sector and national demand patterns of Sweden on a summer day (left) and a winter day (right)

5.1.3 EUS demand patterns

Figure 5.5 shows the aggregated demand patterns on EUS and the residential sector demand pattern of Sweden on a summer and winter day. Most EUS demand patterns comply with the pattern that is to be expected considering the daily activity in the residential sector (i.e. a peak in the morning and a peak in the evening). As expected, lighting is more pronounced on the winter day. The fact that the sector demand pattern is dominated by space heating is not surprising, considering the relatively cold climate and the high share of electric heating in Sweden. However, it is not clear why the demand for water heating is so high on this summer day. On the winter day, this demand is much lower.

Figure 5.6 shows the aggregated demand patterns on EUS and the service sector demand pattern of the Netherlands on a summer and winter day. Not surprisingly, both sector demand patterns are dominated by lighting, which is also more pronounced during daytime in winter. This is related to the low sunlight level on this day.

Some EUS demand patterns in the Netherlands show unrealistic peaks and unusual high electricity demand at night. This anomaly is the result of the adjustment applied for the base year. Remarkably, this anomaly is also present in the report by Pout et al. (2008) from which the EUS patterns in this research are derived. A comparable modification is done, resulting in EUS demand patterns showing similar anomalies. The deviation might be the result of modelling inaccuracies, or the result of considerable measuring errors. Unfortunately, no explanation is offered by the authors.

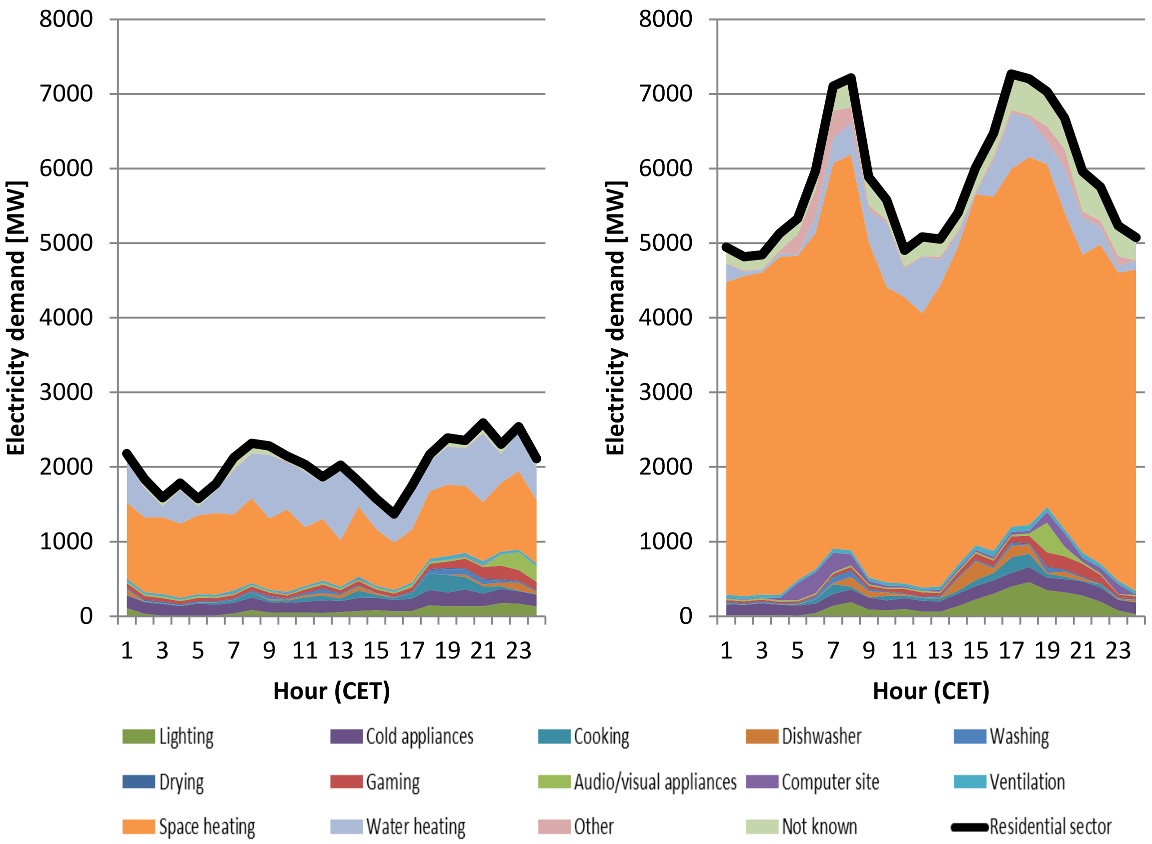

Figure 5.5: current aggregated EUS and residential sector demand patterns of Sweden on a summer day (left) and a winter day (right)

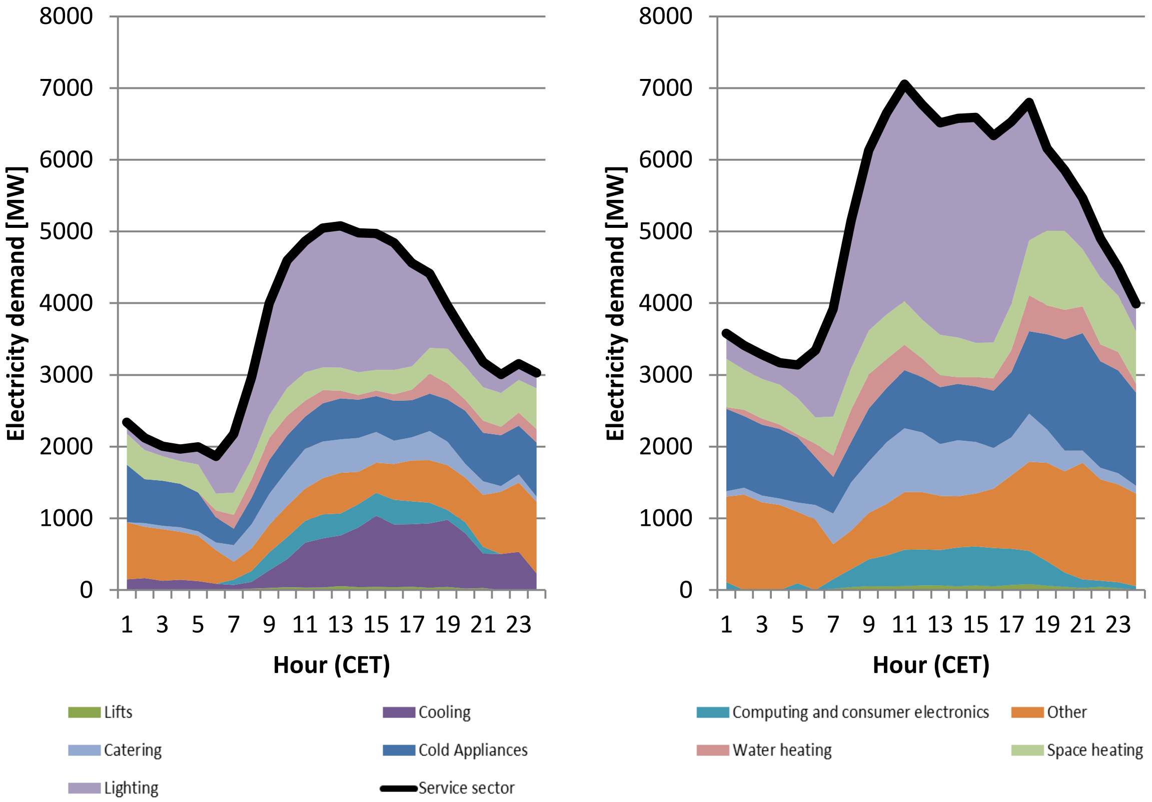

Figure 5.6: current aggregated EUs and service sector demand patterns of the Netherlands on a summer day (left) and a winter day (right)

5.2 Future demand patterns

In this section, the modelled future demand patterns are reviewed in the form of:

- A comparison between the current demand patterns, the BAU pattern and the 4 'single parameter scenarios' ('Efficiency', 'Heat', 'Transport' and 'Onsite')
- A comparison between the current demand patterns, the BAU pattern and the 2 'combined parameters scenarios ' ('4DS' and '2DS')

Both comparisons are done on national level for each country. In order to keep the results condensed, the effect on sector level is observed only for the residential and service sectors of the Netherlands. The review is limited to these 2 sectors because the individually modelled factors only affect the demand patterns of these sectors. The Netherlands is selected for the review because most factors are modelled to have a relatively high impact in this country.

5.2.1 Single parameter scenarios

5.2.1.1 National demand patterns

In figures 5.7 - 5.9, the current demand pattern and the BAU, Efficiency, Heat, Transport and Onsite demand patterns in 2050 are presented on national level for a summer and winter day in the Netherlands, Spain and Sweden. Increased efficiency in the residential and service sectors decreases the daily peak demand in each country in summer and winter. This is caused by the fact that the residential and service sectors are largely responsible for the daily peak.

The increase in electric heating increases the demand on this summer and winter day in the Netherlands. Electric heating in Spain and Sweden is not expected to increase significantly. In Spain, this is caused by relatively warm climate, in which demand for heating is low compared to other EUSs. In Sweden, the penetration of heating is already very high. The demand for electric heating cannot increase much further, because the remaining potential for electric heating is low. In addition, efficiency increase of heating equipment and improved isolation compensates for an increase in the penetration of electric heating.

The increase in demand for uncontrolled charging of electric vehicles increases electricity demand in each country, although the effect is relatively low compared to the other factors.The biggest impact in the Netherlands is caused by an increase of onsite generation by PV. As expected, this impact is high in summer and low in winter. The effect in Spain and Sweden is minimal as a result of the underlying assumptions for the scenarios. For Spain, it is assumed that centralized PV generation will maintain priority over onsite (decentralized) PV generation. In Sweden, this technology is expected to not show any significant growth in the next decades.

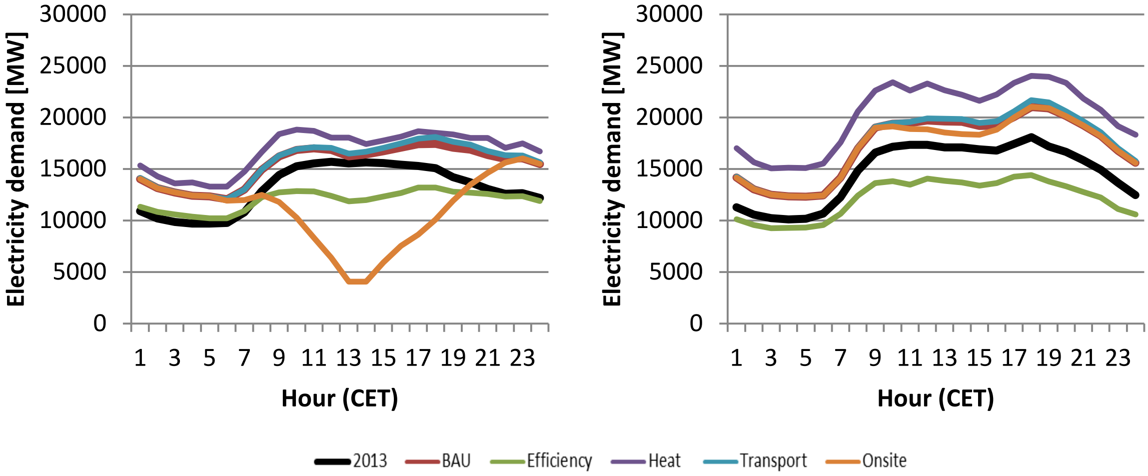

Figure 5.7: the current demand patterns and BAU, Efficiency, Heat, Transport and Onsite national demand patterns in 2050 on a summer and winter day in the Netherlands

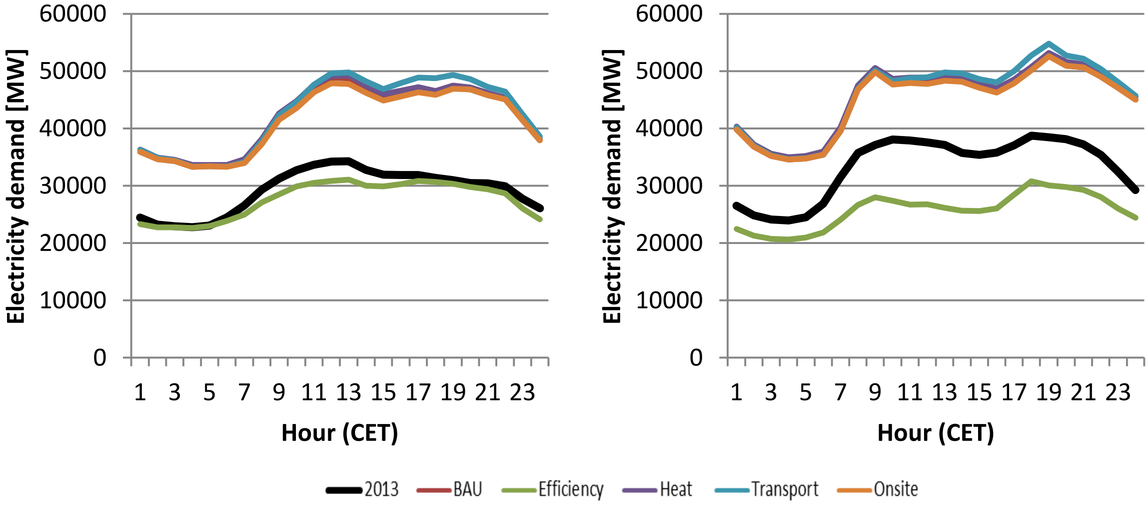

Figure 5.8: the current demand patterns and BAU, Efficiency, Heat, Transport and Onsite national demand patterns in 2050 on a summer and winter day in Spain

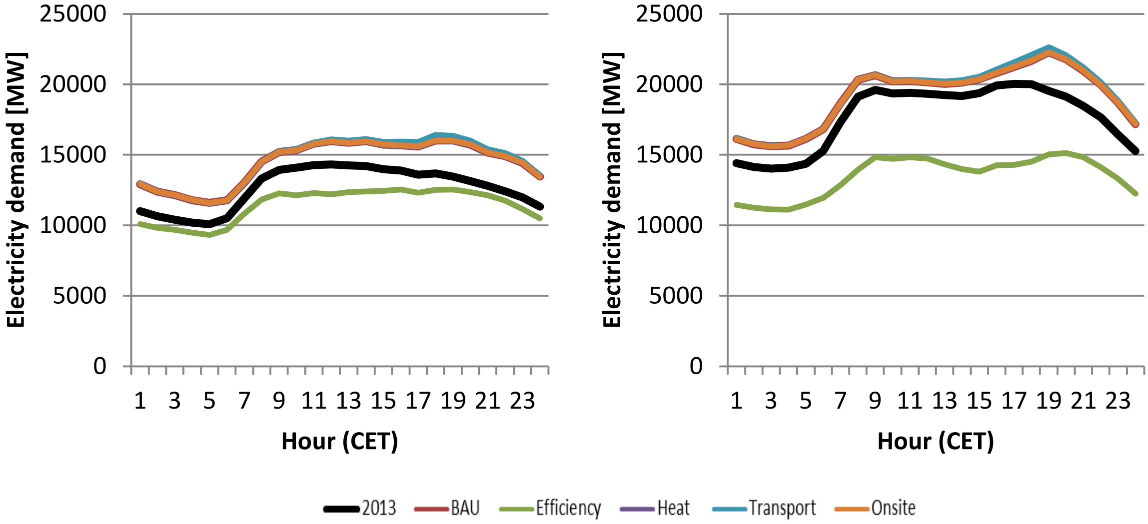

Figure 5.9: the current demand patterns and BAU, Efficiency, Heat, Transport and Onsite national demand patterns in 2050 on a summer and winter day in Sweden

5.2.1.2 Sector demand patterns

In figures 5.10 and 5.11, the current demand pattern and the BAU, Efficiency, Heat, Transport and Onsite demand patterns in 2050 are given on national level for a summer and winter day in the Netherlands, Spain and Sweden. The impacts of the 4 individually modelled factors are similar to the impacts on national level in the Netherlands. The effects of all individually modelled factors are more pronounced in both sectors, since the modelling of these factors is also limited to the residential and service sectors.

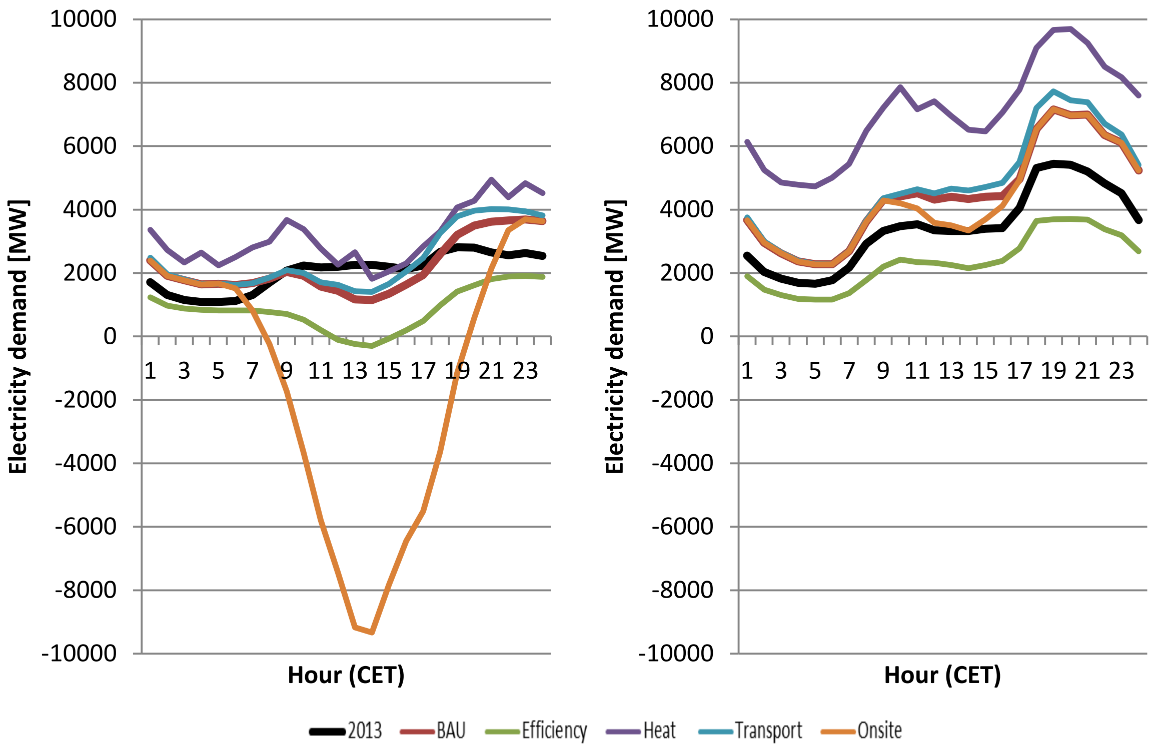

Figure 5.10: the current demand patterns and BAU, Efficiency, Heat, Transport and Onsite national demand patterns in 2050 on a summer and winter day in the residential sector of the Netherlands

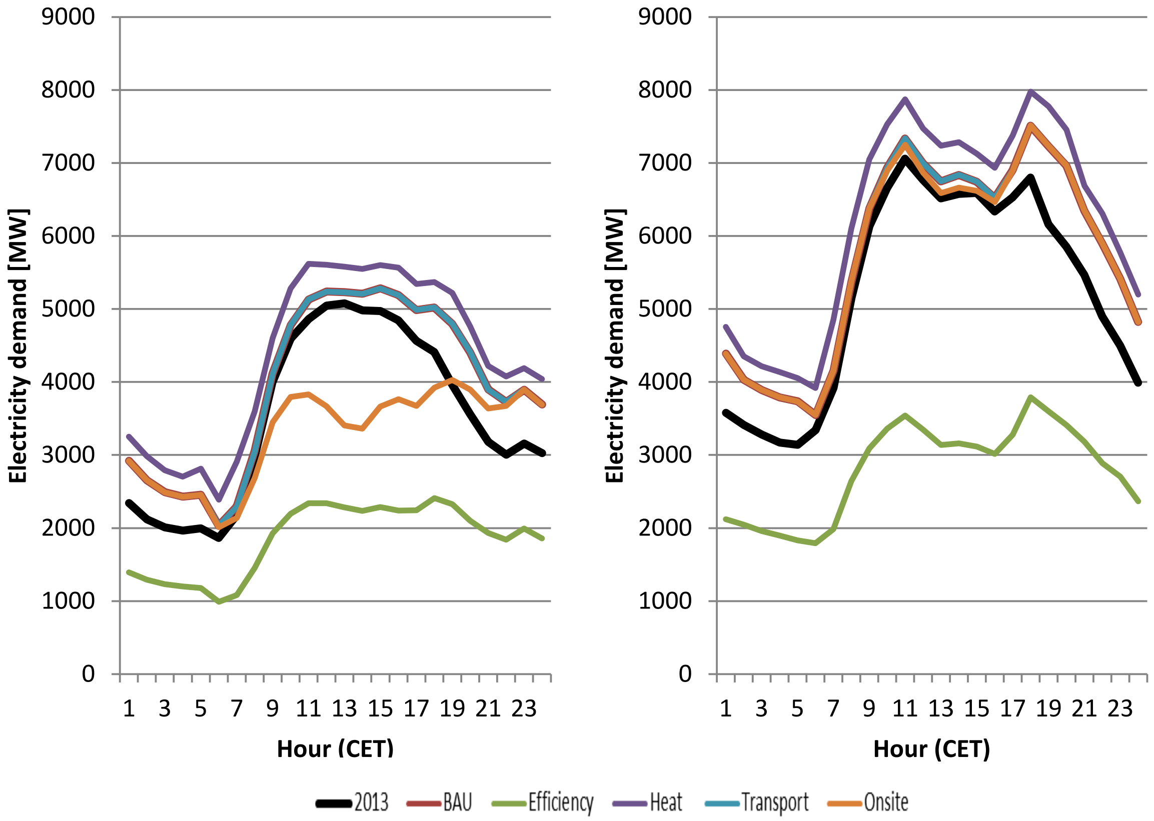

Figure 5.11: the current demand patterns and BAU, Efficiency, Heat, Transport and Onsite national demand patterns in 2050 on a summer and winter day in the service sector of the Netherlands.

5.2.2 Combined parameter scenarios

5.2.2.1 National demand patterns

In figures 5.12 - 5.14, the current demand pattern and the BAU, 4DS and 2DS demand patterns are presented on national level in 2050 for a summer and winter day in the Netherlands, Spain and Sweden.

First of all, the differences in assumptions and inputs between used modelling studies are clearly visible. While both originally used as ‘reference’ scenario in previous modelling studies, the BAU and 4DS scenario differ considerably. The main focus of this comparison is therefore set on differences between 2013 and the 4DS and 2DS scenarios.

The impact of the 4DS scenario is significant in each country. Demand is consistently higher in each country in both winter and summer. The shape of the demand patterns remains generally equal, except for the Netherlands where some impact of onsite generation by PV is visible.

The impact of the 2DS scenario is also significant in each country. Demand is consistently lower in each country in both winter and summer. Demand increases because of electrification of heat and transport are offset by increases in efficiency and electricity savings. The shape of the demand pattern in the Netherlands is significantly affected by onsite generation of PV electricity. In Spain and Sweden, the changes in the shape of the demand patterns are caused by increased efficiency.

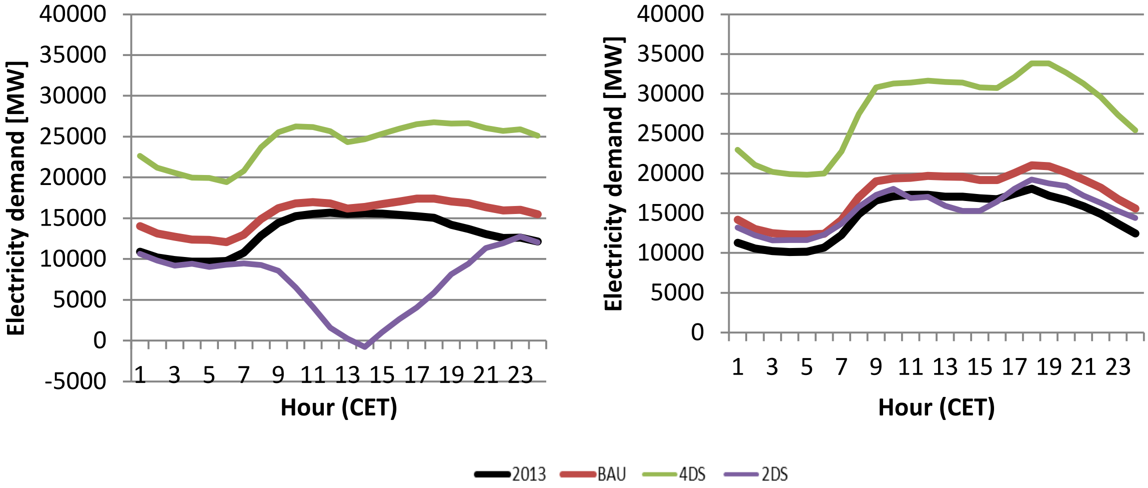

Figure 5.12: the current demand patterns and BAU, 4DS and 2DS national demand patterns in 2050 on a summer and winter day in the Netherlands

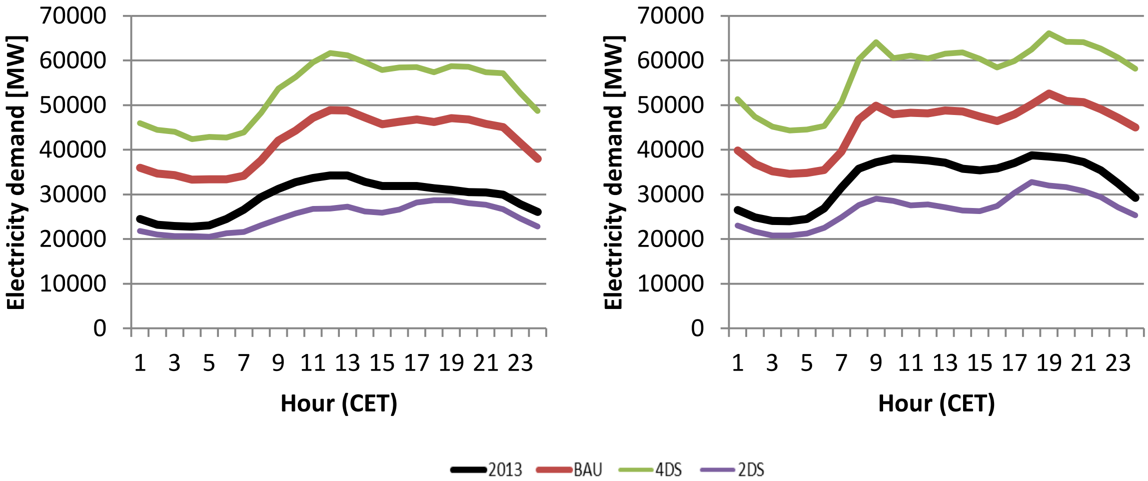

Figure 5.13: the current demand patterns and BAU, 4DS and 2DS national demand patterns in 2050 on a summer and winter day in Spain

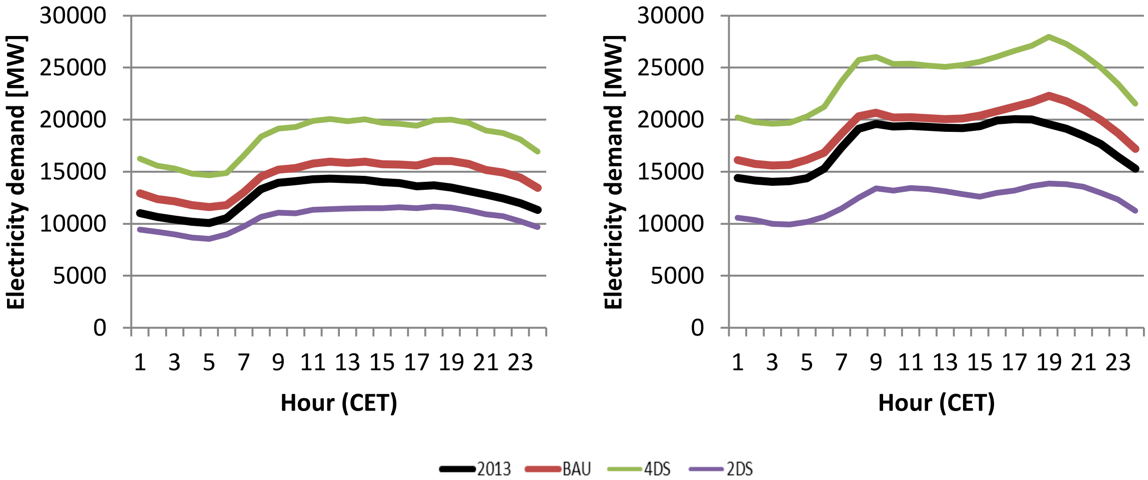

Figure 5.14: the current demand patterns and BAU, 4DS and 2DS national demand patterns in 2050 on a summer and winter day in Sweden

5.2.2.2 Sector demand patterns

In figures 5.15 and 5.16, the current demand pattern and the BAU, 4DS and 2DS demand patterns are given on national level in 2050 for a summer and winter day in the Netherlands, Spain and Sweden. The impact of the 4 individually modelled factors in these scenarios is again more pronounced compared to the impacts on national level in the Netherlands, since the modelling of these factors is limited to the residential and service sectors.

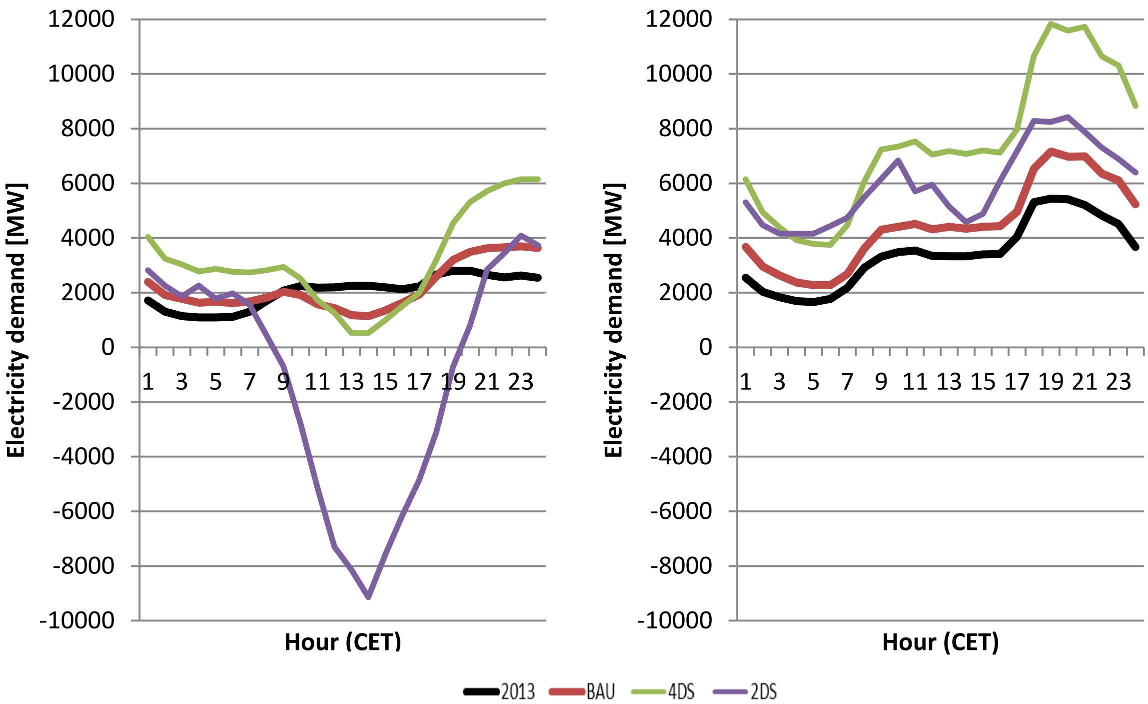

Figure 5.15: the current demand patterns and BAU, 4DS and 2DS national demand patterns in 2050 on a summer and winter day in the residential sector of the Netherlands

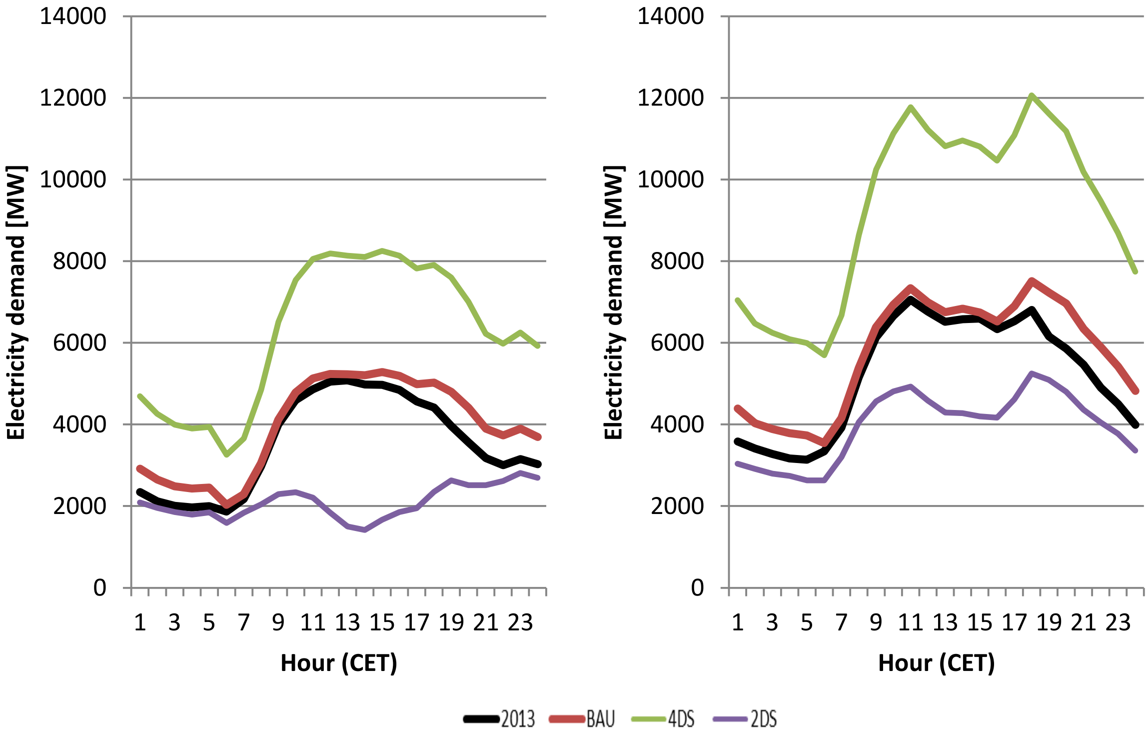

Figure 5.16: the current demand patterns and BAU, 4DS and 2DS national demand patterns in 2050 on a summer and winter day in the service sector of the Netherlands

5.3 Effect on power system requirements

In this section, the effects of the forecasted national demand patterns on the requirements for the supply side of the power system are reviewed. For this, three indicators are evaluated with respect to national demand patterns:

- *Peak demand* – Indicator for required generation and transmission capacity.
- *Minimum demand* – Indicator for base load
- *Mean Absolute Step Change (MASC)* – Depicts the fluctuation in demand as an indicator for required load following and peaking power capacity

Figures 5.17 – 5.19 show per country these indicators for the current demand patterns and the 7 future demand scenarios.

Peak demand is increased in all countries in most scenarios, indicating that future demand requires additional generation and transmission capacity. Only an increase of efficiency in the Efficiency and 2DS (Sweden) scenarios results in lower peak demand. In the Netherlands, peak demand currently occurs during winter time, when heating demand is also high. Increased electrification of heat will therefore increase peak demand further. Onsite generation does not affect peak demand, since peak demand usually occurs after sundown in winter time.

Minimum demand is increased for most countries in most scenarios, indicating that base load increases in those situations. Again increased efficiency counteracts this effect in the Efficiency and 2DS scenarios. In the Netherlands, minimum demand becomes negative in scenarios with significant PV generation increases, indicating that base load decreases to zero.

The MASC also increases in every scenario, indicating a more volatile electricity demand and a larger requirement for load following and peaking power capacity. As a result of annual demand increases for each country in the 4DS scenario, the MASC values also increases in each country for this scenario. In the Netherlands and Spain, electrification of heat and onsite generation particularly increases demand fluctuation, because of the highly fluctuating demand patterns of these technologies.

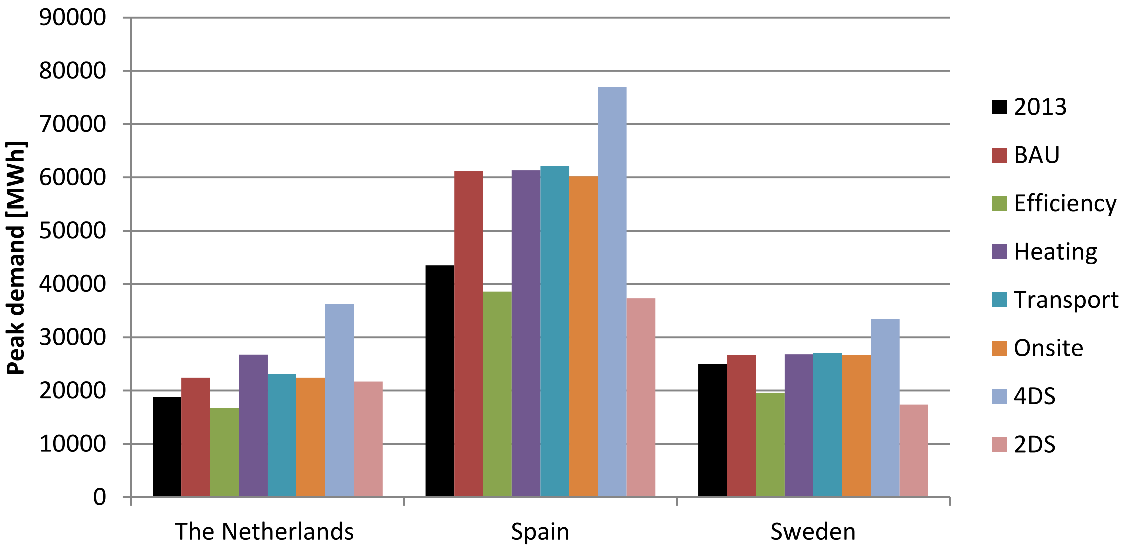

Figure 5.17: peak demand in the current national demand pattern and in the national demand patterns of the 7 demand scenarios

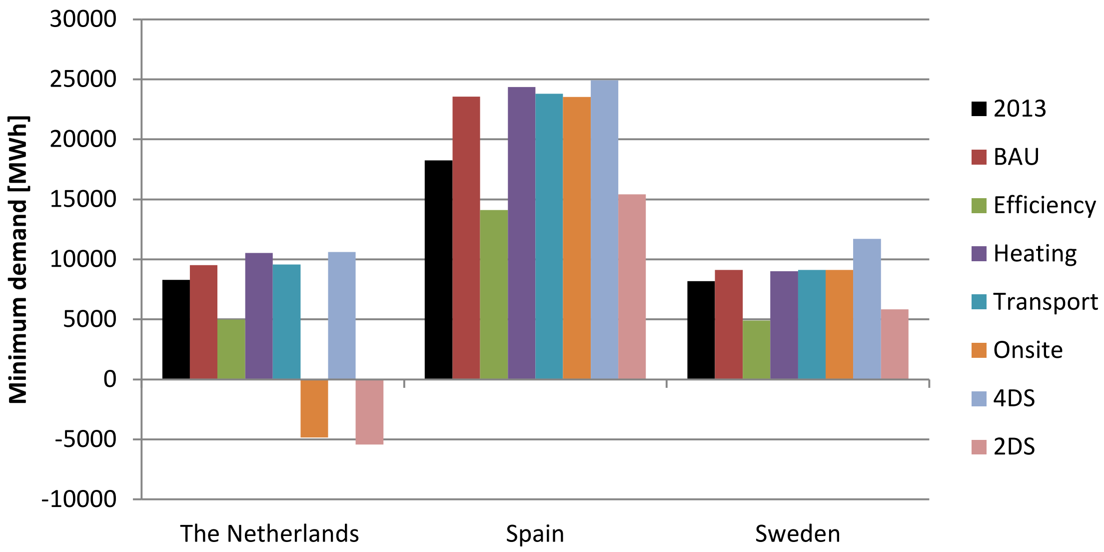

Figure 5.18: minimum demand in the current national demand pattern and in the national demand patterns of the 7 demand scenarios

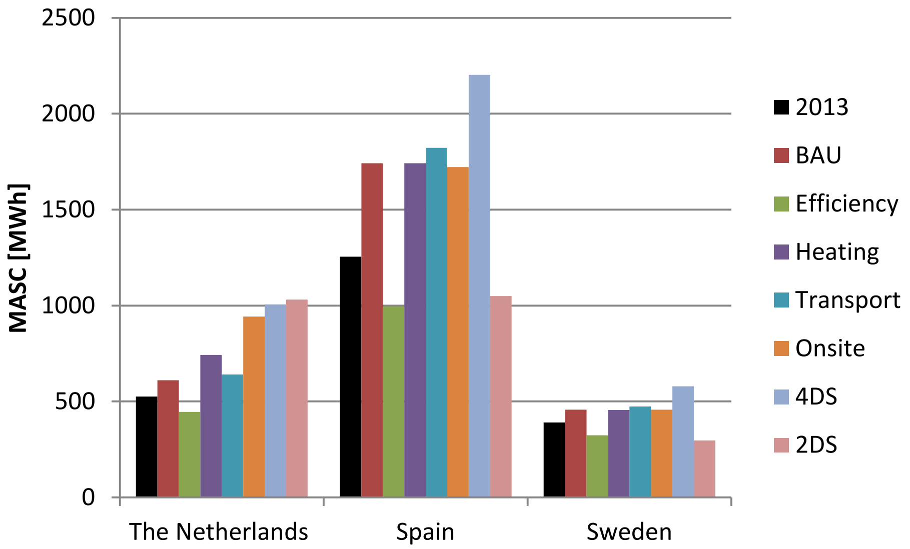

Figure 5.19: the MASC in the current national demand pattern and in the national demand patterns of the 7 demand scenarios

6 Discussion

In this thesis, an analysis of both current and future electricity demand patterns on national, sector and End Use Service (EUS) level has been conducted for the Netherlands, Spain and Sweden. Additionally, the effect of future demand patterns on power system requirements is analysed.

There are several remarks that can be made about the methodology that is used for the analysis of current demand patterns. First of all, a smaller resolution would make the demand patterns more accurate. Several sources provided quarter-hourly data, in which the demand showed additional fluctuation. A smaller time resolution would make the results more reliable, but it would also greatly increase the amount of necessary data. Second, the disaggregation of current demand pattern required several adjustments to be made to the collected data on sector and EUS level. These adjustments were necessary to enable modelling of future demand patterns out of the current demand patterns. The method that is used only adapted the demand patterns on sector and EUS level. Alternatively, the national demand pattern could also be adjusted in such a way that the overall adjustments were minimal.

Third, limited data availability made it necessary to use demand data from other countries to fill gaps in the analysis on sector and End Use Service (EUS) level (an overview of this is provided in section 3.3.3). This reduces the representativeness of the calculated demand patterns, since local conditions are likely to influence the demand pattern. Additionally, lack of data made it necessary to use sectors and EUS demand data which is collected in years other than the national data. This reduces the representativeness of the calculated demand patterns, since demand fluctuates between years due to for example variations in weather (Hekkenberg et al., 2009).

Fourth, the current demand patterns on sector and EUs level are created based on samples of consumers within a sector. The representativeness of these samples is not assessed quantitatively. However, it is clear that the representativeness of most demand patterns could be improved by collecting additional data. In sectors which contain many subsectors, this would be increasingly difficult. Fifth, sensitivity in the analysis of the current demand patterns is not explored due to a lack of time. Exploring the effects of alternative adjustment approaches could be particularly relevant.

Additionally, there are several remarks that can be made about the methodology that is used for the analysis of future demand patterns. First of all, the modelling of major factors that influence electricity demand is limited to 4 factors, only in extreme ('worst case') scenarios. Additional factors are included by means of the collective modelling approach, but the resulting effect on the demand pattern is only expressed in annual demand changes. In addition, the effects of individual factors included in the set of factors cannot be distinguished. The analysis would be improved if more factors were modelled individually.

Second, the modelling of individual factors could be improved. For example, the shape of the future demand patterns of electric heating and transport is based on data of current electric heating and EV charging. It would be relevant to consider whether the shape of these demand patterns would change over time. Additionally, the extreme situations which are now depicted are in many ways unrealistic. Under the current assumptions, the amount of generation and transmission capacity would need to increase drastically in order to accommodate many of the forecasted demand patterns. An increase in capacity would lead to an increase in electricity prices, which causes consumers to switch to other fuels. Also, expensive measures to decrease electricity and heat demand (such as isolation) would become much more feasible. Moreover, this situation would strongly stimulate the development of electricity storage and 'smart' solutions which would flatten the demand pattern.

To accommodate this, the current scenario analysis could be expanded with several parameters. This would include:

- Intelligent solutions in electric heating and transport (i.e. inclusion of peak-shaving);
- Delayed charging of EVs;
- Onsite PV generation in combination with storage solutions.

Third, no uncertainty and sensitivity analyses are done on the input parameters of the scenarios. The scenarios do indicate a range of possibilities, but this range also depends on several assumptions. Since the amount of input parameters and assumptions is high, uncertainty and sensitivity analysis analyses would be extensive.

The results of this study are unique in the sense that, to my knowledge, no other such comprehensive studies op current and future demand pattern are conducted for the Netherlands, Spain and Sweden. However, comparable analyses have been performed for other countries, such as Pout et al. (2008), Schade et al. (2009) and Hostick et al. (2012). In these studies, methods for disaggregation of current demand have not been extensively described, which may be a result of the fact that these studies are performed by government-funded institutes. This thesis therefore adds particularly to the existing knowledge base of methodologies for disaggregation of current demand.

The analyses performed in this thesis implicate several future research avenues. These include:

1. The analysis of demand patterns on EUS level in other sectors besides the residential and service sectors.
2. Analysis of the impact of electric heating, electric transport and onsite generation on future electricity demand patterns in combination with 'smart' solutions and electricity storage.

7 Conclusion

In the analysis of the first research question, the current national demand patterns of the Netherlands, Spain and Sweden are disaggregated into demand patterns of sectors and End Use Services (EUS). The results for the current demand patterns show a distribution of national demand patterns into 6 sectors, of which the industry, residential and service sectors are dominant in all countries. The transport and energy sector demand patterns are less influential; the agricultural sector has only a significant role in the Netherlands. The demand patterns of the residential and service sectors are further disaggregated into demand patterns of 15 and 9 EUSs, respectively. The most significant demand patterns on EUS level are lighting and space heating, respectively.

In the analysis of the second research question, significant impacts of low-carbon technologies on the demand patterns of 2050 are shown. Large increases in electric heating and electric transport cause the national demand pattern to increase; increased efficiency and onsite generation of PV decreases the demand pattern. A post-analysis of the effects on power system requirements shows that both electric heating and transport increase the requirement for generation and transmission capacity. Both these factors (and onsite PV) also increase the required load following and peaking power capacity. In contrast, base load is negatively affected by an increase of efficiency and onsite generation of PV.

This research shows that future power systems are significantly influenced by future development of electricity demand patterns. Generation, transmission, load following and peaking power capacities need to increase whereas base load will decrease. Increased efficiency could compensate for this. If emission targets are to be fulfilled through considerable electrification of heating and transport and an increase in onsite generation, it seems that equal efforts need to be put into efficiency gains.

Further research is needed to improve the knowledge base of current demand patterns. That way, future demand patterns can be modelled more accurately. In addition, significant differences are observed between the demand patterns of the Netherlands, Spain and Sweden. Future analyses should therefore also be conducted for other countries. The results of the scenario analysis of future demand patterns show that in the context of climate change mitigation, it is necessary to investigate solutions that counteract the impact of increases in electric heating and transport and decentralized generation. It is shown that efficiency gains can have a positive effect on demand stability. Future research should focus on additional solutions such as demand side management or electricity storage.

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Appendices

Appendix A: Overview of factors that influence future demand

In this appendix, an overview of factors that influence future electricity demand is presented (table A-1). The overview is created by screening literature for factors that influence electricity demand on a national, sector or EUS level. The factors found are categorized within the following categories:

- Technology
- Environment
- Economy
- Society
- Policy
- Demographics

Table A-1: screening of factors mentioned in previous research that may influence future electricity demand

A. Technology	Environment	Economy	Source
End use energy efficiency, renewables, electrification (appliances, heating, cooling, transport), Advanced transmission and distribution grids, smart metering	(change of) Degree days and the relation to heating	Carbon and energy (import) prices, market structure (competition), Gross Domestic Product (GDP), technology cost	European Commission (2011b, 2013)
Efficiency improvement (including insolation), fuel shift (electrification of transport, heating, cooling), electrification of process heat (industry), demand response, smart technologies	Temperature	GDP, energy intensity, increasing contribution of the service sector, carbon price	European Climate Foundation (2010)
New technologies and materials, efficiency gains, switch of room to central air conditioning, increase in electric transport and heating, demand response	Climate change (change in temperature and degree days) (decrease in heating, increase in cooling)	GDP, electricity prices (demand elasticity), growth in disposable income (more electric appliances), decreasing share of energy intensive industry	Hostick et al. (2012)
(End use) Energy Efficiency, demand side management, Renewable generation, electrification (heat pumps, cooking equipment, air conditioning, electric vehicles), energy saving, changes in building stock,	Impact of climate change (temperature) on heating and cooling demand	GDP, fuel prices, the financial crisis of 2008	(Pfluger et al., 2011;Schade et al., 2009)
Energy efficiency, energy	Effect of climate	-	Pout et al. (2008)

saving, electrification (heat pumps, air conditioning), onsite electricity generation (PV, wind, CHP and micro CHP)	change induced weather patterns on the end use demand for cooling and heating		

B. Society	Policy	Demographics	Source
Public perception, public acceptance, energy saving (other than through efficiency), fuel switching	Policies intended to limit climate change (by means of Targets, standards, information campaigns, taxation, pricing, etc.)	Population	European Commission (2011b, 2013)
Level of comfort (inside temperature)	Policies intended to limit climate change (by means of EU-ETS, targets)	Population	European Climate Foundation (2010)
Behavioural influences, fuel switching	Carbon mitigation measures (by means of specific controls or through pricing incentives or disincentives)	Population, growing share of population over 65 (more demand for medical and monitoring equipment)	Hostick et al. (2012)
Behaviour of heating system operators and end users, fuel substitution	The geo-political and climate policy context (by means of GHG emissions trading, promoting energy efficiency, standards and norms that drive technological development, etc.)	Population	(Pfluger et al., 2011;Schade et al., 2009)
-	-	-	Pout et al. (2008)

Appendix B: Remarks about the data used in the analysis of RQ1

This appendix lists the remarks about anomalies and solutions to deal with them in the analysis of RQ1. Included are:

- Remarks in the ENTSO-E data used for establishing national demand patterns (tables B-1 through B-4)
- Remarks in the data used for establishing sector and EUS demand patterns (tables B-5 & B-6)

Table B-1: general remarks of the ENTSO-E load data

	Remark	Solution
1	ENTSOE-E data retrieved on 6/1/2014	-
2	There are some anomalies in the data because of daily saving time: in March, there is 1 value less (3:00 is marked N/A) and in October, there is 1 value more. There is an extra column (3:00b) for that purpose (ENTSO-E, 2014).	The extra column was deleted to get better graphic results, resulting in 1 day in March with 1 hour less and 1 day in October with 1 hour more. When time is set forward, 2 a.m. becomes 3 a.m. Therefore, the value of 2:00 is left empty in those instances.

Table B-2: remarks of the Dutch ENTSO-E load data

	Remark	Solution
1	The ENTSO-E annex states: 'until 2008, data represented 93% of national load so a compensation factor of 1.07 is used' (ENTSO-E, 2010). However, no compensation factor is observed in the 2009 – 2013 data.	The data is assumed to represent 100% of the national load
2	For several years, generation from CHP (in greenhouse horticulture) and small renewables has increased rapidly. These amounts are not known exactly, but installed capacity is in the order of 8000 – 9000 MW (ENTSO-E, 2010). Therefore, the given values of national load are not certain.	*(see below)
3	The year 2012 (the selected base year for the Netherlands) has 366 days (leap year) (ENTSO-E, 2010)	**(see below)

* For the Netherlands, a compensation factor is used to obtain the ENTSO-E national loads out of TenneT's measurements. This is necessary, because decentralized CHPs and renewables also produce a feed into the network. This feed has increased considerably in the last years; the exact contribution is not known and the value of correction factor used is unclear (ENTSO-E, 2010). In order to investigate this, data from Tennet is observed from 2008 onwards. It appears that Tennet's 'total feed' (Dutch: totale invoeding) from 2008-2012 is multiplied with a factor of 1.058 to obtain the national demand depicted in the ENTSO-E data; the 2013 and 2014 feed is corrected with a factor of 1.124 (TenneT, 2014). This abrupt, significant change (approximately 6% higher) suggests that new measurements of decentralized generation are taken into account. This abrupt change also suggests that the factor used in the period 2009-2012 (and probably also before that) is too low.

After having observed this problem with the Netherlands, it may also be an issue in Spanish and Swedish data. However, these countries were not mentioned in the ENTSO-E description. In the end, the effect of this anomaly on the load values does not matter for the analyses in this research since only hourly fractions are derived from this data.

** An adaptation was made to the base year for the Netherlands. Because this base year is 2012, which is a leap year, one day was removed from the eventual base year. This way, it was easier to adapt sector and electricity service profiles to the base year. Also, it is more convenient and consistent to exclude leap years from the analysis. To this end, December 30 was removed which shifted up December 31. A day at the end of the year was selected and not February 29 (the extra day), because the pattern of week and weekend days remains intact. It was decided to keep December 31 within the base year, because it is believed to be a unique day with a specific pattern. As a result, the MASC value of this year changed, which means the main criterion to select the base year is altered. However, by making this alteration, the MASC changed slightly to a value which is actually closer to the average MASC value. Hence, this adaptation made the base year not less suitable.

Table B-3: remarks of the Spanish ENTSO-E load data

	Remark	Solution
1	The loads of 2009 represent 98% of national load. In 2010-2013 representativeness is 100% (ENTSO-E, 2014). No reason is described for the change.	All values of 2009 are divided by 0.98.
2	The value 0 is featured every year on October 31 at 24:00 except for 2010 (ENTSO-E, 2014). A value on August 6 2009 is very low (ENTSO-E, 2014).	The values are not corrected. This influences the standard deviation, mean average deviation and the mean absolute step change but only in the order of a 0.001% change in value. A low load value creates both a large negative and a large positive value that cancel each other out. It does not influence the selection of the base year and therefore it is deemed negligible. The base year is eventually not corrected since 2010 is selected.
3	In 2011 data there is an extra 3:00 value on September 30 in the country package; there is a double row for September 30 in the monthly data (ENTSO-E, 2014).	The extra row was deleted in the adjusted 2011 year.

Table B-4: remark of the Spanish ENTSO-E load data

	Remark	Solution
1	2009 data not available; only 2010 and beyond (ENTSO-E, 2014)	2009 is left out of the analysis for Sweden

Table B-5: remark of the sector demand pattern data

	Remark	Solution
1	Some of the EDSN fraction profiles (used for the Netherlands service and household patterns) do not precisely sum up to 1 (the difference is less than 0.0001%) (EDSN, 2014).	This problem is corrected by applying a correction factor on the final sector profile.

Table B-6: remarks of the EUS demand pattern data

	Remark	Solution
1	The Spanish distribution of EUS demand in the residential sector is obtained from IDAE (2011a). The total consumption of the residential sector in 2010 is considerably lower (approximately 30%) than the base year sector consumption level of 2013 (59980 vs. 83594 GWh).	A small difference is to be expected as the figures represent different years. Also, the figures are established using different assumptions and methods. However, it is not certain whether these reasons could result in a difference of 30%. The distribution obtained from IDAE is assumed to be correct.
2	The service patterns based on Pout et al. (2008) did not provide patterns for days on which time is switched to DST and back to regular time.	The patterns were adapted by removing the excess 2nd hour in March and moving it to the 25th hour in October.

Appendix C: Extrapolation of annual demand to 2013

First, the period is determined on which the trend in demand will be based. For this, national demand (the sum of industry, transport, residential, agriculture, services and the energy sector except for generating auxiliaries/pumped storage) in the period 1990 – 2012 (a larger period was not available at the time) is studied, shown in figure C-1. In this period, a clear change in annual demand can be observed in the period 2008 – 2009 (most prominently in Spain). This is caused by the economic recession of 2008 (Declercq et al., 2011). A period of 10 years (2003 – 2012) is considered most suitable for this analysis, because a period of more than 10 years (e.g. 20) dampens the effect of the recession and taking a period of less than 10 years (e.g. 5) amplifies the effect.

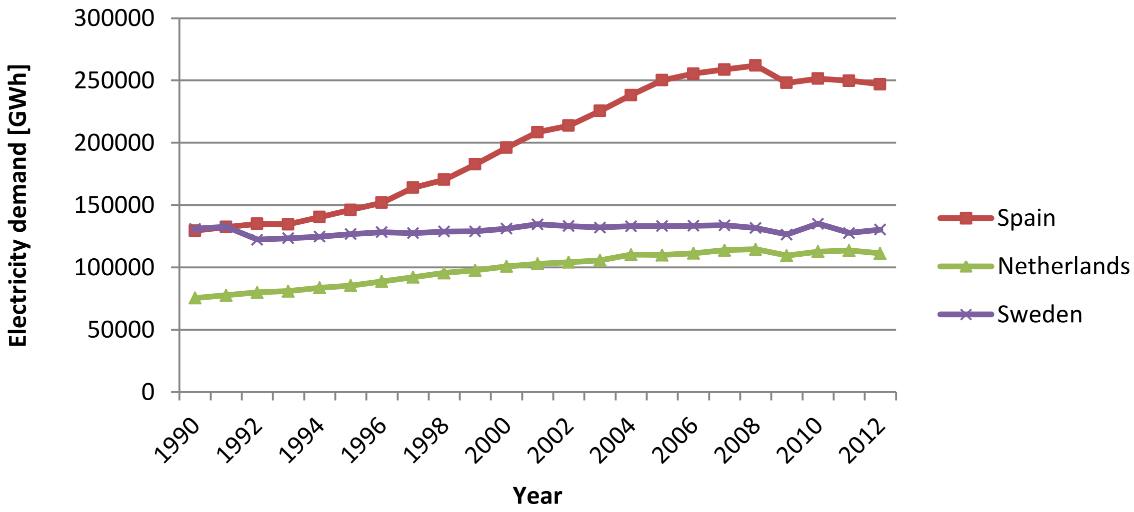

Figure C-1: Annual electricity demand of Spain, the Netherlands and Sweden between 1990 and 2012 (Eurostat, 2014a)

Next, the 10 year trend in demand is calculated for each country. Figure C-2 shows the demand of 2003 – 2012 for the Netherlands and the resulting trend line with formula. This trend line indicates what demand would have been if it had increased gradually. The trend line was extrapolated to obtain the 2013 consumption level.

The forecasting of these type of time series can be a rather complex and time consuming process (Armstrong et al., 2005). In this case, a simple exponential or a linear trend line (dependent on whichever trend line achieved the best fit) extrapolation is used because it is less time consuming and the time series is already reduced to a specific period. A disadvantage of this procedure is that all trend lines achieve a rather bad fit (R^2 in the order of 0.3).

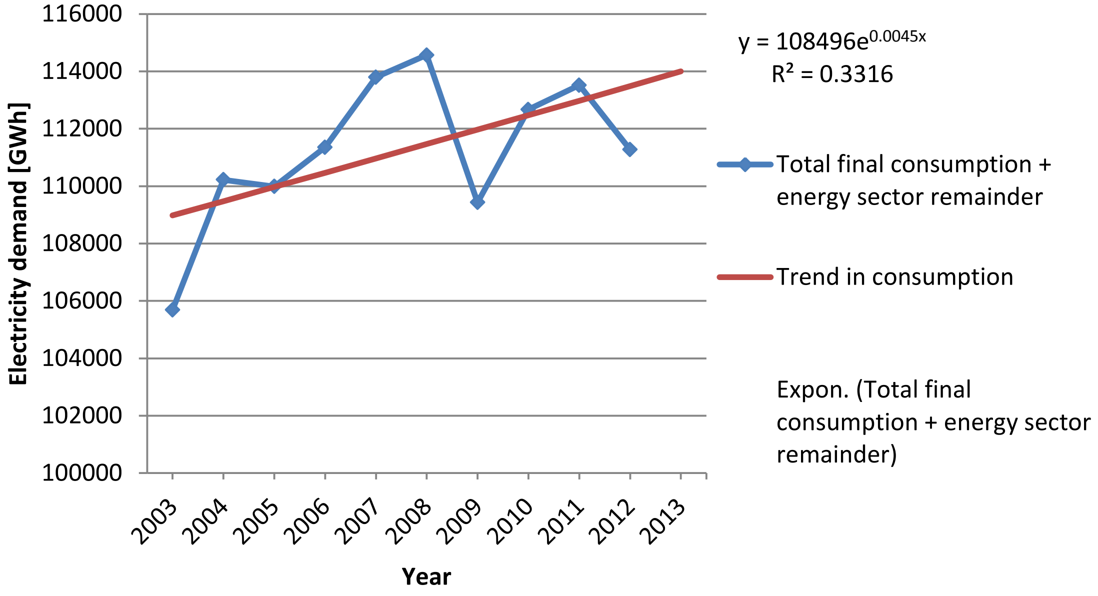

Figure C-2: annual demand and the 10 year trend in demand of the Netherlands (Eurostat, 2014a)

Appendix D: Annual demand on EUS level

The categories found in residential and service sector EUS annual demand statistics from the Netherlands, Spain not match the taxonomy of EUSs. In tables D-1 and D-2, the adaptations are presented for matching the categories found in statistics to the EUS taxonomy. For Sweden, no adaptations are necessary in the residential sector.

Table D-1: adaptation of country specific categories to match the residential EUS taxonomy

Main taxonomy	Corresponding end use categories found for the Netherlands (ECN, 2014a)	Corresponding end use categories found for Spain (IDAE, 2011a, 2011b)
Lighting	Comparable category[9]	Comparable category
Cold appliances	Refrigerators + Freezers	Refrigerators + Freezers
Cooking	Comparable category + Kitchen appliances	Kitchen + Oven
Dishwashing	Comparable category	Comparable category
Washing	Comparable category	Comparable category
Drying	Comparable category	Comparable category
Audio/visual appliances	Comparable category + TV	TV
Gaming	Non existent	Non existent
Computer site	Comparable category	Comparable category
Ventilation	Comparable category	Cooling
Heating	Comparable category	Comparable category
Water heating	Comparable category	Comparable category
Other	Comparable category	Comparable category
Not known	Vacuum cleaner + personal care + Leisure	Non existent
Standby	Non existent	Comparable category

[9] A comparable category of lighting is 'lights', 'illumination', etc.

Table D-2: adaptation of country specific categories to the service sector taxonomy of end use services

Main taxonomy	Corresponding end use categories found for the Netherlands (AgentschapNL, n.d.; Menkveld et al., 2010)	Corresponding end use categories found for Spain (Fleiter et al., 2010)	Corresponding end use categories found for Sweden (Energimyndigheten, 2010)
Lifts	Comparable category	Comparable category	Comparable category + Escalators
Cooling	Comparable category + Pumps (50%)	Ventilation and air-conditioning + Circulation pumps and other heating auxiliaries (50%)	Coolers comfort cooling + Dry Coolers + pumps (50%) + fans
Computing and consumer electronics	ICT central + ICT decentralized	ICT data centres + ICT office	PC + Data centre / server + printer + LCD and plasma TV + Photocopiers
Other	Comparable category + Ventilation + Humidification	Misc. Building technologies + Laundry (in hotels, health)	Cash registers + Circulation Fans + various appliances + Errors and omissions
Catering	Comparable category + Product Preparation	Cooking (in hotels, health)	Kitchen and pantry + oven and grill in the store + Catering / restaurant kitchens
Cold Appliances	Product Cooling	Comparable category	Coolers food cold + Plugin furniture, fridge and freezer + Other electricity in fridge freezers + Compressor electricity in fridge freezers + Electric heating for defrosting freezers
Water heating	Comparable category	Comparable category	*Missing*
Heating	Comparable category + Pumps (50%)	Electric heating + Circulation pumps and other heating auxiliaries (50%)	Electric heating + Heat pumps + pumps (50%) + Electric heating outside the building envelope
Lighting	Indoor lighting + Outdoor lighting + Emergency lighting	Comparable category + Lighting street	Comparable category + Advertising signs + Furniture and interior lighting

Appendix E: Distribution of standard demand profiles in the Dutch residential and service sectors

The different categories of standard profiles listed with EDSN are presented in table E-1. User profiles of multiple years are available. The household profiles (E1) and the street light profile (E4A) are taken from the 2013 user profile data and the small businesses profiles (E2 and E3) are taken from the 2014 user profile data.

Table E-1: different categories of standard profiles listed with EDSN (2012):

Code	Description
E1a	<= 3x 25 Ampère, single counter
E1b	<= 3x 25 Ampère, double counter night tariff
E1c	<= 3x 25 Ampère, dubbel counter evening tariff
E2a	> 3x25 Ampère <= 3x80A, single counter
E2b	> 3x25 Ampère <= 3x80A, double counter
E3a	>3x80 Ampère, < 100 kW, operating time <= 2000 uur
E3b	>3x80 Ampère, < 100 kW, BT > 2000 uur, operating time <=3000 uur
E3c	>3x80 Ampère, < 100 kW, BT > 3000 uur, operating time < 5000 uur
E3d	>3x80 Ampère, < 100 kW, operating time >= 5000 uur
E4A	All measured connections to the street light signal with a connected power of less than 100 kW

Distribution of the profiles

Total consumption data of the 10 different connections in 2014 is obtained from Network Company 1. This company only covers part of the country. Therefore, it is assumed this distribution is representative of the Netherlands.

Deriving a distribution for the residential sector is complicated because Dutch households (profiles E1a-E1c) can choose either a single or double counter tariff structure. The evening tariff is generally only obtainable in two provinces (Limburg and Noord-Brabant), the other provinces have the night tariff (NLE, 2014). Because of the distinction between night and evening tariff, Dutch household demographics obtained from CBS (2014b) were also used to make an accurate approximation of the national shares of the residential sector.

With this data, the shares of the different profiles in the residential and service sectors are determined (table E-2). For confidentiality reasons, only the resulting shares are listed in this report.

Table E-2: distribution of residential (E1) and service sector (E2-E4) profiles

Residential profiles	E1a	30.9%
	E1b	57.0%
	E1c	12.1%
Total		**100%**
Service profiles	E2a	12.0%
	E2b	62.8%
	E3a	10.9%
	E3b	7.6%
	E3c	3.3%
	E3d	0.3%
	E4A	3.1%
Total		**100%**

Appendix F: Distribution of standard demand profiles in the Spanish residential and service sectors

Spanish standard user profiles exist in 4 types and they are obtained from Red Eléctrica de España. The data is presented as fractions of annual demand in hourly time steps. The 2014 (forecasted) profiles are used in the analysis. (REE, 2014). The description of the profiles is adapted from BOE (2013) and presented in table F-1.

Table F-1: different categories of Spanish user profiles (BOE, 2013)

Profile type	Description
A	Consumer with access rate 2.0 A and 2.1 A, and measurement equipment for a single period; rates 2.0A for capacity lower than 10 kW, single period and rates 2.1A for capacity from 10 kW to 15 kW, single period.
B	Consumer with access rate 2.0 DHA and 2.1 DHA, and measurement equipment for 2 periods; rates 2.0DHA for capacity lower than 10 kW, 2 periods and rates 2.1DHA for capacity from 10 kW to 15 kW, 2 periods.
C	Consumer with access rate 3.0 A and 3.1 A, with low voltage metering and measurement equipment for 3 periods; rates 3.0A for capacity above 15 kW and low voltage, 3 periods and rates 3.1A for capacity above 15 kW and high voltage, 3 periods.
D	Consumer with access rate 2.0 DHS and 2.1 DHS, and measurement equipment for 3 periods of time discrimination; rates 2.0DHS for capacity lower than 10 kW, 3 periods and rates 2.1DHS for capacity from 10 kW to 15 kW, 3 periods

The 2014 (forecasted) distribution of demand between the profiles is used to determine the share of the profiles in the Spanish residential and service sectors. This is obtained from CNE (2013) and presented in table F-2. The codes 2.0A – 3.1A correspond to the description of the profile types in table F-1. Demand figures with code 6.1 – 6.4 correspond to large consumers. These statistics indicate that profile type D is not in use.

Table F-2: distribution of consumption of profiles (CNE, 2013)

Code	Code (2)	Annual demand per profile [GWh]	share
2.0	A	62538	26,3%
2.0	DHA	7354	3,1%
2.0	DHS	0	0,0%
2.1	A	6508	2,7%
2.1	DHA	3210	1,4%
2.1	DHS	0	0,0%
3.0	A	37143	15,6%
3.1	A	16632	7,0%
6.1		56377	23,7%
6.2		16883	7,1%
6.3		8219	3,5%
6.4 (1)		22778	9,6%
Total		237643	

From these statistics, the shares of the profiles for the residential and service sectors have to be derived. For this, it is assumed that residential demand is made up only of the code 2.0 and 2.1

demand figures. Using the distribution of Spanish sectors in annual national demand (see section 3.1.2.2), it can be deducted that residential demand makes up approximately 95% of the total demand of the type 2 profiles. The remainder of the type 2 demand is shared among the other sectors. However, it is not known how the remaining 5% is distributed among these 5 remaining sectors. Since the shares of the agriculture, transport and energy sector in national demand are minimal and the industry sector most likely contains typically large users (code 6), it is assumed that the remaining demand of the type 2 profiles can be attributed to the service sector. The resulting distribution of profiles is given in table F-3.

Table F-3: final distribution of Spanish profiles

Residential profiles	Profile type A	86,7%
	Profile type B	13,3%
Service profiles	Profile type A	5,5%
	Profile type B	0,8%
	Profile type C	93,7%

Appendix G: Distribution households by number of residents in Sweden

In the Swedish dataset, measurements are categorized by type of household. The data is sorted according to number of residents within a household, varying from 1 to 5 (or more) residents. The distribution of weights assigned to the different household categories is derived from household statistics (G-1).

Table G-1: Distribution of Swedish households categorized by number of residents per household (Werner, 2014).

Number of residents per household	Weight
1	36%
2	32%
3	13%
4	13%
5 or more	6.4%

Appendix H: Distribution of annual demand in subsectors of the industry, transport and energy sectors in the Netherlands, Spain and Sweden

Table H-1 lists distribution of annual demand of subsectors within the industry sector. This distribution is derived from annual electricity demand statistics of 2012 found in Eurostat (2014a). No demand data is obtained from the construction subsector. Since this is only a small subsector, this is of little consequence for the hourly fractions of the sector. Therefore, the distribution is set up without the contribution of the construction subsector. Additionally, the number of large consumers per subsector is given of which data is obtained from Regional Network Company 1.

Table H-1: distribution of annual electricity demand in industry subsectors derived from Eurostat (2014a)

Industry sub sector	Share in the Netherlands	Share in Spain	Share in Sweden	Number of firms
Iron and Steel	7,9%	18,9%	8,5%	9
Non-Ferrous Metals	8,1%	15,1%	6,0%	6
Chemical and Petrochemical	35,9%	12,0%	8,7%	24
Non-Metallic Minerals	3,6%	9,2%	1,9%	6
Mining and Quarrying	0,6%	1,9%	6,2%	3
Food and Tobacco	18,4%	13,5%	4,6%	15
Textile and Leather	1,0%	2,8%	0,3%	3
Paper, Pulp and Print	7,3%	7,4%	43,4%	9
Transport Equipment	1,5%	3,8%	3,7%	3
Machinery	8,3%	5,4%	6,8%	9
Wood and Wood Products	0,7%	2,0%	3,6%	3
Construction	-	-	-	0
Non-specified (Industry)	6,6%	7,9%	6,2%	9
Total				**99**

Table H-2 lists the subsector contributions of the transport sector obtained from Eurostat (2014a). No data of the sub sector 'Non-specified (Transport)' is obtained. Again, the distribution is set up without the contribution of this particular subsector. Also, the number of large consumers per subsector is given of which data is obtained from Regional Network Company 1.

Table H-2: distribution of electricity consumption in transport subsectors

Transport sub sector	Share in the Netherlands	Share in Spain	Share in Sweden	Number of firms
Rail	100%	98,9%	100,0%	3
Road	0,0%	1,1%	0,0%	3
Consumption in Pipeline transport	0,0%	0,0%	0,0%	3
Non-specified (Transport)	-	-	-	0
Total				**9**

Table H-3 lists the sub sector contributions of the energy sector (without own consumption in electricity, heat and CHP plants) obtained from Eurostat (2014a). Only demand data of the subsectors 'Consumption in Oil and gas extraction' and 'Consumption in Petroleum Refineries' were acquired from Regional Network Company 1. The distribution is set up without the contribution of the remaining subsectors. This excluded a significant number of subsectors (14) from the analysis. Additionally, the number of large consumers per subsector is given of which data is obtained from Regional Network Company 1.

Table H-3: distribution of electricity consumption in energy subsectors

Energy sub sector	Share in the Netherlands	Share in Spain	Share in Sweden	Number of firms
Consumption in Oil and gas extraction	100%	98,9%	100,0%	6
Consumption in Petroleum Refineries	0,0%	1,1%	0,0%	5
Total				**11**

Appendix I: Distribution of annual demand in subsectors of the agricultural sector in the Netherlands

Table I-1 describes the shares of agricultural sub sectors in the main agriculture sector of the Netherlands. The distribution is based on number of firms, obtained from CBS (2014a). Similar to the analysis of the energy and transport sectors, a number of subsectors is not included. Based on the number of firms, these subsectors represent approximately 65% of the agricultural sector in the Netherlands.

Table I-1: distribution of number of firms in agricultural subsectors

Sub sector name	share	Number of profiles
Floriculture	7,6%	3
Raising and breeding of dairy cattle	44,2%	3
Breeding and keeping of poultry	3,7%	3
Breeding and raising pigs	7,9%	3
Cultivation of vegetables and mushrooms + Cultivation of potatoes, sugar beets and other roots and tubers	10,7%	6
Cultivation of cereals, pulses and oilseeds	14,0%	3
Cultivation of ornamental plants (trees and shrubs)	11,8%	3
Total		**24**

Appendix J: Distribution households by number of residents in the Netherlands, Spain and Sweden

In the Swedish dataset, measurements are categorized by type of household. The data is sorted according to number of residents within a household, varying from 1 to 5 (or more) residents. The distribution of weights assigned to the different household categories is derived from various national household statistics (table J-1).

Table J-1: distribution of households categorized by number of residents per household

Number of persons/country & source	The Netherlands (CBS, 2013a)	Spain (INE, 2014)	Sweden (Werner, 2014)
1	37%	24%	36%
2	33%	30%	32%
3	12%	21%	13%
4	13%	18%	13%
5 or more	5.4%	6.1%	6.4%

Appendix K: Overview of national holidays and adaptations made to match the calendars of the demand patterns

Overview of national holidays

The Netherlands

1. New Year’s Day, Good Friday, Easter Sunday and Easter Monday, Queen’s Day/abdication Day/King’s day (April 30/26, except when on Sunday), Ascension Day, Whit Sunday and Whit Monday, Christmas Day and Boxing Day, New Year’s Eve).
2. Christmas holiday (all dates between and including 24 December and 2 January.
3. Single days that are preceded and followed by weekends or holidays (e.g. Friday after Ascension Day; Hekkenberg et al., 2009).

Spain

1. New Year's Day, Epiphany (January 6), Maundy Thursday, Good Friday, Easter Sunday, Labour Day (May 1), Assumption (August 15), Fiesta Nacional de España (October 12), All Saints Day (November 1), Constitution Day (December 6), Immaculate Conception (December 8), Christmas Day (December 25).
2. Single days that are preceded and followed by weekends or holidays (Wikipedia, 2014a)[10].

Sweden

1. New Year´s Day, Epiphany Day (January 6), Good Friday, Easter Sunday, Easter Monday, Labour Day (May 1), Ascension Day, Whit Sunday, Sweden's National Day (June 6), Midsummer´s Eve, Midsummer’s day (the Saturday during the period 20–26 June), All Saint’s Day (the Saturday during the period October31 – November 6), Christmas Eve, Christmas Day, Boxing Day, New Year´s Eve.
2. Single days that are preceded and followed by weekends or holidays (Wikipedia, 2014b).

[10]This source, normally not used in scientific literature, proved to be the most comprehensive source on this subject.

Adaptations for date changes to base years

Because of limited availability of data, established profiles of sectors and services do not always represent the same year as the base year. The following adaptations done to match data from different years to the selected base year are listed in table K-1.

Table K-1: adaptations for date changes to base years

Year change	Needed for:	Adaptations:
2013 to 2012	Industry, agriculture, transport, energy and household sectors in the Netherlands	December 30-31 (2013) are put to January 2 and 3 (base year). Sunday March 25 and April 1 are switched because of the change to summer time.
2014 to 2012	Service sector in the Netherlands	December 29-31 (2014) are put to January 2, 3 and 4 (base year). Sunday March 25 and April 1 are switched because of the change to summer time.
2014 to 2010	Household, service sectors in Spain	January 2-3 are put to December 30-31 (base year). Sunday October 24 and October 31 are switched because of the change to winter time.
2013 to 2010	Industry, transport, energy sectors in Spain	January 2-4 2013 are put to December 29-31 (base year). Sunday October 24 and October 31 are switched because of the change to winter time.
2007 to 2013	Residential sector Sweden, Residential EUS patterns in Sweden	January 22007 is put to December 31 (base year). Sunday March 24 and March 31 are switched because of the change to summer time.
2014 to 2013	Services sector in Sweden	December 31 2014 is put to January 2 (base year).
2007 to 2010	Residential services patterns of Spain	December 29 – 31 (2007) to January 2-4 (base year)
2007 to 2012	Residential services patterns of the Netherlands	December 31 (2007) to January 2 (base year)

Appendix L: Overview of adaptations made to match the efficiency improvements on EUS level to the EUS taxonomy

This appendix includes the adaptations applied to the categories in Schade et al. (2009) to match the EUS taxonomy used in this thesis (table L-1).

Table L-1: Adaptations applied for matching EUS taxonomy to the categories in Schade et al. (2009)

EUS category residential sector	EUS category in Schade et al. (2009)		EUS category residential sector	EUS category in Schade et al. (2009)
Lighting	Lighting		Lifts	Others
Cold appliances	Average of Refrigerators/Freezers		Cooling	AC
Cooking	Cooking		Computing and consumer electronics	TV
Dishwashing	Dishwashers		Other	Others
Washing	Washing machines		Catering	Cooking
Drying	Washing machines		Cold Appliances	Average of Refrigerators/Freezers
Audio/visual appliances	TV		Water heating	Hot water
Gaming	TV		Space Heating	Heating
Computers	TV		Lighting	Lighting
Ventilation	AC			
Space Heating	Heating			
Water heating	Hot water			
Other	Others			
Not known	Others			
Standby	TV			

Appendix M: Overview of scenario inputs for annual demand change on national, sector and EUS level

In this appendix, the annual demand change between 2013 and 2050 is presented in the form of multiplications on national, sector and EUS level. The sources from which they are derived are also provided. The annual demand inputs of the scenarios can be derived from this by multiplying the annual demand of 2013 with these factors.

The inputs are presented in table M-1 for the BAU, Heat, Transport and Onsite scenarios, table M-2 for the Efficiency Scenario, table M-3 for the 4DS scenario and table M-4 for the 2DS scenarios.

Table M-1: changes on national, sector and EUS level in the BAU, Heat, Transport and Onsite scenarios per country and the sources from which these changes are derived.

Level	NL	Source(s)	SP	Source(s)	SW	Source(s)
National	1.2	(European Commission, 2013)	1.4	(European Commission, 2013)	1.1	(European Commission, 2013)
Sector						
Industry	1.1	(ECN, 2014b) (European Commission, 2013)	1.2	Idem	1.1	(Andersson et al., 2013); (European Commission, 2013)
Transport	2.8	Idem	2.2	Idem	1.3	Idem
Residential	1.2	Idem	1.6	Idem	1.1	Idem
Agriculture	1.4	Idem	1.4	Idem	1.1	Idem
Services	1.1	Idem	1.4	Idem	1.1	Idem
Energy	1.2	Idem	1.2	Idem	1.5	Idem
EUS residential sector						
Lighting	0.27	(Menkveld et al., 2010), (European Commission, 2013)	0.27	Idem	0.30	(European Commission, 2013)
Cold appliances	1.2	Idem	2.0	Idem	2.2	Idem
Cooking	0.92	Idem	1.1	Idem	1.2	Idem
Dishwashing	1.2	Idem	2.0	Idem	2.2	Idem
Washing	1.2	Idem	2.0	Idem	2.2	Idem
Drying	1.2	Idem	2.0	Idem	2.2	Idem
Audio/visual apps.	1.6	Idem	2.0	Idem	2.2	Idem
Gaming	-	Idem	-	Idem	2.2	Idem
Computers	1.4	Idem	2.0	Idem	2.2	Idem
Ventilation	3.2	Idem	3.7	Idem	4.1	Idem
Heating	0.70	Idem	0.89	Idem	1.0	Idem
Water heating	0.85	Idem	1.0	Idem	1.1	Idem
Other	0.81	Idem	1.1	Idem	1.2	Idem
Not known	0.81	Idem	-	Idem	1.2	Idem
Standby	-	Idem	2.0	Idem	-	Idem
EUS service sector						
Lifts	1.3	Idem	1.9	Idem	1.4	Idem

Cooling	1.5	Idem	1.9	Idem	1.4	Idem
Computing and consumer electronics	1.6	Idem	1.9	Idem	1.4	Idem
Other	1.0	Idem	1.3	Idem	0.94	Idem
Catering	1.4	Idem	1.9	Idem	1.4	Idem
Cold Appliances	1.3	Idem	1.9	Idem	1.4	Idem
Water heating	0.68	Idem	0.87	Idem	1.0	Idem
Heating	1.7	Idem	0.87	Idem	0.65	Idem
Lighting	0.67	Idem	0.82	Idem	0.61	Idem

Table M-2: changes on national, sector and EUS level in the Efficiency scenario per country and the sources from which these changes are derived.

Level	NL	Source(s)	SP	Source(s)	SW	Source(s)
National	-	(European Commission, 2013)	-	(European Commission, 2013)	-	(European Commission, 2013)
Sector						
Industry	1.1	(ECN, 2014b) (European Commission, 2013)	1.1	Idem	1.1	(Andersson et al., 2013); (European Commission, 2013)
Transport	2.8	Idem	2.8	Idem	2.8	Idem
Residential	-	-	-	-	-	-
Agriculture	1.4	Idem	1.4	Idem	1.4	Idem
Services	-	-	-	-	-	-
Energy	1.2	Idem	1.2	Idem	1.2	Idem
EUS residential sector						
Lighting	0.07	(Menkveld et al., 2010); (European Commission, 2013); (Schade et al., 2009)	0.07	(European Commission, 2013) ; (Schade et al., 2009)	0.08	(European Commission, 2013); (Schade et al., 2009)
Cold appliances	0.49	Idem	0.84	Idem	0.93	Idem
Cooking	0.72	Idem	0.88	Idem	0.98	Idem
Dishwashing	0.57	Idem	0.94	Idem	1.0	Idem
Washing	0.34	Idem	0.55	Idem	0.61	Idem
Drying	0.33	Idem	0.55	Idem	0.61	Idem
Audio/visual apps.	0.77	Idem	0.97	Idem	1.1	Idem
Gaming	-	Idem	-	Idem	1.1	Idem
Computers	0.70	Idem	0.9	Idem	1.1	Idem

			7			
Ventilation	1.5	Idem	1.7	Idem	1.9	Idem
Heating	0.33	Idem	0.42	Idem	0.46	Idem
Water heating	0.73	Idem	0.82	Idem	0.90	Idem
Other	0.57	Idem	0.77	Idem	0.85	Idem
Not known	0.57	Idem	-	Idem	0.85	Idem
Standby	-	Idem	0.97	Idem	-	Idem
EUS service sector						
Lifts	0.91	Idem	1.37	Idem	1.0	Idem
Cooling	0.70	Idem	0.90	Idem	0.67	Idem
Computing and consumer electronics	0.75	Idem	0.94	Idem	0.69	Idem
Other	0.71	Idem	0.89	Idem	0.66	Idem
Catering	1.1	Idem	1.5	Idem	1.1	Idem
Cold Appliances	0.53	Idem	0.80	Idem	0.60	Idem
Water heating	0.59	Idem	0.75	Idem	0.86	Idem
Heating	0.55	Idem	0.42	Idem	0.39	Idem
Lighting	0.17	Idem	0.20	Idem	0.15	Idem

Table M-3: changes on national, sector and EUS level in the 4DS scenario per country and the sources from which these changes are derived.

Level	NL	Source(s)	SP	Source(s)	SW	Source(s)
National	1.9	(Schade et al., 2009)	1.8	(Schade et al., 2009)	1.4	(Schade et al., 2009)
Sector						
Industry	1.7	(ECN, 2014) (European Commission, 2013)	1.5	Idem	1.4	(Andersson et al., 2013); (European Commission, 2013)
Transport	4.5	Idem	2.8	Idem	1.6	Idem
Residential	1.9	Idem	2.0	Idem	1.4	Idem
Agriculture	2.3	Idem	1.8	Idem	1.3	Idem
Services	1.8	Idem	1.8	Idem	1.3	Idem
Energy	1.9	Idem	1.5	Idem	1.9	Idem
EUS residential sector						
Lighting	0.4	(Menkveld et al.,	0.3	(European	0.3	(European

	3	2010); (European Commission, 2013);	5	Commission, 2013)	8	Commission, 2013)
Cold appliances	1.9	Idem	2.6	Idem	2.8	Idem
Cooking	1.5	Idem	1.4	Idem	1.6	Idem
Dishwashing	2.0	Idem	2.6	Idem	2.8	Idem
Washing	2.0	Idem	2.6	Idem	2.8	Idem
Drying	1.9	Idem	2.6	Idem	2.8	Idem
Audio/visual apps.	2.6	Idem	2.6	Idem	2.8	Idem
Gaming	-	Idem	-	Idem	2.8	Idem
Computers	2.3	Idem	2.6	Idem	2.8	Idem
Ventilation	5.1	Idem	4.7	Idem	5.2	Idem
Heating	1.1	Idem	1.1	Idem	1.2	Idem
Water heating	1.4	Idem	1.2	Idem	1.3	Idem
Other	1.3	Idem	1.4	Idem	1.5	Idem
Not known	1.3	Idem	-	Idem	1.5	Idem
Standby	0.43	Idem	2.6	Idem	-	Idem
EUS service sector						
Lifts		Idem	2.5	Idem	1.8	Idem
Cooling		Idem	2.4	Idem	1.8	Idem
Computing and consumer electronics	2.1	Idem	2.5	Idem	1.8	Idem
Other	2.4	Idem	1.6	Idem	1.2	Idem
Catering	2.5	Idem	2.5	Idem	1.8	Idem
Cold Appliances	1.6	Idem	2.5	Idem	1.8	Idem
Water heating	2.3	Idem	1.1	Idem	1.0	Idem
Heating	2.0	Idem	1.1	Idem	0.81	Idem
Lighting	1.1	Idem	1.0	Idem	0.76	Idem

Table M-4: changes on national, sector and EUS level in the 2DS scenario per country and the sources from which these changes are derived

Level	NL	Source(s)	SP	Source(s)	SW	Source(s)
National	0.86	(Schade et al., 2009)	0.84	(Schade et al., 2009)	0.72	(Schade et al., 2009)
Sector						
Industry	0.67	(ECN, 2014) (European Commission, 2013)	0.73	Idem	0.88	(Andersson et al., 2013); (European Commission, 2013)
Transport	5.7	Idem	5.8	Idem	5.0	Idem
Residential	0.96	Idem	0.81	Idem	0.42	Idem
Agriculture	0.70	Idem	0.75	Idem	0.49	Idem
Services	0.70	Idem	0.75	Idem	0.49	Idem
Energy	1.3	Idem	1.2	Idem	1.4	Idem

EUS residential sector						
Lighting	0.11	(Menkveld et al., 2010); (European Commission, 2013);	0.07	(European Commission, 2013)	0.05	(European Commission, 2013)
Cold appliances	0.83	Idem	0.91	Idem	0.65	Idem
Cooking	1.2	Idem	0.95	Idem	0.68	Idem
Dishwashing	0.96	Idem	1.0	Idem	0.73	Idem
Washing	0.57	Idem	0.60	Idem	0.43	Idem
Drying	0.55	Idem	0.60	Idem	0.43	Idem
Audio/visual apps.	1.3	Idem	1.1	Idem	0.75	Idem
Gaming	-	Idem	-	Idem	0.75	Idem
Computers	1.2	Idem	1.1	Idem	0.75	Idem
Ventilation	2.5	Idem	1.9	Idem	1.3	Idem
Heating	0.55	Idem	0.45	Idem	0.32	Idem
Water heating	1.2	Idem	0.88	Idem	0.63	Idem
Other	0.95	Idem	0.83	Idem	0.60	Idem
Not known	0.95	Idem	-	Idem	0.60	Idem
Standby	-	Idem	1.1	Idem	-	Idem
EUS service sector						
Lifts	1.2	Idem	1.4	Idem	1.1	Idem
Cooling	0.92	Idem	0.95	Idem	0.72	Idem
Computing and consumer electronics	0.98	Idem	0.98	Idem	0.75	Idem
Other	0.93	Idem	0.94	Idem	0.72	Idem
Catering	1.5	Idem	1.6	Idem	1.2	Idem
Cold Appliances	0.69	Idem	0.85	Idem	0.65	Idem
Water heating	0.77	Idem	0.79	Idem	1.0	Idem
Heating	0.72	Idem	0.44	Idem	0.42	Idem
Lighting	0.22	Idem	0.21	Idem	0.16	Idem