Changing energy demand in the residential sector due to decentralized generators and the electrification of heating and driving

A case study of the Netherlands towards 2030

Utrecht University

Master thesis

Energy Science

System analysis track

Student:	**P.I. Elshof BEng**
Student number:	**3909123 / f122887**
Email:	**p.i.elshof@students.uu.nl**

Institution:	**Utrecht University**
Faculty:	**Geoscience**
Master program:	**Energy Science**
Supervisor:	**Dr. ir. M.A. van den Broek**
Second reader:	**Dr. ir. W.H.J. Crijns-Graus**

Date: **18-03-2016**

Abstract

The increasing implementation of decentralized generators combined with the electrification of heating and driving causes a shift in energy use within the residential sector. A high degree of decentralized generation could cause problems with the reliability of supply and the efficiency of the grid. Therefore insight in future energy demand is required. This study provides the first realistic hourly forecast of the energy demand in the residential sector per dwelling type accounting for technologies and trends relevant to changing energy demand and aims to answer the following research question:

> *How will decentralized generators, electrification of driving and heating, insulation and other trends affect the demand patterns of district heating, gas and electricity of the residential sector in 2030?*

In this thesis a Baseline Electricity and Baseline Heat use was constructed for 2030 that was expanded with the implementation of photovoltaic systems, solar water heaters, heat pumps, electric vehicles, insulation and trends in energy use towards 2030.

The results of this research predict an increase in the use of district heating, from 11.9 PJ in 2014 to 15.7 PJ in 2030. The largest increase occurs in multifamily dwellings. An improved degree of insulation in many dwellings results in decreasing hourly fluctuations over the year.

The gas demand is expected to reduce substantially towards 2030. It decreases from 325 PJ in 2014 to 234 PJ in 2030, which is mainly a result of the improved insulation of 3.6 million dwellings. Other important influences on the changing gas use are the implementation of heat pumps and increased use of district heating. Due to improved insulation, less energy is required to achieve a comfortable temperature within dwellings, which decreases the peak demand and the hourly fluctuation of gas.

The effects of decreasing electricity use due to improved efficiency of appliances and increasing electricity use caused by the implementation of electric vehicles and heat pumps cancel each other out. Thus, the electricity use towards 2030 is expected to remain approximately constant (92 PJ). The implementation of photovoltaic in 2030 (28% of all dwellings) will decrease the annual net electricity demand from the grid with approximately 30%. The hourly fluctuations of electricity demand will triple in single-family terraced dwellings and are 6 times larger for the whole residential sector in the high scenario. The maximum hourly surplus of electricity in the residential sector in 2030 is predicted to be 11.7 TJ/hr.

Table of contents

List of abbreviations

BEV	= Battery Electric Vehicle
CBS	= Statistics Netherlands
DG	= Decentralized generator
DHPA	= Dutch Heat Pump Association
DSO	= Distribution system operator
ECN	= Energy Research Center Netherlands
EREV	= Extended Range Electric Vehicle
EV	= Electric vehicle
HP	= Heat pump
ICE	= Internal Combustion Engine
KNMI	= Royal Netherlands Meteorological institute
LHV	= Lower heating value
MF	= Multi family
PBL	= Netherlands Environmental Assessment Agency
PHEV	= Plug-in Hybrid Electric Vehicle
PV	= Photovoltaic
RVO	= Netherlands Enterprise Agency
SFD	= Single family detached
SFT	= Single family terraced
SPF	= Seasonal performance factor
SWH	= Solar water heater
TKI	= Top consortium for knowledge and innovation

1. Introduction

1.1 Background

The residential sector of EU-27 is accountable for about 25 percent of the total EU-27 greenhouse gas emission in 2010 (EEA, 2012). The European Commission has set many goals to drastically reduce these emissions by 2030. The Netherlands translated these goals into the energy agreement of sustainable growth, in which the residential sector is stimulated to increase the use of decentralized generators and improve insulation (European Council, 2014; SER, 2013). Studies show that consumers are increasingly investing in decentralized generation technologies (Boon & Dieperink, 2014), often stimulated by climate policies (Vasseur & Kemp, 2015a). With an electricity usage of approximately 84 PJ, a district heating demand of 11 PJ and 283 PJ gas for heating, the Dutch residential sector in 2014 accounted for approximately 14% of the nationwide primary energy demand (figure 1) (CBS, 2014a; CBS, 2015a; CBS, 2015e).

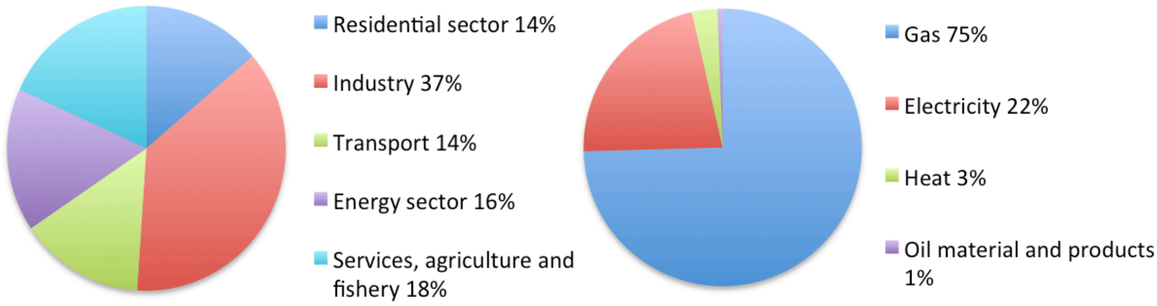

Figure 1: Distribution of primary energy demand per sector in the Netherlands in 2013 (left pie chart) (CBS, 2014a) and share per energy carrier in residential sector in the Netherlands in 2014 (right pie chart) (CBS, 2015a)

1.2 Research problem

The traditional electricity system consists of a centralized producer that delivers electricity trough the grid to an end-user. Decentralized generation (DG) in the residential sector changes this traditional system. In addition, the electrification of heating and driving cause the energy use to shift from gas and gasoline/diesel to electricity. This change will have a positive contribution to the environment. Unfortunately, it will result in an increased demand of residential electricity.

The combination of increased DG technologies and changing energy use[1] in households leads to a radical development in residential energy demand (Drouineau, Maïzi, & Mazauric, 2014; Veldman, Gibescu, Slootweg, & Kling, 2013). Dwellings with high electricity use and intermittent DG technologies may cause large fluctuations and peaks in the net electricity demand[2]. These fluctuations and peak demand accumulate on neighborhood level where similar DGs are adopted. This negatively influences the reliability of the power supply, which leads to inefficient energy generation, curtailment and power outages (Blokhuis, Brouwers, van der Putten, & Schaefer, 2011; Brouwer, Van Den Broek, Seebregts, & Faaij, 2014; Drouineau et al., 2014). High peak demand, negative demand and large fluctuations in net demand of the residential sector requires major revisions of transformers and distribution cables in the electricity grid (Blokhuis et al., 2011; Veldman et al., 2013).

[1] Energy use is the total amount of consumed energy
[2] Net energy demand is the amount of energy withdrawn from the transmission system

Research is required to identify the energy use and demand in the residential sector in 2030. The gained knowledge can be used to find solutions for the expected inefficiency of the grid, curtailment and power outages.

1.3 Previous research into the effects of increased DGs

Many types of studies are conducted relevant to the implementation of DGs in the residential sector. The three most relevant research areas are: the penetration potential per technology, the consequences of a specific demand pattern or implementation rate and finally the forecast models that create an hourly demand pattern. The following sections explain what research has been done and in what way it contributes to the knowledge base.

Many scientists attempted to create a forecast of the penetration of different DGs. These researches include photovoltaic (Confias, Fages, & Berg, 2013; Epia, 2014; Roland Berger, 2015) (NL, global scale, NL), solar water heaters (Ganzevles, van Est, & Brom, 2011; Yamaguchi et al., 2013) (NL, JP) and heat pumps (Dhpa, 2013; Hekkenberg & Verdonk, 2014; Spitalny, Myrzik, & Mehlhorn, 2014) (NL, NL, DE). However, none of the aforementioned studies combines more than two technologies. Furthermore, since the size and location of the case studies vary, it is hard to combine these data.

Some researchers focused on the economic impact of DGs (Joode, Jansen, Welle, & Scheepers, 2009). Others try to get a better understanding of the impact on the distribution network (Drouineau et al., 2014; Lehtonen & Nye, 2009) or attempted to decrease net peak demand by implementing demand side management (Jonge, 2010). These articles assess the consequences (e.g. the reliability of supply) of an estimated penetration instead of studying the penetration and the demand itself. Joode et al. (2009) selected three values of DG penetration, which seem to be chosen at random. These DG technologies were all intermittent or all non-intermittent. No combination was modeled. De Jonge (2010) used a 100% implementation of electric vehicles and heat pumps to find the maximum peak load.

There are studies available that create a forecast model of the residential sectors hourly net energy demand. Veldman et al. (2013) found the peak load of dwellings. However, the research used the most extreme data for all DG technologies and appliances over a year and presented two peak days in summer and in winter. Molenaar (2009) constructed a model based on hourly input. Though, the study analyzed extreme scenarios (e.g. all dwellings with PV potential installed a PV system), it did not include important aspects such as electric vehicles and insulation and did not take weekend days into account. The dissertation by Asare-bediako (2014) created a comprehensive overview of hourly demand patterns. This report included electric vehicles, photovoltaic systems, heat pumps and micro combined heat and power devices for everyday of the week. But, instead of modeling a realistic situation, penetration rates were maximized to find peak loads. Asare-bediako (2014) stresses the importance of accurate energy demand forecasts in the residential sector for further research. The current literature focuses on specific aspects of the problem. An integral model that provides a realistic hourly forecast of the energy demand in the residential sector per dwelling type, accounting for all technologies and trends that are expected to have a significant influence on energy demand is still absent.

1.4 Research question

The previous paragraph concluded that an integral model that provides a realistic hourly forecast of energy demand per dwelling type is still missing. This model could evaluate district heating, gas and electricity demand patterns for the whole residential sector, per dwelling type and for neighborhoods. Therefore, this thesis will focus on answering the following research question;

> *How will decentralized generators, electrification of driving and heating, insulation and other trends affect the demand patterns of district heating, gas and electricity of the residential sector in 2030?*

The following sub-questions need to be answered in order to answer the research question. The questions are all applicable to district heating, gas and electricity and will be treated per type of dwelling and for the whole residential sector.

- I. How will the total energy use in 2030 compare to the total energy use in 2014?
- II. How will the total net energy demand from the transmission system in 2030 compare to the demand in 2014?
- III. How will the minimum and maximum net energy demand per hour in 2030 compare to demand in 2014?
- IV. How will the seasonal energy demand deviation in 2030 compare to the seasonal deviation in 2014?
- V. How do hourly fluctuations of net energy demand in 2030 compare to the fluctuations in 2014?
- VI. What is the effect on the net energy demand of neighborhoods, where dwellings have similar decentralized generators?
- VII. What are the influences per technology on the energy demand patterns?

This study created a model that provides the first realistic hourly forecast of residential energy demand in 2030 per dwelling type, accounting for the changes in technologies and trends relevant to residential energy demand. The research question can be answered by the output of this model and provide a better understanding of the energy use and the required net demand in the residential sector in 2030. This understanding is beneficial for investments strategies and further research of distribution system operators, central energy producers and policy makers. A better grasp on the energy use in 2030 per dwelling type can improve the quality of research into demand side management and local storage. Finally, the scientific knowledge base of the impact per technology per type of dwelling will expand.

1.5 Case study

The Netherlands was used as a case study, because it is quite uniform in DG possibilities as a result of the few geographical differences. The DGs that were considered are photovoltaic (PV), solar water heaters (SWH) and heat pumps (HP). These technologies are expected to have a significant influence in the residential sector in 2030 (Asare-bediako, 2014; Molenaar, 2010; Veldman, Gibescu, Slootweg, & Kling, 2011). Many studies argue that Micro Combined Heat and Power (μCHP) devices are far away from being economically feasible. Over the whole lifetime of a μCHP, the benefits do not outweigh the costs (Ellamla, Staffell, Bujlo, Pollet, & Pasupathi, 2015; Enexis, 2015; Henkes, 2012). Therefore, the μCHP units are assumed to have an insignificant impact in the residential sector in the Netherlands in 2030 and are not taken into account in this study.

This research focuses on the residential district heating, gas and electricity patterns without influence of smart demand measures and local storage. Much research is available on possibilities of smart demand with a given peak demand (Abdisalaam, Lampropoulos, Frunt, Verbong, & Kling, 2012; Claessen et al., 2014; Jonge, 2010; Veldman et al., 2013).

The analysis was performed on hourly basis. A higher resolution was not possible due to a lack of reliable high-resolution data. The impact on the transportation system (e.g. electricity grid) will not be taken into account in this study.

1.6 Reading guide

First, the method of this research is presented using a research framework. Then, the residential sector in 2014 is analyzed followed by the developments towards 2030. Subsequently, the technologies that are expected to have a significant impact on the energy use of dwellings are presented and implementation scenarios are created. Chapter 7 analyzes and answers the sub-questions and research question. Thereafter, the discussion section tests the robustness of the results, considers the implications and compares the results to existing literature. Finally, the conclusion is presented.

2. Method

This chapter presents the approach in which the research question is answered and will guide the reader from a broad modeling approach to a specific research framework.

Energy use in the residential sector can be modeled in two ways; by a top down- and a bottom up approach (Kavgic et al., 2010; Swan & Ugursal, 2009). Both approaches have their strengths and weaknesses. A top down analysis extrapolates a trend on macro level. The strength of such a model lies within the data it requires, which is broadly accessible and easy to use. Weaknesses of a top down approach that are highly relevant to this research are the inability to incorporate new emerging technologies and distinguishing demand for individual dwellings. A bottom up analysis reverses these strengths and weaknesses. The required data in a bottom up analysis is more specific and harder to find, but enables the developments of new technologies and individual dwellings (Kavgic et al., 2010; Swan & Ugursal, 2009). Dwelling types can be modeled by means of the penetration of appliances, the energy use per appliance and the run-time. The energy use of dwellings can be extrapolated to find nationwide demand. This is why a bottom up approach is used to construct a model of the energy pattern in 2030.

2.1 Structure

This study is conducted according to the research framework presented in figure 2. Each block in the framework corresponds with a letter (A to T), which are used to guide the reader through the process. The main structure of the research is as follows. First, an overview of the most recent reliable data is presented (letters A to O). Then, a model is created that converts the raw data into multiple hourly net demand patterns (letters P and Q). These patterns are then analyzed and will answer the research question (letters R and T). Finally, the strength of the model is discussed in the sensitivity analysis and the discussion section (letter S). The collection of data and the construction of the model are briefly discussed in the following sections.

2.1.1 Data collection

This paragraph presents an overview of the required data for modeling the energy use of the residential sector in a bottom up approach. Creating a forecast of the implementation rate and impact of technologies requires much research and modeling. In the time available, it is neither possible nor feasible to complete a full research per technology. Therefore, I combine other researches that have studied the impact and implementation of DG technologies, EVs, insulation and trends in energy use.

Three main data collection areas are distinguished. The first is dwellings and their energy use Baseline. The second includes the trends in dwellings and insulation and the last area studies DG technologies and EVs. The research framework visualizes the path from data collection through output of the model to the analysis of the output. This paragraph discusses letters A to O.

Blocks A and B present an overview of the dwellings in the Netherlands. A provides the total number of dwellings in 2014 and the development towards 2030. B divides the sector into three types of dwellings; single family detached (SFD), single-family terraced (SFT) and multi family (MF). This distinction was based on the most reliable and extensive data source (Agentschap NL, 2011). Additionally, the dwellings were further specified by construction period: before 1965, between 1966-1974, 1975-1991, 1992-2005, 2005-2014, and 2015-2030.

Block C finds the heat demand per type of dwelling per hour without incorporating heat pumps (these will be added from block L) in 2014 and 2030. Heat in this context is the amount of energy required to heat a dwelling, which is later allocated to district heating, gas or electricity. This heat demand will be referred to as Baseline Heat in the rest of this report.

The net electricity demand per type of dwelling per hour is discussed in block D. The purpose of this block is to find net electricity demand in 2014 and a forecast of the development of electricity use towards 2030 without incorporating DG technologies, electric vehicles, etc. This is referred to as Baseline Electricity.

Block E accounts for climate change and other deviations in energy use due to climate data (e.g. hourly heat requirements). Block F distinguishes trends relevant to energy use. These trends are translated to technologies or appliances in block G and quantified in block H. The specific usage and accompanied energy use, generation or savings pattern is examined in block I.

The combination of blocks C, D and I results in blocks J and K. These blocks represent the heat and electricity demand per hour including the changes due to climate change and trends in the residential sector.

The final area of data collection distinguishes relevant DG technologies (block L). The output of DGs is influenced by climate data, that is the reason these blocks (E and L) are connected. The amount of DGs in the residential sector is analyzed in block M and the distinction per dwelling type is discussed in block N. Block O examines the associated energy use and generation.

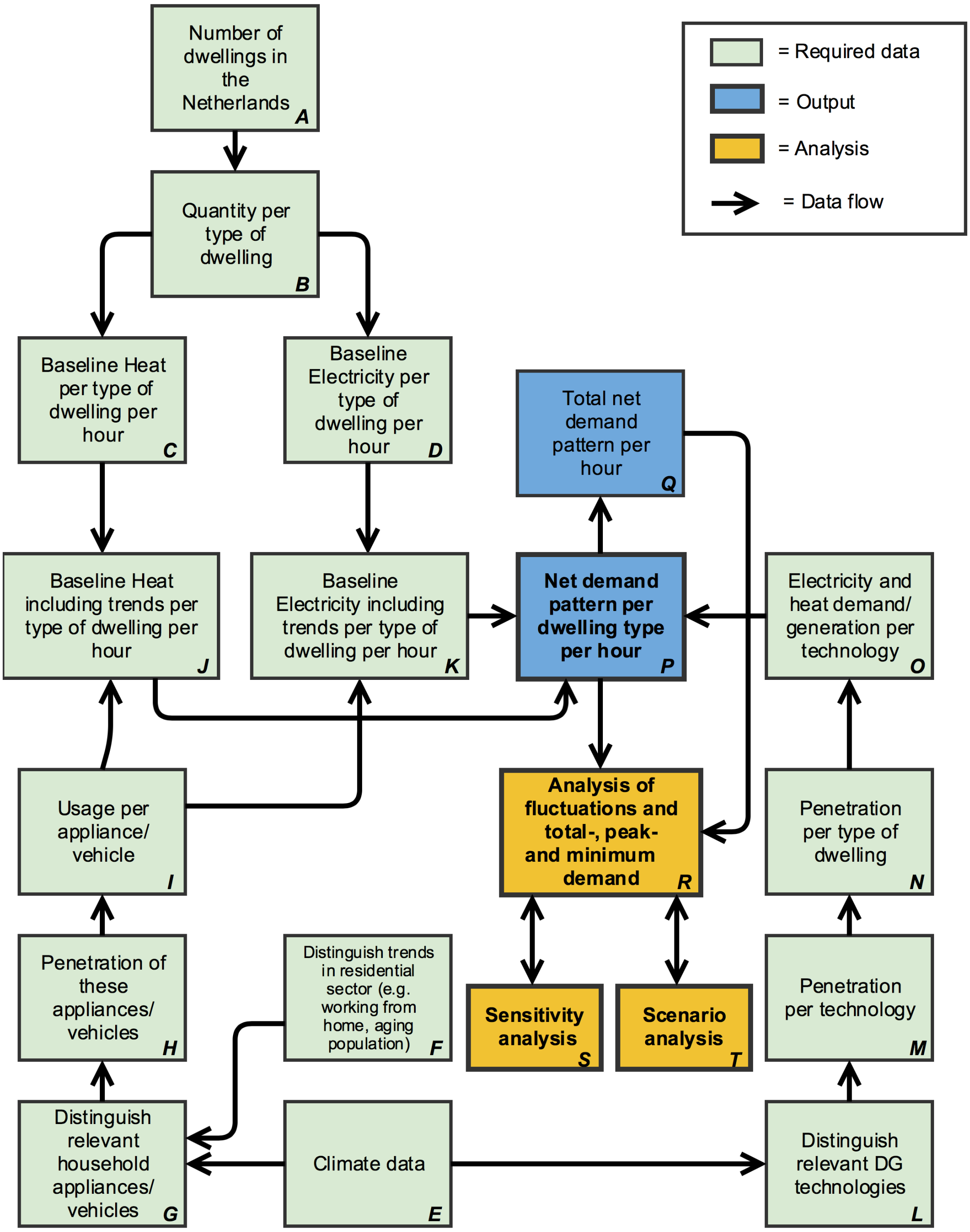

Figure 2: Research framework

2.1.2 Model

The model uses the abovementioned data to create two full years of 8,760 hours in Microsoft Excel. The first year in the first spreadsheet simulates the situation in 2014 and the second year in the second spreadsheet the situation in 2030. For each dwelling type, one average dwelling is created. Meaning, an implementation of 20% PV with an average size of 3.5 kWp in SFD dwellings is modeled as 20% of 3.5 kWp in each SFD dwelling. This model can be used to examine an average dwelling, all dwellings of each type and the whole residential sector.

Each factor that influences the energy use of a dwelling is added or subtracted from one another. For HPs, the model has one column that represents heat delivered per dwelling type, based on the heat demand of that dwelling and the implementation of HPs. Additionally, one column represents the associated electricity use of that HP, based on the seasonal performance factor. The delivered heat (block *O*) is subtracted from the heat demand of the dwelling type (block *C*) and the electricity required by the HP (block *O*) is added to the electricity use of the dwelling (block *D*). This process is repeated for all devices and trends, based on blocks *G* and *L*. The last step is to allocate the heat to district heating and gas based on forecasts about the development of district heating and the efficiency of boilers. This results in an hourly use and demand pattern per dwelling type (block *P*).

2.1.3 Analysis

Block *R*, *S* and *T* represent the analysis of this study. Block *R* presents the hourly demand patterns for district heating, gas and electricity per dwelling type. By analyzing these patterns, the sub-questions of this study can be answered.

A scenario analysis is performed to find a range of possible outcomes and therefore strengthens the results of this study (block *T*). First, a mid scenario is presented, then, the low- and high scenario are further specified and presented. The scenarios consist of implementation rates per technology per dwelling type and absolute implementation values per dwelling type. The low- and high scenarios are constructed to sketch the lower- and upper bound of the implementation in 2030. Although both are not likely to occur, it is useful to find extreme values. The scenarios are based on economic growth characteristics, governmental influence and changes in the oil price (table 1) (Luiten et al., 2013).

Scenarios	Low	Most likely	High
Economic	No economic growth	Limited economic growth	Firm economic growth
Governmental influence	No incentives for the transition to a sustainable world	Less coordinated national incentives / ad hoc incentives	Global coordinated incentives
Oil price	Stable	Fluctuating	Rapidly increasing

Table 1: Growth scenarios, based on Luiten et al. (2013)

A sensitivity analysis (block *S*) assesses the strength of the results. The analysis determines the variables that have a significant influence on the results of this study and evaluates the reliability of these variables.

3. Residential sector in 2014

This chapter presents an introduction to the residential sector in 2014. First, the amount of dwellings and the subdivision of dwelling types are presented. Followed by the Baseline Heat demand in 2014, after which the associated hourly pattern is examined. Finally, the Baseline Electricity and hourly pattern of electricity use are discussed.

3.1 Dwellings

Each type of dwelling has specific characteristics and associated preferences. The amount of dwellings per type and their characteristics are discussed here. The residential sector in the Netherlands consists of about 7.5 million dwellings in 2014. One million are SFD, four million are SFT and approximately 2.5 million are MF (Agentschap NL, 2011; BAG, 2015; BZK, 2013).

In general, SFD dwellings have the largest surface area, are often located in rural areas and require the most energy. The characteristics of MF dwellings are the opposite; they have the smallest surface area, are often located in urban areas and require the least energy. The characteristics of SFT dwellings lay somewhere in the middle of these two types (Agentschap NL, 2011; CBS, 2015b; Jones et al., 2014). Another important distinction is the household income level; SFD households have the highest income, followed by the SFT households (Bedir, Hasselaar, & Itard, 2013; Jones et al., 2014). These characteristics can be translated into behavioral characteristics of households towards the adoption of energy saving measures. SFD households are most inclined to purchase EVs, PV systems, SWHs and HPs. The willingness to adopt these measures is smaller in SFT households and the smallest in MF households (Dhpa, 2013; Harris & Webber, 2014; Lemmens et al., 2014; Maat & Kasraian, 2014; Vasseur & Kemp, 2015). The smaller willingness to adopt energy savings measures for SFT households can still result in a larger impact than the impact of SFD households since there are about 4 times as much SFT dwellings.

3.2 Baseline Heat demand 2014

This paragraph presents the annual heat demand per dwelling type in 2014 and the hourly pattern of that demand. The annual heat demand data over 2014 is based on a combination of sources. Gas use per construction period per dwelling type until 2005 is adapted from the Netherlands Enterprise Agency (Agentschap NL, 2011). Gas demand of newly constructed (2006-2014) SFD and SFT dwellings is available (Huis Bouwen, 2015). To find gas demand in MF dwellings constructed between 2006 and 2014, the percentage of decreased gas demand for MF dwellings in 2006-2014 are assumed to be equal to the percentage of decreased demand of SFD and SFT in the same period.

The data per construction period from the Netherlands Enterprise Agency (2011) is published in 2011 and accounts for dwellings until 2005. This is the most reliable and most recent source with a distinction per technology. When translating these data to 2014 values, a correction factor is applied to correct for the outdated data. Many sources published the average gas demand of a dwelling in 2012 and 2013 in the Netherlands. Table 2 provides an overview of these data. The average gas demand per year without correction is 1,939 m^3 per household. By including a correction factor of 0.75, the average gas demand becomes 1,454 m^3 per year per household. This value is in line with the decreasing gas demand of Dutch dwellings that are presented in table 2 (Hekkenberg & Verdonk, 2014).

Year	Gas demand [m3/household]	Source
2010	1,869	BZK, 2013
2012	1,341	Gerdes, Marbus, & Boelhouwer, 2014
2012	1,600	Milieu Centraal, 2015
2012	1,500	Hekkenberg & Verdonk, 2014
2012	1,500	CBS, 2015b
2013	1,500	Schoots & Hammingh, 2015

Table 2: Different sources for average gas demand in dwellings in the Netherlands

The amount of gas is turned into heat demand by accounting for the types and efficiencies of boilers in dwellings, the share of dwellings with district heating, the amount of HPs and the number of SWHs in 2014 (table 3). All of the utilized gas in the Netherlands is extracted in Groningen and the calorific value of gas from Groningen is 31.65 MJ/m^3 LHV (Heslinga & Harmelen, 2006).

Technology 2014	Value		Source
Types of boilers and their share of the total amount of boilers in the residential sector	HR 107 HR 104 VR CR	77% 7% 13% 2%	BZK, 2013
Efficiency of boilers LHV	HR 107: HR 104: VR: CR:	97% 94% 83% 75%	Duurzaamthuis, 2015; Energie Actief Soest, 2015
District heating	4.6% of all dwellings in the Netherlands		Schoots & Hammigh, 2015; Voorbeeldwoningen, 2011
Average heat supplied per district heating connection	34 GJ/yr		Milieu Centraal, 2015
Number of heat pumps in the Netherlands	121,226		CBS, 2015c
Heat produced per heat pump	18,461 MJ/yr		CBS, 2015c
Amount of SWHs	128,959		CBS, 2014
Heat produced per SWH	4,614 MJ/yr		CBS, 2014

Table 3: Technologies implemented in 2014 with the associated efficiency or production

Tap water and cooking accounts for approximately 25% of the total heat demand (Expertgroep aardgas; Menkveld, 2009; NEDU, 2014). Based on this distinction, the heat demand for space heating and tap water in 2014 is presented in table 4.

	Construction period	Space heating [GJ/yr]	Tap and cooking [GJ/yr]
SFD	<1965	79.49	26.00
	1965-1974	69.06	22.58
	1975-1991	43.96	14.37
	1992-2005	31.62	10.34
	2006-2014	20.43	6.68
	SFD average	**57.16**	**18.69**
SFT	<1965	51.23	16.75
	1965-1974	38.76	12.68
	1975-1991	28.21	9.23
	1992-2005	21.87	7.15
	2006-2014	19.16	6.27
	SFT average	**35.75**	**11.69**
MF	<1965	29.33	9.59
	1965-1974	23.01	7.52
	1975-1991	15.70	5.14
	1992-2005	12.80	4.19
	2006-2014	9.75	3.19
	MF average	**21.18**	**6.93**
Sector	**Average**	**34.10**	**11.15**

Table 4: Gas use and heating requirements distinguished per dwelling type and construction period

The hourly allocation of this heat demand for space heating, tap water and cooking in 2014 is based on data supplied by NEDU (2015). Their data is created from gas supply patterns. I assume that gas supply patterns are equal to heat demand patterns. Data from historical measurement campaigns have resulted in 3 types of consumption profiles: dwellings with a consumption of < 5,000 m^3/year and a gas meter ≤ G6 (max 10 m^3/hour), residential dwellings that do not fit in the first category and buildings with a consumption between 5,000 and 170,000 m^3/year (NEDU, 2015). The first profile fits best to residential dwellings. Therefore, this profile is selected to model the hourly pattern in 2014.

The profile is supplied in four columns of 8,760 rows (one for each hour), these columns represent: the heating temperature (the averaged thermostat setting of all dwellings), the regression series (a fraction of the temperature dependent usage per degree that needs to be heated per hour), the independent profile (an hourly percentage of the annual heat usage independent from the outside temperature) and the temperature coefficient (a historical determined value that represents the outside temperature) (Energiekamer, 2013; NEDU, 2015). These variables can be used to calculate 2 types of consumption profiles, a temperature independent profile and a temperature dependent profile. The temperature independent profile is allocated to the heat demand for tap water/cooking and the dependent profile is assigned to space heating (figure 3).

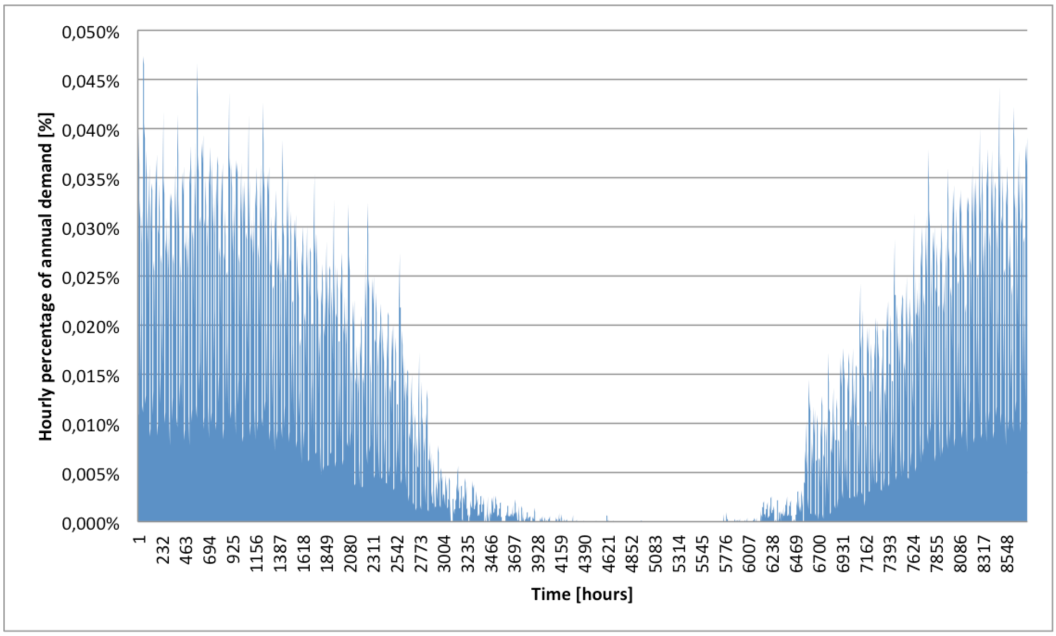

Figure 3: Space heating demand pattern for 2014, adapted from NEDU (2015)

3.3 Baseline Electricity use 2014

This paragraph discusses the annual electricity use in 2014 and the associated hourly distribution. The electricity use in 2014 is found by combining the net electricity demand data from multiple sources, correcting for the time (i.e. make sure it is applicable for 2014) and correcting for the difference in net electricity demand and electricity use (i.e. including generation by PV).

Many sources provide data for average net electricity demand per dwelling in the Netherlands. An overview of these sources is presented in table 5. This data is used to conduct an extrapolation. An annual improvement percentage is calculated from the data in 2010 and 2013 (Hekkenberg & Verdonk, 2014; Schoots & Hammingh, 2015). Resulting in an annual decrease of electricity demand of 0.5%. The annual decrease is used to calculate electricity demand in 2014 from the average demand in 2012, since many sources are available that provide data about 2012. The average electricity demand in 2014 per dwelling is approximately 3,342 kWh. This net demand is turned into electricity use by accounting for the electricity that is generated by PV. The electricity use in 2014 is approximately 3,448 kWh/dwelling.

Year	Electricity demand [kWh]	Source
2010	3,300	Hekkenberg & Verdonk, 2014
2012	3,233	CBS, 2015b
2012	3,417	BZK, 2013
2012	3,495	Gerdes, Marbus, & Boelhouwer, 2014
2012	3,500	Milieu Centraal, 2015
2013	3,250	Schoots & Hammingh, 2015

Table 5: Different sources for average net electricity demand of dwellings in the Netherlands

It is important to distinguish electricity use per dwelling type since a clear correlation exists (Jones et al., 2014; Yohanis, Mondol, Wright, & Norton, 2008). Statistics Netherlands (CBS) provides additional data, about the average net electricity demand per dwelling type (CBS, 2015b), this is used to assign a percentage of the average electricity use to a dwelling (table 6). The correlation between construction year and the electricity use of a dwelling is never proven. Some studies found a higher electricity use in older dwellings, others found a lower electricity use and some studies did not find any significant effect (Jones, Fuertes, & Lomas, 2014). Therefore, I assume that there are no differences in electricity use per construction period.

Dwelling type	Electricity use in 2014 [kWh/yr]
SFD	4,861
SFT	3,737
MF	2,459
Average	**3,450**

Table 6: Electricity use in 2014 subdivided per dwelling type

The hourly percentage of annual net demand is supplied by NEDU (2015), who created these values with a combination of measurement campaigns and historical data. Distribution system operators (DSOs) separate their customers per connection type, which encompasses the capacity and the type of electricity counter. Ten types of connections are provided (table 7). I use the connections smaller than 3x25 Ampere for residential profiles. There are three profiles that meet this requirement: E1a, E1b and E1c. E1a presents a profile of dwellings with a single counter. This counter does not distinguish night and day tariff. The E1b profile represents dwellings with a night tariff starting at 11 pm and E1c represents dwellings with a night (evening) tariff starting at 9 pm.

Code	Description
E1a	**<= 3x 25 Ampere, single counter**
E1b	**<= 3x 25 Ampere, double counter night tariff (23h)**
E1c	**<= 3x 25 Ampere, double counter evening active tariff (21h)**
E2a	**> 3x25 Ampere <= 3x80A, single counter**
E2b	**> 3x25 Ampere <= 3x80A, double counter**
E3a	**>3x80 Ampere, < 100 kW, BT<= 2000 hour**
E3b	**>3x80 Ampere, < 100 kW, BT > 2000 hour, BT <=3000 hour**
E3c	**>3x80 Ampere, < 100 kW, BT > 3000 hour, BT < 5000 hour**
E3d	**>3x80 Ampere, < 100 kW, BT >= 5000 hour**
E4A	**All measured connections switched to the signal of public lighting with a power less than 100 kW**

Table 7: Description of different electricity demand profiles associated with data from NEDU, 2015 (Gaslicht, 2015)

I prefer to assign each profile to a dwelling type instead of taking an average of the profiles. Taking average values would smoothen the peaks of electricity demand, which is not according to reality. The E1a profile shows a small peak in the morning (around 9 am) and a larger peak in the evening (from 6 pm to 10 pm). The E1b profile shows a relative even distribution of electricity throughout the day and The E1c profile presents a long lasting peak in the evening. According to Yohanis et al. (2008), households with a high-income level have higher and longer electricity demand peaks in the evening. SFD dwellings fall within this category and therefore are linked to the E1c profile (Jones et al., 2014; Yohanis et al., 2008). Yohanis et al. (2008) linked an even distribution throughout the day to dwellings with unemployed, retired or single residents. These characteristics are closest related to MF dwellings. The profile of E1a is mostly related to SFT dwellings because of the small peak in the morning and larger peak in the evening (Yohanis et al., 2008).

4. Development of the residential sector towards 2030

This chapter discusses the developments of dwellings towards 2030. First, the trends in the residential sector relevant to the energy use are discussed. Second, the development of the number of dwellings towards 2030 is presented. Finally, the Baseline Heat and Baseline Electricity demand are extended towards 2030.

4.1 Trends relevant to energy use

Many trends influence the energy use within a dwelling. The most influential trends for changing energy use until 2030 are: the increasing number of one occupant dwellings, the increasing number of appliances, changes in cooking, the increasing number of dwellings connected to district heating and the ageing of the population (Bosseboeuf, 2015; BZK, 2013; Gerdes et al., 2014; Schoots & Hammingh, 2015; Hekkenberg & Verdonk, 2014). These trends are analyzed in the following sections.

4.1.1 One person occupied dwellings

The increasing number of one person occupied dwellings (table 8) causes the amount of dwellings in the Netherlands to increase and the energy use per dwelling to decrease (BZK, 2013; Hekkenberg & Verdonk, 2014). A dwelling occupied by one person uses 19% less electricity than a dwelling occupied by two people (Jones et al., 2014). This trend is accounted for by the relative fast increasing number of MF dwellings presented in the next paragraph.

Year	1 occupant	2 occupants	3 occupants	4 occupants	5 or more occupants
2011	36%	33%	12%	13%	6%
2015	37%	33%	12%	12%	5%
2020	38%	33%	12%	12%	5%
2025	39%	33%	12%	11%	5%
2030	41%	32%	11%	11%	5%

Table 8: Development of number of occupants per dwelling in the Netherlands (BZK, 2013)

4.1.2 Changing energy use of appliances

The next trends oppose each other, the number of small appliances is increasing while the energy use of the large appliances is decreasing (Bosseboeuf, 2015). The trend of more efficient appliances is to a large extend driven by the wide implementation of energy labels and eco-design regulations for energy guzzling devices (Agentschap NL, 2010; Bosseboeuf, 2015). The improvement due to the energy labels and eco-design regulations are expected to stabilize around 2025 (Hekkenberg & Verdonk, 2014). Expected policy in 2019 could tighten the regulation for large appliances even further, which would cause the trend to remain present after 2025 (Schoots & Hammingh, 2015). The quantitative influence of these trends on the electricity use of dwellings is discussed in the paragraph 4.4 ('Baseline Electricity use in 2030').

4.1.3 Cooking

A clear trend in cooking can be distinguished as well. Stoves were traditionally gas based. Many new installed stoves however, are powered by electricity. There are also an increasing number of people who eat instant meals, heated by a microwave. The share of dwellings with a microwave increased from 8% in 1987 to 45% in 2010. Similarly, the use of electric water heaters increased from 8% in 1987 to 85% in 2010 (Gerdes, Marbus, & Boelhouwer, 2014). The impact of cooking on the development of electricity use will be discussed in paragraph 4.4 ('Baseline Electricity use in 2030'). The heat demand for tap water and cooking (temperature independent profile) decrease 2.5% per year due to this trend (figure 4) (Gerdes et al., 2014).

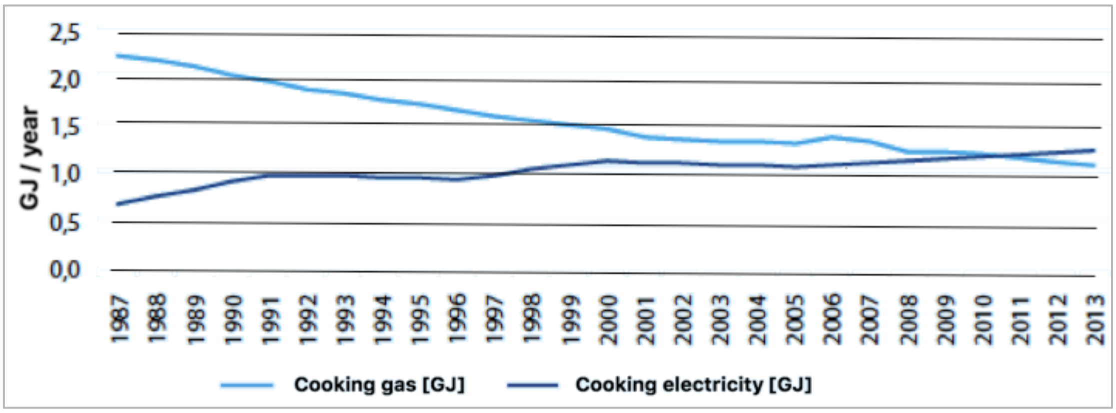

Figure 4: Development of energy use for cooking in the Netherlands (Gerdes et al., 2014)

4.1.4 District heating
The following trend that is discussed are the increasing number of dwellings connected to district heating. In 2014, approximately 350 thousand dwellings are connected to district heating, this is expected to increase to 500 thousand in 2030 (Schoots & Hammingh, 2015). The growth will predominantly focus on new constructed dwellings, which will result in approximately 6.3% of all heat demand that is covered by district heating in 2030 (Schoots & Hammingh, 2015). About half of the district heating is currently installed in MF dwellings (58%), the other half in SFT dwellings (42%), district heating is not used in SFD dwellings (Agentschap NL, 2011). The current ratio between dwelling types is extrapolated to 2030.

4.1.5 Ageing of the population
The final trend is the ageing of the population. Table 9 presents the share of residents over 65. People who are retired are expected to spend more time at home. Assuming that this group uses more electricity seems logical. However, the results of studies regarding electricity use of elderly vary. This might be caused by the relative little use of electrical appliances (Jones et al., 2014). Residents that are present during the day do increase the heat demand in a dwelling (Guerra Santin, Itard, & Visscher, 2009). Yet, there is no specific quantification of this trend and the retirement age in the Netherlands is rising. Therefore, this trend will not be quantified in the model.

Year	65+ and older (x1,000)	Share 65+ of total population
2011	2,595	16%
2015	3,006	18%
2020	3,400	20%
2025	3,798	22%
2030	4,197	24%

Table 9: Development of the ageing of the population in the Netherlands (BZK, 2013)

4.2 Development of the building stock
This paragraph discusses the amount of decommissioned and new constructed dwellings towards 2030 and presents an overview of the amount of dwellings in 2030.

New constructed buildings and decommission rates per construction period are used to model the building stock for 2030. The Ministry of Interior and Kingdom Relations have created a prognosis of the added and decommissioned dwellings per year until 2030

(BZK, 2013). The Ministry provides decommission rates per construction period from 2005 until 2011. These decommission rates are expected to remain approximately equal towards 2030 (BZK, 2013; Opstelten, Sinke, Bruijn, Borsboom, & Krosse, 2007). Table 10 and table 11 present the number of decommissioned dwellings per year distinguished per construction period and the annual construction of new dwellings.

Construction year	Decommission rate
<1965	71.1 %
1966 – 1974	15.9 %
1975 – 1991	5.7 %
1992 – 2005	1.3 %
2005 – 2014	0 %

Table 10: Share of annual dwelling decommissioning per construction period (BZK, 2013)

Requirement for new housing	Decommission / year	Gross adding / year
2010-2014	16,700	67,400
2015-2019	18,660	69,200
2020-2024	19,580	55,200
2025-2029	19,840	42,000

Table 11: Annual decommissioned and new constructed dwellings (BZK, 2013)

From the tables above, one can conclude that the residential sector in 2030 will consist of about 8.1 million dwellings (BZK, 2013). The share of one-person occupied dwellings in comparison to all dwellings is expected to increase 4% compared to 2015 (table 8) (BZK, 2013). I assume that the share of MF dwellings in comparison to all dwellings in the Netherlands is 4% higher in 2030 than it was in 2014. The amount of dwellings in the residential sector in 2014 and 2030 is presented in table 12.

	Building stock	2014	2030
SFD	<1965	441,000	419,395
	1965-1974	119,000	114,533
	1975-1991	221,000	219,407
	1992-2005	178,000	177,629
	2006-2014	67,038	67,038
	2015-2030	0	82,101
	SFD Total	**1,026,038**	**1,080,103**
SFT	<1965	1,286,000	1,203,478
	1965-1974	748,000	730,938
	1975-1991	1,103,000	1,096,915
	1992-2005	526,000	524,582
	2006-2014	256,060	256,060
	2015-2030	0	313,591
	SFT Total	**3,919,060**	**4,125,564**
MF	<1965	917,000	784,475
	1965-1974	433,000	405,599
	1975-1991	470,000	460,227
	1992-2005	359,000	356,723
	2006-2014	411,216	411,216
	2015-2030	0	503,608
	MF Total	**2,590,216**	**2,921,848**
Total		**7,535,315**	**8,127,515**

Table 12 Building stock in 2014 and in 2030

4.3 Baseline Heat demand in 2030

This paragraph presents a forecast of the annual heat demand per dwelling type in 2030 and the hourly pattern of that demand. The heat demand for space heating in 2030 is dependent on a number of variables: the thermostat settings, the outside temperature and the degree of insulation. This chapter will finish off by discussing the heat demand for cooking and tap water.

4.3.1 Thermostat settings

A report by Tigchelaar & Leidelmeijer (2013) provides average thermostat settings for dwellings in 2013. Each day is divided into five time blocks in which the thermostat settings are constant. However, the report by Tigchelaar & Leidelmeijer (2013) only model days during the week (table 13). Therefore, the report by Leidelmeijer & Grieken (2005) is taken into account to create a full profile for the whole week (table 14). The weighted average of the weekend thermostat setting is 19.8 °C. One would assume that the night temperature would decrease due to increasing awareness of climate change. But instead of decreasing, the night setting has increased almost one degree Celsius since 2000 (Tigchelaar & Leidelmeijer, 2013). This results in a smaller heat demand fluctuation between day and night. I assume that the preferred inside temperature for residents in the Netherlands in 2014 does not change towards 2030. The thermostat settings presented in table 13 and table 14 are combined in table 15 and are used to model heat demand in 2030.

Average temperature settings during the week	Temperature [°C]
23:00 - 06:00	15.8
06:00 - 08:00	17.5
08:00 - 16:00	18.8
16:00 - 19:00	19.3
19:00 - 23:00	20.0

Table 13: Profile for thermostat setting during the week (Tigchelaar & Leidelmeijer, 2013)

	Weekend	Share
Profile 1	16.2	4%
Profile 2	18.5	16%
Profile 3	20	35%
Profile 4	19.8	8%
Profile 5	20.1	11%
Profile 6	21.1	5%
Profile 7	21.7	20%

Table 14: Profile of different temperature settings in the weekend and the associated share of dwellings (Tigchelaar & Leidelmeijer, 2013)

Week	Temperature [°C]	Weekend	Temperature [°C]
23:00 - 06:00	15.8	**23:00 - 08:00**	15.8
06:00 - 08:00	17.5	**08:00 - 23:00**	19.8
08:00 - 16:00	18.8		
16:00 - 19:00	19.3		
19:00 - 23:00	20.0		

Table 15: Thermostat profile per week used in the model

4.3.2 Outside temperature

The Royal Netherlands Meteorological institute (KNMI) presents daily temperature data for different climate scenarios in 2030 (KNMI, 2015). An analysis of adjacent years (2028 to 2032) presents major fluctuations between years. These fluctuations are caused by model uncertainties and natural variation (Klein Tank, Beersma, Bessembinder, van den Hurk, & Lenderink, 2015). This data is unfit to model future climate patterns. The scenario most in line with the research of Vuuren et al. (2008) assumes a 1°C temperature rise in 2050 compared to 1990 and does not account for major changes in air circulation patterns. A linear temperature increase of 1°C from 1990 to 2050 would cause an increase from 2014 to 2030 of 0.25°C. Since no specific pattern is fit for modeling, the hourly temperature in 2030 is expected to increase 0.25°C relative to temperatures in 2014. To get a more realistic picture of the heat demand, values for Leeuwarden (in the north of the Netherlands), de Bilt (center) and Valkenburg (south) are all one third responsible for the calculation of the heat demand (KNMI, 2015a).

4.3.3 Insulation

The last variable that influences the space heating demand and the heat demand pattern is insulation. This paragraph starts with explaining the equation for total degree of insulation per dwelling. Then, the changes in insulation towards 2030 are discussed.

The heat transfer coefficients (U) [$Wm^{-2}K^{-1}$] per type of surface area per type of dwelling per construction period in 2011 are published by the Netherlands Enterprise Agency (Agentschap NL, 2011). This coefficient presents the degree of insulation per surface area. These data enable the creation of a total value for the *Degree of insulation* per dwelling[3] (equation 1).

$$Degree\ of\ insulation\ per\ dwelling = \sum_{1}^{N} (A_N * U_N)\ / A_{total} \qquad \text{(Eq. 1)}$$

N = Number of surfaces
A_N = Surface area of surface N [m^2]
U_N = Heat transfer coefficient of surface N [$Wm^{-2}K^{-1}$]
A_{total} = Total surface area of a dwelling [m^2]

The insulation improvements of dwellings towards 2030 are studied using the Energy Agreement for Sustainable Growth. This agreement on energy provides a guideline towards a sustainable society (SER, 2013). The agreement is widely supported, it is signed by forty-seven parties, among which the government. One of the goals is to improve the energy labels of 300,000 existing dwellings per year by two label steps. The Energy Research Center Netherlands (ECN) predicts that 300,000 annual improved dwellings is an optimistic forecast. Their report expects 225,000 dwellings to improve with two label steps each year, which sums up to 3.6 million dwellings until 2030 (Hekkenberg & Verdonk, 2014).

The energy label of a dwelling can be improved by adding insulation, installing a PV system, a SWH, etc. Awareness campaigns, simplification of measures and financial incentives are created to help reach the aforementioned goal.

One of the communication channels of the Dutch government is a website that provides advice on which energy saving measure to implement. The preferred measure for label improvements of dwellings built before 1991 is extra facade insulation (BZK, 2013; Milieu Centraal, 2015a). According to Milieu Centraal (Energielabel, 2015), the insulation of the facade of a SFT dwelling (which was not equipped with extra insulation before) increases the energy label by approximately 1.5 steps. The next logical step, according to the Ministry of Internal Affairs (BZK, 2013) is the insulation of windows. Together, this contributes to an improvement of two energy label steps (Energielabel, 2015). I follow the reasoning of the ECN and model the improvement of 225,000 dwellings per year, assuming that these measures are taken in the dwellings with the worst insulation values.

The dwellings that are constructed before 1974 have the worst insulation values. These improve by two label steps, which equal 3.6 million dwellings. All facades become insulated, all single glass windows become double glass and all double glass windows become HR glass.

4.3.4 Annual heat demand in 2030

The heat demand in 2030 per dwelling per construction period is constructed by accounting for the change in the degree of insulation. An improvement factor per dwelling can be calculated by dividing the *Degree of insulation* in 2030 by the *Degree of insulation* in 2011. The annual heat demand in 2030 is calculated by multiplying the improvement factor with the annual heat demand in 2014. Since the thermostat settings are assumed to remain constant, the only resulting aspect is correcting for climate

[3] All values for the *Degree of insulation* per dwelling type per construction period are presented in table 23

change. Equation 2 presents an example calculation for SFD dwellings constructed before 1965 with improved insulation and changes due to global warming.

$$Heat\ demand\ SFD < 1965_{2030} =$$

$$\frac{DoI\ SFD < 1965_{2030}}{DoI\ SFD < 1965_{2011}} * Hd\ SFD < 1965_{2014} * \left(1 - \frac{\Delta t_{CC}}{t_t - t_o}\right) \quad \text{(Eq. 2)}$$

DoI SFD < 1965_{2030}	= Degree of insulation of SFD dwellings built before 1965 in 2030 [$Wm^{-2}K^{-1}$]
DoI SFD < 1965_{2011}	= Degree of insulation of SFD dwellings built before 1965 in 2011 [$Wm^{-2}K^{-1}$]
Hd SFD < 1965_{2014}	= Heat demand of SFD dwellings built before 1965 in 2014 [$MJyear^{-1}$]
Δt_{CC}	= The temperature difference between 2014 and 2030 due to climate change (0.25 °C) [°C]
t_t	= Average temperature of thermostat setting in 2014 [°C]
t_o	= Average outside temperature in 2014 (De Bilt) [°C]

The space heating demand of dwellings constructed between 2014 and 2030 cannot use the same formula. Energy performance requirements of dwellings are tightened since 2015. The energy performance coefficient (EPC) for new buildings in the residential sector cannot exceed 0.4. The European Parliament has set guidelines for new dwellings from 2020 onwards. These dwellings are required to be almost energy neutral, in other words, have an EPC of 0 or lower (Europees Parlement en de raad van de Europese Unie, 2010; Hekkenberg & Verdonk, 2014; SER, 2013). I assume that the trend of improved insulation in new dwellings remains constant and extrapolate this for space heating demand for dwellings constructed between 2014 and 2030. EPC values of 0 can be achieved by the implementation of DGs.

The heat demand for cooking and tap water towards 2030 is discussed in the paragraph 4.1 ('Trends') and decreases with 2.5% per year.

4.3.5 Heat demand pattern 2030

The space heating demand pattern is the hourly heat that is required to heat a dwelling to the temperature set by the thermostat. This can be found by calculating the heat gains and heat losses within a dwelling. The most relevant heat flows in a dwelling are: Conduction, ventilation and infiltration (Bell & Lowe, 2014). The equations for these terms are presented below (Engineeringtoolbox, 2015).

$$Q_{conduction} = A * U * (t_{in} - t_{out}) \quad \text{(Eq. 3)}$$

$Q_{conduction}$	= Heat loss through conduction [W]
A	= Surface area connected to the outside [m^2]
U	= Heat transfer coefficient [$Wm^{-2}K^{-1}$]
t_{in}	= Thermostat setting [°C]
t_{out}	= Outside temperature [°C]

$$Q_{ventilation} = C_p * \rho * q_v * (t_{in} - t_{out}) \quad \text{(Eq. 4)}$$

$Q_{ventilation}$ = Heat loss through ventilation [W]
C_p = specific heat capacity of air = 1005 $Jkg^{-1}K^{-1}$
ρ = Density of air = 1.205 kgm^{-3}
q_v = air volume flow [m^3]

$$Q_{infiltration} = n * V * \rho * C_p * (t_{in} - t_{out}) \quad \text{(Eq. 5)}$$

$Q_{infiltration}$ = Heat loss through infiltration [W]
n = Number of air shifts [shifts/second] = 10^{-4} 1/second
V = Volume of the dwelling [m^3]

The demand pattern is calculated by dividing the hourly heat loss by the total heat loss. The value of the heat transfer coefficient is not required for calculating the heat demand pattern since it is constant over the year. The most influential values in the equations for the demand pattern are the outside temperature and the thermostat settings. Therefore, the following pattern can be equated for space heating demand in 2030 (see figure 5).

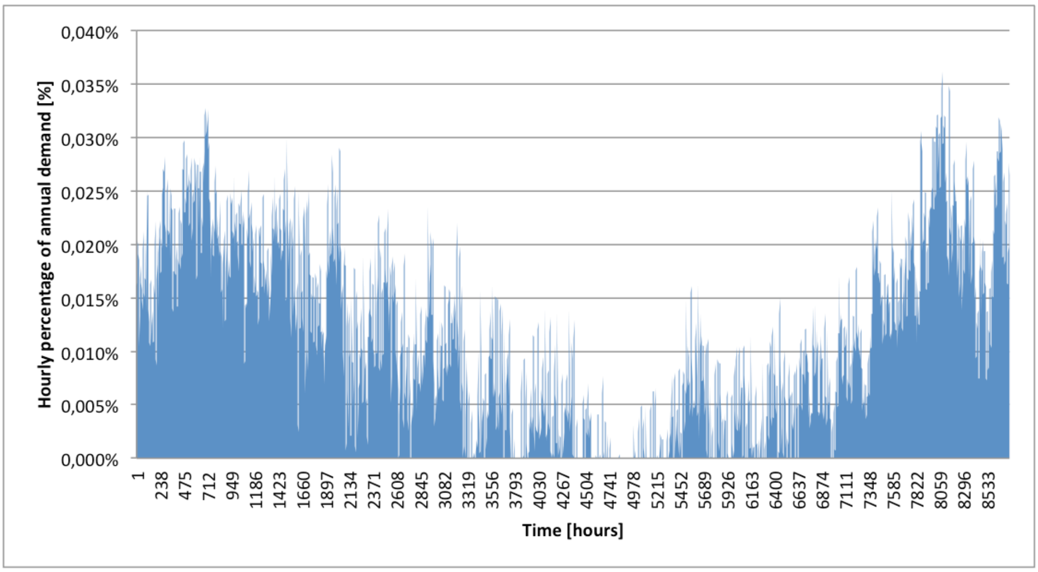

Figure 5: Space heating demand pattern for 2030, created from equation 3, 4 & 5

The gas supply pattern that is created by NEDU uses average values of historical measurements to find the gas supply pattern for 2014 (NEDU, 2015). This causes the pattern to be smoother than the one calculated here.

The specific pattern for tap water and cooking created by the NEDU (temperature independent pattern) is implemented in the model. Since no specific forecast can be constructed, the hourly pattern in 2030 remains equal to the pattern in 2014.

4.4 Baseline Electricity use in 2030

This section discusses the development of the annual Baseline Electricity use towards 2030 and the hourly pattern.

The ECN in combination with PBL, CBS and RVO created a forecast about the development of electricity use in the residential sector (Hekkenberg & Verdonk, 2014; Schoots & Hammingh, 2015). This forecast accounts for the increasing number of dwellings, increasing number of appliances and efficiency improvements of appliances. The forecast does not account for EVs and the increasing amount of HPs. Therefore, it is a solid baseline that can be extended by modeling the implementation of DGs and EVs. According to Hekkenberg & Verdonk (2014) and Schoots & Hammingh (2015), the annual Baseline Electricity use per dwelling reduces with 1.9% per year.

The efficiency improvements of appliances are expected to occur mainly in white goods and lighting. Scientific literature regarding the exact hourly impact of these improvements is not available (Hekkenberg & Verdonk, 2014). Therefore, the hourly distribution of the annual Baseline Electricity demand in 2030 is assumed to be equal to the distribution in 2014. The hourly electricity use and generation from DGs and EVs will be added or subtracted from the baseline pattern.

5. Technologies influencing energy use in 2030

Several technologies influence the energy demand of dwellings. This chapter takes the technologies most relevant to the research question into account. These are: photovoltaic systems, solar water heaters, heat pumps and electric vehicles. Their implementation rate, specific energy generation and/or demand and their expected impact are discussed.

5.1 Photovoltaic

This paragraph first presents an overview of PV systems in the Netherlands in 2014. Then, the development towards 2030 is discussed. The topics that are treated are: the number of PV systems, the efficiency in 2030, distinction per dwelling type and model difficulties. Finally, the high and low scenario for PV implementation is discussed.

5.1.1 Photovoltaic in 2014

The photovoltaic market is increasing rapidly and expected to grow even faster as a result of efficiency improvements, price reductions, growing environmental awareness and a growing number of lease companies (Confias et al., 2013; IEA, 2014). Due to this fast growing market, it is difficult to find reliable data on the number and power of PV systems in the residential sector in 2014. Multiple databases present figures about the amount of PV systems. These databases are mostly based on compulsory registration by buyers. There is, however, no penalty involved if consumers do not register or fill in the wrong data (Groene Courant, 2015; CBS, 2015). Table 16 presents an overview of different sources for installed PV power in the Netherlands as a whole and for the residential sector.

Time	Installed power [MWp]	Sector	Source
End of 2010	90	All	CBS, 2015h
End of 2011	149	All	CBS, 2015h
End of 2012	369	All	CBS, 2015h
2013	466	Residential	Epia, 2014
2013	665	All	Epia, 2014
End of 2013	746	All	CBS, 2015h
End of 2013	650	Residential	Stichting Monitoring Zonnestroom, 2014
End of 2013	722	All	Stichting Monitoring Zonnestroom, 2014
End of 2013	516	Residential	CBS, 2015
End of 2013	739	All	CBS, 2015
End of 2014	1,064	Residential	Groene Courant, 2015
End of 2014	1,100	All	EnerGO, Solar Energy, & Switch2SmartGrids, 2015
End of 2014	1,000	All	Roland Berger, 2015
End of 2014	1,048	All	CBS, 2015h

Table 16: Overview of sources for installed PV power in the Netherlands

The overview does not provide a clear share of residential PV power compared to total PV power in the Netherlands. Since no trend can be found, an average percentage is constructed that presents the share of the total PV power that is installed in the residential sector. The data from table 16 results in a residential share of PV in the Netherlands of 83%. The last four sources present installed PV power in the

Netherlands at end of 2014, by accounting for this 83%, an average installed power of 918 MWp can be calculated for the end of 2014.
A recent study established the electric output of an average PV system in the Netherlands per kWp. This value is 878 kWh/kWp (Sark, 2014). Therefore, the electricity generated by PV in the residential sector in the Netherlands in 2014 is approximately 806 GWh. This yield is generated by 259,325 dwellings (Groene Courant, 2015). Thus the average power per PV system is approximately 3.5 kWp and the average generated energy is about 3,100 kWh.

5.1.2 Photovoltaic in 2030

According to a study by Roland Berger (2015), the decreasing price of PV and the increasing technological development of batteries result in an installed power of 10 GWp in the Netherlands in 2030. Other studies present a goal for 2030 with an installed PV power of 20 GWp (DNV GL, 2015; EnerGO, Solar Energy, & Switch2SmartGrids, 2015). The goal of the report by Roland Berger is to create a forecast as accurate as possible, without much company interest in the outcome. The studies by DNV and TKI present the implementation of PV with respect to their ambition, both parties gain from a larger governmental push on PV implementation. Therefore, the forecast by Roland Berger is used to model the mid scenario. The other studies are implemented in the high growth scenario. By accounting for the 83% residential share, an overall installed capacity of 10 GWp leads to 8.3 GWp installed power in the residential sector, which is equal to an annual growth rate of 14.6 %. Since the Baseline Electricity use towards 2030 is decreasing, the power per PV system is not required to increase for dwellings to generate their own electricity use. Therefore, I assume that the average power per system in 2030 remains 3.5 kWp (this assumption only influences the implementation percentage, not the absolute values of generation).

The relation between peak power and generated electricity is continuously improving. Commercial PV modules in 2014 have efficiencies between 13 and 20% (Tanaka, 2010). Recent studies have created modules with efficiencies up to 46% (figure 6) (NREL, 2015). However, these efficiencies are measured in a laboratory and are most likely to expensive for private use in 2030 (PV-Tech, 2015). Experts expect an efficiency of about 29% for new commercial PV in 2030 (PV-Tech, 2015). The assumed output ratio for the installed PV in 2030 is 1,000 kWh/kWp (EnerGO et al., 2015). Therefore, the installed power in 2030 (8.9 GWp) is assumed to generate roughly 8,900 GWh electricity per year.

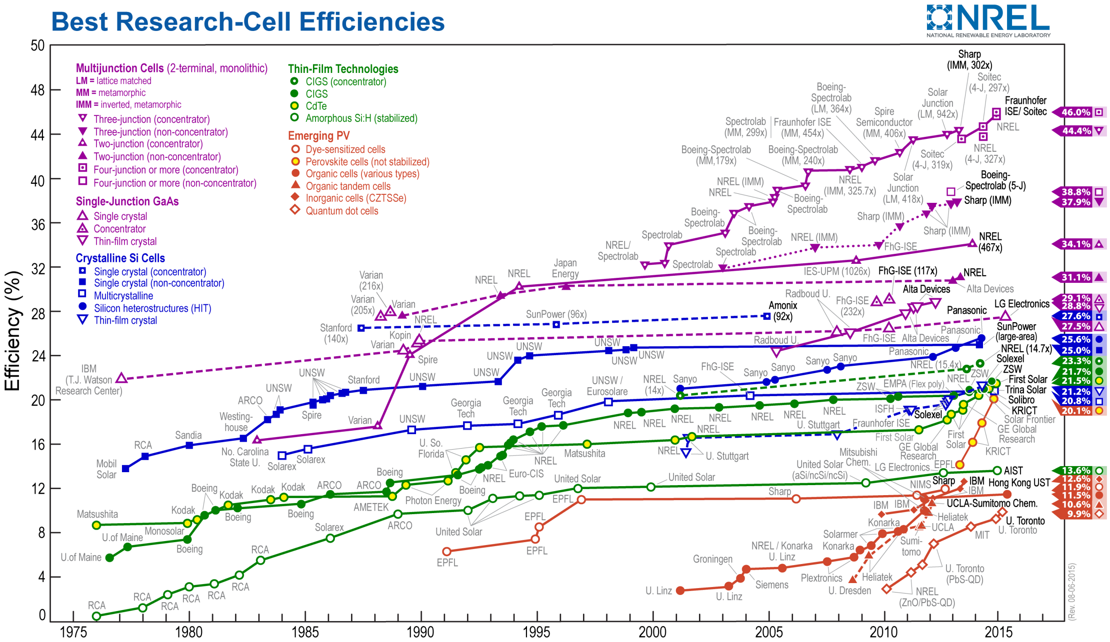

Figure 6: Best research cell efficiencies of PV modules (NREL, 2015)

The 8.9 GWp of PV needs to be assigned to dwelling types, this section presents the reasoning behind the distribution. The average available roof surface for the installation of PV on SFD dwelling is approximately 1.5 times larger than SFT dwellings and 3 times larger than MF homes (Lemmens et al., 2014). Furthermore, Vasseur and Kemp (2015) found that residents of SFD dwellings and SFT dwellings have a more positive attitude towards adoption of PV than MF dwellings. The main barrier for the adoption of a PV system are the investment costs (Vasseur & Kemp, 2015). The majority of current MF dwellings are in the category social housing, these dwellings can only be rented by households with a below average income (Agentschap NL, 2011). Therefore, the investment barrier for MF dwellings is relatively high compared to the other dwelling types. Most SFT dwellings are privately owned and approximately a third falls in the social housing category. SFD dwellings are almost all privately owned and households in SFD dwellings have the highest income (Agentschap NL, 2011; Jones et al., 2014). One can assume that the investment barrier is the lowest for SFD dwellings and the highest for MF dwellings. All these factors agree that the highest implementation of PV will occur in SFD dwellings and the lowest in MF dwellings. However, no specific ratio between dwelling types is available. Thus, an assumption is made that SFD dwellings have an implementation that is 1.5 times larger than the average, SFT dwellings have an implementation that is 1.3 times larger and the remaining (0.4 times the average) is placed on MF dwellings. Which results in an implementation of PV systems per dwelling type of: 42% for SFD, 37% for SFT and 11% for MF. Since no specific implementation values per dwelling type are available for 2014, these ratios will be applied to model 2014 as well.

Creating a forecast of cloud behavior in 2030 is a difficult, if not, impossible task. Cloud formations have a large impact on the output of PV (figure 7). It is therefore important to incorporate clouds into the model. The approach in the model is to assume the exact same hourly irradiance in 2030 as was measured in 2014. The solar irradiance is used in the same manner as the temperature. Thus measurements in 2014 in Leeuwarden, de Bilt and Valkenburg are used (KNMI, 2015a). Each dwelling type is assigned to a location to avoid smoothening the pattern by using an average value and avoid a complete collapse of PV generated electricity if a cloud is passing the measurement location. The following equations show the relation between the output of a PV panel and the dependent variables (Skoplaki, Boudouvis, & Palyvos, 2008).

$$P_{module} = AG_T\eta$$

$$P_{module} = 0.12 * AG_T\left(1 - 0.004\left(T_A + \omega\left(\frac{0.32}{8.911 + 2 * V_f}\right) * G_T - 25\right)\right) \quad \text{(Eq. 6)}$$

P_{module}	= Power output of a PV panel [W]
A	= Surface area of the panel [m^2]
G_T	= Irradiance [Wm^{-2}]
η	= Efficiency of the PV panel [-]
T_A	= Ambient temperature [°C]
ω	= Mounting coefficient [-]
V_f	= Free stream wind speed [ms^{-1}]

The electric output of PV is dependent on three variables that vary per hour: irradiance, temperature and wind speed. The temperature and irradiance are already discussed. The wind speed per location is published by the same source as the temperature and irradiance (KNMI, 2015a). The mounting coefficient influences PV output by distinguishing between flat roofs and sloped roofs. The coefficient for sloped roofs is 1.8 and for flat roofs is 1.2 (Skoplaki et al., 2008). SFD dwellings are modeled as sloped roofs, SFT dwellings are modeled as if 50% of all dwellings have a flat roof and MF dwellings are modeled as completely flat roofed. The direction of the panel is not taken into account separately for each system. The average losses due to deviations from the south orientation are already accounted for in the output ratio. The annual electricity per dwelling type is divided by the sum of the P_{module} over a year and multiplied by the P_{module} per hour. Figure 7 shows the outcome of the model on three typical example days, cloudy in the summer, sunny in the summer and sunny in the winter.

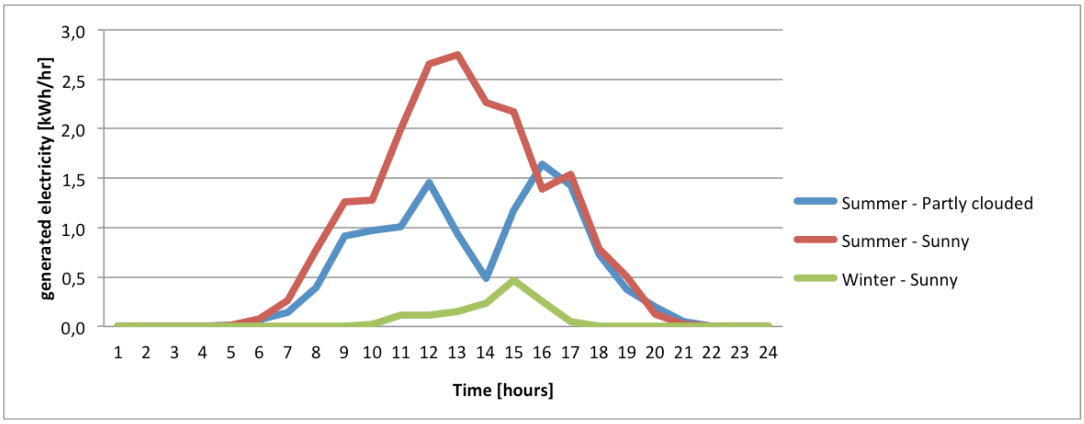

Figure 7: Electricity generated by an average PV system on a typical day in summer (clouded and sunny) and winter [kWh/hr]

5.1.3 High and low scenario

The implementation in the high scenario is determined by the studies mentioned earlier, 20 GWp of PV in the Netherlands in 2030 (DNV GL, 2015; EnerGO et al., 2015). By accounting for the 83% residential share, an overall installed capacity of 20 GWp leads to 16.6 GWp installed capacity in the residential sector, which is equal to an annual growth rate of 19.7%. Reliable studies with conservative forecasts are not available. Therefore the implementation of PV in the low scenario is based on the extrapolation of the average absolute amount of installed PV in the past five years (Groene Courant, 2015). The annual growth percentage of this scenario is 11.1%, which leads to an installed capacity of 4.2 GWp.

5.2 Solar water heaters

Solar water heaters (SWHs) generate the most heat when there is a lot of solar irradiation and the outside temperature is high. That causes the majority of solar water heaters to be applied for the heating of tap water instead of space heating (Friedel, Oostendorp, & Wagener, 2012). This paragraph presents the contribution of SWHs to heating in 2014, the development towards 2030, the distinction per dwelling type and the incorporation into the model.

5.2.1 Solar water heaters in 2014

A few types of SWHs can be distinguished; first there are covered and non-covered systems. These systems can use passive heat exchange (thermo siphon) or active heat exchange. Active heat exchange is used in the majority of SWH systems in the Netherlands. A report by the CBS divides the active SWH market in three areas; covered systems under 6 m^2 collector surface, covered system above 6 m^2 and non-covered. The first category is mainly used in the residential sector, the second for utility and the last for swimming pools (CBS, 2014). Table 17 presents an overview of the development of SWHs under 6m^2 collector surface in the Netherlands. The number of annual additional installed SWHs decreases. This is partially caused by the price that remained nearly constant for many years. This is a large burden on the technology since the major competitor is PV, whose prices dropped significantly over the past years. Another reason for the downturn is the unreliable subsidy arrangement (CBS, 2014). Additionally, the electrification of heating in the domestic sector does not contribute to the attractiveness of SWHs.

SWH Covered <6 m2	Number of SWH	Surface [m2]	Production [TJ]
2010	119,808	341,000	555
2011	125,589	354,000	576
2012	127,169	360,000	586
2013	128,959	366,000	595
2014 [4]	130,459	372,000	603
2030 [5]	159,389	452,364	735

Table 17: Overview of solar water heaters in the residential sector in the Netherlands (CBS, 2014)

The installed capacity of SWHs can theoretically contribute to approximately 0.2% of the heat demand in the residential sector in 2014. This percentage is based on the heat demand (table 4), amount of dwellings (table 12) and production of SWHs (table 17). The amount of heat that can actually be used is lower since the energy has to be used in the dwelling that generated the heat. Dependent on the dimensioning, the storage module can reach its maximum heat capacity on summer days with abundant solar irradiation within a few hours. This causes the system to remain inactive for the rest of the day when no hot water is required and thus the storage module remains full.

5.2.2 Solar water heaters in 2030

A forecast by Holland Solar predicts that SWHs generate 13 PJ heat in 2030, which is about 5% of the heat demand in the residential sector (Brom, 2011). This optimistic

[4] 2014 is based on extrapolation of the data from 2010 until 2013

[5] 2030 is modeled by assuming a constant implementation and decommission rate until 2030 that is equal to the rate in 2013

forecast is constructed with the assumption of a doubling of the gas price between 2007 and 2015, a constant subsidy scheme and major information campaigns. The gas price in 2015 is 19% higher than it was in 2007 and the current subsidy schemes are arranged on regional level and not applicable to the whole country (CBS, 2015d). No forecast can be found that uses realistic assumptions. Since there are no major changes expected in technological progress or price (CBS, 2014), I make the assumption that the implementation and decommission rate of 2013 follows through until 2030. This assumption results in a total SWH production of 735 TJ, which covers approximately 0.3% of the total heat demand in 2030. The 159,389 SWHs in 2030 realize an implementation of approximately 2%.

The reasoning behind implementation per type of dwelling has many similarities to the distribution of PV. Important factors are: available roof space, investment costs and attitude towards PV panels. Roof space and investment costs can be used for both PV and SWH implementation. I assume that households that have a positive attitude towards PV have the same attitude towards SWHs. Resulting in a higher adoption rate in SFD and SFT dwellings than MF dwellings. Therefore, the same implementation principle holds: 1.5 times the average distribution for SFD, 1.3 for SFT and 0.4 for MF. Since no specific distinction is available in SHWs in 2014, the implementation distribution between dwelling types is modeled for both 2014 and 2030.

Three of the steps taken in the model are discussed: the hourly distribution of the annual generation, the maximum capacity and the utilization. The average annual heat generated per dwelling type is allocated to an hour by dividing the annual heat by the total annual irradiation (de Bilt, Leeuwarden and Valkenburg) and multiplying that number with the hourly irradiation. This is the amount of heat that will flow towards the storage module. The amount of heat that can be stored in the storage module is dependent on the volume of the module. The storage volume of a standard residential SWH can range from 80 to 200 liter, I model the storage of a SWH using a storage volume of 150 liter, an incoming water temperature of 10°C and a maximum water temperature of 80°C (Zegers, 2013). This results in a maximum heat capacity of approximately 44 MJ. The hourly heat demand for tap water is deducted from the heat in the storage module.

5.2.3 High and low scenario

The SWH implementation in the upper bound scenario is presented earlier in this chapter. A study by Holland Solar based on optimistic assumptions found a total heat contribution of 13 PJ by SWHs in the Netherlands in 2030 (Brom, 2011). 13 PJ heat generated in 2030 is evident to an annual growth rate of 21.2%. The lower bound is calculated by extrapolating the trend where less SHWs are installed each year and the same amount is decommissioned, which results in an annual growth of 0.8% and a total heat contribution of approximately 0.7 PJ (CBS, 2014).

5.3 Heat pumps

Over two thirds of the residential energy use in the EU is used for space heating (European Comission, 2011). Therefore, the electrification of thermal energy use could have a major impact on the load profiles of gas and electricity. This paragraph discusses the different types of heat pumps, their impact in 2014, the development towards 2030 in all scenarios, the distinction per dwelling type and the implementation into the model.

5.3.1 Heat pumps in 2014

Three types of HPs are expected to have a significant impact on the energy use of dwellings in 2014 and 2030. These are: ground source based, air/water based and hybrid systems (Wagener & Mosterd, 2013). Most heat pumps installed in 2014 are ground source based (79%). These HPs have the highest seasonal performance factor (SPF) (table 18) and are almost solely installed in new constructed dwellings (Dhpa, 2013; Wagener, 2015). Air/water and hybrid heat pumps are much more popular in renovation. 15% of the HPs installed in 2014 are air/water based, these are easier to implement in existing dwellings, are cheaper but they have a lower SPF (Dhpa, 2013; Kleefkens, 2014; Wagener, 2015). Hybrid systems work in combination with the existing heating system and cover a limited heat demand. This results in lower investment costs but also in a lower SFP, 6% of the heat pumps in the Netherlands are hybrid systems (Dhpa, 2013; Kleefkens, 2014; Wagener, 2015).

Heat pump	Seasonal performance factor
Ground system	4.5
Air/water system	4.0
Hybrid system	3.5

Table 18: Seasonal performance factors per type of heat pump (Wagener, 2015)

The Dutch Heat Pump Association (DHPA) and CBS supplied data on the total amount of heat produced by HPs and their implementation per dwelling type. In 2014, a total of 2,238 TJ heat is produced by 121,226 HPs (CBS, 2015c), which is equal to about 0.4% of the residential heat demand. SFD dwellings have an implementation of 2.5%, SFT of 1.8% and MF of 0.9% (Dhpa, 2013).

5.3.2 Heat pumps in 2030

Hekkenberg & Verdonk (2014) and Schoots & Hammingh (2015) create two scenarios of HP implementation with different policy measures in the residential sector in the Netherlands. One with current adopted policies and one with intended policies. The DHPA created a forecast of heat pump implementation until 2020 distinguished per dwelling type and HP type (table 19) (Wagener & Mosterd, 2013).

Year	Policy	Heat pump implementation	Source
2020	Adopted	**4%**	Hekkenberg & Verdonk, 2014
2020	Adopted	**5%**	Schoots & Hammingh, 2015
2020	Intended	**6%**	Dhpa, 2013
2020	Intended	**6%**	Hekkenberg & Verdonk, 2014
2020	Intended	**6%**	Schoots & Hammingh, 2015
2030	Adopted	**6%**	Schoots & Hammingh, 2015
2030	Adopted	**7%**	Hekkenberg & Verdonk, 2014
2030	Intended	**8%**	Schoots & Hammingh, 2015
2030	Intended	**9%**	Hekkenberg & Verdonk, 2014

Table 19: Overview of heat pump implementation in dwellings values for different policies and sources, the percentage represents the number of residential heat pumps in the Netherlands divided by the amount of dwellings in the Netherlands

The implementation of HPs in 2020 in the report by the DHPA (2013) represents the goal that the organization is trying to reach and is only achievable, according to the DHPA, if extra policy measures are taken. Hekkenberg & Verdonk (2014) and Schoots & Hammingh (2015) find the same implementation in 2020 in the intended policy scenario, current policy results in a smaller implementation. Thus, the intended policy scenario is used for the high scenario and the adopted policy scenario is used for the mid scenario. The study by Schoots & Hammingh (2015) is a follow up study on the report by Hekkenberg & Verdonk (2014), thus the implementation of Schoots & Hammingh is used to model HPs in 2030. An implementation of 6% is equal to about 490,000 HPs. Their specific heat generation is dependent on the heat demand and the heating pattern of dwellings. The distinction per type of HP and per dwelling type constructed by the DHPA (2013) is adopted in the model (table 20).

Types of HPs	SFD	SFT	MF
Ground	46,577	102,811	22,880
Air/water	66,511	41,558	9,235
Hybrid	87,583	91,134	19,361
Total	200,671	235,503	51,477
	18.6%	5.7%	1.8%

Table 20: Implementation of heat pumps per type with a distinction per dwelling type in the mid scenario in 2030 (total implementation of 6%) (Dhpa, 2013)

Table 20 shows a high implementation of HPs in SFD dwellings relative to SFT and MF dwellings. This is caused by the high technical potential in comparison to SFT and MF dwellings. The larger heat demand and the above average income of SFD and SFT dwellings also contribute to this difference (Wagener & Mosterd, 2013). Building regulations result in a high percentage of HPs in new constructed dwellings. However, due to the relative large amount of existing dwellings, the amount of heat pumps in existing dwellings is larger in absolute numbers (Dhpa, 2013).

The HPs are modeled based on the heat demand of dwellings. The ground based heat pumps and air/water based heat pumps account for the total heat demand of the dwelling in which they are installed. The hybrid heat pump accounts for the base load, which is modeled as half of that dwellings peak load. This results in a share of about 90% of the dwellings heat demand that is accounted for by the hybrid heat pump. The heat output per HP is divided by the specific SPF factor to find the required hourly electricity input.

5.3.3 High and low scenario

The expected policy scenario by Schoots and Hammingh (2015) predicts an implementation of 8% in 2030 and is adopted as the high scenario. Since there is no literature available about a scenario were there is no economic growth, no incentives and a stable oil price, the growth of heat pumps in the low scenario is based on the following assumption. Half of the heat pumps installed between 2014 and 2030 in the mid scenario are installed in the low scenario. This results in an overall implementation of 3.7%, the ratio between dwelling types remains equal.

5.4 Electric vehicles

Electric vehicles (EVs) decrease the environmental impact of transport and lower the dependency of oil exporting countries. However, the additional electricity demand of dwellings could cause problems. This paragraph focusses on the implementation of EVs and their impact, first in 2014, later the development towards 2030.

5.4.1 Electric vehicles in 2014

Electric vehicles can be subdivided into three types, battery electric vehicles (BEV), extended range electric vehicles (EREV) and plug-in hybrid electric vehicles (PHEV). BEV only have an electric motor and have the possibility to be a zero emission vehicle, the battery capacity can be up to 90 kWh (Tesla, 2015). EREV typically have a smaller battery capacity (10-20 kWh) but are still able to function as a BEV, they have the possibility to extend their range by using their internal combustion engine (ICE) (CE Delft & Tno, 2014; Shahan, 2015). PHEV are hybrid vehicles that are meant to drive low speeds on the electric motor and high speeds (i.e. freeway) on the ICE. They can be charged using a plug and typically have a small battery capacity in the range of 3 to 10 kWh (CE Delft & Tno, 2014). Table 21 presents the amount of EVs in the Netherlands in 2014, EREV and PHEV are presented as one number.

Type	31-12-2013	31-12-2014	31-10-2015
BEV	**4,161**	**6,825**	**9,161**
EREV + PHEV	**24,512**	**36,937**	**56,735**
All cars	7,932,290	7,979,082	-
Share BEV	0.05%	0.09%	-
Share EREV + PHEV	0.31%	0.46%	-
Share EV	**0.36%**	**0.55%**	-

Table 21: Number of electric vehicles in the Netherlands (RVO, 2015; CBS, 2015f)

EVs are still in the early adopter phase, eventually, the demographic characteristics will not differ much from current vehicle owners with an ICE (Luiten et al., 2013). The owners of an EV in 2014 have a higher than average income on household level and received a higher degree of education (Harris & Webber, 2014). According to a report by the University of Technology in Delft, SFD dwellings have a high potential for electric vehicles. This potential is caused by the often rural location of the house and the fact that SFD dwellings often have more than one car (Maat & Kasraian, 2014). The option for home charging of EVs gives an advantage for SFD and SFT dwellings over MF dwellings (Maat & Kasraian, 2014). Based on the above-mentioned characteristics, I assume that the implementation of EVs in 2014 in SFD dwellings is 1.5 times larger than the average, the implementation of EVs in SFT dwellings are 1.3 times larger than the average and the remaining (0.4 times the average) is implemented in MF dwellings.

5.4.2 Electric vehicles in 2030

The developments of EVs towards 2030 will encompass an increased amount of EVs, an improved battery capacity, increased charging time and changed demographic characteristics of EV drivers.

The Netherlands is ambitious in the improvement and implementation of EVs. They set a goal to have 1 million EVs in 2025. Financial incentives, improved charging infrastructure and communication campaigns are created to contribute to a high adoption rate. Moreover, research into batteries is stimulated to increase their capacity and reduce prices (RVO, 2011). Still, the development of the amount of EVs towards 2030 is hard to predict, which is shown by the large deviations in literature. Table 22 presents an overview of studies and their result.

Time	Region	Prognosis	Source
2030	Worldwide	20% of all cars are PHEV/EREV 7% of all cars are BEV	(IEA, 2011)
2020	Europe	8% of new cars are BEV in 2020	(Mosquet et al., 2011)
2020	Deutschland	High scenario: rapid technical progress, high state support. 6-8% of new cars is BEV in 2020; 6-8% of new cars is PHEV/EREV in 2020 Low scenario: slow technical progress, low state support. 0.5% of new cars is BEV in 2020; 1% of new cars is PHEV/EREV	(Heymann, Koppel, & Puls, 2011)
2020	Netherlands	140,000 EVs (1.6% of fleet)	(Woelderen, 2011)
2020	Netherlands	7% of new cars is BEV in 2020	(Woelderen, 2011)
2037	Netherlands	>50% of new cars is EV in 2037	(Autolease Wereld, 2012)
2025	Netherlands	Ambition of 1 million EV	(RVO, 2011)
2020	Netherlands	200,000 EV in the Netherlands	(Schroten, Aarnink, & van Essen, 2015)
2030	Netherlands	Low scenario: 17% of new cars is EV in 2030 0.65 million cars in Netherlands Mid scenario: 35% of new cars is EV in 2030 1.2 million cars in Netherlands High scenario: 59% of new cars is EV in 2030 3.2 million cars in Netherlands	(Luiten et al., 2013)

Table 22: Overview of sources regarding implementation of EV in the future

Luiten et al. (2013) constructs three growth scenarios based on a literature study on the following combination of sources: Ministry of Economic Affairs (RVO, 2011), the International Energy Agency (IEA, 2011), Boston Consultancy Group (Mosquet et al., 2011), the Deutsche Bank (Heymann et al., 2011), ING (Woelderen, 2011), RAI (Autolease Wereld, 2012) and Shell (Shell, 2008). The results from Luiten et al. (2013) are presented in figure 8 and are adopted in the model.

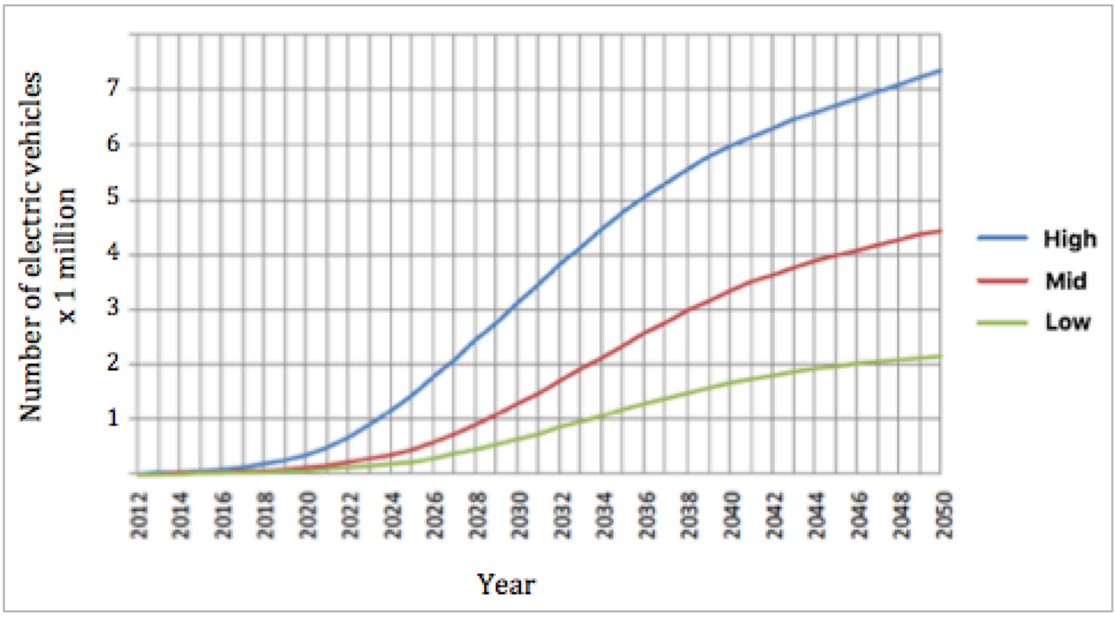

Figure 8: Forecast of electric vehicle implementation in the Netherlands (Luiten et al., 2013)

The change in battery capacity can influence the distance driven on the electric motor and therefore can affect the electricity use of dwellings. A trend in EV models in the near future (until 2018), that are already announced by the car industry, shows that the battery capacity of EVs is increasing and the average price per vehicle is decreasing (RVO, 2015a). Worldwide efforts from governments and from private concerns are made to improve the research into battery technologies (CE Delft & Tno, 2014). A major influence on the price of the batteries is the production volume, recent developments, such as Tesla's Gigafactory, will increase the production volume to a large extend (Tesla, 2015a; The Boston Consulting Group, 2010). The Boston Consultancy group predicts that the volume of all EV batteries in 2020 will be about three times the size of all lithium-ion batteries in consumer applications in 2010 (The Boston Consulting Group, 2010).

A load profile is constructed to measure the impact of EVs on the electricity use of the residential sector. EV drivers prefer to charge their vehicles at home, therefore it affects the electricity use pattern of their dwelling (Harris & Webber, 2014; Jabeen, Olaru, Smith, Braunl, & Speidel, 2013). Harris and Webber (2014) find that distinguishing for EV type has a very small impact on the load profile. Therefore, no distinction is made between PHEV and BEV. Luiten et al. (2013) constructed a scenario where all charging occurs at home without demand side management (i.e. charging start when the car is plugged in and stops when it is plugged out or when the battery is full). The profile is created using mobility data from 2010, which encompasses arrival time and average driving distance, which are provided by the CBS. Luiten et al. (2013) assumed that each car is immediately plugged in at arrival, that the average battery capacity of an EV in 2030 is 50 kWh and that the average driving range is 250 km. The resulting load profile is presented in figure 9.

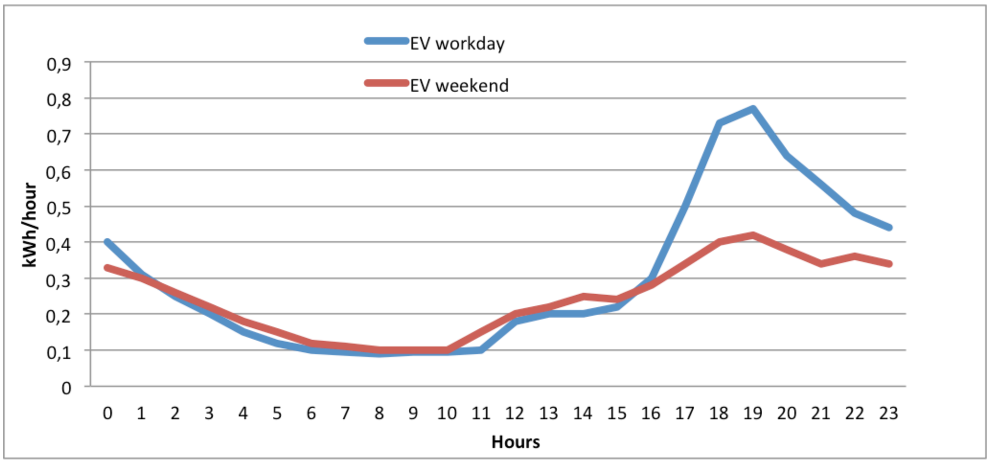

Figure 9: Load profile of an average EV in the Netherlands in 2030 (Luiten et al., 2013)

According to Luiten et al. (2013), the total electricity transferred per day in 2030 for an average EV is 7.2 kWh during a weekday and 5.9 kWh during a weekend day. The assumption they made was that an EV is able to drive 5 km/kWh, which is still a valid assumption since new EVs are still slightly below 5 km/kWh and are expected to become more efficient in the future (Harris & Webber, 2014; Tesla, 2015). Therefore, Luiten et al. use an average driving distance in 2030 of 36 km during the week and 29.5 km in the weekend. The average distance traveled by car in 2010 was 14.4 km/day and the average distance in 2014 was 15.6 km/day (CBS, 2015g; Luiten et al., 2013). However, one should take into account that the purchase of an EV is in general more expensive than a similar ICE vehicle and the price per kilometer of an EV is cheaper. Thus, it seems logical that EV owners have a larger average driving distance than ICE owners. Furthermore, the often rural location of EV owners has an increasing effect on the average driving distance (Maat & Kasraian, 2014) and the major financial incentive in the Netherlands to stimulate EV sales is focused on businesses (RVO, 2015b). The average distance traveled for a business meeting in 2014 was 41 km and the average for commuting was 24.6 km (CBS, 2015g). These factors in combination with the increasing distance traveled by cars each year are in line with the results from Luiten et al. (2013). The study by Spoelstra (2014) shows similar results regarding charging behavior.

The further the development of EVs, the lower the demographic differences will be between EV drivers and ICE drivers (Luiten et al., 2013). The mid scenario expects 1.2 million EVs in the Netherlands in 2030, which equals 15% of all cars. The EV demographics related to income and education are expected to fade out over time (Luiten et al., 2013). Easy accessible charging locations near their homes remains an important consideration for possible EV owners (Radtke et al., 2012). SFD and SFT dwellings are more likely to have a private parking spot than MF dwellings. Making the differences between dwelling types somewhat less skewed. Based on these factors, I assume that the EV ratio in 2030 per dwelling type will be 1.2 times the average for both SFD and SFT dwellings and 0.65 the average for MF dwellings.

5.4.3 High and low scenario

The scenarios constructed by Luiten et al. (2013) (table 22 and figure 8) are adopted as low, mid and high scenario. The high scenario results in an implementation of 3,100,000 EVs, which is equal to an annual growth of 31%. The low scenario expects an implementation of 700,000 EVs in 2030 and an annual growth of 19%.

6. Scenarios

This chapter presents an overview of the constructed scenarios throughout this study.

6.1 Mid scenario

The mid scenario is based on the literature research and assumptions summarized throughout this report. The best available literature or the average of multiple sources is used to find implementation rates and other characteristics per technology. These data are used to create the mid scenario. Implementation values for DGs and EVs are distinguished per dwelling type and insulation values are additionally categorized per construction period (table 23). Implementation percentages represent the percentage of dwellings that have adopted a specific technology. The average implementation for the whole residential sector is: 28% PV, 6% HP, 2% SWH and 15% EV.

<table>
<tr><th colspan="3">Implementation ratio</th><th colspan="6">Types of dwellings</th></tr>
<tr><th colspan="3"></th><th colspan="2">Detached</th><th colspan="2">Terraced</th><th colspan="2">Multi family</th></tr>
<tr><th colspan="3"></th><th>2014</th><th>2030</th><th>2014</th><th>2030</th><th>2014</th><th>2030</th></tr>
<tr><td rowspan="10">Technologies</td><td colspan="2">Photovoltaic</td><td>5.2%</td><td>42%</td><td>4.5%</td><td>37%</td><td>1.2%</td><td>11%</td></tr>
<tr><td colspan="2">Heat pump</td><td>2.6%</td><td>19%</td><td>1.9%</td><td>6%</td><td>0.8%</td><td>2%</td></tr>
<tr><td colspan="2">Solar water heater</td><td>2.6%</td><td>2.9%</td><td>2.3%</td><td>2.5%</td><td>0.7%</td><td>0.8%</td></tr>
<tr><td colspan="2">Electric vehicles</td><td>0.8%</td><td>18%</td><td>0.7%</td><td>18%</td><td>0.2%</td><td>10%</td></tr>
<tr><td rowspan="6">Insulation [W/m^{2}K]</td><td><1965</td><td>1.76</td><td>1.21</td><td>2.03</td><td>1.30</td><td>1.97</td><td>1.38</td></tr>
<tr><td>1965-1974</td><td>1.65</td><td>1.12</td><td>1.69</td><td>1.11</td><td>1.69</td><td>1.31</td></tr>
<tr><td>1975-1991</td><td>1.01</td><td>1.01</td><td>0.98</td><td>0.98</td><td>0.81</td><td>0.81</td></tr>
<tr><td>1992-2005</td><td>0.54</td><td>0.54</td><td>0.56</td><td>0.56</td><td>0.49</td><td>0.49</td></tr>
<tr><td>2006-2014</td><td>0.44</td><td>0.44</td><td>0.45</td><td>0.45</td><td>0.42</td><td>0.42</td></tr>
<tr><td>2015-2030</td><td>0.34</td><td>0.34</td><td>0.34</td><td>0.34</td><td>0.35</td><td>0.35</td></tr>
</table>

Table 23: Implementation ratios in 2030 in mid scenario, the percentages represent the amount of DGs per dwelling type divided by the amount of dwellings of that dwelling type

The associated absolute values (i.e. energy generation, use and savings) of all dwellings within a type are presented in table 24. Positive values express required energy and negative values express generated or saved energy. Heat pumps have a positive and negative column, the negative column represents the heat delivered and the positive column represents the required electricity. The electricity required by the pump of active SWHs is not taken into account because this will have an insignificantly small effect. The top two rows of table 24 present the total energy use of all dwellings within a dwelling type in 2030.

Energy requirement			Types of dwellings					
			Detached		Terraced		Multi family	
			2014	**2030**	2014	**2030**	2014	**2030**
Heat demand in 2030 [TJ]				**50,852**		**128,725**		**45,985**
Electricity use in 2030 [TJ]				**18,964**		**51,428**		**22,591**
Technologies	**Photovoltaic [TJ]**		-589	**-5,943**	-1,949	**-19,673**	-1,380	**-4,197**
	Heat pump (heat) [TJ]		-488	**-9,215**	-1,349	**-6,814**	-402	**-825**
	Heat pump (el) [TJ]		156	**2,388**	432	**1,715**	129	**207**
	Solar water heater [TJ]		-120	**-147**	-398	**-485**	-85	**-104**
	Electric vehicles [TJ]		76	**1,721**	251	**6,574**	50	**2,497**
	Insulation [TJ]	<1965	-	**-10,407**	-	**-22,256**	-	**-6,950**
		1965-1974	-	**-2,556**	-	**-9,761**	-	**-2,057**
		1975-1991	-	**-**	-	**-**	-	**-**
		1992-2005	-	**-**	-	**-**	-	**-**
		2006-2014	-	**-**	-	**-**	-	**-**
		2015-2030	-	**-**	-	**-**	-	**-**

Table 24: Energy generation, use or savings [TJ] per technology for all dwellings in the Netherlands of that type in 2014 and 2030 in the mid scenario (negative values represent generation or savings, positive values represent use)

6.2 High and low scenario

The low and high scenarios are created using literature that is available for the upper- and lower bound implementation values. The high and low scenarios are previously discussed for all technologies except for insulation. These are presented in the following section.

6.2.1 Insulation

The mid scenario follows the reasoning of the ECN that 300,000 improved dwellings per year are optimistic. The high scenario assumes that the goal of the energy agreement of sustainable growth is reached. Thus, until 2030, 4.5 million dwellings (300,000 per year) improve their energy label by two steps due to improved insulation. The low scenario assumes that from 2014 to 2030 only the windows receive additional insulation. The amount of additional insulated dwellings is adapted from the energy agreement (300,000 per year, 4.5 million in total). The manner of improvement stays the same as well; single glass becomes double glass and double becomes HR glass.

An overview of the absolute energy generation, use and savings per scenario for the whole residential sector is presented in table 25. Appendix I present the implementation percentages, the absolute values per scenario per dwelling type and an overview of the implementation percentages per scenario for the whole sector.

Energy requirement for the whole residential sector			2014	Scenarios 2030 Low	Scenarios 2030 Mid	Scenarios 2030 High
Total heat demand [TJ]			**151,939**	**288,632**	**225,562**	**229,010**
Total electricity use [TJ]			**93,547**	**87,415**	**92,983**	**111,428**
Technologies	**Photovoltaic [TJ]**		-3,918	-18,299	-29,813	-59,627
	Heat pump (heat) [TJ]		-2,238	-12,510	-16,854	-21,983
	Heat pump (el) [TJ]		717	3,199	4,310	5,622
	Solar water heater [TJ]		-603	-687	-735	-3,975
	Electric vehicles [TJ]		377	6,296	10,793	27,881
	Insulation [TJ]	<1965	-	-7,719	-39,614	-39,614
		1965-1974	-	-3,654	-14,374	-14,374
		1975-1991	-	-2,631	-	-5,212
		1992-2005	-	-	-	-
		2006-2014	-	-	-	-
		2015-2030	-	-	-	-

Table 25: Energy generation, use and savings in 2030 in the whole residential sector for different scenarios

7. Results

This chapter presents the results of the model regarding energy use in 2030. The changes in energy use towards 2030 are the effect of; the electrification of heating and driving, implementation of DGs and improved insulation. An overview of the findings of the model are presented based on eight sections, the first seven analyze and answer the sub research questions. The results from these questions provide the required knowledge for the final section, which answers the research question. All sections are written as if the output of the model is the truth. However, the results depend on the assumptions in this study. Bear this in mind while reading this chapter. The hourly demand patterns per energy carrier with a distinction per technology are presented in Appendix V.

7.1 How will the total energy use in 2030 compare to the total energy use in 2014?

The total electricity use in 2030 is based on developments between 2014 and 2030. The improved efficiency of appliances causes the electricity use to decrease. However, the electrification of heating and driving (i.e. HPs and EVs) and the increasing number of dwellings has the opposite effect on the electricity use. Table 26 shows that the electricity use does not change much between 2014 and 2030 (mid). The improved efficiency and increased DGs balance each other out. The energy use per average dwelling is presented in table 27. The electricity use per dwelling declines in SFT and MF dwellings. The relative large increase in implementation of HPs in SFD dwellings causes the electricity use towards 2030 to increase in those dwellings. Differences in electricity use in mid and high scenario occur mostly due to an increased implementation of EVs.

The changes in gas use from 2014 towards 2030 are mainly caused by the improved degree of insulation and the increased implementation of HPs. This effect is enhanced by the incremental temperature increase of 0.25 °C due to global warming. These combined changes result in a major decrease in gas use (approximately 92 PJ) (table 26). Approximately half of the declined gas use results from an improved degree of insulation.

The number of dwellings connected to district heating increases with 40% between 2014 and 2030. The improved insulation of dwellings cause the amount of energy supplied by district heating to increase only by 30% towards 2030 in the mid scenario, from 11.9 PJ in 2014 to 15.7 PJ in 2030. The largest increase of district heating will occur in MF dwellings.

	2014	2030		
		Mid	Low	High
Electricity [PJ]				
SFD	17.9	18.7	17.2	22.2
SFT	52.7	50.9	47,6	61.9
MF	22.9	22.5	21.4	26.5
Residential sector	93.5	92.1	86.2	110.6
Gas [PJ]				
SFD	79.3	52.9	65.3	48.6
SFT	181.4	134.0	157.8	127.8
MF	63.8	46.7	51.8	46.1
Residential sector	324.5	233.6	274.9	222.6
District heating [PJ]				
SFD	0.0	0.0	0.0	0.0
SFT	6.5	7.0	8.2	6.7
MF	5.4	8.7	10.3	8.3
Residential sector	11.9	15.7	18.5	15.0
Total energy use [PJ]	**429.9**	**341.4**	**379.6**	**348.1**

Table 26: Energy use in the residential sector for all dwellings in 2014 and 2030, with low and high scenario as range [PJ]

	2014	2030		
		Mid	Low	High
Electricity [MJ]				
SFD	17.1	17.3	16.0	20.5
SFT	13.1	12.3	115	15.0
MF	8.5	7.7	7.3	9.1
Gas [MJ]				
SFD	77.3	49.0	60.5	45.0
SFT	46.3	32.5	38.2	31.0
MF	24.6	16.0	17.7	15.8
District heating [MJ]				
SFD	0.0	0.0	0.0	0.0
SFT	1.7	1.7	2.0	1.6
MF	2.1	3.0	3.5	2.8

Table 27: Energy use in the residential sector per average dwelling in 2014 and 2030, with low and high scenario as range [PJ]

7.2 How will the total net energy demand from the transmission system in 2030 compare to the demand in 2014?

The net energy demand is the amount of energy that is supplied by the transmission grid. The only DG that has a significant effect on the difference from energy use to net energy demand is PV. Therefore, only electricity demand is taken into account.

The overall implementation in the residential sector of 28% PV (mid) has such a large influence on the net electricity demand that the picture of electricity use is completely reversed. The low scenario has a larger demand and the high scenario has a smaller demand than the mid scenario. PV systems generate approximately a third of the total electricity use in the residential sector.

The total net electricity demand in 2030 relative to net demand in 2014 is decreased by approximately 30% due to the influence of PV (table 28). In the high scenario, the electricity demand decreases with almost 45%.

SFD dwellings have the largest implementation of PV (42%); however, the relative small amount of SFD dwellings (approximately 1 million) result in a medium influence on electricity demand. The somewhat smaller implementation of PV in SFT dwellings (37%) has a much larger absolute influence on electricity demand due to the large amount of SFT dwellings (approximately 4 million).

Figure 10 presents the share per energy carrier of the total net energy demand in the residential sector. An interesting result is that the share of gas and net electricity demand will remain approximately equal. The electricity use however, increases and will account for 28% of the total energy use. The share of district heating increases with about 2% of the total energy demand.

Electricity [PJ]	2014	2030		
		Mid	Low	High
SFD	17.6	12.7	13.6	10.3
SFT	51.2	31.2	35.5	22.5
MF	21.9	18.3	18.8	18.1
Residential sector	**90.6**	**62.2**	**67.9**	**50.9**

Table 28: Net electricity demand of all dwellings of a type in the residential sector in 2014 and 2030, with low and high scenario as range [PJ]

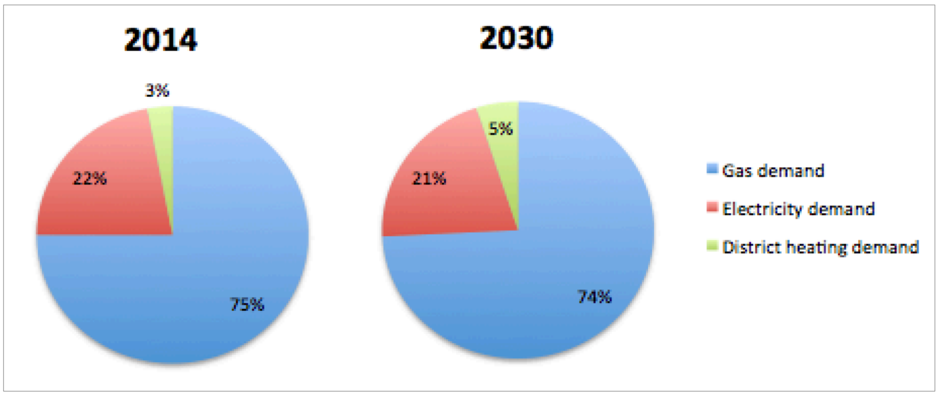

Figure 10: Comparison of the share of net energy demand per energy carrier in the residential sector in 2014 (total energy demand 427 PJ) and the mid scenario in 2030 (total energy demand 312 PJ)

7.3 How will the minimum and maximum net energy demand per hour in 2030 compare to demand in 2014?

The minimum and maximum net energy demand per hour in 2030 are expected to deviate substantially from those in 2014 due to the implementation of energy using and energy generating devices. Figure 11 and figure 12 present histograms of the hourly demand in 2014 and the mid scenario in 2030. Minimum and maximum energy demand per scenario and per dwelling type are presented in Appendix II.

The differences between minimum values of net electricity demand in 2014 and 2030 can almost completely be attributed to implementation of PV. Without PV, the minimum values in 2030 are quite similar to the ones in 2014. With PV, there are hours in which there is a surplus of 11.7 TJ/hr in the residential sector. This electricity needs to be transported and utilized in other sectors. Even in the low scenario, there are hours in which 3.5 TJ/hr excess electricity is generated. The high scenario anticipates hours of -33.4 TJ/hr. The most influential aspect of increasing the maximum net electricity demand is the implementation of EVs. The improved efficiency of appliances compensates for this increased peak demand. Figure 11 shows that there will be many hours per year where an electricity surplus occurs in the residential sector.

The most extreme values in net demand over the whole residential sector are for SFT dwellings. However, the average SFD shows the largest peaks for average dwellings. These peaks are caused by the relative high implementation of PV.

The minimum gas demand occurs on summer days where gas is only required for tap water and cooking. The implementation of SWHs in combination with the increased number of electric stoves results in slightly lower values in 2030 than in 2014. The small impact of SWHs can be deduced from the limited differences between the scenarios. The maximum gas demand in 2030 is significantly lower than it was in 2014 due to the improved degree of insulation and the electrification of heating. The maximum hourly demand in 2014 was 128 TJ and is expected to be 80 TJ in 2030.

The maximum hourly demand without improved insulation would be 97 TJ, while the maximum demand without HPs would be 84 TJ in 2030. Thus, insulation has a larger impact than the HPs. However, the largest impact can be attributed to the decommissioning of old energy inefficient dwellings and the construction of new energy efficient dwellings.

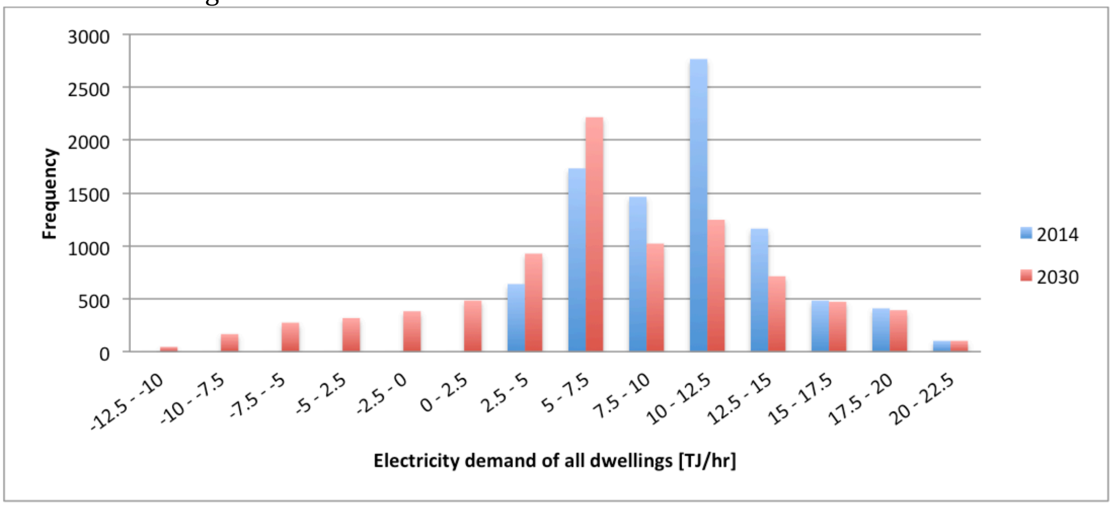

Figure 11: Histogram of the number of hours with a specific net electricity demand of all dwellings in the residential sector in 2014 and 2030 in the mid scenario

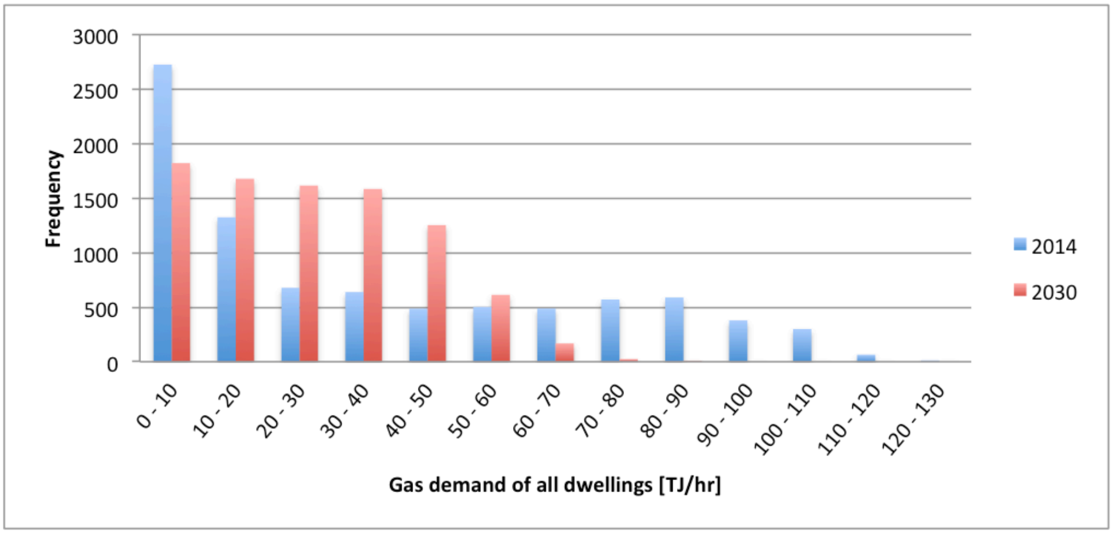

Figure 12: Histogram of the number of hours with a specific gas demand of all dwellings in the residential sector in 2014 and 2030 in the mid scenario

7.4 How will the seasonal energy demand deviation in 2030 compare to the seasonal deviation in 2014?

This section analyzes the seasonal deviation in energy demand, a division is made by dividing the year into a summer period (1st of April until the 30st of September) and a winter period (1st of October until the 31th of March). For each season, the electricity-, gas- and district heating demand is depicted for SFD, SFT and MF dwellings. An overview of the findings is shown in figure 13. Appendix III presents a more comprehensive overview.

The net electricity demand in summer and winter in 2014 are quite similar. The demand in winter is slightly higher mostly due to the higher need for illumination. The electrification of heating and the implementation of PV in the mid scenario in 2030 results in an net electricity demand in summer that is 55% lower than demand in winter. The demand in summer is 40% smaller in the low scenario and 90% in the high scenario.
SFT dwellings in the high scenario provide a remarkable result; more electricity is generated than required over the whole summer period. Despite the high implementation of electric vehicles in the high scenario (48%), the photovoltaic impact (74% implementation) is large enough to cover all electricity use. The higher implementation of HPs in SFD dwellings is the reason that the net demand of SFT dwellings is negative and that of SFD dwellings is positive.

The gas demand shows a reversed trend; the differences between summer and winter in 2014 are relatively large and decrease towards 2030. The declining gap between the seasons is a result of improved insulation and to a lesser effect of HPs, which both reduce gas demand in the winter.

The relative deviation of district heating between seasons declines towards 2030. Similar to gas demand, the increased amount of insulation plays an important role. However, due to the increase of district heating connected dwellings in 2030, the absolute seasonal deviation increases in all scenarios.

SFT dwellings are responsible for the largest deviations between summer and winter for all energy carriers, both in 2014 and in 2030. The relative large number of SFT dwellings in the residential sector achieves this influence.

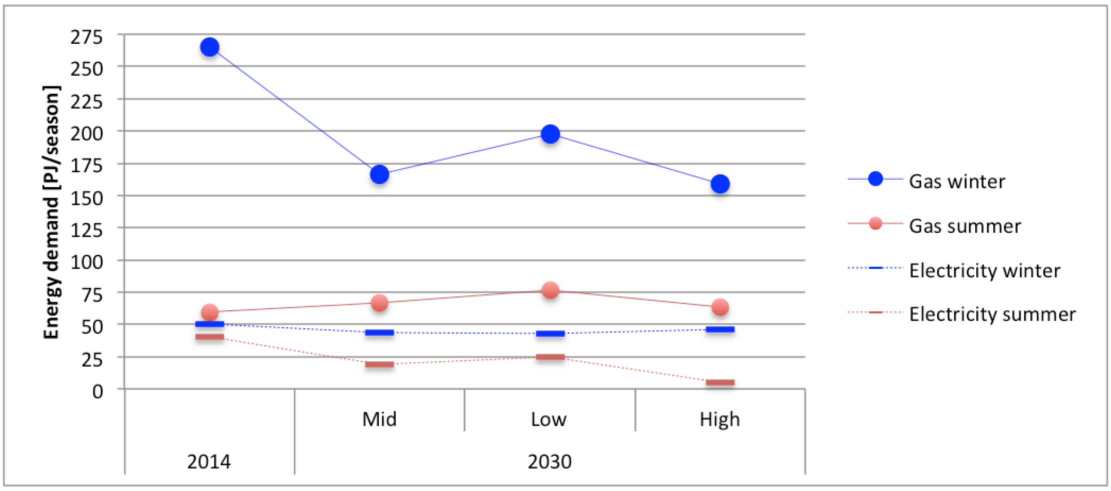

Figure 13: Seasonal net electricity and gas demand in 2014 and three scenarios in 2030 [PJ/season] (the lines between scenarios are drawn for visual reasons)

7.5 How do hourly fluctuations of net energy demand in 2030 compare to the fluctuations in 2014?

The hourly fluctuations of energy demand are analyzed by calculating the standard deviation of the hourly net demand patterns. This measure provides insight into the variation of the demand pattern per energy carrier over a year. The height of the standard deviation acts as a proxy for the degree of fluctuation in the net energy demand. Table 29 presents the standard deviation per dwelling type and for the whole sector for all energy carriers in 2014 and 2030. The standard deviation of electricity and district heating increases while the standard deviation of gas decreases. This effect is partly driven by the seasonal deviation. Therefore, in order to analyze the hourly fluctuations without the seasonal effect, the standard deviation of the change in energy per hour relative to the previous hour is calculated (table 30). This provides a great insight in the change in hourly volatility of energy demand.

In addition, standard deviations over shorter time periods are constructed. These deviations provide a better insight in the moments that extreme fluctuations occur. These results are presented in Appendix IV.

The standard deviation of net electricity demand increases towards 2030 in all scenarios in a range of 1.2 to 3.1 times the deviation in 2014 (table 29). The deviation relative to the previous hour increases in a range of 1.1 to 2.8 times the value in 2014 (table 30). However, the standard deviation in January 2014 is similar to January 2030 (mid). In the summer, when PV has a larger influence, the standard deviation increases drastically. The standard deviation in SFT dwellings triples in the mid scenario and is 6 times larger for the whole residential sector in the high scenario. This will increase the burden on the electricity grid and the distribution system operator (DSO). Additionally, it will be harder to match demand to supply.

The standard deviation of gas demand over the whole year and the deviation relative to the previous hour in the mid scenario in 2030 are approximately half of the deviation in 2014 and decreases significantly in all other scenarios as well. The winter months are responsible for these changes. The improved insulation decreases the required heat to maintain a comfortable temperature. Therefore decreasing the peaks in gas demand. In the summer months, standard deviation in 2030 is higher than it was in 2014. This is caused by the construction of the demand pattern. Gas demand patterns in 2030 are based on outside temperatures. Therefore, heating in summer is required when the outside temperature is lower than the thermostat setting. Values in 2014 are based on averaged historical data. These historical data expect an almost negligible space heating demand in summer.

	2014	2030		
		Mid	Low	High
Electricity [TJ]				
SFD	0.8	1.4	1.0	2.5
SFT	2.3	4.1	2.9	7.9
MF	0.8	1.1	0.9	1.8
Residential sector	**3.9**	**6.4**	**4.6**	**11.9**
Gas [TJ]				
SFD	8.0	3.7	4.7	3.4
SFT	18.2	9.4	11.4	8.9
MF	6.4	3.3	3.7	3.3
Residential sector	**32.6**	**16.3**	**19.8**	**15.6**
District heating [TJ]				
SFD	0.0	0.0	0.0	0.0
SFT	0.7	0.5	0.6	0.5
MF	0.5	0.6	0.7	0.6
Residential sector	**1.2**	**1.1**	**1.3**	**1.0**

Table 29: Standard deviation of net demand per energy carrier of all dwellings per type over a complete year in 2014 and 2030 [TJ]

	2014	2030		
		Mid	Low	High
Electricity [TJ]	1.4	2.1	1.5	3.9
Gas [TJ]	7.7	3.9	4.6	3.8
District heating [TJ]	0.28	0.27	0.31	0.25

Table 30: Standard deviation of hourly change in net energy demand relative to the previous hour over a year [TJ]

7.6 What is the effect on the energy demand of neighborhoods, where dwellings have similar decentralized generators?

Four types of neighborhoods are constructed (table 31) in order to answer sub question six. These fictional neighborhoods are intended to show that neighborhoods can substantially deviate from the average energy demand of all dwellings in the Netherlands. Each neighborhood consists of 1,000 SFT dwellings.

Stricter EPC regulations influence the construction of new buildings. In order to comply with these regulations, energy saving or energy generating measures have to be implemented. This could result in newly constructed neighborhoods where each dwelling is equipped with a HP or a PV system. Furthermore, some housing corporations renovate all dwellings in a neighborhood with standard DGs measures (Schoots & Hammingh, 2015; Enexis, 2015). Thus, homogeneity within neighborhoods could exist while large heterogeneity between neighborhoods might occur. These effects result in the possibility of large deviations in energy demand between neighborhoods.

Neighborhoods	Type 1	Type 2	Type 3	Type 4
PV	None	Full	Full	Mid scenario
SWH	None	Mid scenario	Mid scenario	Mid scenario
HP	None	Mid scenario	Full	Full
EV	None	Mid scenario	Full	Full
District heating	None	None	Full	None

Table 31: implementation of DGs in four types of neighborhoods, PV Full is calculated as one 3.5 kWp PV system per dwelling, HP and EV Full is modeled as one system per dwelling and district heating full is modeled as if all heat is supplied by district heating

The difference in implementation of DGs, EVs and district heating can have a major effect on the net energy demand of a neighborhood. On the one hand, gas demand can increase, relative to the mid scenario in 2030. A gas demand of 36 TJ/yr could occur in neighborhoods without any implementation of DGs, EVs and district heating. On the other hand, neighborhoods that are completely connected to district heating do not require any gas (figure 14).

The annual net electricity demand can fluctuate between 1.2 and 14.7 TJ/yr/neighborhood, dependent on the specific implementation of DGs in that neighborhood. The minimum and maximum hourly net electricity demand are able to fluctuate substantially per area (figure 15). The maximum hourly demand in neighborhood three and four are approximately 2.5 times higher than maximum demand in the mid scenario. In addition, the minimum hourly demand of neighborhood one is 0.5 GJ/hr while the minimum demand of neighborhood two is -7.8 GJ/hr.

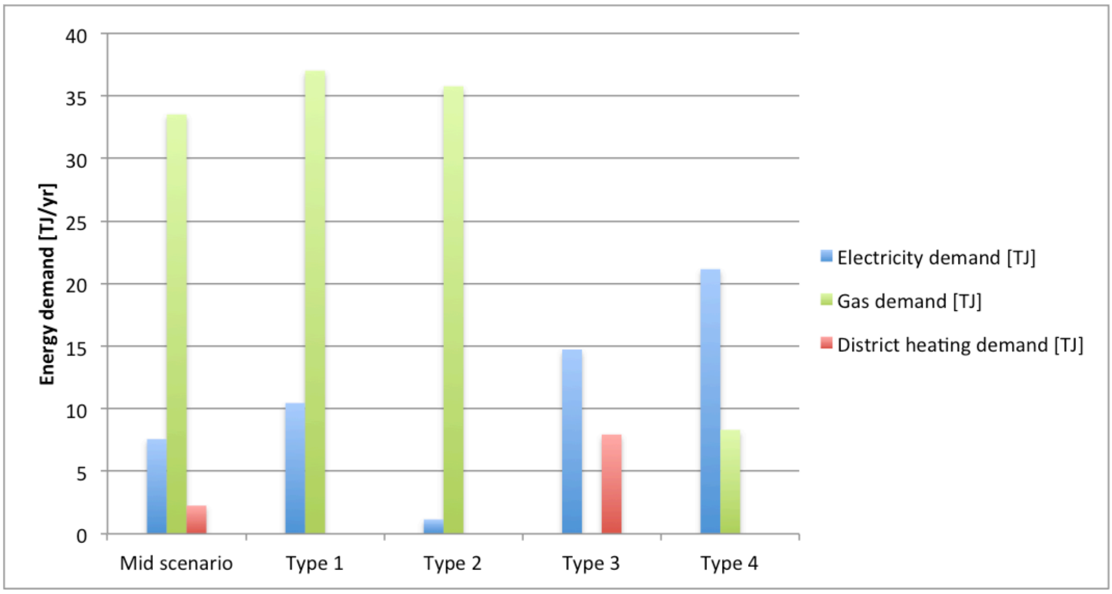

Figure 14: Net energy demand of neighborhoods of 1,000 SFT dwellings in 2030 in different types of neighborhoods compared to the average neighborhood in the mid scenario

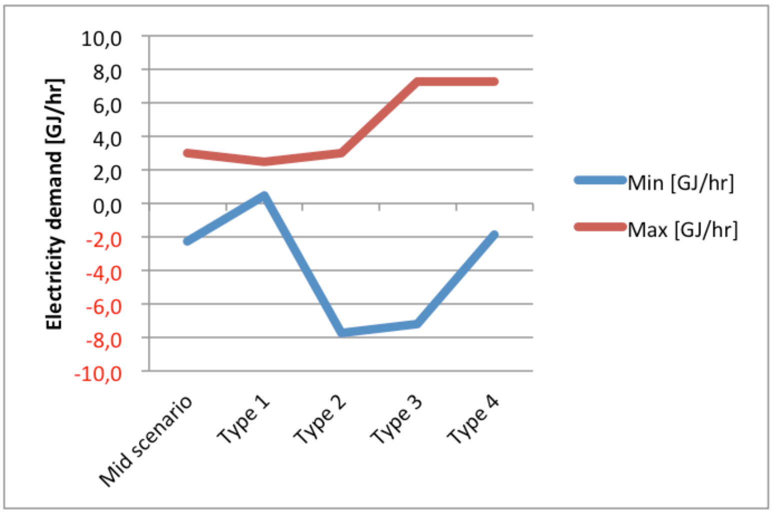

Figure 15: Minimum and maximum hourly net electricity demand in neighborhoods of 1,000 SFT dwellings with different DG implementation [GJ/hr[

7.7 What are the influences per technology on the energy demand patterns?

The influence per technology on the net energy demand pattern is analyzed with two measures. The first effect that is analyzed is the difference in standard deviation of energy demand in 2030 when a technology is not incorporated. The second effect is the total annual energy generation, use or savings per technology. The combination of these effects determines the influence per technology on the demand pattern.

Figure 16 presents the standard deviation of the hourly electricity demand pattern in 2030. The first (blue) column depicts the standard deviation in the mid scenario in 2030. The error bar depicts the low and high scenario. The other columns present the standard deviation in 2030 when a specific technology is not taken into account. This figure shows that PV has the largest influence on the standard deviation of net electricity demand in all scenarios on all dwelling types. The implementation of PV causes the standard deviation (hourly fluctuations) to increase with approximately 165% in the mid scenario (130% in the low- and 250% in the high scenario). The second most influential technology for standard deviation in electricity demand are EVs, followed by HPs.

The standard deviation of hourly gas demand is presented in figure 17, which shows that insulation brings about the largest deviations. The implementation of insulation has a positive effect on the hourly fluctuations, improved insulation results in a flatter demand pattern. SFT dwellings show the largest change in standard deviation, both absolute and relative. This results from the large amount of SFT dwellings and the relative low degree of insulation in 2014. Therefore, the improved insulation has a larger effect on SFT dwellings than it has on SFD or MF dwellings. The technology with the most impact on the hourly fluctuations after insulation is the HP, followed by the SWH.

The annual generation, use and savings per technology in the mid scenario in 2030 are presented in table 24, distinguished for electricity and heat demand. The technology with the most impact on energy use is insulation (37 PJ savings compared to 2014), which explains the large influence on the hourly fluctuations. The most influential technology for net electricity demand is PV (30 PJ additional generation compared to 2014). The number of dwellings per type causes the energy savings and generation to be mainly found in SFT dwellings.

Thus, this sub question requires answers regarding the influence of technologies on the hourly fluctuations and the total saving, generation or use. Insulation has the largest impact on both. It results in less energy use and lower hourly fluctuations. The second largest contributor is PV, which on the one hand decreases the demand for electricity and on the other hand increases the hourly fluctuations.

Figure 18 and Figure 19 present the net electricity demand pattern of two example days in winter and in summer. These figures provide a comprehensible overview of the influence per technology and therefore contribute to answering this sub question. HPs have a substantial and quite constant influence on net electricity demand in winter months and almost no influence in the summer. PV systems have a relative small influence in winter and a very large contribution to net electricity demand in summer months. While the impact of EVs on the electricity demand is similar in winter and summer months and increases demand mostly in the evening.

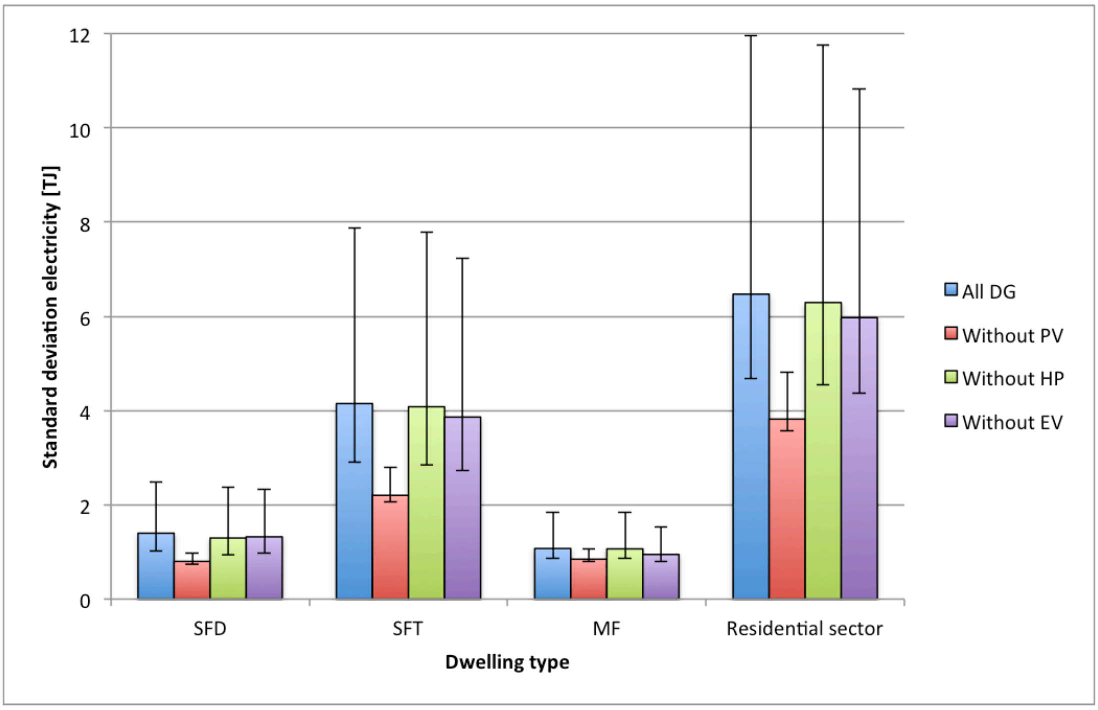

Figure 16: Standard deviation of hourly net electricity demand pattern [TJ] in 2030 (blue) and the standard deviation when specific DGs are not incorporated in the model. The error bar depicts the standard deviations in the high and low scenario

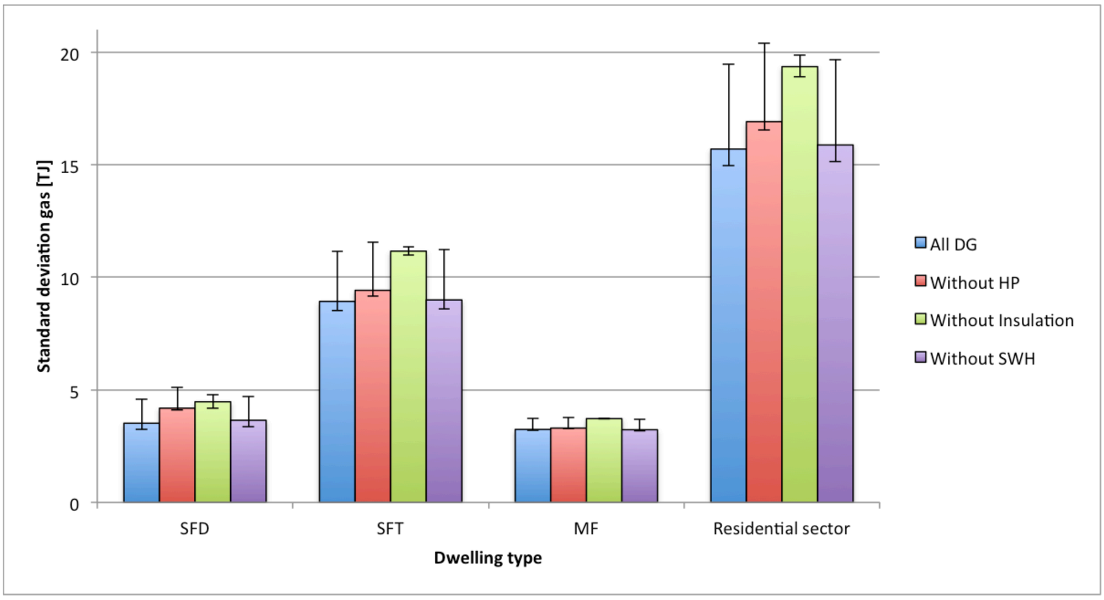

Figure 17: Standard deviation of hourly gas demand pattern [TJ] in 2030 (blue) and the standard deviation when specific DGs are not incorporated in the model. The error bar depicts the standard deviations in the high and low scenario

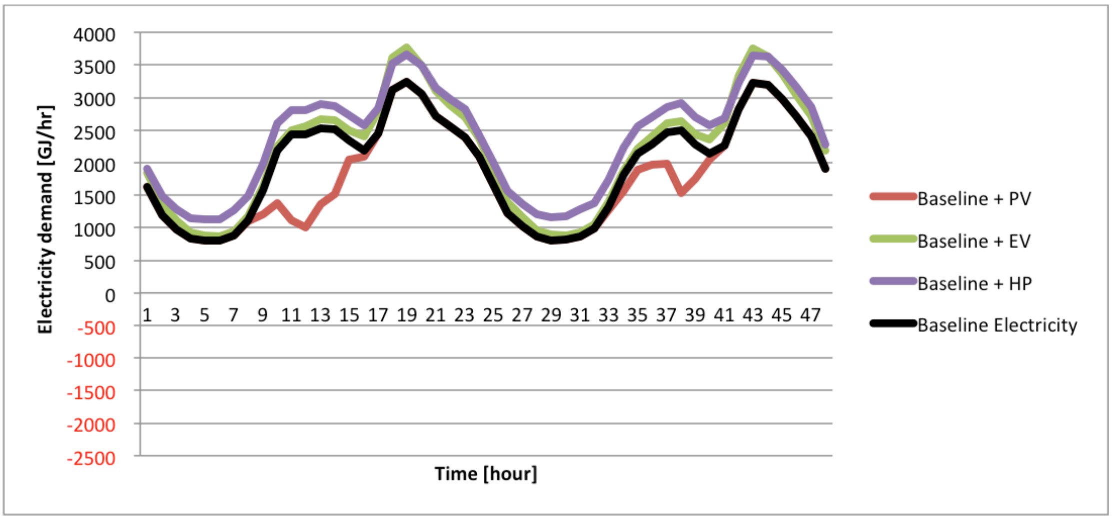

Figure 18: Net electricity demand of two example days in winter for SFD dwellings in 2030 [GJ/hr]

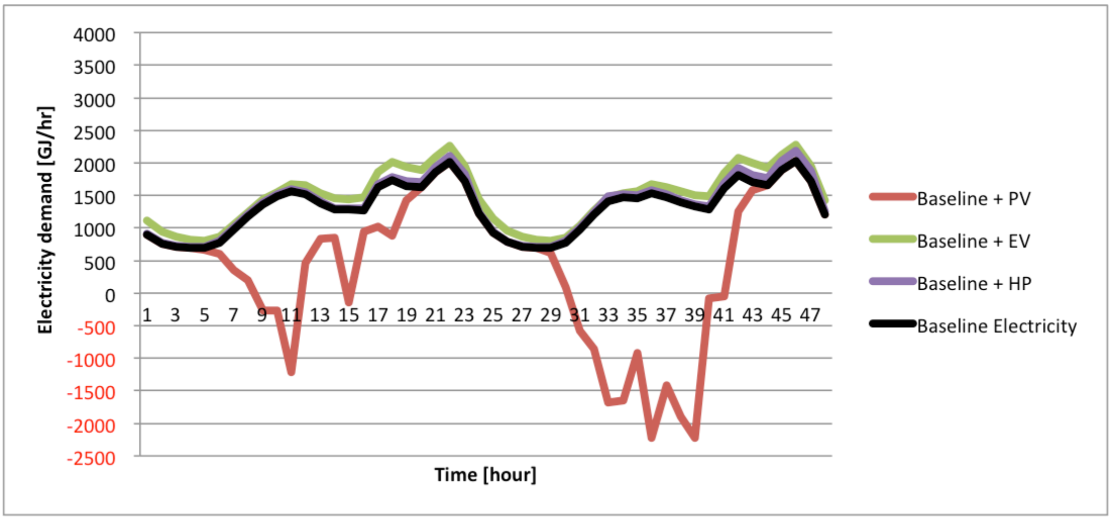

Figure 19: Net electricity demand of two example days in summer for all SFD dwellings in the Netherlands in 2030 [GJ/hr]

7.8 How will decentralized generators, electrification of driving and heating, insulation and other trends affect the demand patterns of district heating, gas and electricity of the residential sector in 2030?

The number of dwellings connected to district heating increases with 40% between 2014 and 2030. The improved insulation of dwellings cause the amount of energy supplied by district heating to increase only by 30% towards 2030 in the mid scenario, from 11.9 PJ in 2014 to 15.5 PJ in 2030.

The gas demand is expected to reduce substantially towards 2030. It decreases from 325 PJ in 2014 to 234 PJ in 2030, which is mainly a result of the improved insulation of 3.6 million dwellings. Other important influences on the changing gas use are the construction and decommissioning of dwellings, implementation of heat pumps and increased use of district heating. Less energy is required to achieve a comfortable temperature within dwellings due to the improved degree of insulation. This lowers the peak demand and the hourly fluctuation of gas use. The demand in winter decreases with approximately 40%, which results in smaller seasonal deviations.

SFT dwellings constructed before 1974 have on average the worst insulation values. The effect of improved insulation in these dwellings brings about the largest influence on the heat demand in 2030. The large number of SFT dwellings in the residential sector increases this effect.

Increasing efficiency of household appliances in combination with electrification of heating and driving results in an electricity use that will remain approximately constant between 2014 and 2030 (93 PJ). The net electricity demand however, which is electricity use including PV, leads to a decreased demand in the residential sector of 30%. These savings are mainly achieved in the summer months.

The large implementation of PV (28%) leads to an increase in net hourly demand fluctuations. The standard deviation of electricity demand in summer is almost three times higher in 2030 than it was in 2014. Additionally, hours occur where 11.7 TJ/hr surplus electricity is generated in the residential sector (3.5 and 33.4 TJ/hr in the low and high scenario, respectively). Most of which is generated in SFT dwellings. SFD dwellings have the largest implementation of PV, which results in the highest surplus electricity and hourly fluctuations per average dwelling (figure 20 and figure 21).

Thus, the implementation of PV is the most influential change for the net electricity demand in all scenarios. The net demand decreases and the hourly fluctuations increases. Improved insulation has the most influence on gas demand and district heating in 2030. The total heat demand decreases, as do the hourly fluctuations.

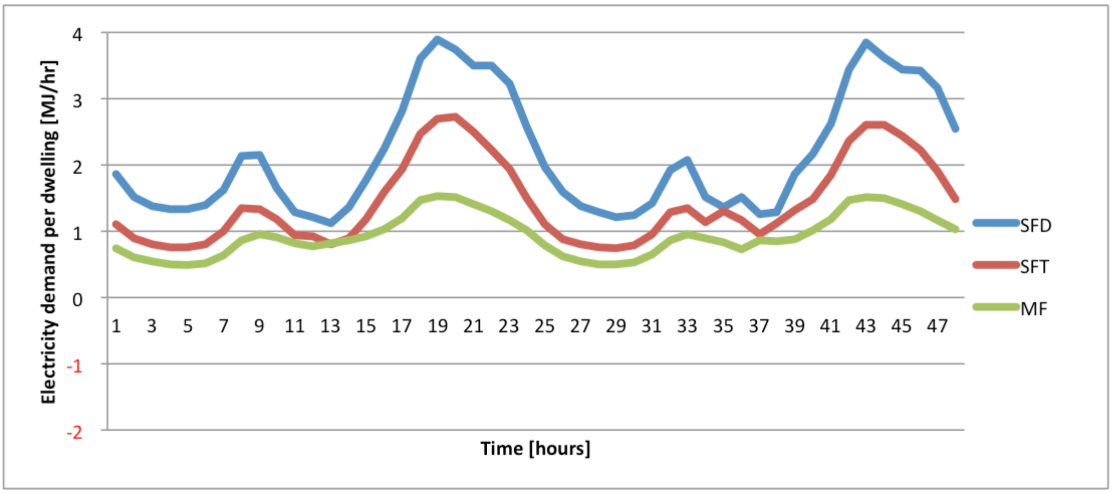

Figure 20: Net electricity demand per average dwelling on two example days in winter [MJ/hr]

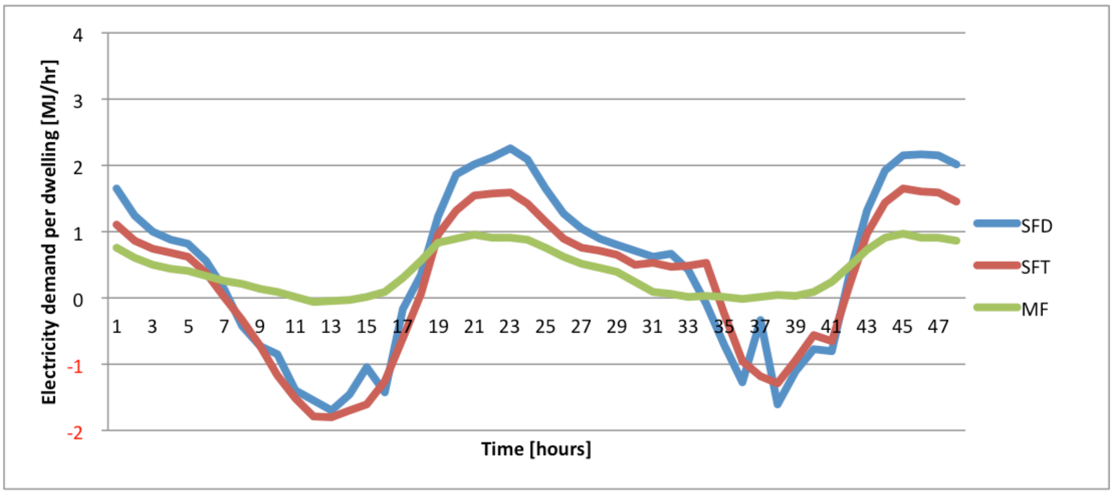

Figure 21: Net electricity demand per average dwelling on two example days in summer [MJ/hr]

8. Discussion

The robustness of the results presented in the previous chapter are dependent on a number of aspects, these are assessed here. First, the assumptions in the model are evaluated. Then, the data used to construct the model is analyzed and a sensitivity analysis is performed. After this, other points of consideration and the implications are discussed. Finally, the results are compared to existing literature and recommendations for follow up research is provided.

8.1 Assumptions

Wainwright and Mulligan (2004) discuss the nature of assumptions, they state that assumptions have to be made in order to turn a real life situation into a model. In some cases, assumptions will be wrong, which is not necessarily a problem. The important thing is to make sure that these wrong assumptions do not have a large influence on the models output. The most important assumptions are discussed here. The main assumption of this research is the selection of the DG technologies that are incorporated in the model. Even though the selection is based on extensive literature review, the possibility exists that, for example, μCHP will have a much larger influence in 2030 than expected. Furthermore, new emerging technologies might affect the way we use energy or the manner in which we generate energy.

The next important assumption is that the implementation of technologies does not influence each other. The implementation is based on a combination of sources that focus on one or two technologies since there are no reliable sources available that provide an overview of all DG implementation in the Netherlands. Influence on each other might alter the implementation scenarios of DGs. A third important assumption is the construction of the base hourly electricity demand pattern in 2030, which is equal to the net hourly demand pattern in 2014, minus the efficiency gains. It is unlikely that the efficiency gains are spread out evenly over all hours. In addition, other appliances, such as air conditioning, may have a larger influence in 2030. However, the electricity demand in 2014 creates a plausible demand pattern as baseline for the scenarios in 2030. Furthermore, the distribution of PV systems, SWHs and EVs per dwelling type are based on assumptions. The division of PV and SWH per dwelling type is based on multiple studies that encompass roof availability, attitude towards implementation, barriers and opportunities per dwelling type. However, the actual distribution is hard to predict. Less literature is available for the distribution of EVs among dwelling types, studies state that the distribution of EVs in 2030 does not differ much from regular vehicle distribution. The availability of a private parking spot where the vehicle can be charged is expected to be the decisive factor. This assumption cannot be further broken down and the effect of this assumption on the model result needs to be assessed.

The final major assumption is the improvement of insulation. This study assumes that all label improvements occur in the currently worst insulated dwellings. Furthermore, the improvement of energy labels cannot only be realized with insulation, but also with the implementation of DGs. The effect of a lower degree of insulation is shown in the low scenario and results in a smaller decrease of gas use and larger hourly fluctuations.

Other, less influential assumptions are made as well, which are discussed here. The space heating demand pattern is calculated by heat loss through conduction, ventilation and infiltration. However, the only variables that differ per hour are the outside temperature and the thermostat settings. The values that are constant over a year (e.g. surface area, heat transfer coefficient, etc.) do not influence the hourly distribution since the pattern is calculated as hourly distribution of the total demand value over the year and not as absolute demand. In addition, the effect of electrical appliances, solar irradiation, wind, retained heat in walls and the deactivation of heating systems in summer are not accounted for in the heat demand pattern. These factors combined would decrease heat demand in the summer and increase heat demand in the winter, expanding the seasonal deviation slightly. The heat demand pattern for 2014 (provided by NEDU (2015)) results from the average of historical data over a period of 14 years. Therefore, automatically accounting for these neglected effects. Thus, minor alterations in seasonal deviations between 2014 and 2030 are a result of the modeling technique.

In the absence of forecasts regarding the thermostat settings of dwellings towards the future; the settings in 2013 are assumed to be constant towards 2030. On the one hand, smart thermostats and increasing awareness regarding climate change could bring about lower thermostat settings and on the other hand, increasing welfare and the implementation of PV and HPs could result in relatively lower energy costs and therefore diminishing the incentive to act. The effect of both scenarios is assessed in the sensitivity analysis.

The final point of consideration is the assumption that all EVs are directly plugged in at arrival and are all charged at home. The actual charging could occur later (e.g. due to night tariff). This would decrease peak demand in the evening and relocate the electricity requirement to an off peak moment. Charging locations of EVs on convenient locations will expand towards 2030, this will negatively effect the share of home charges (Bradley & Quinn, 2010). The effect of this change could decrease peak demand and lower hourly fluctuations, especially between 5 and 9 pm. The effect on the total electricity demand is assessed in the sensitivity analysis.

8.2 Data uncertainties

Uncertainties exist in the collection of data for scenarios in 2030. Some are more uncertain and more relevant for the result of this research than others. These data are analyzed and their influence on the results is tested by means of a sensitivity analysis. The most apparent uncertainty in the data is the implementation ratio per technology in 2030. This uncertainty is analyzed by means of a scenario analysis and therefore will not be subjected to a sensitivity analysis.

Uncertainty is present in the energy demand in 2014. The CBS (CBS, 2015a) provided provisional data of the energy demand in 2013 and 2014. Table 32 compares these values to the energy demand in the model in 2014. Between data from the CBS in 2014 and the model in 2014, a deviation of 8% is found for electricity and district heating demand and 14% for gas demand. The data shows that the models outcome for 2014 lays somewhere in the middle of the data for 2013 and 2014 of the CBS.

The total energy demand of the residential sector is calculated by multiplying the average energy demand per dwelling by the number of dwellings. The average energy use per energy carrier per dwelling in this model is based on multiple sources that show similar values (table 2 and table 5), the same applies for the amount of dwellings (Agentschap NL, 2011; BAG, 2015; BZK, 2013). Since all energy carriers show a deviation in the same direction, it seems logical that this is caused by a difference in the amount of dwellings. The most recent data provided by the CBS about the building stock is available for 2012. The difference between the amount of dwellings used in this model for 2014 and provided by CBS in 2012 is 269,020. It is possible that the CBS used dwelling data of 2012 to predict energy demand in 2014. No specifics about the forecast are provided. If this where the case, electricity and district heating demand of the CBS would correspond to the model and the deviation in gas demand would almost be divided in half.

Energy demand [PJ]	CBS 2013	CBS 2014	Model 2014	Deviation CBS 2014 from model 2014
Electricity	84	84	91	8%
Gas	359	283	324	14%
District Heating	14	11	12	8%

Table 32: Net energy demand in the residential sector [PJ], comparing provisional data of Statistics Netherlands (CBS, 2015a) to the outcome of the model in 2014

The previous chapter concluded that PV has a large influence on the net energy demand in the residential sector. The amount of electricity generated by PV is dependent on the output ratio (kWh/kWp), which is based on a report by TKI Urban Energy (EnerGO et al., 2015). However, this ratio might be different in reality from what is expected. Therefore, the volatility of the output ratio will be tested in a sensitivity analysis.

Another technology with data uncertainty is the EV. Changes in average driving distance affect the daily electricity demand. Since it is hard to predict with certainty what the average distance driven by EVs will be, a sensitivity analysis is performed on the influence of driving distance on the results. Furthermore, developments in fast charging at home increases peak electricity usage. This could result in larger hourly electricity fluctuations.

8.3 Sensitivity analysis

A sensitivity analysis is performed to test the models output volatility to changes in the input values. The input for this analysis is determined in paragraphs 8.1 and 8.2. Table 33 presents the effect of a changing distribution of EVs among dwellings types. The effect of extreme distribution values on electricity demand in SFD and SFT dwellings is relatively small; however, the effect on MF dwellings could be substantial. In a scenario where all EVs are evenly distributed, the net electricity demand of MF dwellings increases with 7.5% and the standard deviation of electricity demand in 2030 increases with 0.1 TJ. Many neighborhoods exist consisting of mostly MF dwellings. The deviations in EV distribution could have a substantial influence in these areas.

EV Distribution			Electricity demand [PJ]			Standard deviation [TJ]		
SFD	SFT	MF	SFD	SFT	MF	SFD	SFT	MF
1.0	1.0	1.0	12.7	30.7	19.8	1.4	4.1	1.2
1.1	1.1	0.8	12.9	31.2	19.1	1.4	4.1	1.1
1.2	1.2	0.6	13.0	31.8	18.4	1.4	4.1	1.1
1.3	1.3	0.5	13.2	32.3	17.7	1.4	4.2	1.0
1.4	1.4	0.3	13.3	32.9	17.0	1.4	4.2	1.0
1.5	1.5	0.1	13.5	33.4	16.3	1.4	4.2	1.0

Table 33: Sensitivity analysis of EV distribution over dwelling types and the influence on the net electricity demand and standard deviation of net electricity demand over 2030; the EV distribution (left columns) represent the factor that the distribution deviates from the average value

Figure 22 introduces the effect of a deviating degree of home charging and a changing PV output ratio of dwellings; plotted against the net electricity demand of the residential sector. The most influential factor for net electricity demand is the PV output ratio. However, the output ratio of PV in 2014 is 878 kWh/kWp (i.e. -12% in figure 22) and is unlikely to decrease over time (Sark, 2014). TKI Solar predicts a most optimistic output ratio in 2030 of 1,200 kWh/kWp (i.e. 20% in Figure 22) (EnerGO et al., 2015).

The increasing amount of convenient charging locations for EVs towards 2030 (Bradley & Quinn, 2010) decreases the overall electricity demand (blue line in figure 22). Even though EV drivers prefer charging at home, it is possible that 50% of all charging occurs elsewhere. This could lower overall net electricity demand by 9.5%. However, increasing driving ranges could cause the same effect in a positive direction.

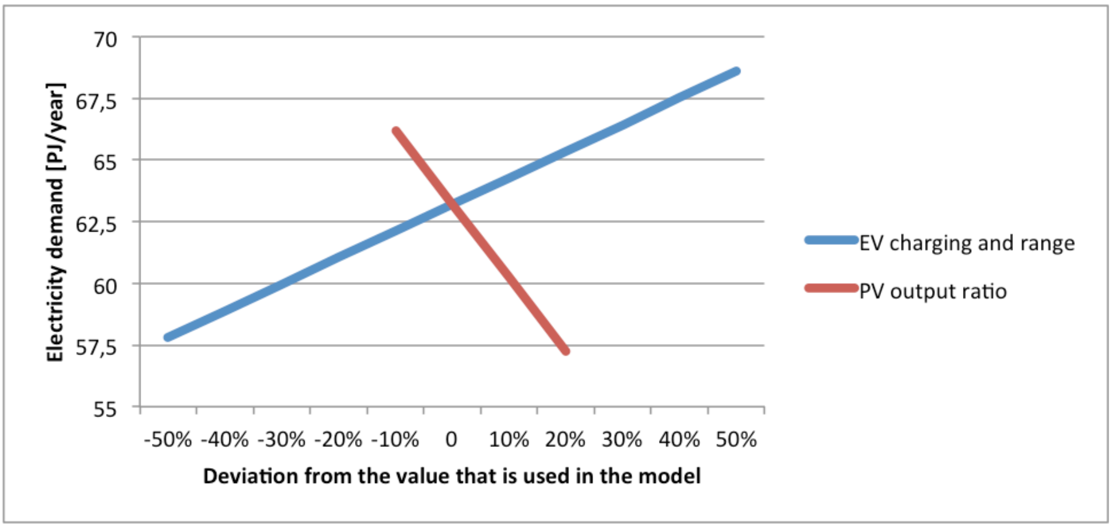

Figure 22: Sensitivity analysis net electricity demand in all dwellings in 2030, x-axis represents deviation from 'regular' value in the model; the y-axis represents the associated net electricity demand [PJ/year]

The sensitivity of the standard deviation of net electricity demand in 2030 on changing parameters is plotted in figure 23. The effect of changing thermostat settings is taken into account as well in addition to PV and EVs. This figure strengthens the result found in the previous chapter, which stated that PV has the largest influence on the standard deviation of net electricity demand. The influences of home charging and thermostat settings are much smaller. Thus, improved efficiency of PV modules result in larger fluctuations in net electricity demand and increases the difficulty to match supply and demand.

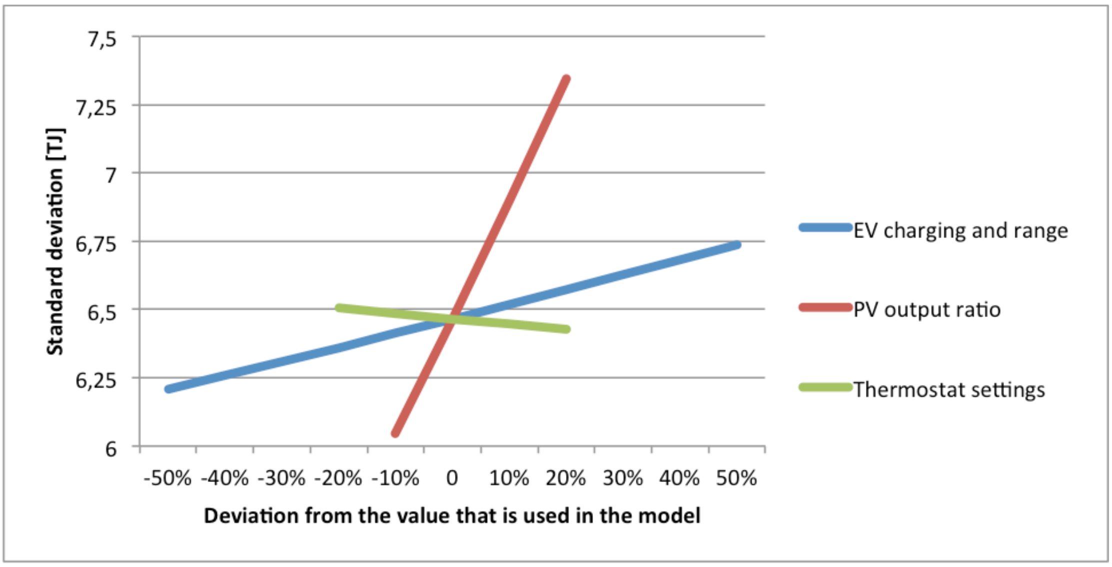

Figure 23: Sensitivity analysis of standard deviation of net electricity demand in all dwellings in 2030, x-axis represents deviation from 'regular' value in the model; the y-axis represents the associated standard deviation [TJ]

The influence of thermostat settings on the standard deviation of gas demand in 2030 is substantial (figure 24). However, one can say with a high degree of certainty that some values will not occur. 20% Lower thermostat settings represent a temperature in the evening (highest temperature of the day) of 16°C and 20% higher settings represents 24°C. These average evening temperatures already seem quite extreme. Within that range the standard deviation can still vary between 13 and 20 TJ. Thus, the behavior of residents regarding thermostat setting will have a substantial impact on the hourly fluctuations of gas in 2030.

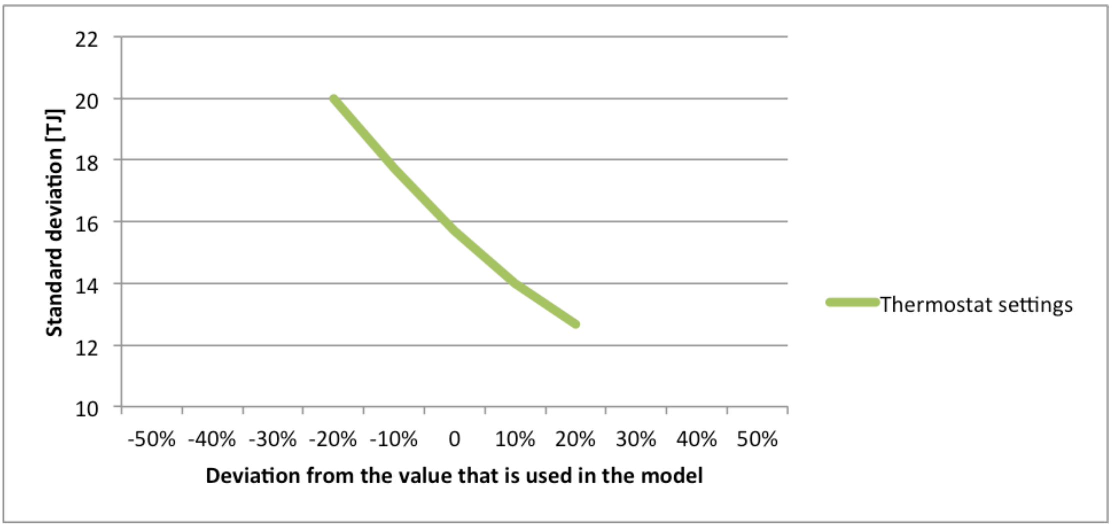

Figure 24: Sensitivity analysis of standard deviation of gas demand in all dwellings in 2030, x-axis represents deviation from 'regular' value in the model; the y-axis represents the associated standard deviation [TJ]

8.4 Points of consideration

Other points of consideration are analyzed in this paragraph. Results that are specified on micro level (i.e. per dwelling), are based on average values per dwelling type. One should bear in mind that individual cases will deviate substantially from these average dwellings. Furthermore, the outputs from SWHs are modeled as if they are directly depended on the irradiation and all energy that can be stored is used. In reality, the output of SWHs is also dependent on other factors, such as ambient temperature. Additionally, the stored energy decreases over time when tap water is not used. However, the influence of the SWH on the residential sector is very small, therefore, these simplifications have an insignificant effect.

Another point of consideration is the time resolution. The used resolution was per hour, since this was the smallest time step for which complete and reliable data was available. The electricity supply has to match demand at every moment, and not just per hour, this relative large time step smoothens the results. In reality, larger peak demand and peak generation is expected for shorter time periods.

Moreover, EV drivers prefer faster charging and would pay an additional fee for a reduced charging time (Schroeder & Traber, 2012; Skippon & Garwood, 2011). Reduced charging time increases the peak electricity demand caused by EVs and therefore increases the hourly fluctuations of dwellings.

A noteworthy addition to the results found in the previous chapter is the rebound effect. The rebound effect is a situation in which the perceived cost of energy declines (e.g. due to DGs or improved insulation), which causes the behavior of actors to change. A study by Aydin et al. (2013) states that the expectations of policies for the residential sector are often overestimated due to this effect and can result in a rebound effect of 41% in rental dwellings and 27% for private owned dwellings.

8.5 Implications

PV systems provide the most electricity during the day when electricity use is low. This causes the self-consumption of electricity to decrease when the implementation of PV increases. A low degree of self-consumption implies that much excess electricity is transmitted to the grid, which can cause large fluctuations in net demand. These large fluctuations in the electricity grid increase the difficulty for the Dutch Transmission System Operator (TSO) to ensure that demand and supply are identical. Furthermore, the range between minimum and maximum net hourly electricity demand is expected to increase in the whole residential sector. This range can increases even further on neighborhood level where identical technologies are adopted. The minimum net electricity demand in some neighborhoods can be 3.5 times smaller and the maximum net demand can be 2.5 times larger compared to an average neighborhood. The electricity demand in these neighborhoods is predicted to lead to bottlenecks in the capacity of the grid. Significant additional investments are required by Distribution System Operators (DSOs) to prevent these bottlenecks (Enexis, 2015). A study by PBL & DNV GL (2014) find that an implementation of 4 GWp PV in the Netherlands could require adjustments in the electricity grid if the 4 GWp is not evenly distributed. A scenario in which 20 GWp is installed is expected to result in substantial losses due to grid failure and required curtailment. Section 5.1.3 provides a range of PV power in the residential sector in 2030, which lies between 4.2 and 16.6 GWp. The mid scenario finds an installed PV capacity of 8.9 GWp. Thus, it is expected that actions have to be taken to prevent efficiency losses and curtailment. PBL & DNV GL (2014) create an estimation of additional investment costs for the grid in order to be able to cope with net peak demand with an installed capacity of 10 GWp PV. The additional investments costs are approximately two billion euros until 2030. This however, does not solve the problem of excess electricity; it simply enables the electricity to be transported.

Transport costs are paid to DSOs for maintaining a reliable distribution network. These costs encompass a connection fee, standing charge, capacity fee, system services and measurement equipment (Liander, 2015). When the net electricity demand declines while at the same time transport requirement doesn't (due to negative and positive net demand), the costs for transport per unit electricity will rise. The same applies for the transportation of gas. Increasing cost of electricity and gas combined with the decreasing costs of DG can act as catalyst for homeowners to become completely self-sufficient. When the number of dwellings that are disconnected from the grid increases, the costs of transport will increase even more. This feedback loop could be irreversible.

The current business model of electricity suppliers relies on the sales of electricity. The low electricity demand in summer and even negative demand of SFT dwellings in the high scenario, result in periods where almost no electricity is sold. This might require a new approach from electricity suppliers. This is in line with the opinion of the CEO of a large electricity supplier in the Netherlands who stated that the focus of the company should change from an energy selling company to an energy managing company (Haas, 2015).

Homeowners are not incentivized to increase their self-consumption since the surplus electricity can be sold to the grid at retail price. This netting arrangement will be analyzed in 2020 and could change to flexible electricity prices for consumers or might be cancelled (Kamp, 2015; SER, 2015). This raises the incentive for consumers to increase their self-consumption, which can be increased by adding storage or by implementing demand side management. Many storage possibilities exist, among which batteries is appointed as most promising (Dunn, Kamath, & Tarascon, 2011). High investment costs of storage technologies and a lacking incentive for homeowners to increase their self-consumption are the most substantial barriers in 2014. However, the uncertainty of the netting arrangement and the declining price of batteries resulting from economies of scale due to EVs are two stepping-stones in the direction of local storage. Demand side management can increase self-consumption as well, EVs can be used as storage modules and time independent devices (e.g. washer and dryer) can be activated when an electricity surplus exists. I did not take storage and demand side management into account. However, the net peak demand (high and low), hourly fluctuations and overall net electricity demand presented in the previous chapter demonstrate that demand for these technologies will substantially increase.

8.6 Literature comparison

The Energy Research Center Netherlands (ECN) in combination with PBL, CBS and RVO created a forecast of the development of electricity and gas use in the residential sector (Hekkenberg & Verdonk, 2014; Schoots & Hammingh, 2015). These studies did not take the effect of EVs into account, which accounts for an average electricity use per dwelling of 1.3 GJ and a total use of 10.8 PJ in the whole residential sector in this model. When correcting for EV, the electricity use and net demand between the studies are quite similar (see table 34).

	Mid scenario	Hekkenberg & Verdonk, 2014	Schoots & Hammingh, 2015
Electricity use	92 PJ	80 PJ	75 PJ
Net electricity demand	62 PJ	53 PJ	54 PJ
Electricity use of an average dwelling	11.5 GJ	10.1 GJ	-
Gas demand	234 PJ	280 PJ	276 PJ

Table 34: Literature comparison between the output of the model in the mid scenario and two forecast studies

The gas demand however, deviates substantially from the studies by the ECN. This difference is most likely caused by the manner of modeling the gains in energy labels. In this thesis, I assume that all improvements are made due to insulation. Each year 225,000 of the worst insulated dwellings improve their insulation to gain two label steps. The ECN uses a different technique, insulation does not just occur in poorly insulated dwellings and DGs are used as well to gain a better energy label. Furthermore, Hekkenberg & Verdonk (2014) and Schoots & Hammingh (2015) do not account for the effect of global warming, which has a substantial impact on the heat demand of dwellings (approximately 6 PJ).

The study of Veldman et al. (2013) provides a forecast of the energy demand in the residential sector in 2040 using high adoption rates of DG technologies. The days with minimum and maximum net electricity demand are presented in order to assess the effect of flexible load implementation. Figure 25 and figure 26 present a comparison between the minimum and maximum net electricity demand of the models output and the results from Veldman et al. (2013). Even though the report by Veldman et al. (2013) provides a forecast for 2040 instead of 2030, the deviations clearly show that the differences between a realistic and a high implementation forecast are enormous. Therefore, the result of this realistic forecast contributes substantially to the scientific knowledge and provides a great baseline for further research.

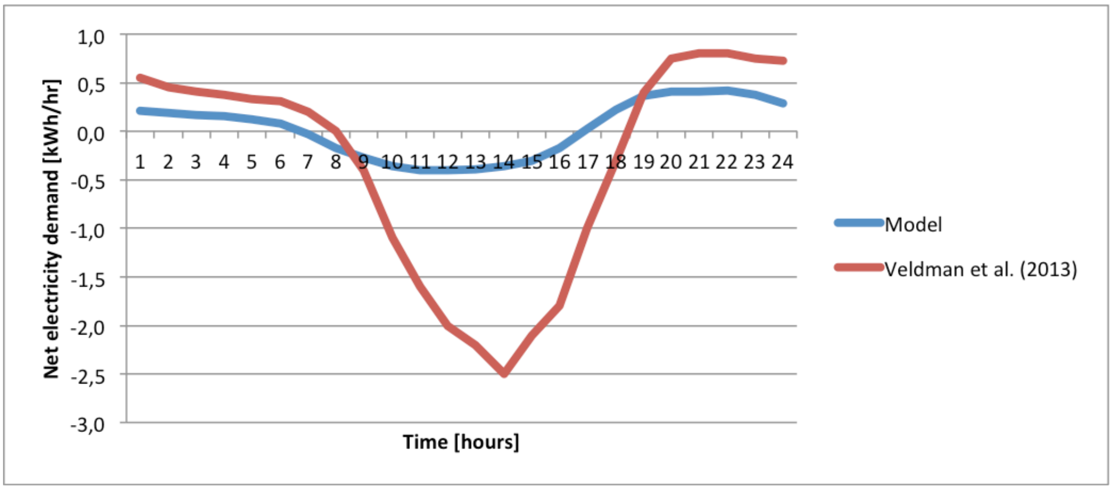

Figure 25: Net electricity demand of an average dwelling on the day with the lowest demand per hour [kWh/hr]. The blue line represents the data from this study in 2030 and the red line represents the results from Veldman et al. (2013) in 2040

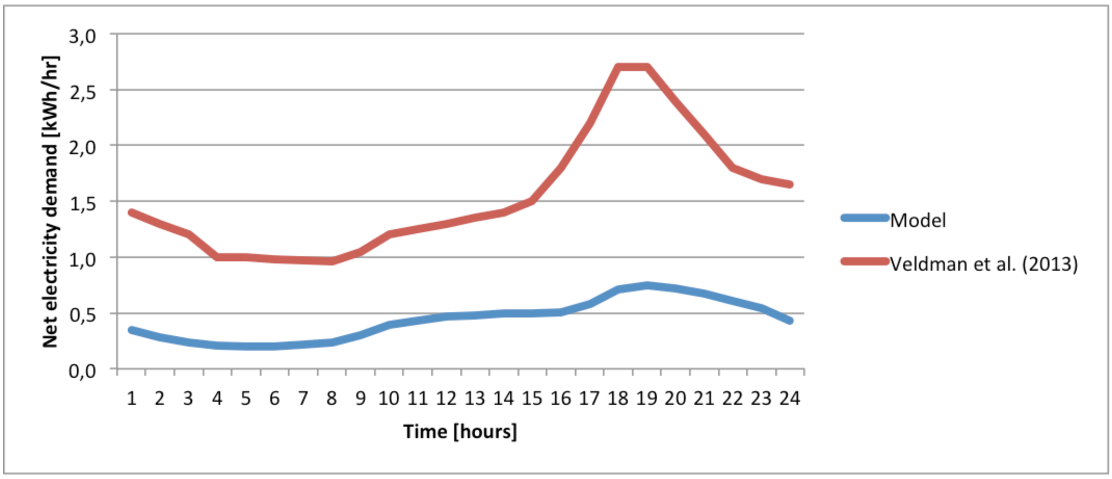

Figure 26: Net electricity demand of an average dwelling on the day with the highest demand per hour [kWh/hr]. The blue line represents the data from this study in 2030 and the red line represents the results from Veldman et al. (2013) in 2040

8.7 Recommendations

The previous paragraphs show that a forecast of energy use towards 2030 has its limitations and should not be obtained as the truth. However, this study presents the assumptions in a clear manner and analyzes the limitations. The results from the scenario analysis provide three possible pathways towards 2030. These paths contribute to the scientific knowledge and provide specific starting points for further research. Additionally, decisions for policy makers regarding the netting arrangement or flexible prices can use this research as baseline and discover the effects of their decisions. DSOs can study the required investments based on the scenarios presented in this study. Thus, this research provides a solid starting point for many interesting studies yet to come.

The recommendations for follow up research follow logically from the previous sections. First, when additional data becomes available, the impact of DGs on the residential sector with a smaller time resolution would contribute to a better knowledge of the changes ahead. In addition, a study focused on the demand pattern of all sectors in the Netherlands could contribute to understanding how the other sectors can cope with changes in the residential sector.

This scenario-based analysis contributes to the scientific knowledge of energy demand in the residential sector. More specific research can be done on the reinforcement of the grid using the results from this study, which will contribute to the investment decisions of DSOs. Additionally, the effect of the abolishment of the netting arrangement will assist policy makers in the decision yet to come.

Flexible electricity prices for consumers can be beneficial for capacity overloads and help match supply and demand. The effects of the implementation of these prices should be analyzed. Furthermore, additional studies regarding the technologies that achieve a higher degree of self-consumption (e.g. storage and demand side management) are recommended as well. These studies would help provide a better picture of what the costs of DGs for the society are.

9. Conclusion

This study has created a realistic hourly forecast of the energy demand in the residential sector per dwelling type, accounting for all technologies and trends that are expected to have a significant influence on energy demand in 2030. More specifically, the changes in energy demand are studied per energy carrier on three levels: for the whole residential sector, per dwelling type and per neighborhood.

The study shows that the gas use in the residential sector will decrease substantially. The mid scenario predicts gas savings of 92 PJ in 2030 compared to 2014, which is approximately 28% of the gas use in 2014. This saving is mainly accomplished by improved insulation, which is partly induced by the Energy Agreement for sustainable growth (Schoots & Hammingh, 2015). The exact impact of the agreement on insulation is not identical in all scientific literature. Therefore, the number of insulated dwellings could be smaller than assumed in this study. The other technologies responsible for the decreased gas use are HPs and district heating.
The improved insulation reduces the heat required to keep a dwelling at a comfortable temperature. This causes the hourly fluctuations to decrease substantially and the maximum hourly gas demand in 2014 to decrease with 40% towards the mid scenario in 2030. The largest gas savings occur in SFD dwellings. This is a result of the relative high implementation of HPs in SFD dwellings compared to SFT and MF dwellings.

The electricity use in the mid scenario of 2030 is expected to be equal to 2014. Electrification of heating and driving causes the electricity use to increase while efficiency gains in household appliances result in decreasing electricity use. These effects are predicted to balance each other out. The net electricity demand incorporates the generated electricity by PV systems. The mid scenario in this study expects PV systems to generate approximately 30% of the total electricity use in 2030. In addition, these systems play a major part in the decrease of minimum hourly net electricity demand from 4.6 TJ/hr in 2014 to -11.7 TJ/hr in 2030. SFD dwellings have on average the lowest minimum hourly demand (-2.8 MJ/hr/average SFD dwelling). SFT dwellings have the largest impact on excess electricity in the whole sector due to the large number of SFT dwellings in the Netherlands.

In addition, the standard deviation of hourly demand fluctuation over a year increases from 3.9 TJ in 2014 to 6.4 TJ in the mid scenario in 2030. This is a result seasonal and short-term fluctuations. Short-term fluctuations are a result of low (or even negative) demand during the day due to PV systems and high demand in the evening due to the electrification of heating and charging of EVs. The seasonal deviation increases due to the adoption of HPs and PV systems. The net electricity demand in summer is expected to be 50% lower in 2030 than it was in 2014. The net demand in winter is predicted to decrease slightly.

The high scenario provides an interesting outcome. The overall net electricity demand from 1st of March until the 31st of August is negative for SFT dwellings. Despite the high implementation of electric vehicles in the high scenario (almost 50%), the photovoltaic impact (74% implementation) is large enough to cover all electricity use. These extreme values in combination with low self-consumption could result in periods where much electricity is transported through the grid and no electricity is sold. This scenario outcome substantially impacts the business case of electricity suppliers that earn money by selling electricity. The CEO of a large electricity supplier in the Netherlands stated that the focus of the company should change from an energy selling company to an energy managing company (Haas, 2015).

In addition, the hourly fluctuations of net electricity demand in summer months in the mid scenario in 2030 almost triple with respect to values in the summer of 2014. Thus, the intermittent characteristics of photovoltaic, which has a major influence on net electricity demand, will increase the difficulty to match demand and supply. This will amplify the likelihood of altering the netting arrangement, raising the incentive for consumers to increase their self-consumption. Therefore, increasing the demand for storage possibilities and demand side management.

The demand for district heating is expected to increase approximately 30% from 2014 until 2030. The largest increase of district heating will occur in MF dwellings. The hourly fluctuations in demand are expected to decrease due to the improved degree of insulation.

Stricter EPC regulation in combination with renovation from housing corporations might result in homogeneity within neighborhoods and heterogeneity between neighborhoods. Maximum hourly net electricity demand in a specific neighborhood could be 2.5 times higher than the maximum demand in an average neighborhood in 2030. This neighborhood effect mainly influences the distribution system. Homogeneity within neighborhoods results in larger investment requirements by DSOs.

One should bear in mind that these results are based on a scenario-based forecast, which has its limitations. Two of the most important limitations are: the interaction between technologies and the distribution of technologies among dwelling types. The technologies where studied separately, thus the effect of implementation of a specific technology does not influence another technology. This could affect the implementation scenarios. The distribution of technologies is carefully selected based on literature or clearly stated assumptions. However, due to a lack of literature on the exact allocation, distribution in the model might deviate from reality.

10. Bibliography

Abdisalaam, A., Lampropoulos, I., Frunt, J., Verbong, G.P.J., & Kling, W.L. (2012). Assessing the economic benefits of flexible residential load participation in the Dutch day-ahead auction and balancing market. *9th International Conference on the European Energy Market, EEM 12*, 1–8. http://doi.org/10.1109/EEM.2012.6254645

Agentschap NL. (2010). *EnergieVademecum*. Den Haag.

Agentschap NL. (2011). *Voorbeeldwoningen 2011 Bestaande bouw*. Den Haag.

Asare-bediako, B. (2014). *SMART Energy Homes and the Smart Grid*. Technical University Eindhoven.

Aydin, E., Brounen, D., & Kok, N. (2013). The Rebound Effect in Residential Heating, 1–33. Tilburg University.

BAG. (2015). Basisregistraties Adressen en Gebouwen. *Mutaties in de woningvoorraad*. Retrieved 8 July 2015, from http://vois.datawonen.nl/quickstep/QSReportAdvanced.aspx?report=cow13_103&geolevel=nederland&geoitem=1&period=1985,1990,1995,2000,200

Bell, M., & Lowe, R. (2014). Building Regulation and Sustainable Housing.Pt 2: Technical Issues. *Structural Survey, BSRIA, Soft Landings*. Retrieved from http://www.bsria.co.uk/services/design/soft-landings/

Blokhuis, E., Brouwers, B., van der Putten, E., & Schaefer, W. (2011). Peak loads and network investments in sustainable energy transitions. *Energy Policy*, *39*(10), 6220–6233. http://doi.org/10.1016/j.enpol.2011.07.021

Boon, F.P., & Dieperink, C. (2014). Local civil society based renewable energy organisations in the Netherlands: Exploring the factors that stimulate their emergence and development. *Energy Policy*, *69*, 297–307. http://doi.org/10.1016/j.enpol.2014.01.046

Bosseboeuf, D. (2015). Energy Efficiency Trends and Policies in the Household and Tertiary Sectors. Angers.

Bradley, T.H., & Quinn, C.W. (2010). Analysis of plug-in hybrid electric vehicle utility factors. *Journal of Power Sources*, *195*(16), 5399–5408. http://doi.org/10.1016/j.jpowsour.2010.02.082

Brom, F.W.H. (2011). *Energie in 2030. Maatschappelijke keuzes van nu*. (J. Ganzevles & R. van Est, Eds.). Boxtel: Æneas. Retrieved from http://depot.knaw.nl/9950/

Brouwer, A.S., Broek, M.A. van den, Seebregts, A., & Faaij, A. (2014). Impacts of large-scale Intermittent Renewable Energy Sources on electricity systems, and how these can be modeled. *Renewable and Sustainable Energy Reviews*, *33*, 443–466. http://doi.org/10.1016/j.rser.2014.01.076

BZK. (2013). Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. *Cijfers over Wonen en Bouwen 2013*. Den Haag.

CBS. (2014). Centraal bureau voor de Statistiek. *Hernieuwbare energie in Nederland 2013*. Den Haag/Heerlen.

CBS. (2014a). Centraal Bureau voor de Statistiek. Energiebalans; aanbod, omzetting en verbruik, 1995-2013 [Data file]. Retrieved 19 December 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=70846ned&D1=0&D2=15,20&D3=0,32&D4=17-18&HDR=G1,G2,G3&STB=T&VW=T

CBS. (2015). Centraal Bureau voor de Statistiek. *Zonnestroom naar sector* [Data file]. Retrieved 19 December 2015 from http://www.cbs.nl/nl-NL/menu/themas/industrie-energie/cijfers/incidenteel/maatwerk/2014-zonnestroom-per-sector-mw.htm

CBS. (2015a). Centraal Bureau voor de Statistiek. *Energieverbruik huishoudens; energiedragers* [Data file]. Retrieved 14 October 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82375ned&D1=0&D2=0-2,6-8&D3=35-39&HDR=T,G1&STB=G2&VW=T

CBS. (2015b). Centraal Bureau voor de Statistiek. *Kerncijfers wijken en buurten 2009-2012* [Data file]. Retrieved 19 September 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=70904NED&D1=52-57&D2=0,8998,9011,90

CBS. (2015c). Centraal Bureau voor de Statistiek. *Warmtepompen; aantallen, thermisch vermogen en energiestromen* [Data file]. Retrieved 24 September 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82380ned&D1=0-8&D2=a&D3=1&D4=18-20&HDR=T&STB=G2,G1,G3&VW=T

CBS. (2015d). Centraal Bureau voor de Statistiek. *Aardgas en elektriciteit, gemiddelde prijzen van eindverbruikers* [Data file]. Retrieved 29 September 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=81309ned&D1=0-1&D2=1&D3=0,l&D4=4,9,14,19,24,29,34,39&HDR=T&STB=G2,G3,G1&VW=T

CBS. (2015e). Centraal Bureau voor de Statistiek. *Energiebalans; kerncijfers* [Data file]. Retrieved 17 October 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37281&D1=11&D2=0&D3=143,148&HDR=G2,G1&STB=T&VW=T

CBS. (2015f). Centraal Bureau voor de Statistiek. *Motorvoertuigenpark; inwoners, type, regio, 1 januari* [Data file]. Retrieved 18 September 2015, from http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=7374hvv&D1=2-11&D2=0&D3=a&HDR=T&STB=G2,G1&VW=T

CBS. (2015g). Centraal Bureau voor de Statistiek. *Mobiliteit in Nederland; vervoerwijzen en motieven, regio's* [Data file]. Retrieved 30 November 2015, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=81129NED&D1=a&D2=a&D3=0-1&D4=a&D5=0&D6=l&HDR=G4,G1,T,G5&STB=G2,G3&VW=T

CBS. (2015h). Centraal Bureau voor de Statistiek. *Hernieuwbare elektriciteit; productie en vermogen* [Data file]. Retrieved 7 February 2016, from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=82610ned&D1=1,6-7&D2=5&D3=20-24&HDR=T&STB=G1,G2&VW=T

CE Delft, & Tno. (2014). *Brandstoffen voor het wegverkeer Kenmerken en perspectief*. Delft.

Claessen, F.N., Claessens, B., Hommelberg, M.P.F., Molderink, A., Bakker, V., Toersche, H.A., & Broek, M.A. van den. (2014). Comparative analysis of tertiary control systems for smart grids using the Flex Street model. *Renewable Energy*, *69*, 260–270. http://doi.org/10.1016/j.renene.2014.03.037

Confias, E., Fages, E., & Berg, W. van der. (2013). *Solar PV could be similar to shale gas disruption for the utilities industry*. Paris.

DNV GL. (2015). *Nationaal actieplan zonnestroom 2016*. Retrieved from www.nationaalactieplanzonnestroom.nl

Drouineau, M., Maïzi, N., & Mazauric, V. (2014). Impacts of intermittent sources on the quality of power supply: The key role of reliability indicators. *Applied Energy*, *116*, 333–343. http://doi.org/10.1016/j.apenergy.2013.11.069

Dunn, B., Kamath, H., & Tarascon, J.M. (2011). Electrical Energy Storage for the Grid: A Battery of Choices. *Science*, *334*(6058), 928–935. http://doi.org/10.1126/science.1212741

Duurzaamthuis. (2015). HR-ketel verwarming. Efficiënt, duurzaam, milieuvriendelijk je huis verwarmen. Overzicht voor- en nadelen | Duurzaam thuis. Retrieved from http://www.duurzaamthuis.nl/energie/verwarming/hr-ketel

EEA. (2012). *Households and industry responsible for half of EU greenhouse gas emissions from fossil fuels.* Retrieved from http://www.eea.europa.eu/highlights/households-and-industry-responsible-for

Ellamla, H.R., Staffell, I., Bujlo, P., Pollet, B.G., & Pasupathi, S. (2015). Current status of fuel cell based combined heat and power systems for residential sector. *Journal of Power Sources*, *293*(MAY), 312–328. http://doi.org/10.1016/j.jpowsour.2015.05.050

Energie Actief Soest. (2015). *Korte historie verwarmingsketels*. Retrieved from http://www.energieactiefsoest.nl/korte-historie-verwarmingsketels.html

Energielabel. (2015). *Energielabel woningen*. Retrieved from http://www.energielabel.nl/woningen

EnerGO, Solar Energy, & Switch2SmartGrids. (2015). *TKI URBAN ENERGY*. Utrecht.

Energy Saving Trust. (2008). Measurement of Domestic Hot Water Consumption in Dwellings. *Energy Savings Trust*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Measurement+of+Domestic+Hot+Water+Consumption+in+Dwellings#0

Enexis. (2015). *Kwaliteits- en Capaciteitsdocument Elektriciteit 2016-2025*. 's-Hertogenbosch. Retrieved from http://www.hoogspanningsnet.com/wp-content/uploads/KCD-elektriciteit-Stedin-2010-2016.pdf

Engineeringtoolbox. (2015). Heat Loss from Buildings. Retrieved from http://www.engineeringtoolbox.com/heat-loss-buildings-d_113.html

Epia. (2014). *Global Market Outlook- For Photovoltaics 2014-2018*. *European Photovoltaic Industry Association*. Brussels.

European Comission. (2011). *Energy Efficiency Plan 2011*. Brussels.

European Council. (2014). *2030 Framework for climate and energy policies*. Brussels.

Europees Parlement en de raad van de Europese Unie. (2010). *Richtlijn 2010/31/EU van het Europees Parlement en de Raad betreffende de energieprestatie van gebouwen* (Vol. 2010). Strassbourg.

Expertgroep aardgas, & NEDU. (2014). *profielen Aardgas 2015 [Data file]*. Amersfoort.

Friedel, P., Oostendorp, P., & Wagener, P. (2012). *Warmte in de woonomgeving*. Groningen: GasTerra.

Gerdes, J., Marbus, S., & Boelhouwer, M. (2014). *Energietrends, 2014*. (n.p.)

Groene Courant. (2015). Forse toename geregistreerde huishoudens met zonnepanelen - Groene Courant. Retrieved from http://groenecourant.nl/zonne-energie/forse-toename-geregistreerde-huishoudens-met-zonnepanelen/

Guerra Santin, O., Itard, L., & Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy and Buildings*, *41*(11), 1223–1232. http://doi.org/10.1016/j.enbuild.2009.07.002

Guerra Santin, O. (2010). Actual energy consumption in dwellings. Amsterdam: Ios Press.

Haas, J. de. (2015). *Sustainability challenge 2015.* Presentation, Marten Meesweg 5, 3068 AV Rotterdam.

Harris, C.B., & Webber, M.E. (2014). An empirically-validated methodology to simulate electricity demand for electric vehicle charging. *Applied Energy*, *126*, 172–181. http://doi.org/10.1016/j.apenergy.2014.03.078

Hekkenberg, M., & Verdonk, M. (2014). *Nationale Energieverkenning 2014*. *ECN-O--14-036*. Petten.

Henkes, T. (2012). *De toepassing van micro-warmtekrachtkoppeling in woningen*. Universiteit Hasselt.

Heslinga, D.C., & Harmelen, A.K. van. (2006). *Vaststellingsmethodieken voor CO2 - emissiefactoren van aardgas in Nederland*. Apeldoorn.

Heymann, E., Koppel, O., & Puls, T. (2011). Electromobility. *Gene Therapy*, *9*(19), 1286–90. http://doi.org/10.1038/sj.gt.3301799

Huis Bouwen. (2015). *Hoeveel m3 gas wordt verbruikt in een nieuwbouw woning?*. Retrieved from http://www.huisbouwen.nl/hoeveel-m3-gas-wordt-verbruikt-in-een-nieuwbouw-woning/

IEA. (2011). International Energy Agency. Technology roadmap: Electric and plug-in hybrid electric vehicles. *International Energy Agency, Tech. Rep*, (June), 52. http://doi.org/10.1109/IEMBS.2004.1403974

IEA. (2014). International Energy Agency. Technology Roadmap: Solar Photovoltaic Energy, 60. http://doi.org/10.1007/SpringerReference_7300

Jabeen, F., Olaru, D., Smith, B., Braunl, T., & Speidel, S. (2013). Electric Vehicle Battery Charging Behaviour : Findings From a Driver Survey. *Australasian Transport Research Forum 2013 Proceedings*, 1 – 15.

Jones, R.V, Fuertes, A., & Lomas, K.J. (2014). The socio-economic , dwelling and appliance related factors affecting electricity consumption in domestic buildings. *Renewable and Sustainable Energy Reviews*, *43*, 901–917. http://doi.org/10.1016/j.rser.2014.11.084

Jonge, B.S.F. de. (2010). *Business models for demand side management*. Technical University Eindhoven.

Joode, J. de, Jansen, J.C., Welle, A.J. van der, & Scheepers, M.J.J. (2009). Increasing penetration of renewable and distributed electricity generation and the need for different network regulation. *Energy Policy*, *37*(8), 2907–2915. http://doi.org/10.1016/j.enpol.2009.03.014

Kamp, H.G.J. (2015). *Beantwoording vragen over het artikel "zonne-energie voor de massa."* Den Haag.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment*, *45*(7), 1683–1697. http://doi.org/10.1016/j.buildenv.2010.01.021

Kleefkens, O. (2014). *Status rapportage warmtepompen technologie en markt in Nederland*. Den Haag.

Klein Tank, A., Beersma, J., Bessembinder, J., van den Hurk, B., & Lenderink, G. (2015). *KNMI '14 climate scenarios for the Netherlands*. De Bilt.

KNMI. (2015). Koninklijk Nederlands Meteorologisch Instituut. *KNMI Klimaatscenario's* [Data file]. Retrieved 25 September 2015, from http://climexp.knmi.nl/Scenarios_monthly/

KNMI. (2015a). Koninklijk Nederlands Meteorologisch Instituut. *Uurgegevens van het weer in Nederland* [Data file]. Retrieved 1 June 2015, from http://www.knmi.nl/nederland-nu/klimatologie/uurgegevens

Lehtonen, M., & Nye, S. (2009). History of electricity network control and distributed generation in the UK and Western Denmark. *Energy Policy*, *37*(6), 2338–2345. http://doi.org/10.1016/j.enpol.2009.01.026

Leidelmeijer, K., & Grieken, P. van. (2005). *Wonen en Energie*. Amsterdam.

Lemmens, J., Burgt, J. van der, Bosma, T., Wijngaart, R. van den, Bemmel, B. van, & Koelemeijer, R. (2014). *Het potentieel van zonnestroom in de gebouwde omgeving van Nederland*. Arnhem.

Liander. (2015). *Aansluit- en transporttarieven elektriciteit*. Arnhem.

Luiten, R., Visser, R., Chang, M., Groenewoud, P., Duffhues, J., & Wolse, H. (2013). Laadstrategie Elektrisch Wegvervoer Autorisatieblad Laadstrategie Elektrisch Wegvervoer, 1–95. http://doi.org/IN13117 1 / EN - RL - 120022359 / Versie 1.0

Maat, K., & Kasraian, D. (2014). *Analysis of consumers ' EV potential*. Delft.

Milieu Centraal. (2015). *Gemiddeld energieverbruik.* Retrieved from http://www.milieucentraal.nl/energie-besparen/snel-besparen/grip-op-je-energierekening/gemiddeld-energieverbruik/

Milieu Centraal. (2015a). Verbeter Uw Huis. Retrieved 20 September 2015, from http://www.verbeteruwhuis.nl

Autolease Wereld (2012). *RAI: groei elektrische auto's op koers.* Retrieved 29 November 2015, from http://www.autoleasewereld.nl/nieuws/1/4656-rai__groei_elektrische_auto_s_op_koers

Molenaar, T. (2010). *The Energy Mismatch*. Utrecht University.

Mosquet, X., Devineni, M., Mezger, T., Zablit, H., Dinger, A., Sticher, G., … Russo, M. (2011). Report Powering Autos to 2020. *BCG Report*, *446*, 505–506. Retrieved from http://www.bcg.com/documents/file80920.pdf

NEDU. (2013). Nederlandse Energie Data Uitwisseling. *Informatiecode Elektriciteit en Gas*. Amersfoort.

NEDU. (2015). Nederlandse Energie Data Uitwisseling .*Verbruiksprofielen* [Data file]. Retrieved 27 July 2015, from http://nedu.nl/portfolio/verbruiksprofielen/

NREL. (2015). National Renewable Energy Laboratory. *Best research-cell efficiencies.* Retrieved 14 September 2015, from http://www.nrel.gov/ncpv/images/efficiency_chart.jpg “This pilot is courtesy of the National Renewable Energy Laboratory, Golden, CO”

Opstelten, I.J., Sinke, W.C., Bruijn, F.A. de, Borsboom, W.A., & Krosse, L. (2007). Potentials for energy efficiency and renewable energy sources in the. *Energy*, *2007*(March), 1–16.

Planbureau voor de Leefomgeving & DNV GL. (2014). Het potentieel van zonnestroom in de gebouwde omgeving van Nederland, 35. Retrieved from http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2014-dnv-gl-het-potentieel-van-zonnestroom-in-de-gebouwde-omgeving-van-nederland_01400.pdf

PV-Tech. (2015). Limit for industrial c-Si solar cells reached in 2030: what next?. Retrieved 27 November 2015, from http://www.pv-tech.org/guest-blog/limit_for_industrial_c_si_solar_cells_reached_in_2030_what_next

Radtke, P., Krieger, A., Kirov, S., Maekawa, A., Kato, A., Yamakawa, N., & Henderson, D. (2012). *Profiling Japan's Early EV Adopters*. (n.p).

RVO. (2011). Rijksdienst voor Ondernemend Nederland. Elektrisch Rijden in de versnelling Plan van Aanpak 2011-2015. *Publicaties*, 22. Retrieved from http://www.rijksoverheid.nl/documenten-en-publicaties/kamerstukken/2011/10/03/aanbiedingsbrief-green-deal.html

RVO. (2015). Rijksdienst voor Ondernemend Nederland. Cijfers elektrisch vervoer. Retrieved 27 November 2015, from http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers

RVO. (2015a). Rijksdienst voor Ondernemend Nederland. *Special: Toekomstige EV modellen*. Utrecht.

RVO. (2015b). Rijksdienst voor Ondernemend Nederland. Financiële ondersteuning elektrisch rijden. Retrieved 4 December 2015, from http://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/aan-de-slag/financiele-ondersteuning

Roland Berger. (2015). Snelle opmars zonnepanelen vormt bedreiging voor energiebedrijven. Retrieved 2 October 2015, from http://www.rolandberger.nl/nieuws/2015-06-18-zonnepanelen-bedreiging-energiebedrijven.html

Sark, W. van. (2014). *Opbrengst van zonnestroomsystemen in Nederland*. Utrecht.

Schoots, K., & Hammingh, P. (2015). *Nationale Energieverkenning 2015*. *Ecn-O--14-036*. Petten.

Schroeder, A., & Traber, T. (2012). The economics of fast charging infrastructure for electric vehicles. *Energy Policy*, *43*, 136–144. http://doi.org/10.1016/j.enpol.2011.12.041

Schroten, A., Aarnink, S.J., & van Essen, H.P. (2015). *Werkgelegenheid door elektrisch vervoer in 2020*. Delft.

SER. (2013). Sociaal Economische Raad*. The Agreement on Energy for Sustainable Growth: a policy in practice*. The Hague.

SER. (2015). Sociaal Economische Raad*.* Energieakkoord voor duurzame groei; Voortgangsrapportage 2015. *Report From: Http://Www.Energieakkoordser.Nl/*, (september), 1–146.

Shahan, C. (2015). Chevy Volt Emits Significantly Less Smog-Forming Pollution Than Other PHEVs. CleanTechnica. Retrieved 28 November 2015, from http://cleantechnica.com/2015/05/02/chevy-volt-emits-significantly-less-smog-forming-pollution-phevs/

Shell. (2008). Energy Needs, Choices and Possibilities, Scenarios to 2050, 60. Retrieved from http://www.amazon.com/Possibilities-Scenarios-Exploring-International-Environment/dp/B004XTP0WW?SubscriptionId=1V7VTJ4HA4MFT9XBJ1R2&tag=mekentosjcom-20&linkCode=xm2&camp=2025&creative=165953&creativeASIN=B004XTP0WW

Skippon, S., & Garwood, M. (2011). Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. *Transportation Research Part D: Transport and Environment*, *16*(7), 525–531. http://doi.org/10.1016/j.trd.2011.05.005

Skoplaki, E., Boudouvis, A.G., & Palyvos, J.A. (2008). A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting. *Solar Energy Materials and Solar Cells*, *92*(11), 1393–1402. http://doi.org/10.1016/j.solmat.2008.05.016

Spitalny, L., Myrzik, J.M.A., & Mehlhorn, T. (2014). Estimation of the economic addressable market of micro-CHP and heat pumps based on the status of the residential building sector in Germany. *Applied Thermal Engineering*, *71*(2), 838–846. http://doi.org/10.1016/j.applthermaleng.2013.12.027

Swan, L.G., & Ugursal, V.I. (2009). Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renewable and Sustainable Energy Reviews*, *13*(8), 1819–1835. http://doi.org/10.1016/j.rser.2008.09.033

Tanaka, N. (2010). Technology Roadmap Solar photovoltaic energy. *International Energy Agency*, 1–42. http://doi.org/10.1787/9789264088047-en

Tesla. (2015). *Model S*. Retrieved 28 November 2015, from https://www.teslamotors.com/models

Tesla. (2015a). *Gigafactory* . Retrieved 28 November 2015, from https://www.teslamotors.com/blog/gigafactor

The Boston Consulting Group. (2010). Batteries for Electric Cars. Retrieved from http://www.bcg.com/documents/file36615.pdf

Tigchelaar, C., & Leidelmeijer, K. (2013). Energiebesparing: Een samenspel van woning en bewoner - Analyse van de module Energie WoON 2012. Retrieved from http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2013/12/02/energiebesparing-een-samenspel-van-woning-en-bewoner-analy-se-van-de-module-energie-woon-2012.html

Vasseur, V., & Kemp, R. (2015). A segmentation analysis : the case of photovoltaic in the Netherlands, (2000). http://doi.org/10.1007/s12053-015-9340-8

Vasseur, V., & Kemp, R. (2015a). The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renewable and Sustainable Energy Reviews*, *41*, 483–494. http://doi.org/10.1016/j.rser.2014.08.020

Veldman, E., Gibescu, M., Slootweg, H.J.G., & Kling, W.L. (2011). Impact of electrification of residential heating on loading of distribution networks. *2011 IEEE PES Trondheim PowerTech: The Power of Technology for a Sustainable Society, POWERTECH 2011*, 1–7. http://doi.org/10.1109/PTC.2011.6019179

Veldman, E., Gibescu, M., Slootweg, H.J.G., & Kling, W.L. (2013). Scenario-based modelling of future residential electricity demands and assessing their impact on distribution grids. *Energy Policy*, *56*, 233–247. http://doi.org/10.1016/j.enpol.2012.12.078

Vuuren, D.P. van, Meinshausen, M., Plattner, G.K., Joos, F., Strassmann, K.M., Smith, S.J., … Reilly, J.M. (2008). Temperature increase of 21st century mitigation scenarios. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(40), 15258–15262. http://doi.org/10.1073/pnas.0711129105

Wagener, P., & Mosterd, D. (2013). *Positioning paper "Warmtepompen en economie."* Harderwijk. Retrieved from http://www.dhpa-online.nl/wp-content/uploads/2013/09/Warmtepompen.economie.pdf

Wagener, P. (2015). Impact of heat pumps in residential sector. Utrecht (interview by phone on 16-09-2015)

Wainwright, J., & Mulligan, M. (2004). Environmental modelling. Chichester, West Sussex, England: Wiley.

Woelderen, S. van. (2011). *Invloed elektrische auto op autobranche tot 2020 beperkt*. Arnhem.

Yamaguchi, Y., Akai, K., Shen, J., Fujimura, N., Shimoda, Y., & Saijo, T. (2013). Prediction of photovoltaic and solar water heater diffusion and evaluation of promotion policies on the basis of consumers' choices. *Applied Energy*, *102*(FEBRUARY), 1148–1159. http://doi.org/10.1016/j.apenergy.2012.06.037

Yohanis, Y.G., Mondol, J.D., Wright, A., & Norton, B. (2008). Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use. *Energy and Buildings*, *40*(6), 1053–1059. http://doi.org/10.1016/j.enbuild.2007.09.001

Zegers, F.T.S. (2013). Inventarisatie zonthermische systemen, *31*(0). Retrieved from http://www.zonne-energie-wageningen.nl/wp-content/uploads/2013/07/Rapport-inventarisatie-zonthermisch_mei-2013.pdf

Appendix I

This appendix presents the implementation percentages of decentralized generators, electric vehicles and insulation in the high and low scenario in 2030 (table 35 and table 36). Furthermore, absolute energy generation, saving and use per technology per scenario per dwelling type is presented for the high and low scenario (table 37 and table 38). The final table of this appendix introduces an overview of implementation percentages per technology per scenario (table 39).

Implementation ratio in the High scenario			Types of dwellings					
			Detached		Terraced		Multi family	
			2014	**2030**	2014	**2030**	2014	**2030**
Technologies	**Photovoltaic**		5.2%	**85%**	4.5%	**74%**	1.2%	**22%**
	Heat pump		2.6%	**25%**	1.9%	**8%**	0.8%	**2%**
	Solar water heater		2.6%	**16%**	2.3%	**14%**	0.7%	**4%**
	Electric vehicles		0.8%	**46%**	0.7%	**46%**	0.2%	**25%**
	Insulation [W/m²K]	<1965	1.76	**1.21**	2.03	**1.30**	1.97	**1.38**
		1965-1974	1.65	**1.12**	1.69	**1.11**	1.69	**1.31**
		1975-1991	1.01	**0.90**	0.98	**0.87**	0.81	**0.73**
		1992-2005	0.54	**0.54**	0.56	**0.56**	0.49	**0.49**
		2006-2014	0.44	**0.44**	0.45	**0.45**	0.42	**0.42**
		2015-2030	0.34	**0.34**	0.34	**0.34**	0.35	**0.35**

Table 35: Implementation ratios in 2030 in the high scenario

Implementation ratio in the Low scenario			Types of dwellings					
			Detached		Terraced		Multi family	
			2014	**2030**	2014	**2030**	2014	**2030**
Technologies	**Photovoltaic**		5.2%	**26%**	4.5%	**23%**	1.2%	**7%**
	Heat pump		2.6%	**11%**	1.9%	**4%**	0.8%	**1%**
	Solar water heater		2.6%	**2.7%**	2.3%	**2.4%**	0.7%	**0.7%**
	Electric vehicles		0.8%	**10%**	0.7%	**10%**	0.2%	**6%**
	Insulation [W/m²K]	<1965	1.76	**1.65**	2.03	**1.89**	1.97	**1.85**
		1965-1974	1.65	**1.54**	1.69	**1.55**	1.69	**1.56**
		1975-1991	1.01	**0.95**	0.98	**0.93**	0.81	**0.77**
		1992-2005	0.54	**0.54**	0.56	**0.56**	0.49	**0.49**
		2006-2014	0.44	**0.44**	0.45	**0.45**	0.42	**0.42**
		2015-2030	0.34	**0.34**	0.34	**0.34**	0.35	**0.35**

Table 36: Implementation ratios in 2030 in the low scenario

Energy requirement in the Low scenario			Types of dwellings					
			Detached		Terraced		Multi family	
			2014	**2030**	2014	**2030**	2014	**2030**
Technologies	**Photovoltaic [TJ]**		-589	**-3,648**	-1,949	**-12,075**	-1,380	**-2,576**
	Heat pump (heat) [TJ]		-488	**-6,841**	-1,349	**-5,087**	-402	**-582**
	Heat pump (el) [TJ]		156	**1,773**	432	**1,280**	129	**146**
	Solar water heater [TJ]		-120	**-137**	-398	**-454**	-85	**-97**
	Electric vehicles [TJ]		76	**1,004**	251	**3,835**	50	**1,457**
	Insulation [TJ]	<1965	-	**-2,003**	-	**-4,257**	-	**-1,459**
		1965-1974	-	**-519**	-	**-2,458**	-	**-676**
		1975-1991	-	**-500**	-	**-1,792**	-	**-339**
		1992-2005	-	**-**	-	**-**	-	**-**
		2006-2014	-	**-**	-	**-**	-	**-**
		2015-2030	-	**-**	-	**-**	-	**-**

Table 37: Energy generation, use and savings in 2030 in the low scenario

Energy requirement in the High scenario			Types of dwellings					
			Detached		Terraced		Multi family	
			2014	**2030**	2014	**2030**	2014	**2030**
Technologies	**Photovoltaic [TJ]**		-589	**-11,886**	-1,949	**-39,347**	-1,380	**-8,394**
	Heat pump (heat) [TJ]		-488	**-12,063**	-1,349	**-8,835**	-402	**-1,086**
	Heat pump (el) [TJ]		156	**3,126**	432	**2,224**	129	**273**
	Solar water heater [TJ]		-120	**-792**	-398	**-2,623**	-85	**-560**
	Electric vehicles [TJ]		76	**4,446**	251	**16,983**	50	**6,452**
	Insulation [TJ]	<1965	-	**-10,407**	-	**-22,256**	-	**-6,950**
		1965-1974	-	**-2,556**	-	**-9,761**	-	**-2,057**
		1975-1991	-	**-985**	-	**-3,545**	-	**-682**
		1992-2005	-	**-**	-	**-**	-	**-**
		2006-2014	-	**-**	-	**-**	-	**-**
		2015-2030	-	**-**	-	**-**	-	**-**

Table 38: Energy generation, use and savings in 2030 in the high scenario

Implementation ratio for the whole residential sector			2014	Scenarios		
				2030		
				Low	Mid	High
Technologies	**Photovoltaic**		3.4%	17.4%	28.3%	56.6%
	Heat pump		1.6%	3.7%	6.0%	8.0%
	Solar water heater		1.7%	1.8%	2.0%	10.6%
	Electric vehicles		0.5%	8.6%	14.8%	38.1%
	Average insulation [W/m2K]	<1965	1.98	1.84	1.31	1.31
		1965-1974	1.69	1.55	1.18	1.18
		1975-1991	0.92	0.87	0.92	0.82
		1992-2005	0.53	0.53	0.53	0.53
		2006-2014	0.44	0.44	0.44	0.44
		2015-2030	0.35	0.34	0.34	0.34

Table 39: Implementation overview for the whole residential sector with different scenarios

Appendix II

Appendix II complements paragraph 7.3, it presents the minimum and maximum net hourly demand for gas and electricity in the residential sector. Table 40 presents the demand for all dwellings per type and the whole residential sector. Table 41 presents the net hourly demand per average dwelling type.

	2014		2030					
			Mid		Low		High	
	Min	Max	Min	Max	Min	Max	Min	Max
Electricity [TJ/hr]								
SFD	0.8	4.4	-3.0	4.6	-1.2	4.2	-7.7	5.6
SFT	2.6	12.6	-9.2	12.3	-3.7	11.4	-23.4	15.6
MF	1.1	5.2	-0.6	5.2	0.5	4.8	-3.8	6.4
Residential sector	**4.6**	**21.9**	**-11.7**	**21.9**	**-3.5**	**20.1**	**-33.4**	**27.5**
Gas [TJ/hr]								
SFD	0.6	31.2	0.5	18.4	0.5	22.7	0.4	17.1
SFT	1.3	71.4	1.1	45.8	1.1	54.2	1.1	43.8
MF	0.5	25.1	0.4	15.9	0.4	17.8	0.4	15.7
Residential sector	**2.4**	**127.7**	**1.9**	**80.1**	**2.0**	**94.7**	**1.9**	**76.6**

Table 40: Minimum and maximum net electricity and gas demand in the residential sector in 2014 and 2030, with low and high scenario as a range

	2014		2030					
			Mid		Low		High	
	Min	Max	Min	Max	Min	Max	Min	Max
Electricity [MJ/hr]								
SFD	0.8	4.3	-2.8	4.2	-1.1	3.9	-7.1	5.2
SFT	0.7	3.2	-2.2	3.0	-0.9	2.8	-5.7	3.8
MF	0.4	2.0	-0.2	1.8	0.2	1.7	-1.3	2.2
Gas [MJ/hr]								
SFD	0.6	30.4	0.4	17.0	0.4	21.0	0.4	15.8
SFT	0.3	18.2	0.3	11.1	0.3	13.1	0.3	10.6
MF	0.2	9.7	0.1	5.5	0.1	6.1	0.1	5.4

Table 41: Minimum and maximum net electricity and gas demand in the residential sector per average dwelling in 2014 and 2030, with low and high scenario as a range

Appendix III

Appendix III complements paragraph 7.4, it presents the seasonal deviation for electricity, gas and district heating per scenario. Table 42 depicts the summer period and Table 43 the winter period.

	2014	2030		
		Mid	Low	High
Electricity [PJ]				
SFD	7.8	3.6	4.8	0.7
SFT	22.8	8.0	12.3	-1.8
MF	9.7	7.2	7.9	6.0
Residential sector	**40.4**	**18.8**	**25.0**	**4.9**
Gas [PJ]				
SFD	14.6	15.2	18.3	14.0
SFT	33.3	38.4	44.2	36.6
MF	11.7	13.3	14.5	13.1
Residential sector	**59.7**	**66.9**	**77.0**	**63.7**
District heating [PJ]				
SFD	0.0	0.0	0.0	0.0
SFT	1.2	2.0	2.3	1.9
MF	1.0	2.5	2.9	2.4
Residential sector	**2.2**	**4.5**	**5.2**	**4.3**
Total energy use [PJ]	**102.2**	**90.1**	**107.2**	**72.8**

Table 42: Net energy demand in the summer in 2014 and 2030, with low and high scenario as error bar [PJ]

	2014	2030		
		Mid	Low	High
Electricity [PJ]				
SFD	9.7	9.1	8.8	9.6
SFT	28.4	23.2	23.2	24.3
MF	12.2	11.1	10.9	12.2
Residential sector	**50.3**	**43.5**	**42.9**	**46.0**
Gas [PJ]				
SFD	64.7	37.7	47.0	34.7
SFT	148.0	95.6	113.5	91.2
MF	52.1	33.4	37.3	33.0
Residential sector	**264.8**	**166.7**	**197.8**	**158.9**
District heating [PJ]				
SFD	0.0	0.0	0.0	0.0
SFT	5.3	5.0	5.9	4.8
MF	4.4	6.2	7.4	5.9
Residential sector	**9.7**	**11.2**	**13.3**	**10.7**
Total energy use [PJ]	**324.8**	**221.4**	**254.1**	**215.6**

Table 43: Net energy demand in the winter in 2014 and 2030, with low and high scenario as error bar [PJ]

Appendix IV

Appendix IV complements paragraph 7.5, it presents the standard deviation of electricity, gas and district heating demand over a month per scenario. Table 44 depicts the deviation in January and table 45 the standard deviation in July.

	2014	2030		
		Mid	**Low**	**High**
Electricity [TJ]				
SFD	0.9	0.9	0.8	1.3
SFT	2.8	2.7	2.4	3.8
MF	1.0	1.0	0.9	1.3
Residential sector	**4.7**	**4.6**	**4.2**	**6.3**
Gas [TJ]				
SFD	6.8	2.5	3.1	2.4
SFT	15.5	6.2	7.4	6.0
MF	5.4	2.2	2.4	2.1
Residential sector	**27.7**	**10.9**	**13.0**	**10.5**
District heating [TJ]				
SFD	0.0	0.0	0.0	0.0
SFT	0.6	0.3	0.4	0.3
MF	0.5	0.4	0.5	0.4
Residential sector	**1.0**	**0.7**	**0.9**	**0.7**

Table 44: Standard deviation of energy demand of all dwellings per type in January 2014 and January 2030 [TJ]

	2014	2030		
		Mid	**Low**	**High**
Electricity [TJ]				
SFD	0.5	1.4	0.9	2.8
SFT	1.3	4.4	2.6	9.3
MF	0.5	0.9	0.6	2.0
Residential sector	**2.3**	**6.5**	**3.9**	**13.7**
Gas [TJ]				
SFD	0.7	1.0	1.3	1.0
SFT	1.6	2.7	3.2	2.5
MF	0.6	0.9	1.0	0.9
Residential sector	**2.9**	**4.6**	**5.5**	**4.4**
District heating [TJ]				
SFD	0.0	0.0	0.0	0.0
SFT	0.1	0.1	0.2	0.1
MF	0.0	0.2	0.2	0.2
Residential sector	**0.1**	**0.3**	**0.4**	**0.3**

Table 45: Standard deviation of energy demand of all dwellings per type in July 2014 and July 2030 [TJ]

Appendix V

Appendix V presents an hourly demand pattern per energy carrier per type of dwelling in 2014 and 2030 with a distinction per technology. First, electricity is presented, followed by gas and finally, district heating.

Electricity demand pattern

Further insights in net electricity demand is supplied by means of an electric demand pattern, a histogram of the electricity demand and two example days in winter and two in summer to provide insight into the influence per technology. First an overview of 2014 is presented, then the situation in the mid scenario in 2030 is shown and finally, some data of the low and high scenario is presented.

2014

The net electricity demand per dwelling type in 2014 is presented in figure 27, figure 28 and figure 29. The first hour (value 1 on x-axis) represents the first hour of 2014. The figures show a clear winter and summer trend, more electricity is required in the winter than in the summer months. This is mainly caused by the smaller demand for illumination in the summer.

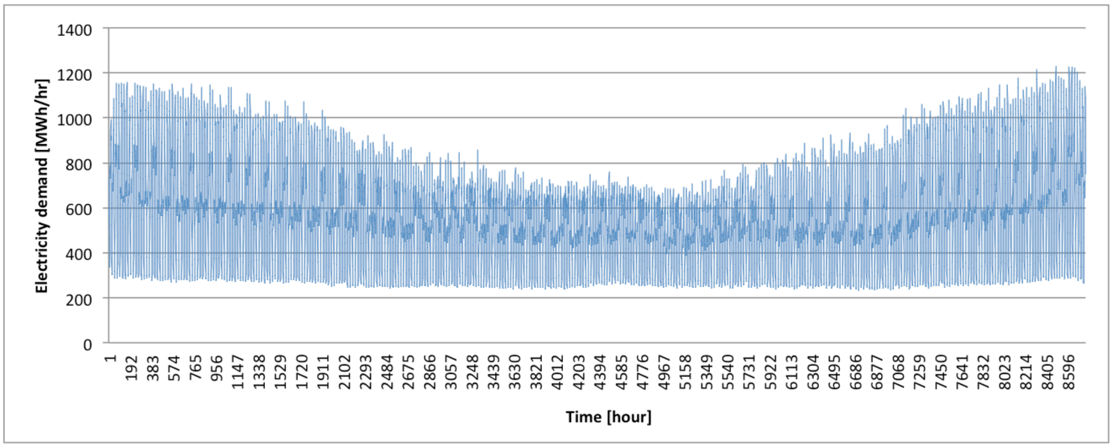

Figure 27: Net electricity demand of all SFD dwellings in 2014 per hour [MWh/hr]

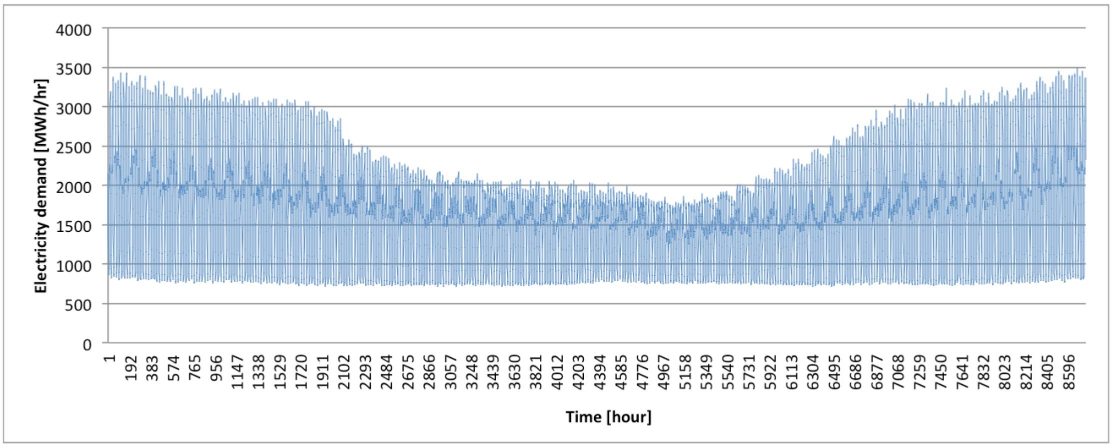

Figure 28: Net electricity demand of all SFT dwellings in 2014 per hour [MWh/hr]

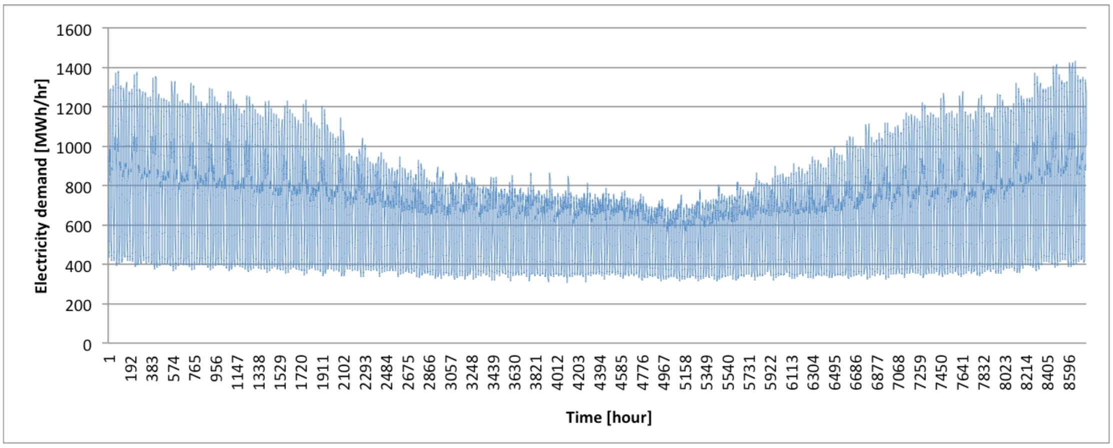

Figure 29: Net electricity demand of all MF dwellings in 2014 per hour [MWh/hr]

The following figures present a histogram of the number of hours that a specific electricity demand occurs, this provides a more comprehensive overview.

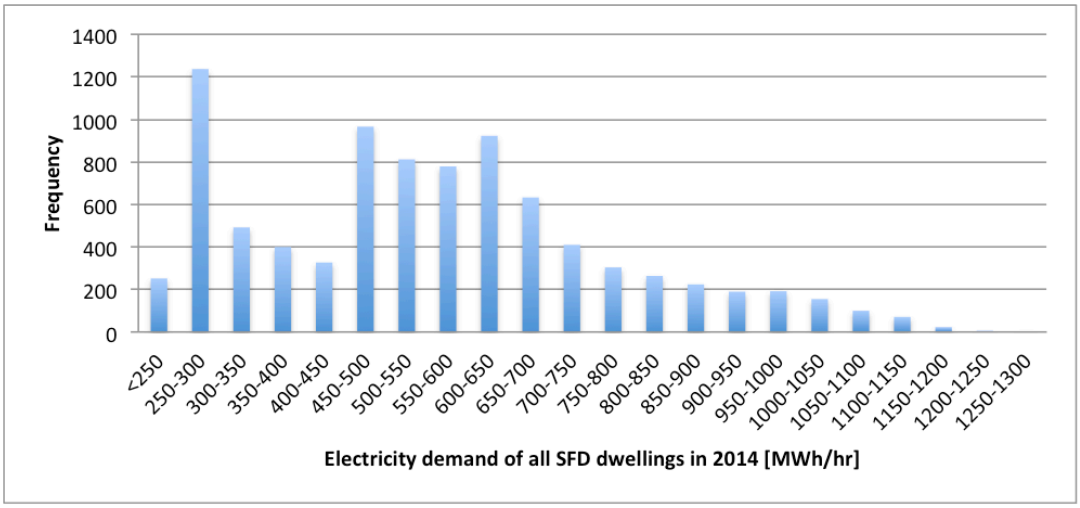

Figure 30: Histogram of the number of hours with a specific net electricity demand of all SFD dwellings in 2014

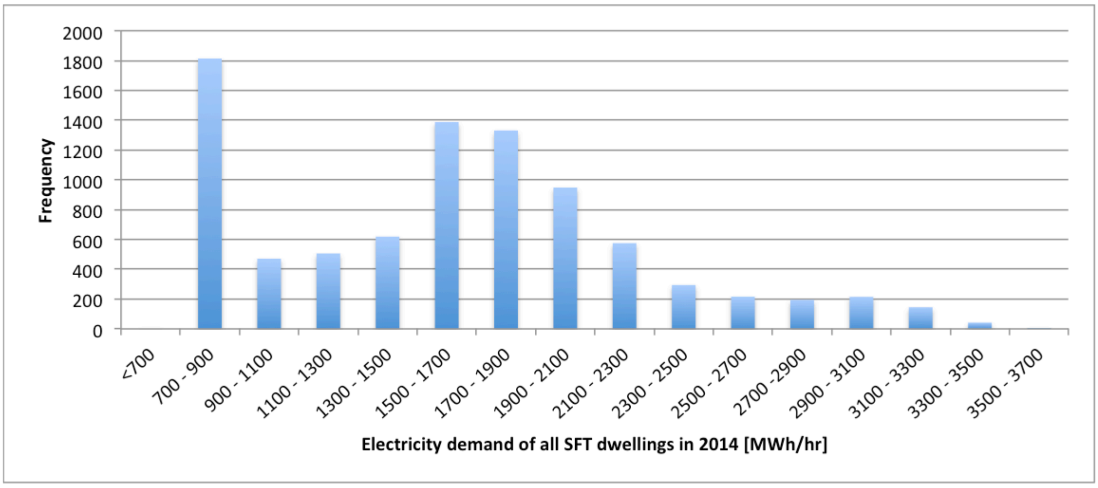

Figure 31: Histogram of the number of hours with a specific net electricity demand of all SFT dwellings in 2014

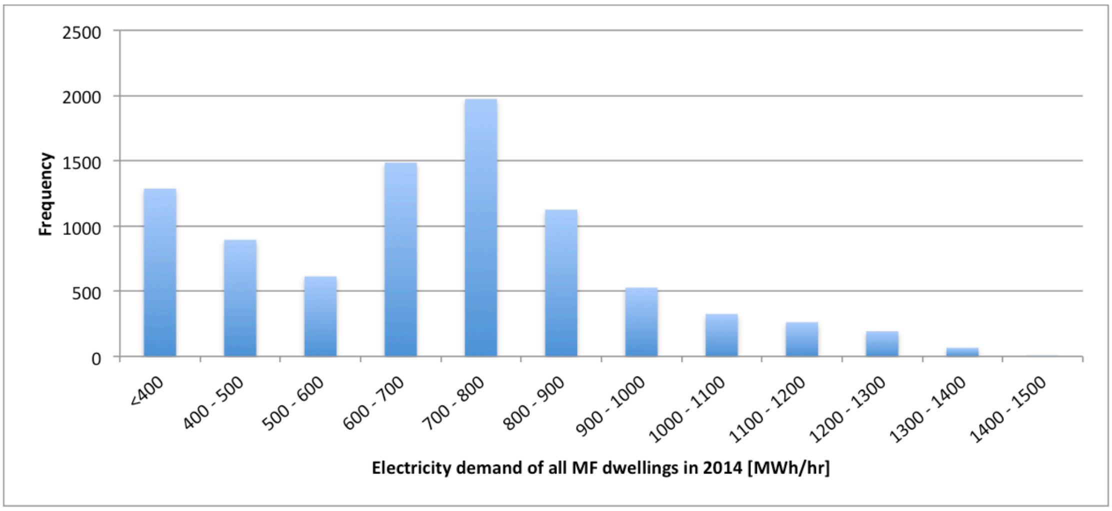

Figure 32: Histogram of the number of hours with a specific net electricity demand of all MF dwellings in 2014

The following figures show the impact of technologies on the electricity demand in 2014. Only Baseline Electricity and 'base + PV' are presented since the impact of other technologies is too small to be visible in the graph. The influence of PV is barely visible in the winter and has a larger impact in the summer.

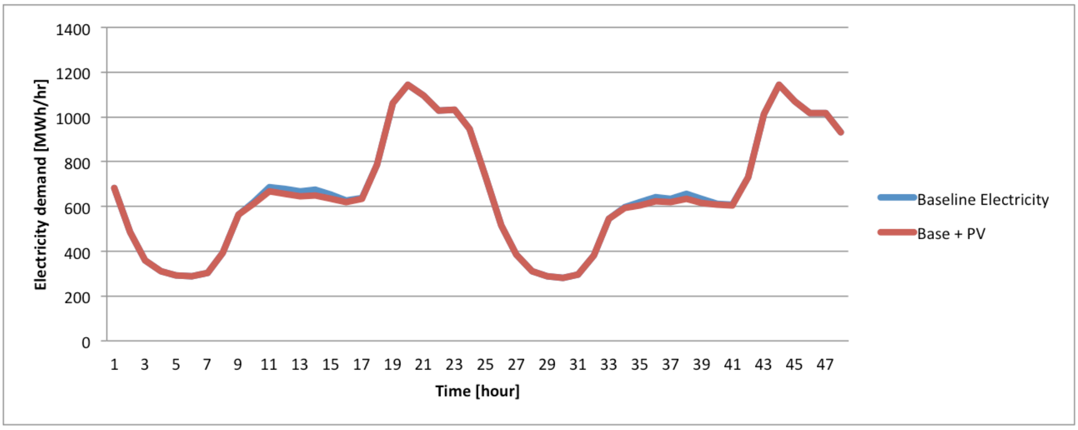

Figure 33: Net electricity demand of two example days in winter for SFD dwellings in 2014

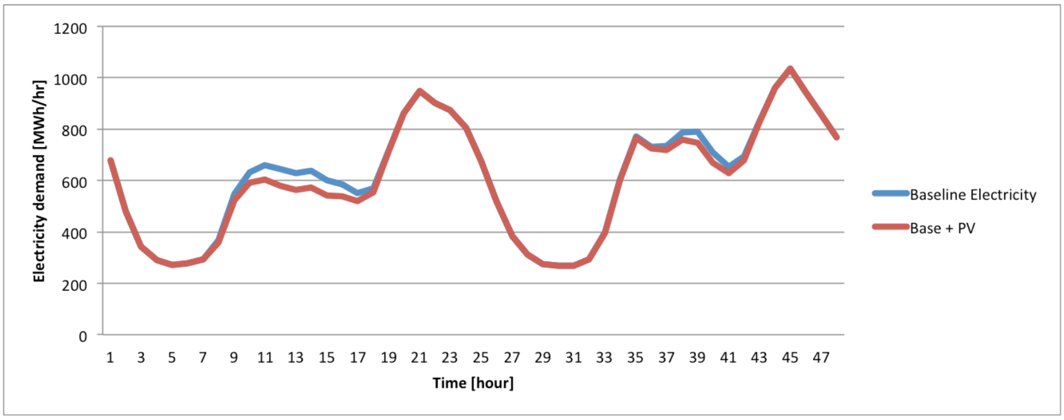

Figure 34: Net electricity demand of two example days in summer for SFD dwellings in 2014

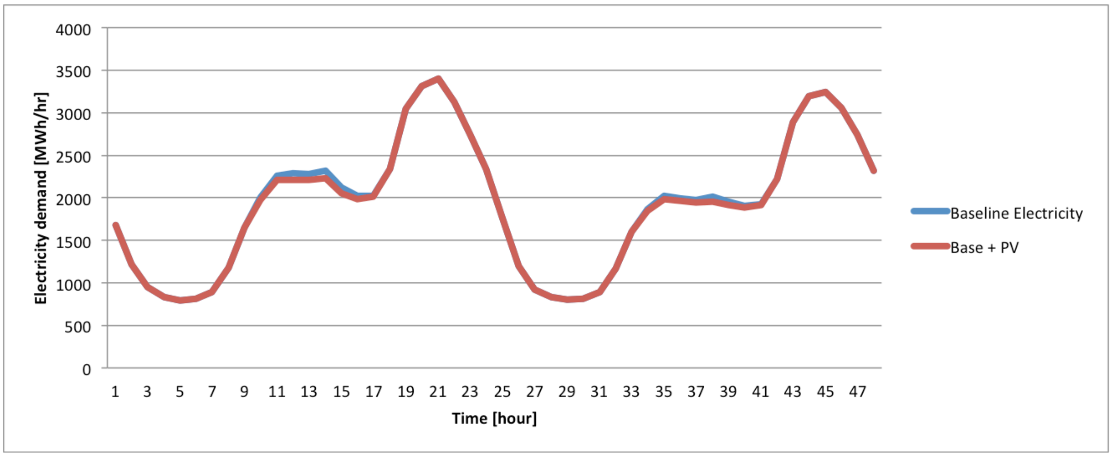

Figure 35: Net electricity demand of two example days in summer for SFT dwellings in 2014

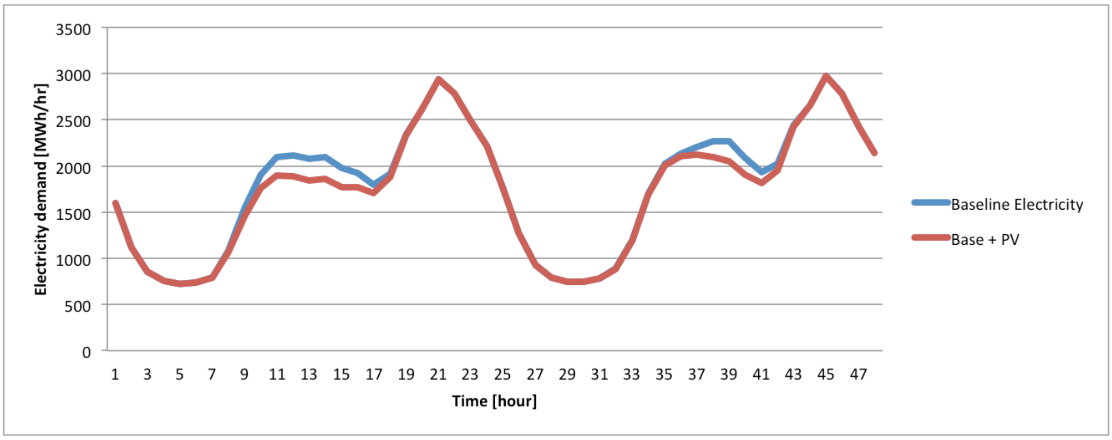

Figure 36: Net electricity demand of two example days in summer for SFT dwellings in 2014

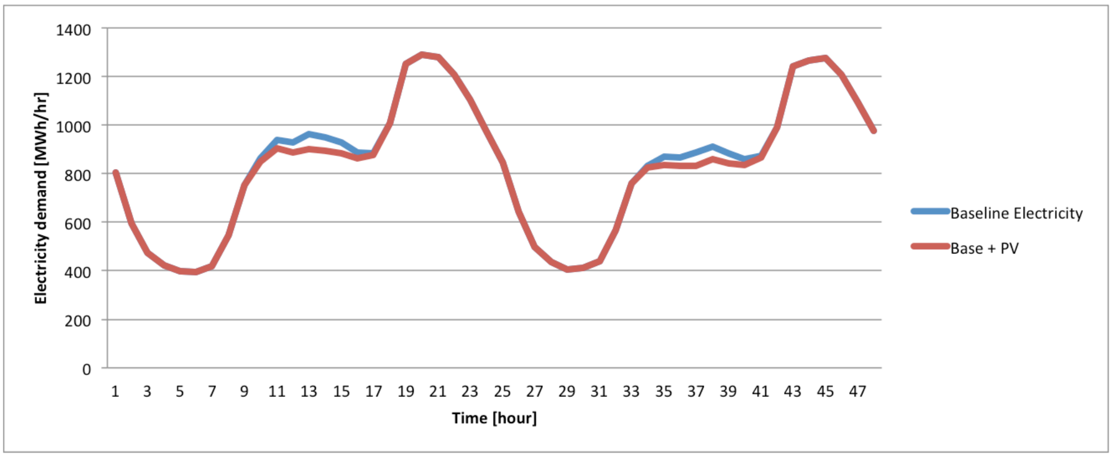

Figure 37: Net electricity demand of two example days in summer for MF dwellings in 2014

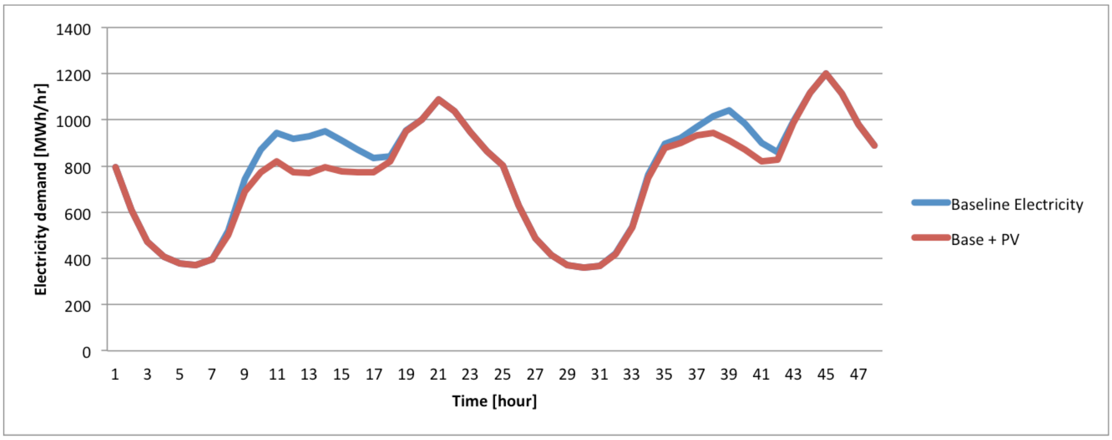

Figure 38: Net electricity demand of two example days in summer for MF dwellings in 2014

2030

The same figures are created for the mid scenario in 2030. The summer and winter trend is even more noticeable in the electricity demand graphs. The electrification of heating amplifies the difference between summer and winter months. Furthermore, the increased implementation of PV causes the electricity demand to decrease even further in the summer.

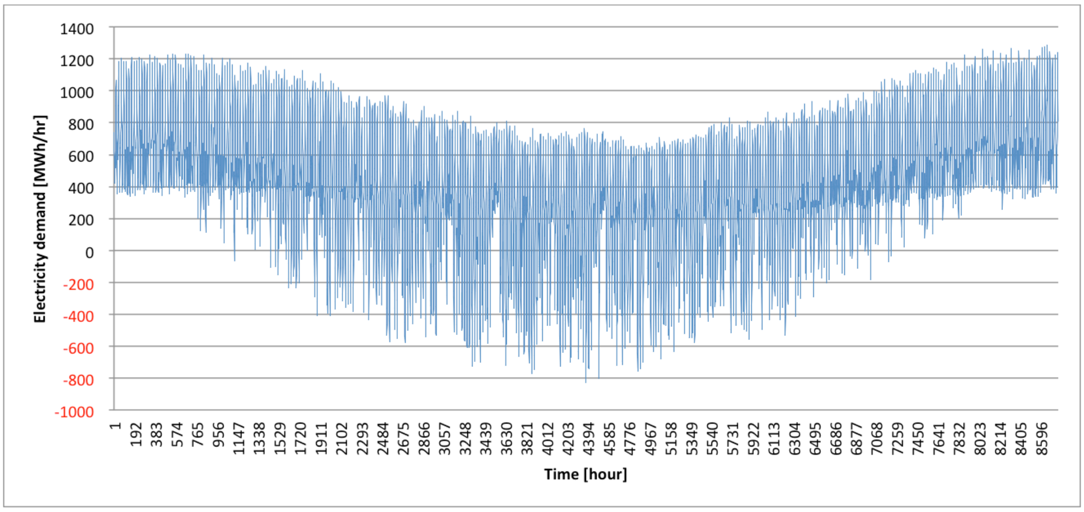

Figure 39: Net electricity demand of all SFD dwellings in 2030 per hour in the mid scenario

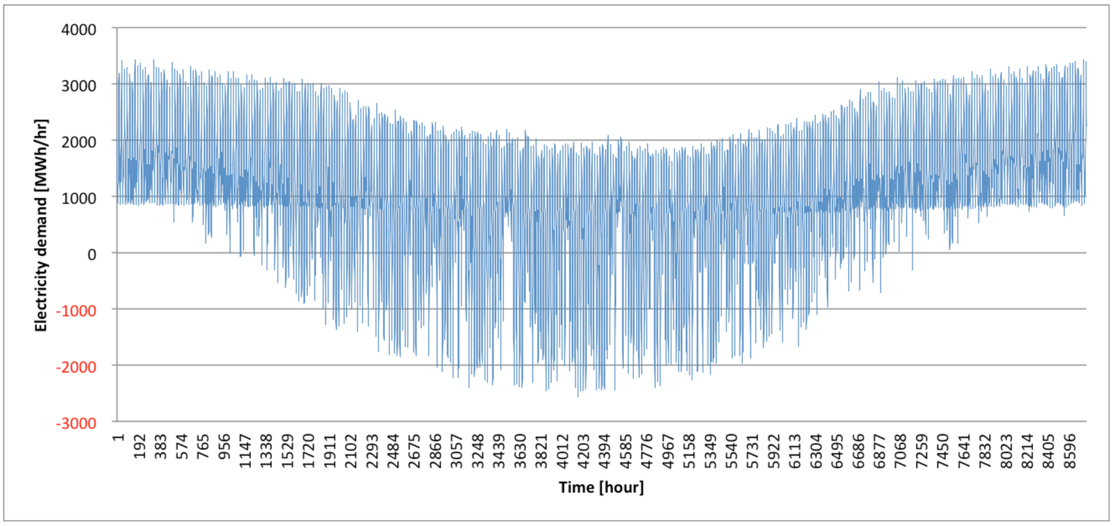

Figure 40: Net electricity demand of all SFD dwellings in 2030 per hour in the mid scenario

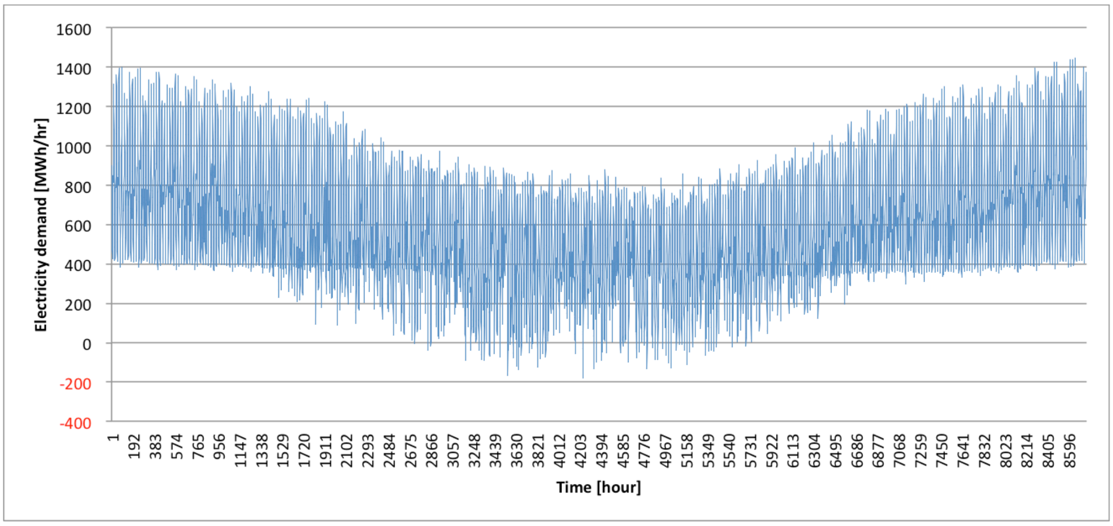

Figure 41: Net electricity demand of all SFD dwellings in 2030 per hour in the mid scenario

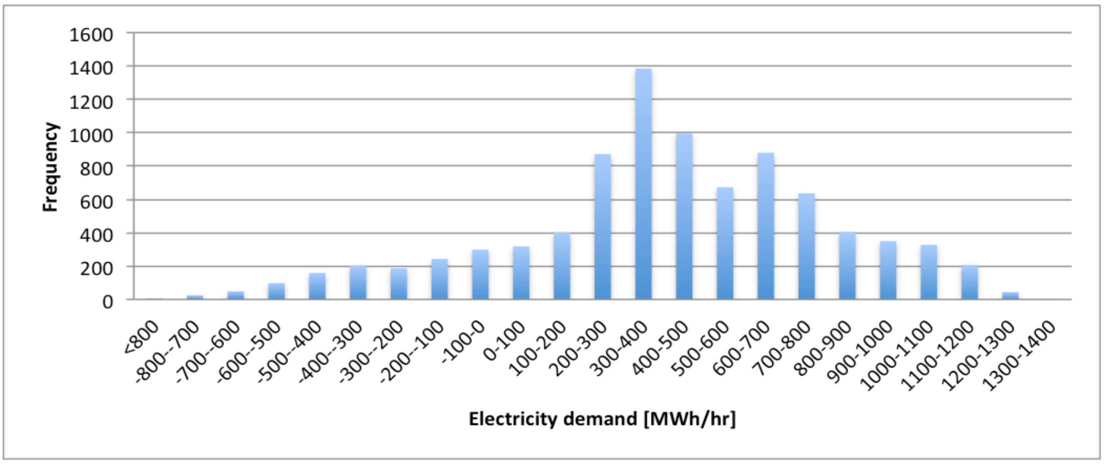

Figure 42: Histogram of the number of hours with a specific net electricity demand of all SFD dwellings in 2030 in the mid scenario

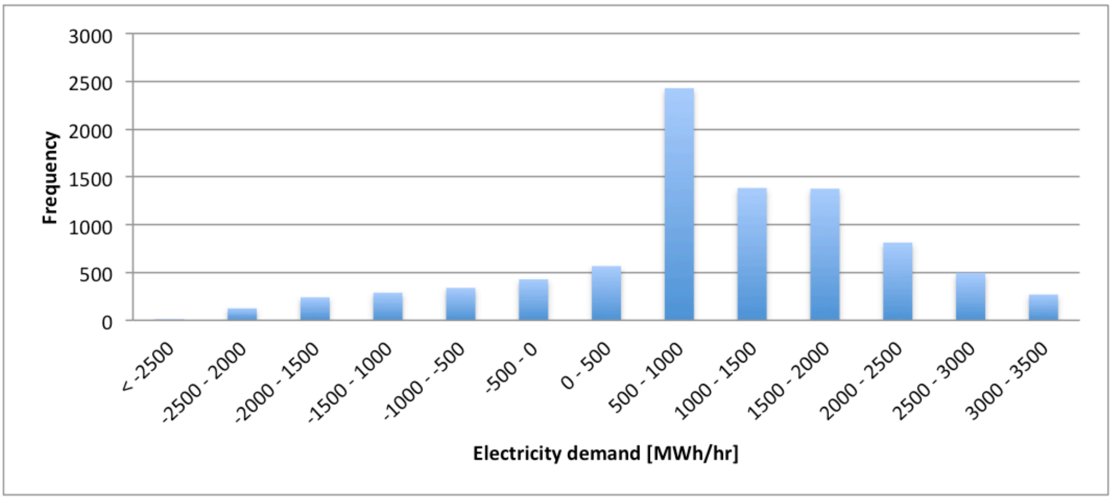

Figure 43: Histogram of the number of hours with a specific net electricity demand of all SFT dwellings in 2030 in the mid scenario

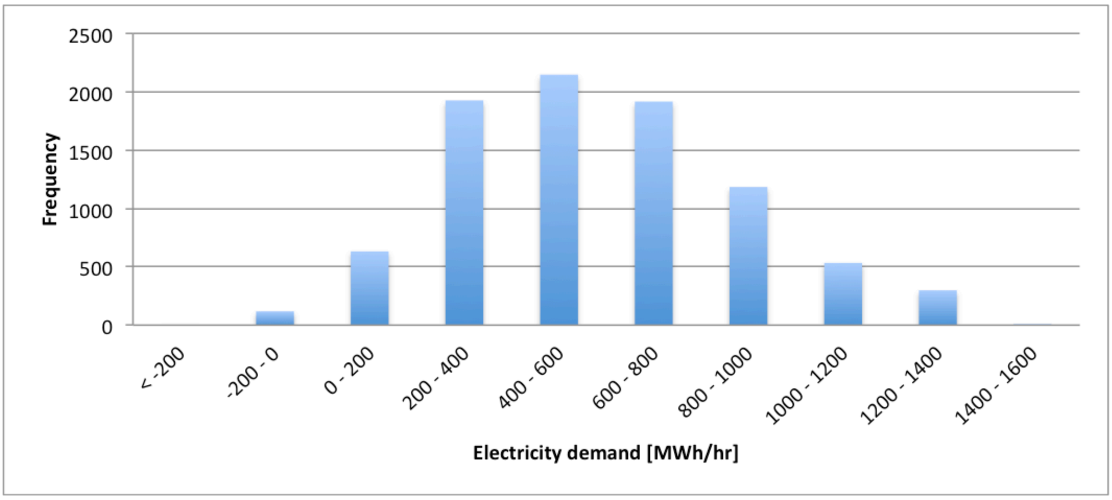

Figure 44: Histogram of the number of hours with a specific net electricity demand of all MF dwellings in 2030 in the mid scenario

The following figures present the electricity demand with a distinction per technology on two example days in winter and summer. These figures show that PV has a large influence on the demand pattern of dwellings, especially in the summer. It is clearly visible that the displayed technologies are expected to have a much larger impact on the electricity demand in 2030 than they had in 2014.

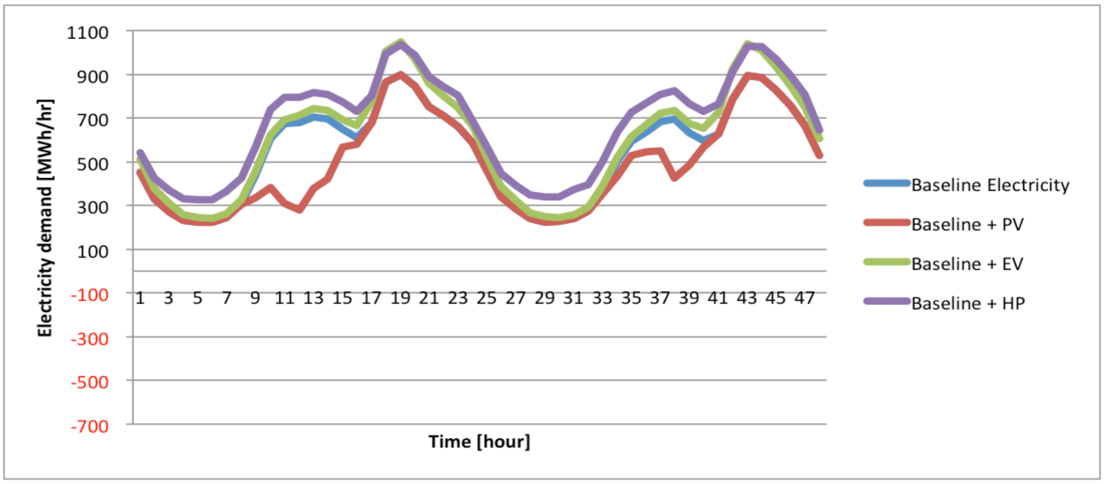

Figure 45: Net electricity demand of two example days in winter for all SFD dwellings in 2030 with a distinction per technology

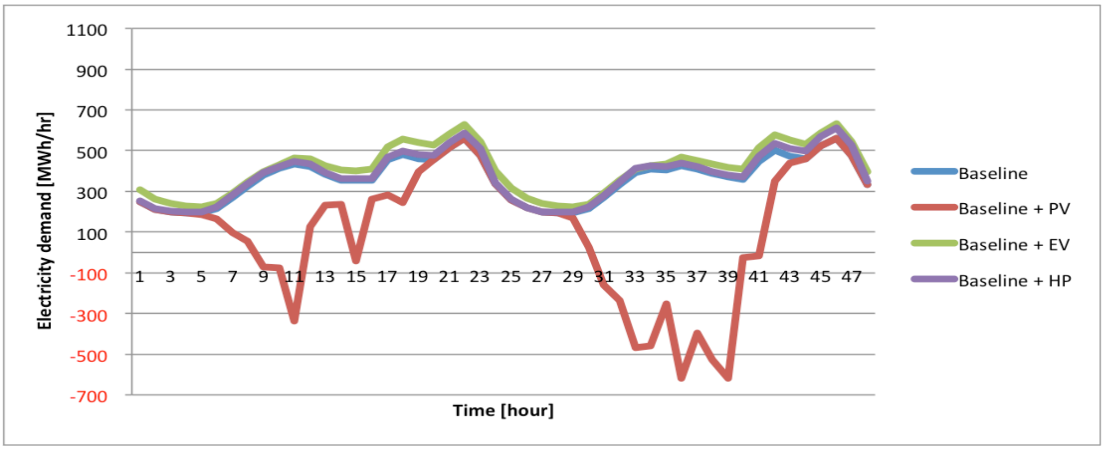

Figure 46: Net electricity demand of two example days in the summer for all SFD dwellings in 2030 with a distinction per technology

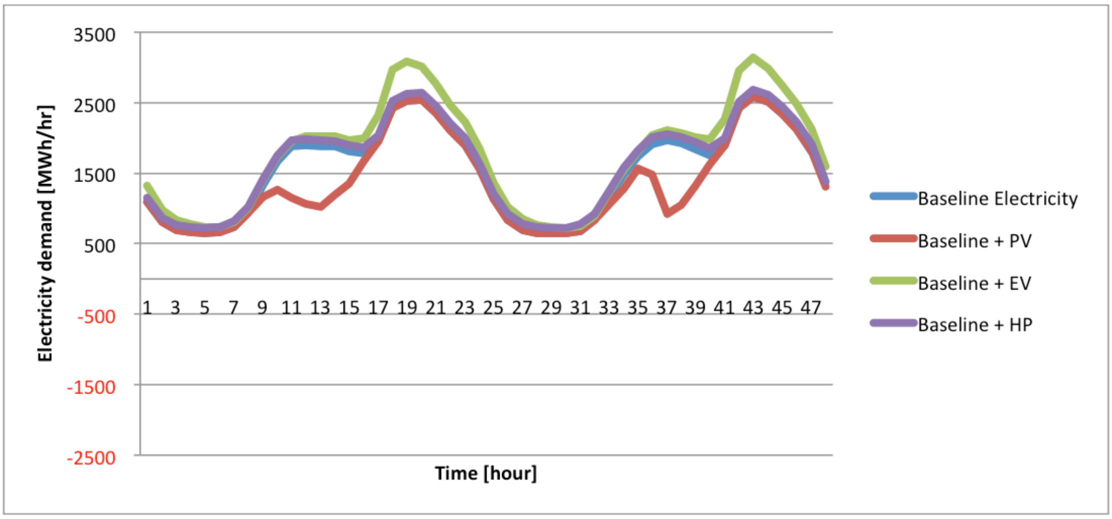

Figure 47: Net electricity demand of two example days in the winter for all SFT dwellings in 2030 with a distinction per technology

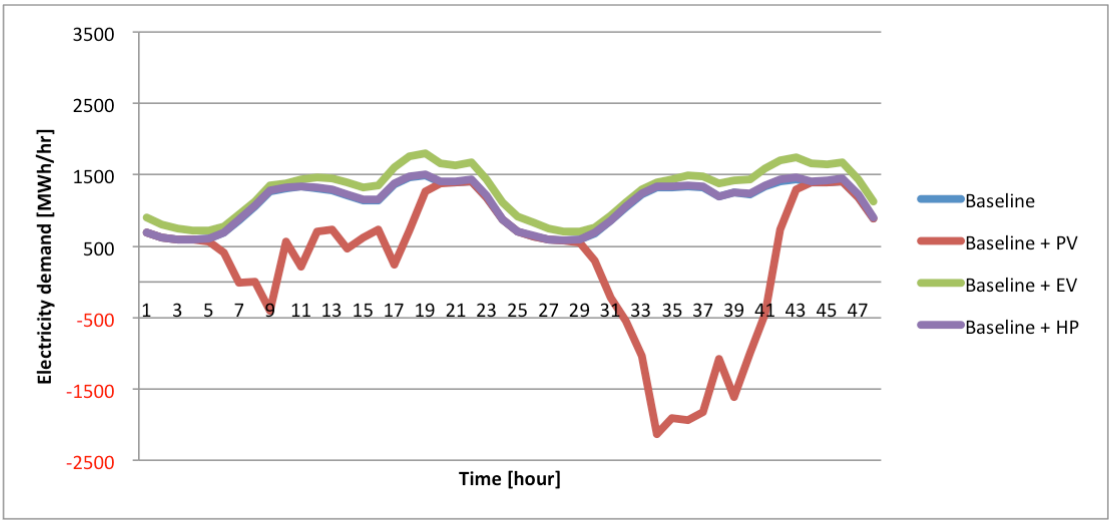

Figure 48: Net electricity demand of two example days in the summer for all SFT dwellings in 2030 with a distinction per technology

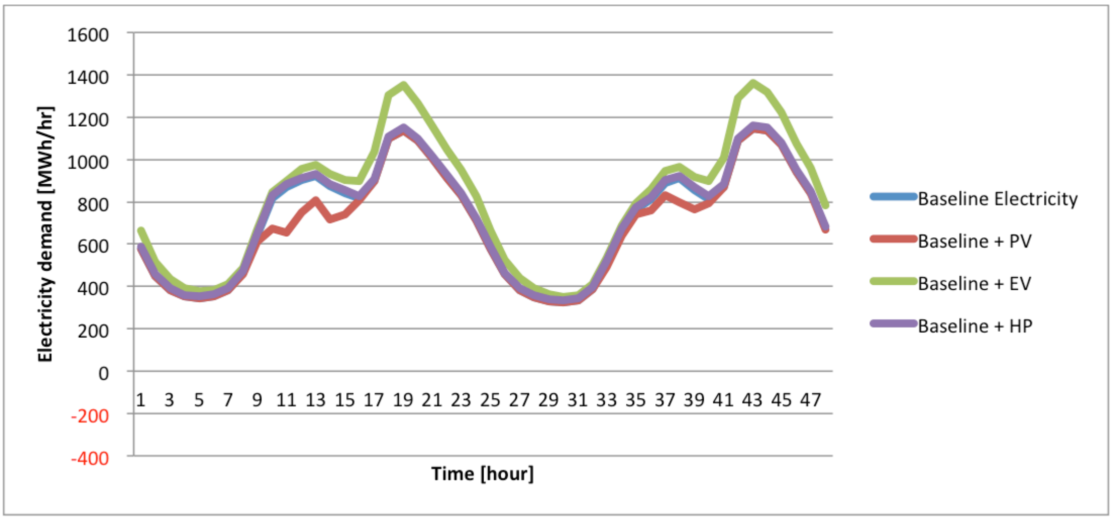

Figure 49: Net electricity demand of two example days in the winter for all MF dwellings in 2030 with a distinction per technology

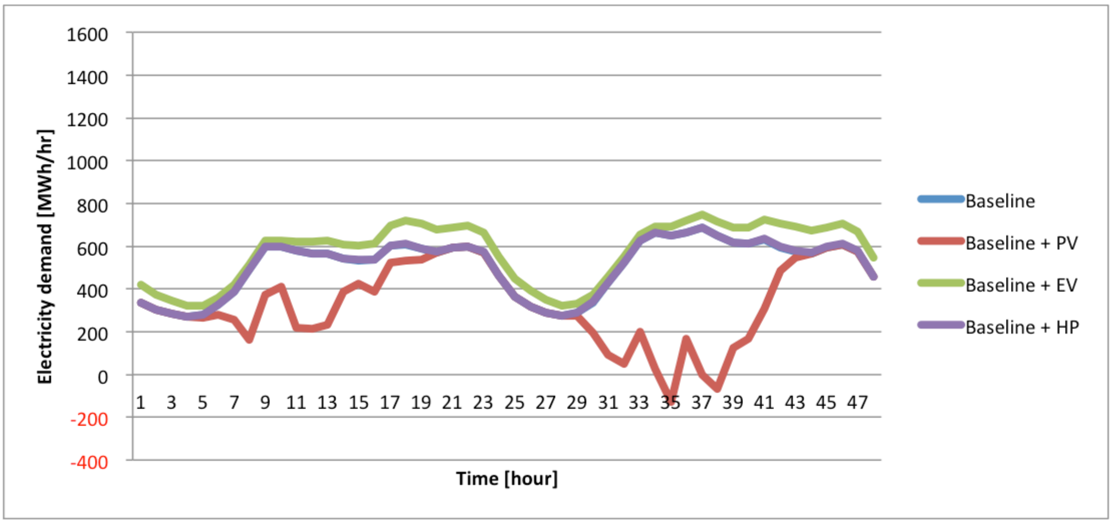

Figure 50: Net electricity demand of two example days in the summer for all MF dwellings in 2030 with a distinction per technology

High and Low scenarios

Histograms of the high and low scenario are constructed to provide an overview of the more extreme values (figure 51 to figure 56).

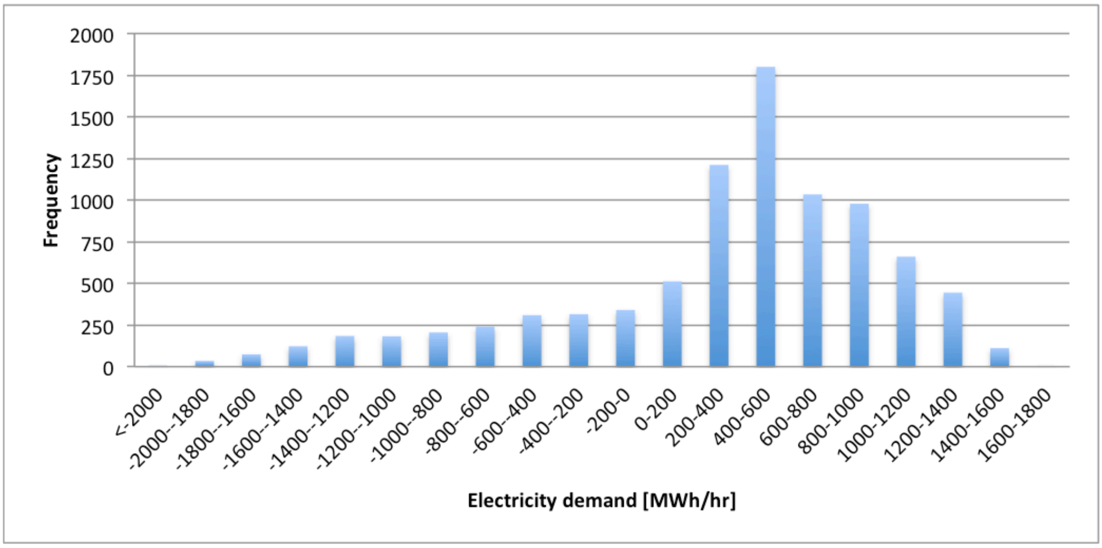

Figure 51: Histogram of the number of hours with a specific net electricity demand of all SFD dwellings in 2030 in the high scenario

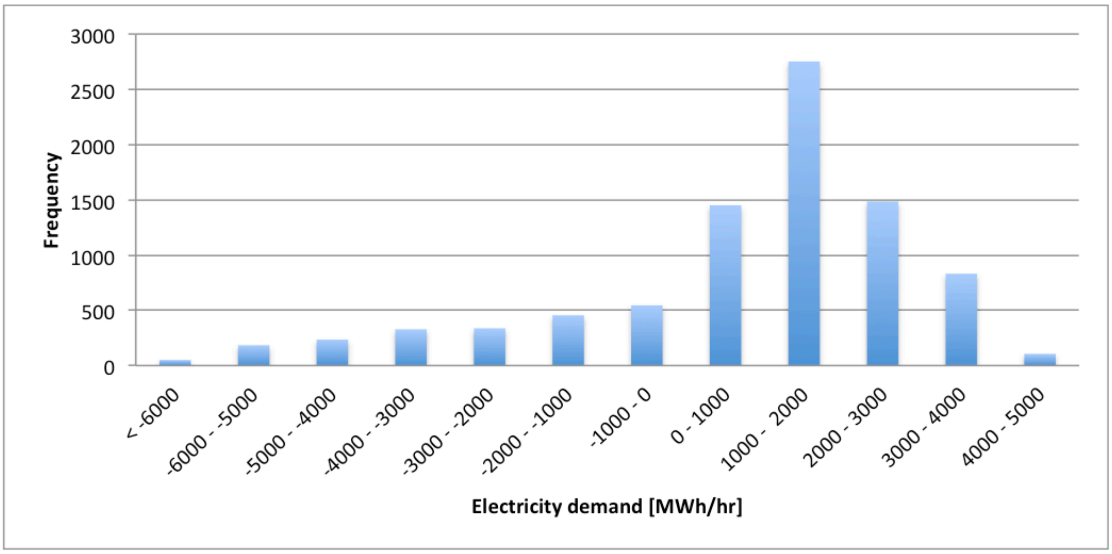

Figure 52: Histogram of the number of hours with a specific net electricity demand of all SFT dwellings in 2030 in the high scenario

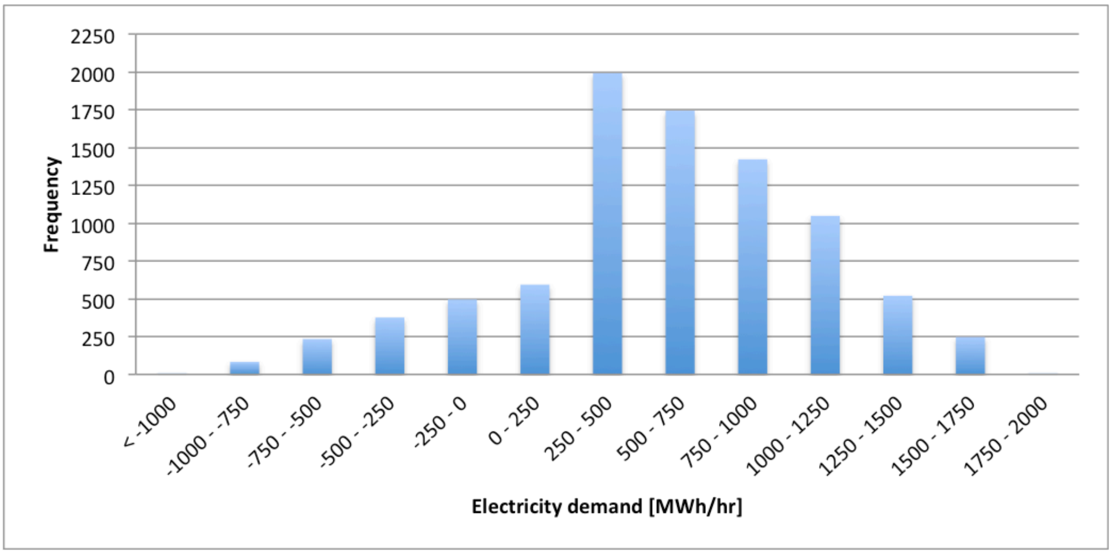

Figure 53: Histogram of the number of hours with a specific net electricity demand of all MF dwellings in 2030 in the high scenario

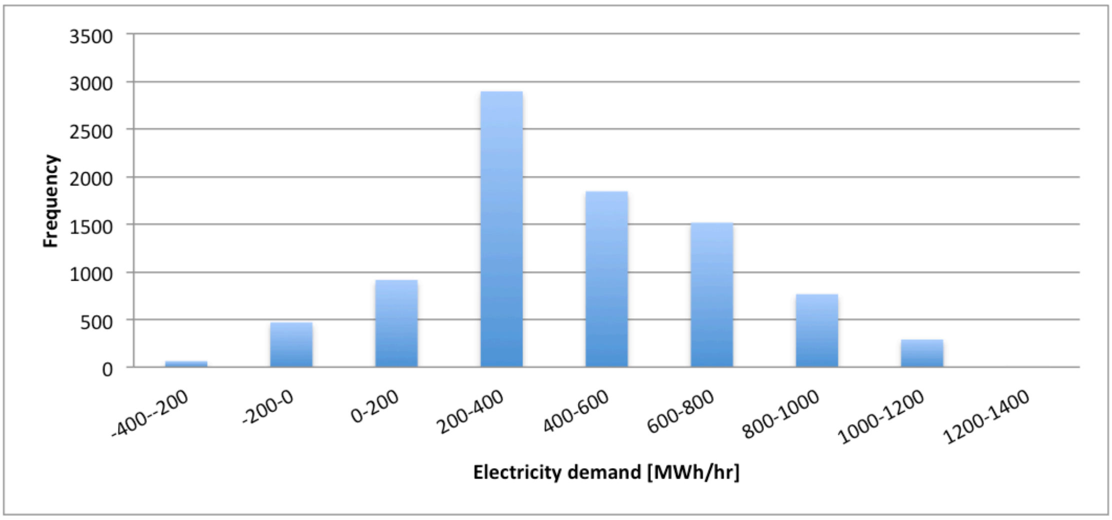

Figure 54: Histogram of the number of hours with a specific net electricity demand of all SFD dwellings in 2030 in the low scenario

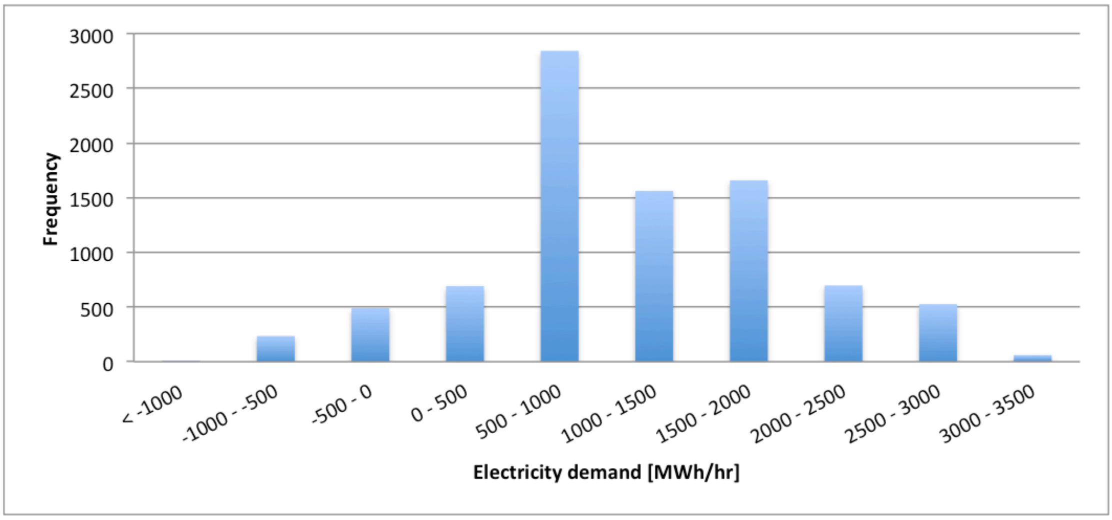

Figure 55: Histogram of the number of hours with a specific net electricity demand of all SFT dwellings in 2030 in the low scenario

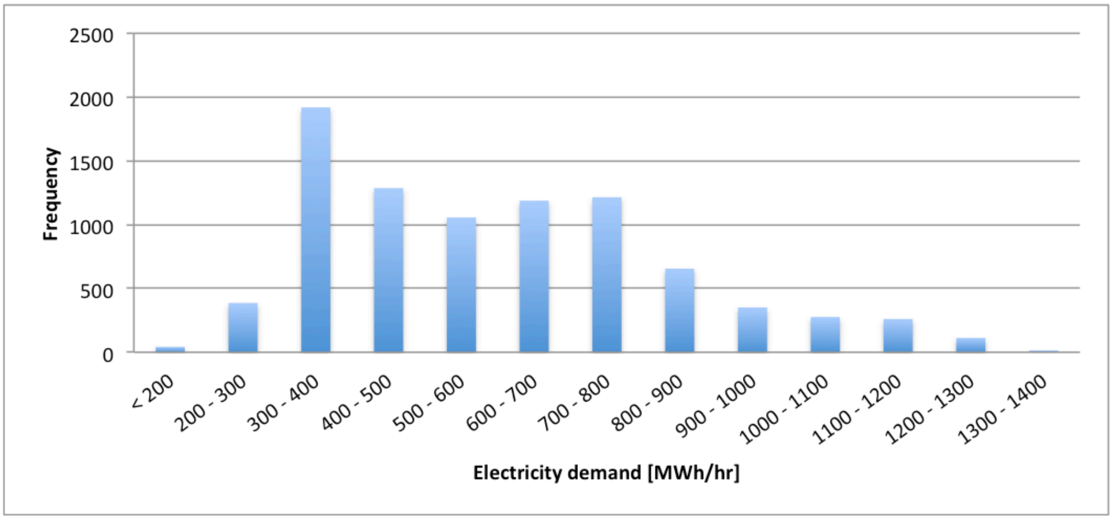

Figure 56: Histogram of the number of hours with a specific net electricity demand of all MF dwellings in 2030 in the low scenario

Gas demand pattern

This section presents the gas demand per type of dwelling in 2014 and 2030. The following figures are provided, a gas demand pattern over the whole year, a histogram for gas demand and build-up per technology; first for 2014 and later for the mid scenario in 2030. This section will finalize with a brief overview of the high and low scenario in 2030.

2014

The following figures present the gas demand per dwelling type over the whole year. Similar to the electricity demand, the gas pattern shows a clear summer and winter trend, little gas is used in the summer and much gas is used in the winter.

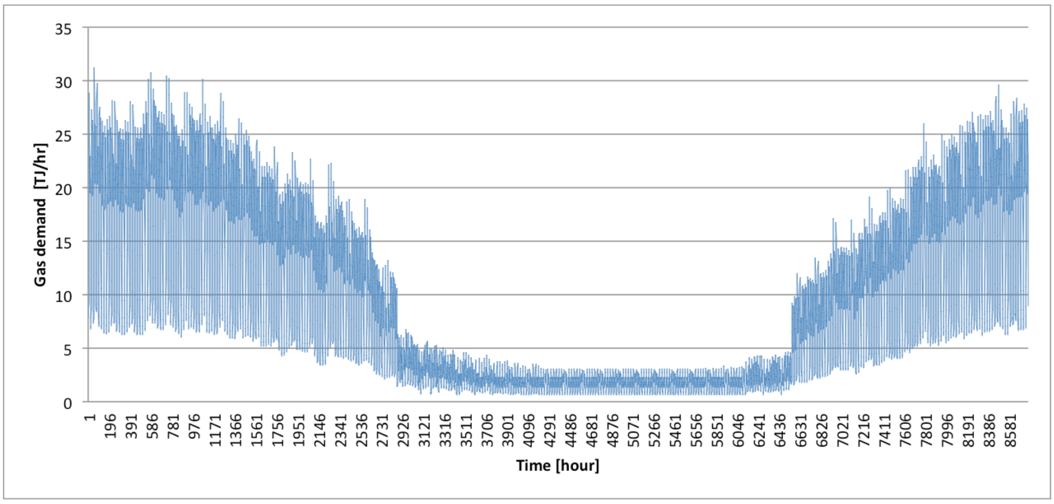

Figure 57: Gas demand of all SFD dwellings in 2014 [TJ/hr]

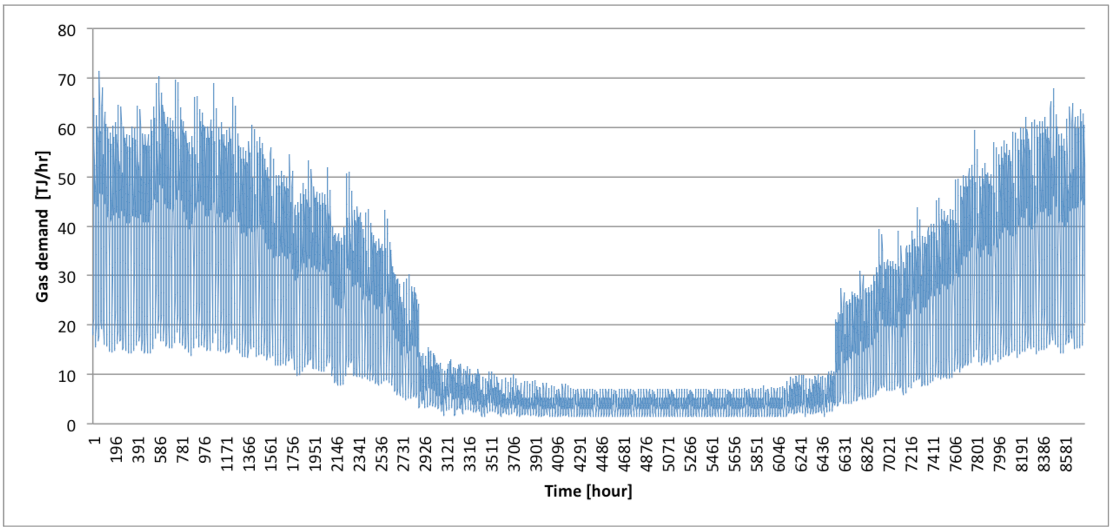

Figure 58: Gas demand of all SFT dwellings in 2014 [TJ/hr]

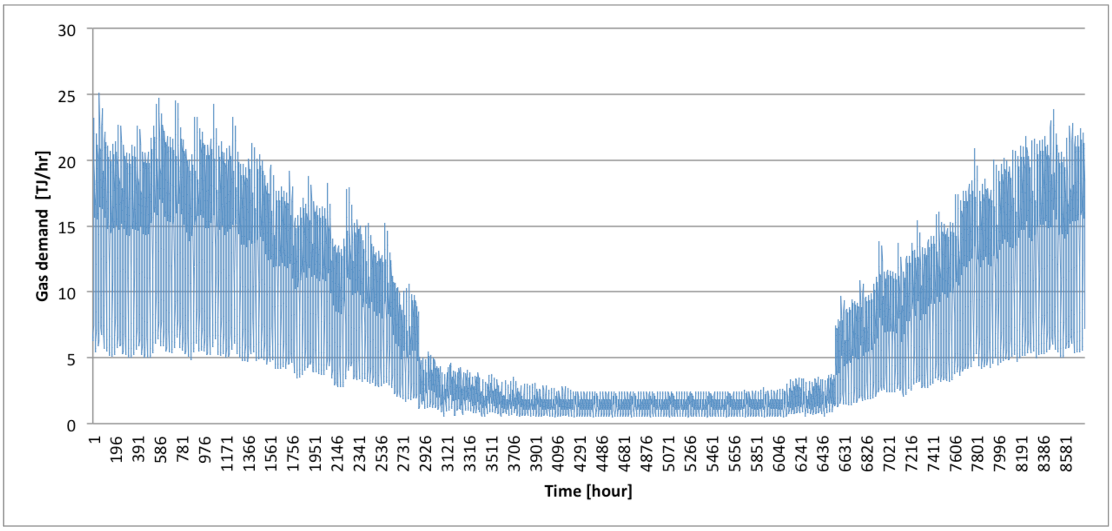

Figure 59: Gas demand of all MF dwellings in 2014 [TJ/hr]

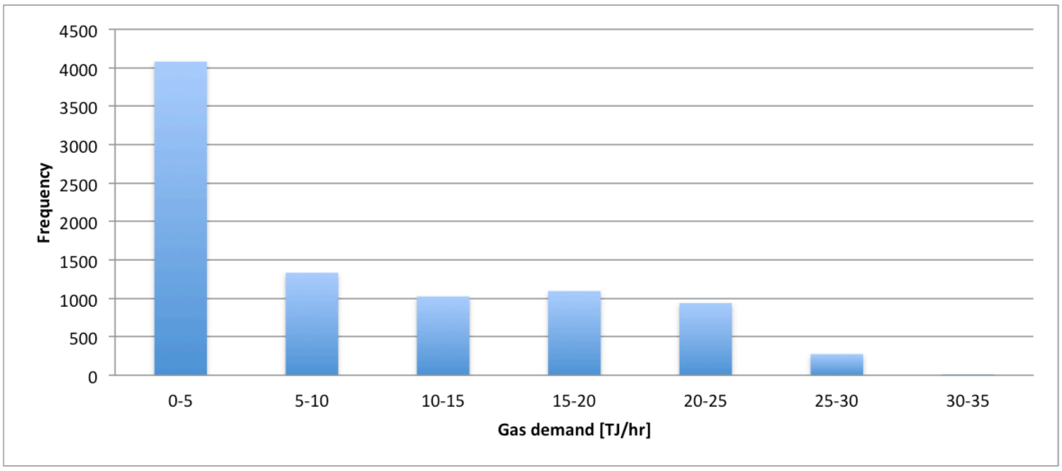

Figure 60: Histogram of the number of hours with a specific gas demand of all SFD dwellings in 2014

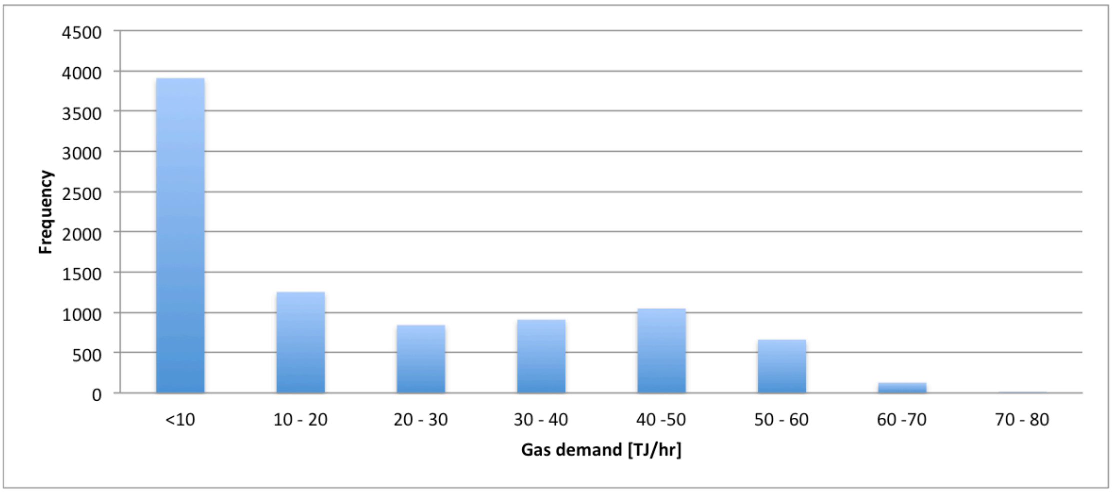

Figure 61: Histogram of the number of hours with a specific gas demand of all SFT dwellings in 2014

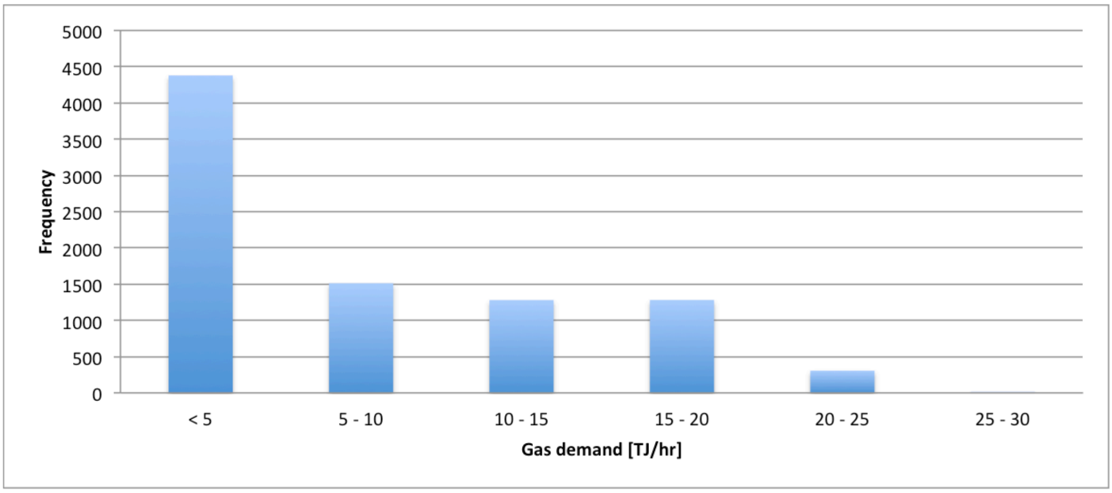

Figure 62: Histogram of the number of hours with a specific gas demand of all MF dwellings in 2014

2030

This section presents the gas demand in 2030 based on different scenarios. The main section presents the mid scenario, the other scenarios are considered briefly at the end of this section.

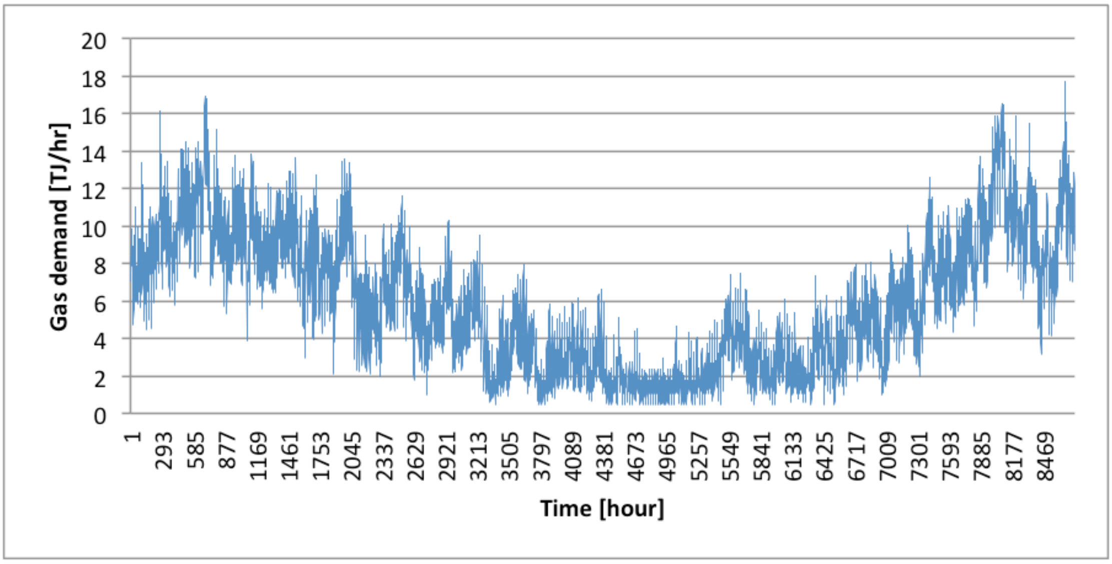

Figure 63: Gas demand of all SFD dwellings in the mid scenario in 2030

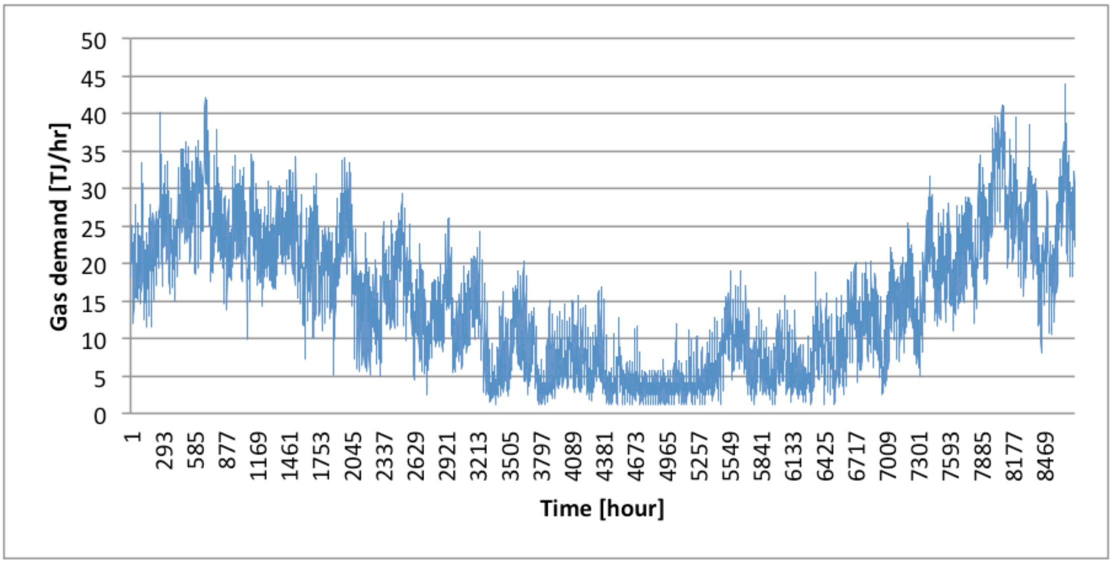

Figure 64: Gas demand of all SFT dwellings in the mid scenario in 2030

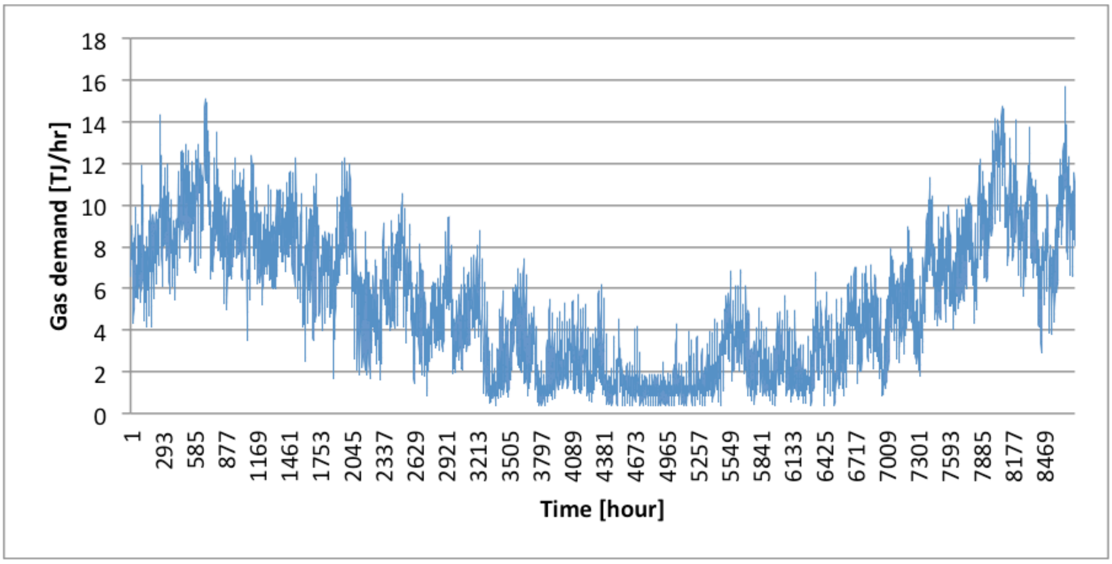

Figure 65: Gas demand of all MF dwellings in the mid scenario in 2030

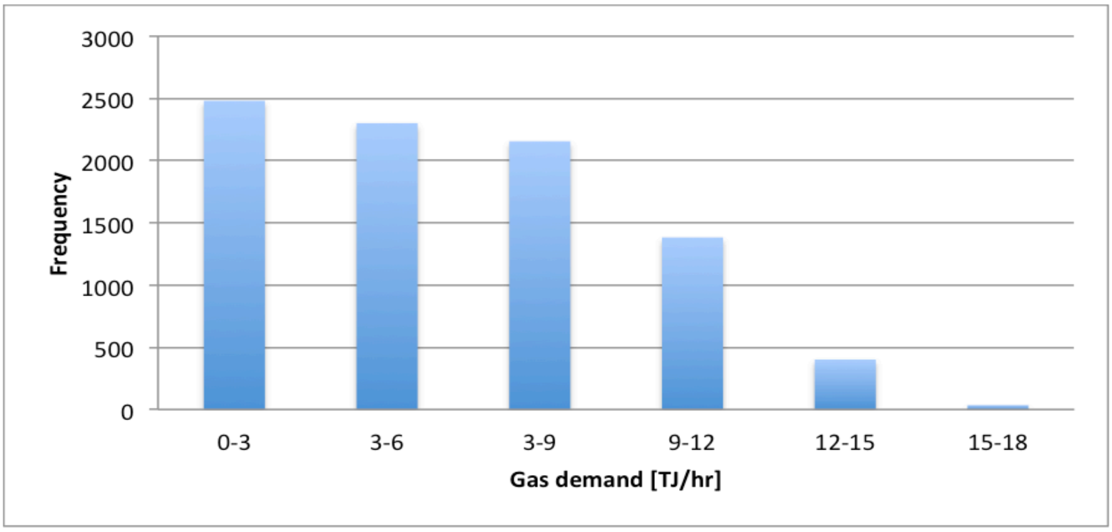

Figure 66: Histogram of the number of hours with a specific gas demand of all SFD dwellings in 2030 in the mid scenario

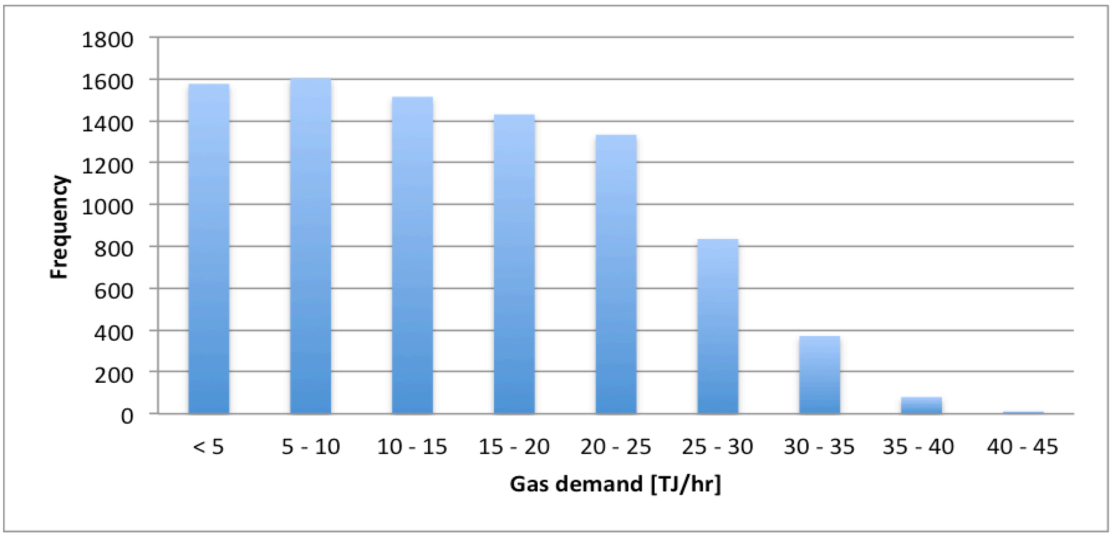

Figure 67: Histogram of the number of hours with a specific gas demand of all SFT dwellings in 2030 in the mid scenario

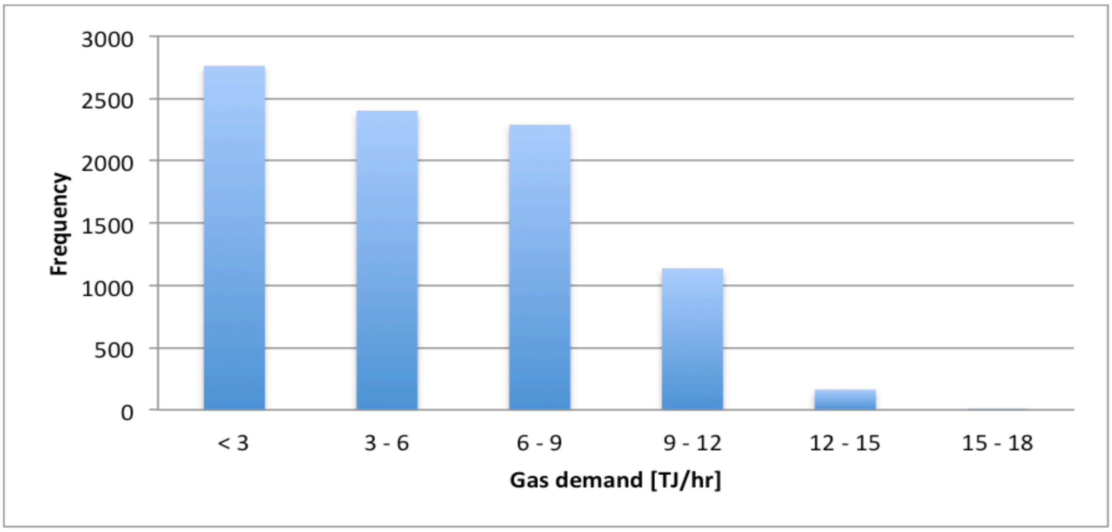

Figure 68: Histogram of the number of hours with a specific gas demand of all MF dwellings in 2030 in the mid scenario

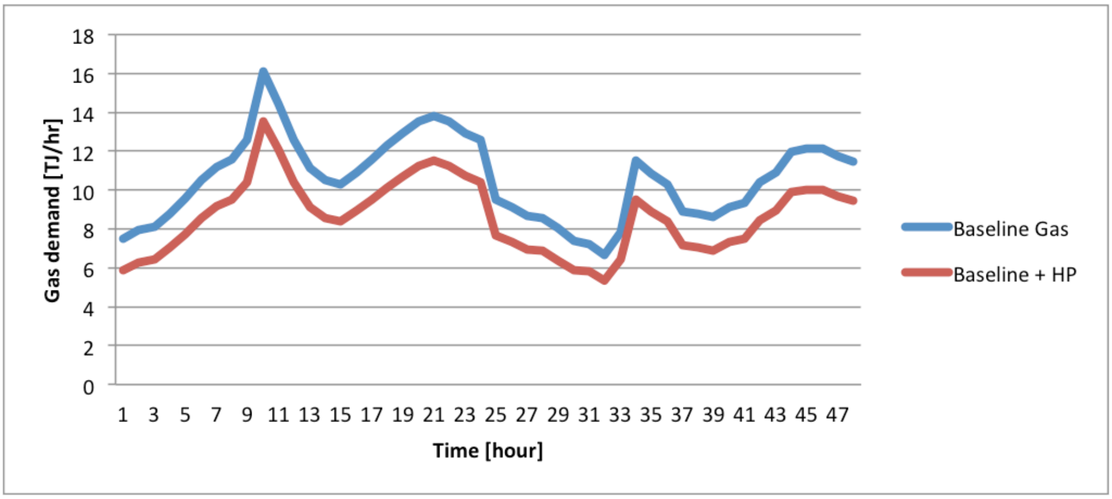

Figure 69: Gas demand on two example days in winter for SFD dwellings in the mid scenario 2030

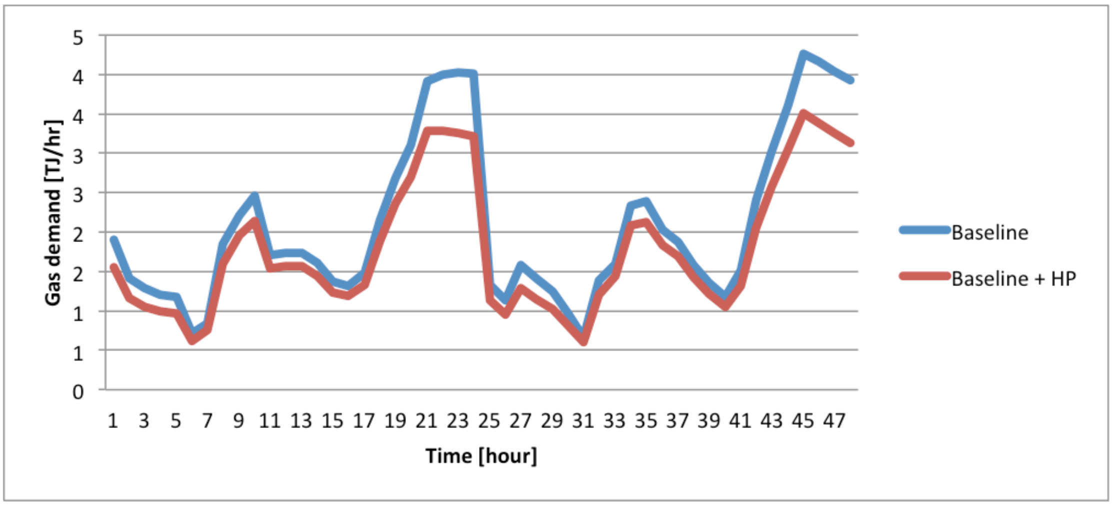

Figure 70: Gas demand on two example days in summer for SFD dwellings in the mid scenario 2030

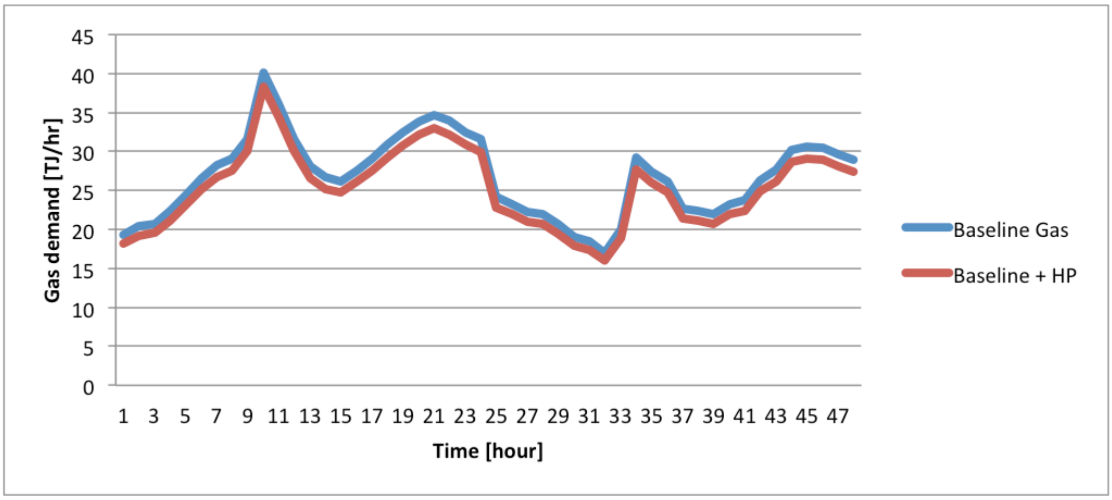

Figure 71: Gas demand on two example days in winter for SFT dwellings in the mid scenario 2030

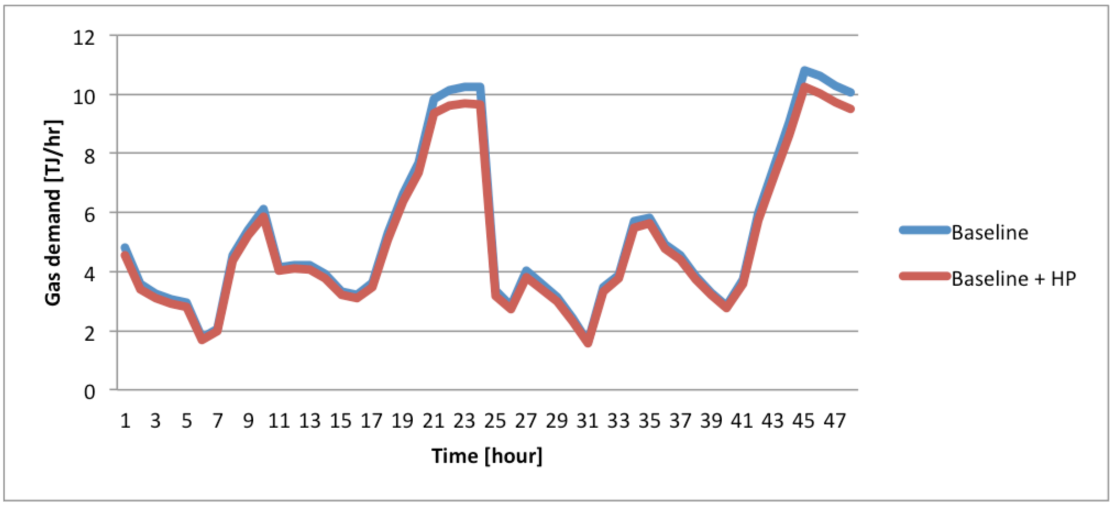

Figure 72: Gas demand on two example days in summer for SFT dwellings in the mid scenario 2030

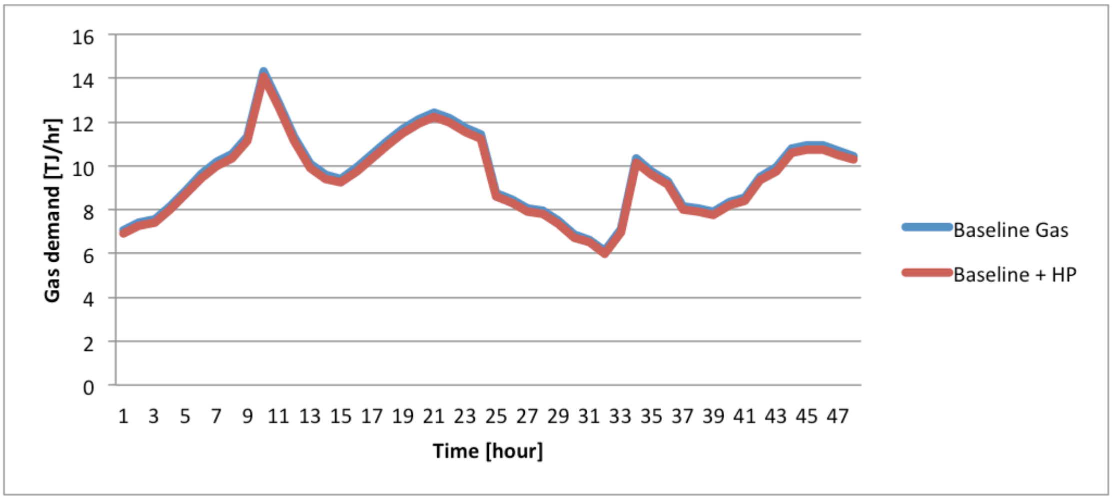

Figure 73: Gas demand on two example days in winter for MF dwellings in the mid scenario 2030

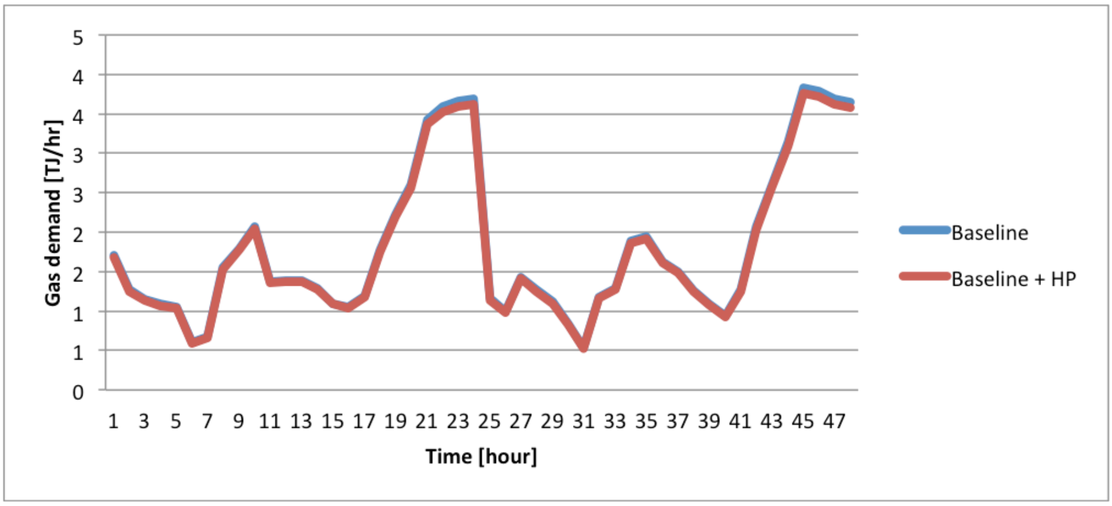

Figure 74: Gas demand on two example days in summer for MF dwellings in the mid scenario 2030

High and Low scenarios

Figure 75 until figure 77 present histograms of the hourly gas demand in 2030 in the high scenario and figure 78 to figure 80 present the low scenario.

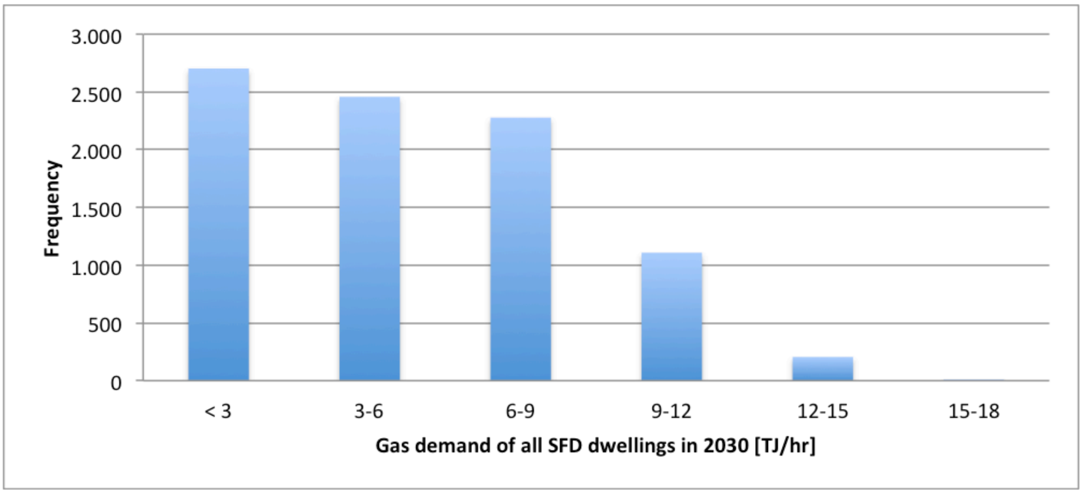

Figure 75: Histogram of the number of hours with a specific gas demand of all SFD dwellings in 2030 in the high scenario

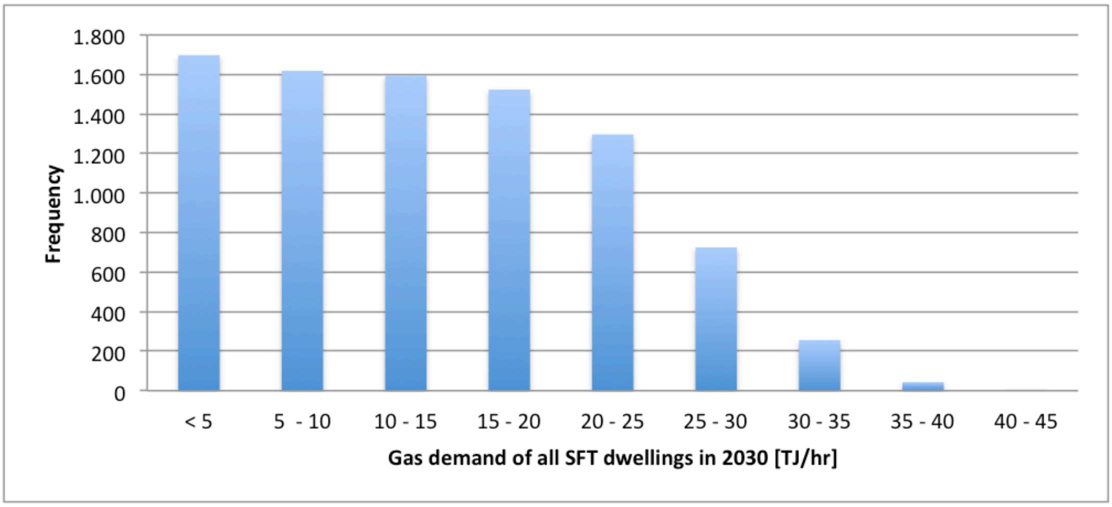

Figure 76: Histogram of the number of hours with a specific gas demand of all SFT dwellings in 2030 in the high scenario

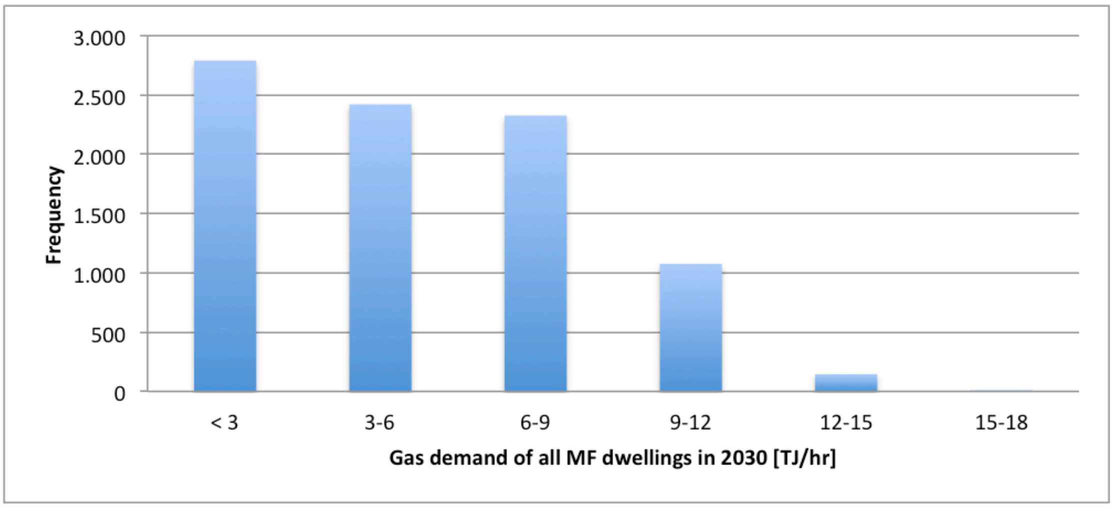

Figure 77: Histogram of the number of hours with a specific gas demand of all MF dwellings in 2030 in the high scenario

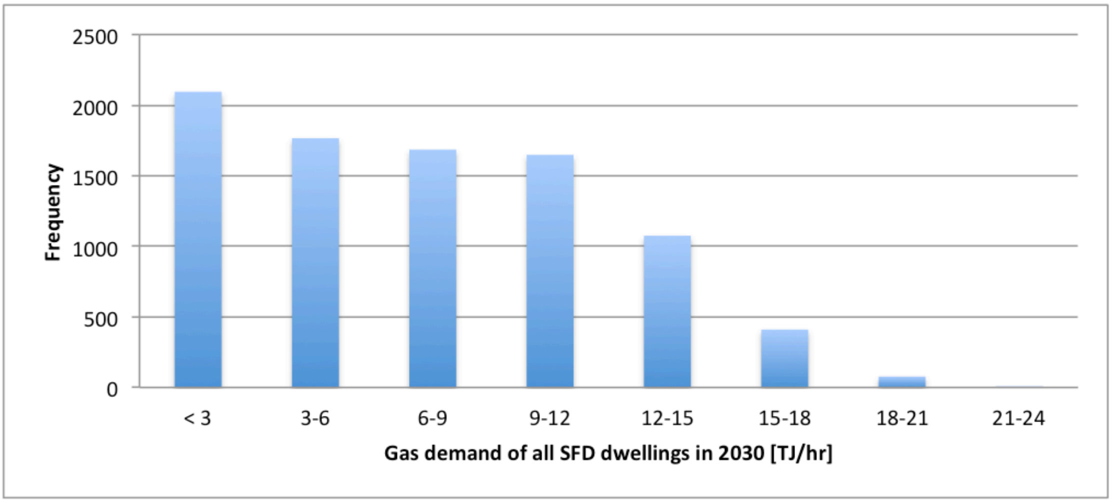

Figure 78: Histogram of the number of hours with a specific gas demand of all SFD dwellings in 2030 in the low scenario

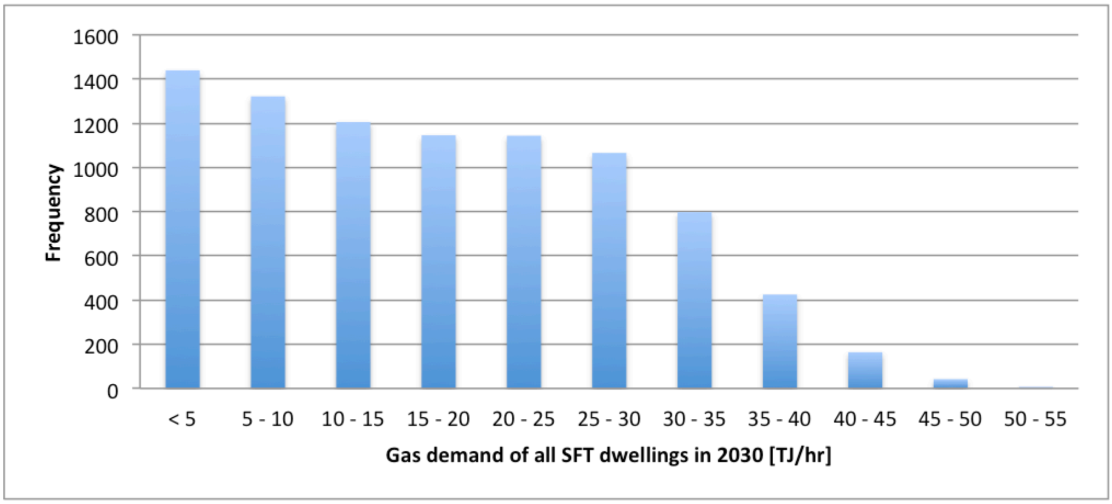

Figure 79: Histogram of the number of hours with a specific gas demand of all SFT dwellings in 2030 in the low scenario

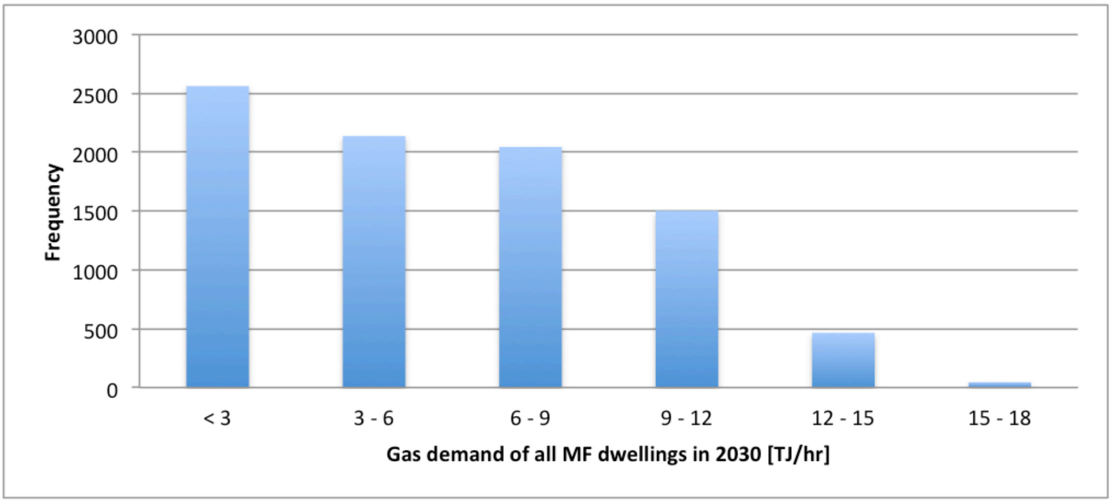

Figure 80: Histogram of the number of hours with a specific gas demand of all MF dwellings in 2030 in the low scenario

District heating demand pattern

This section provides a demand pattern and histogram of district heating, first in 2014 and later in 2030. The distinction per technology is not presented since there is no clear relation between DG implementation and district heating.

2014

Since no distinction for 2014 is made between distribution of gas use per hour and distribution of district heating use per hour, the figures of gas and district heating follow the same curve with deviating absolute values.

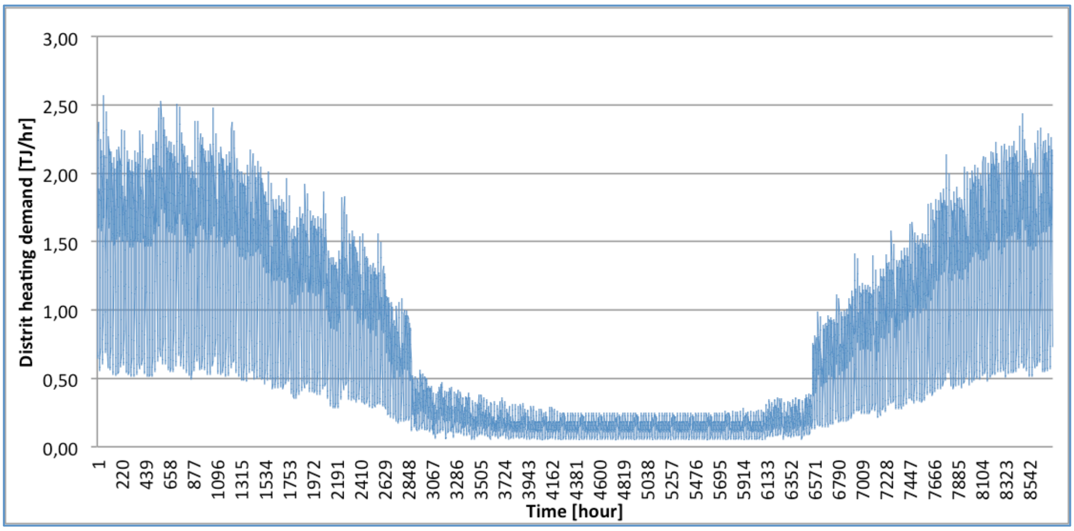

Figure 81: District heating demand of all SFT dwellings in 2014 [TJ/hr]

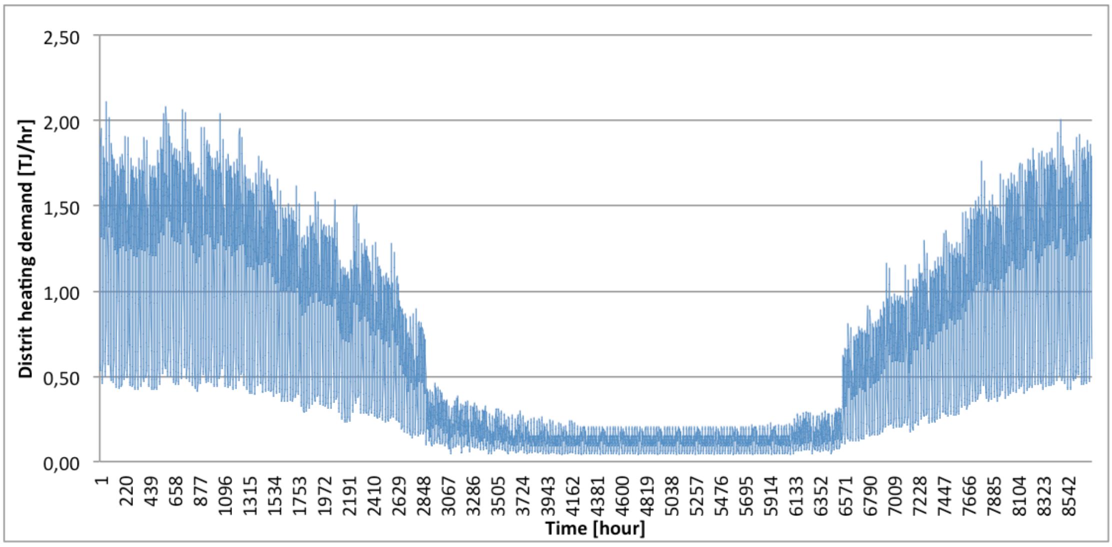

Figure 82: District heating demand of all MF dwellings in 2014 [TJ/hr]

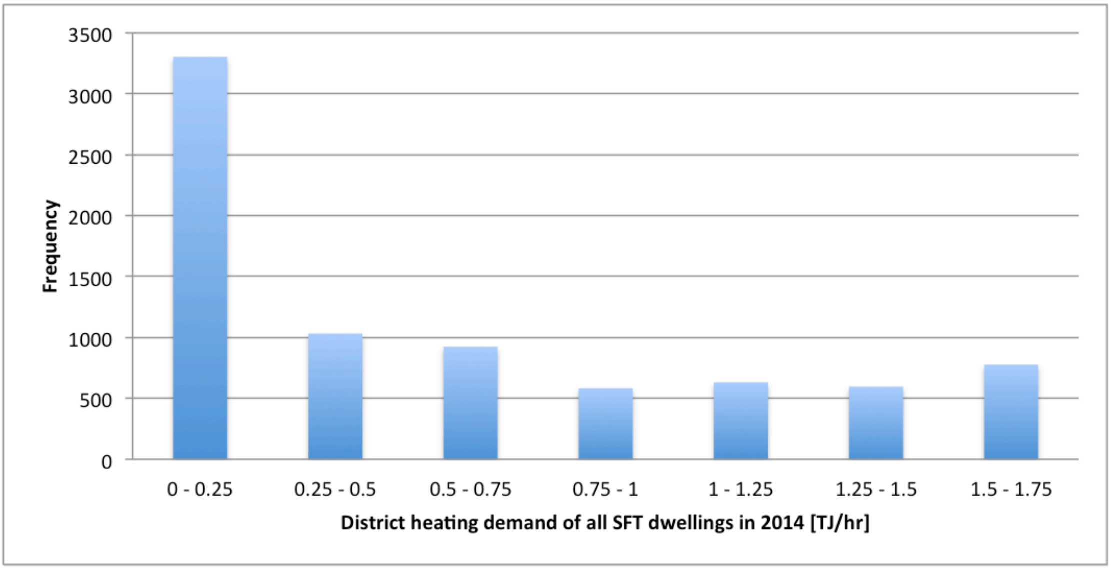

Figure 83: Histogram of the number of hours with a specific district heating demand of all SFT dwellings in 2014

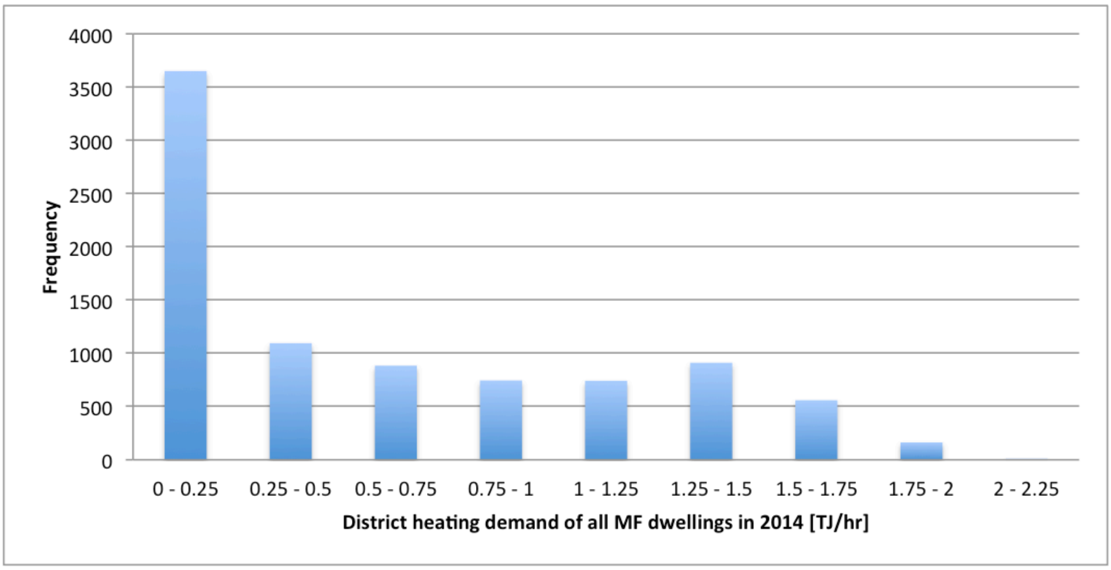

Figure 84: Histogram of the number of hours with a specific district heating demand of all MF dwellings in 2014

2030

This section presents the district heating demand in SFT and MF dwellings in 2030. First the demand pattern is shown, later a histogram of the number of hours a specific demand occurs.

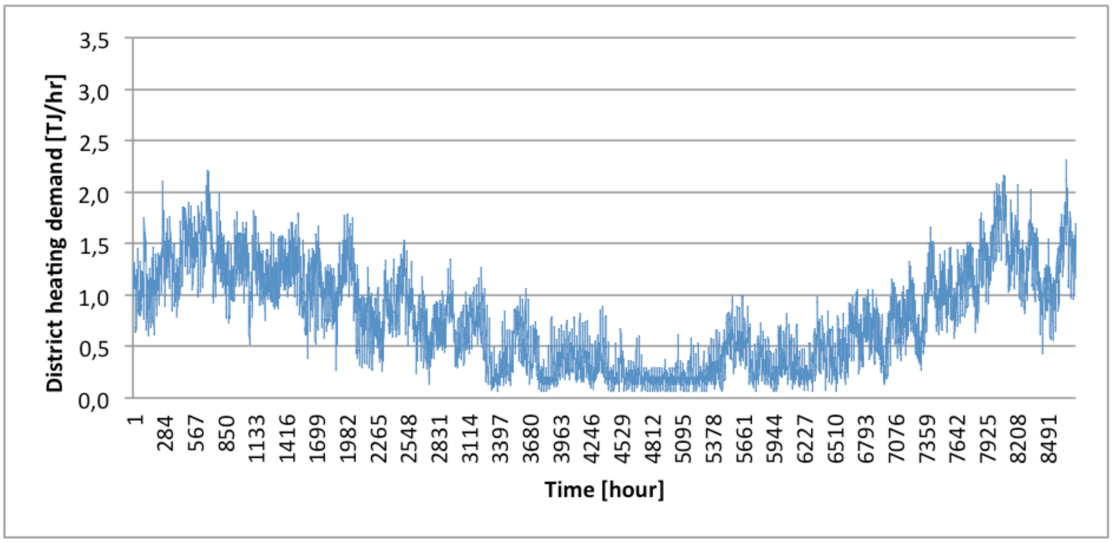

Figure 85: District heating demand of all SFT dwellings in 2030 [TJ/hr]

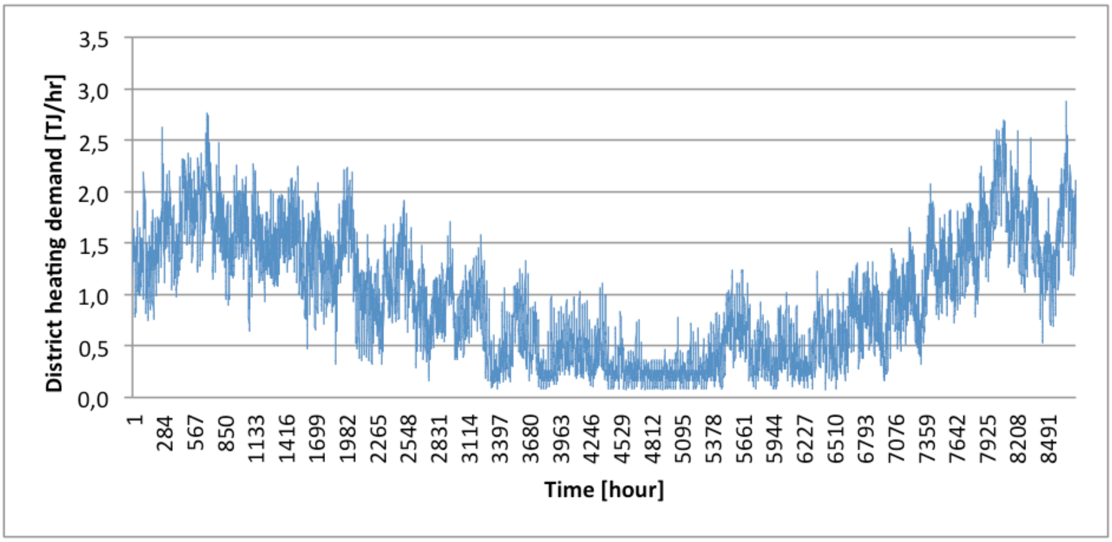

Figure 86: District heating demand of all MF dwellings in 2030 [TJ/hr]

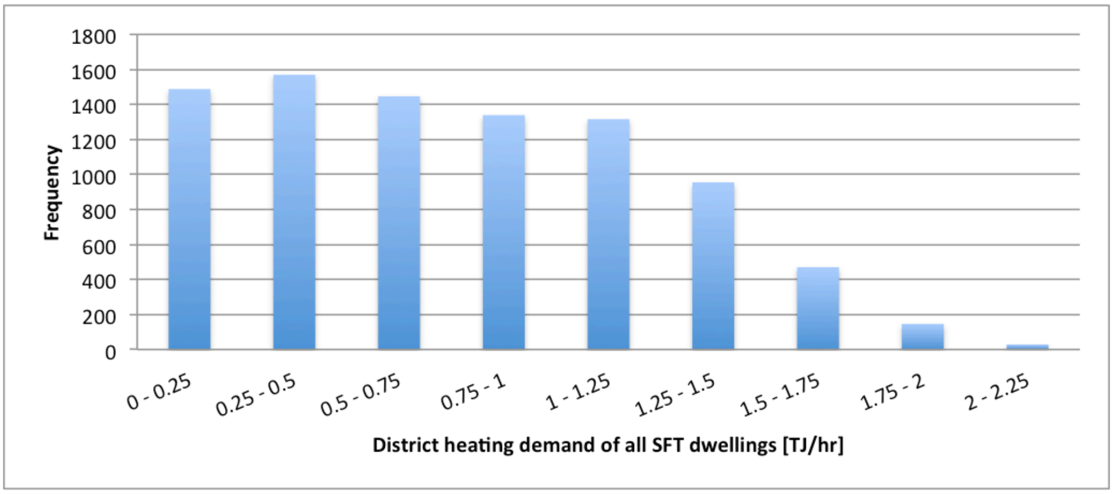

Figure 87: Histogram of the number of hours with a specific district heating demand of all SFT dwellings in 2030 in the mid scenario

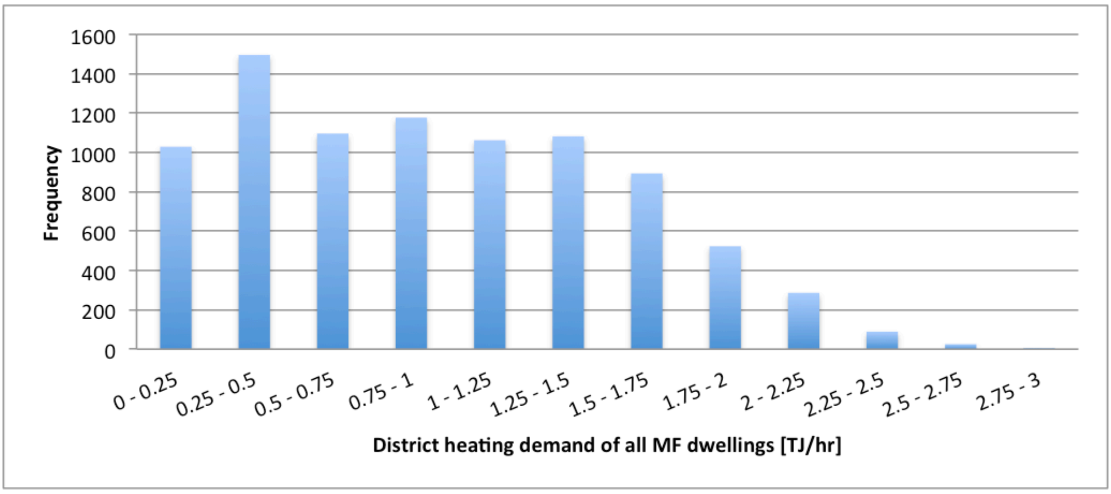

Figure 88: Histogram of the number of hours with a specific district heating demand of all MF dwellings in 2030 in the mid scenario

High and low scenarios

The histograms of the demand for district heating in the high and low scenario are presented below for SFT and MF dwellings.

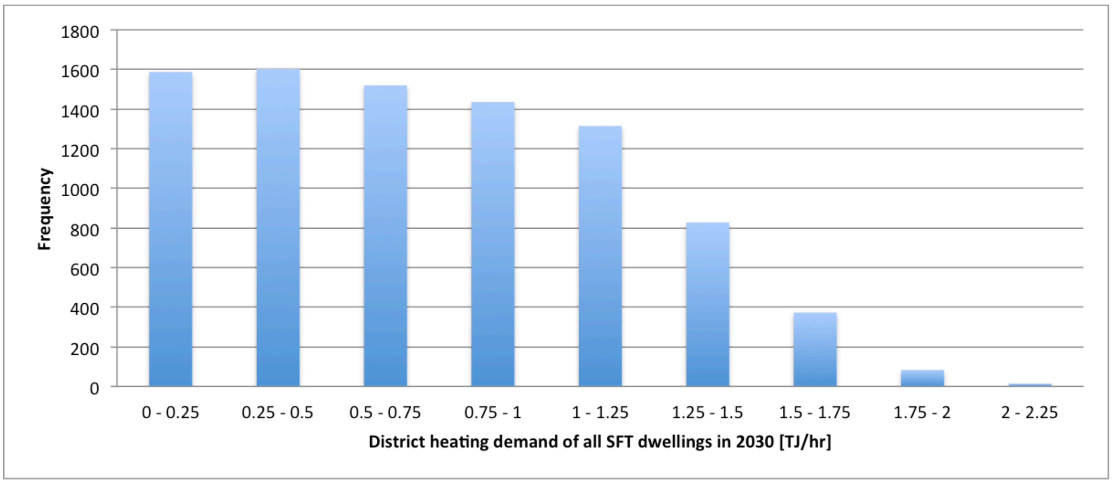

Figure 89: Histogram of the number of hours with a specific district heating demand of all SFT dwellings in 2030 in the high scenario

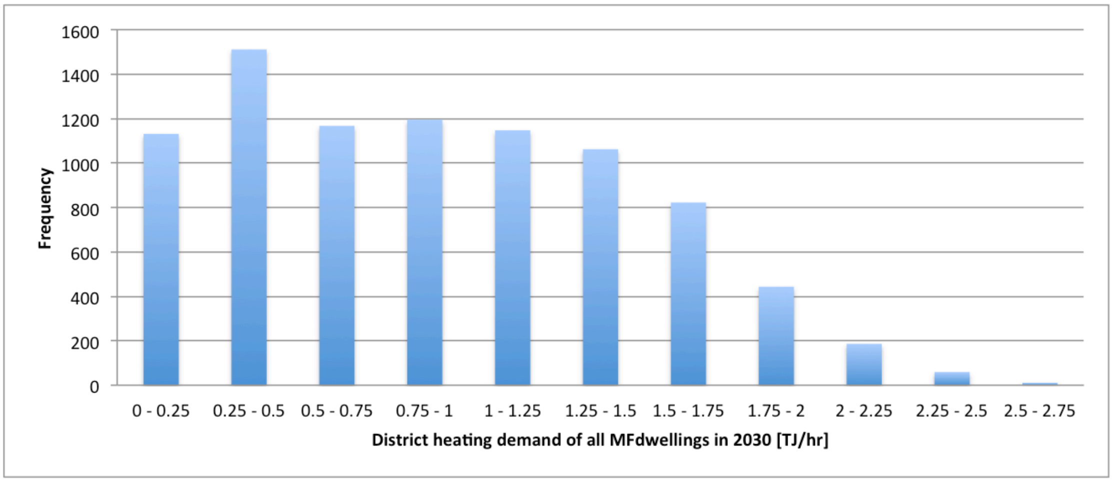

Figure 90: Histogram of the number of hours with a specific district heating demand of all SFT dwellings in 2030 in the high scenario

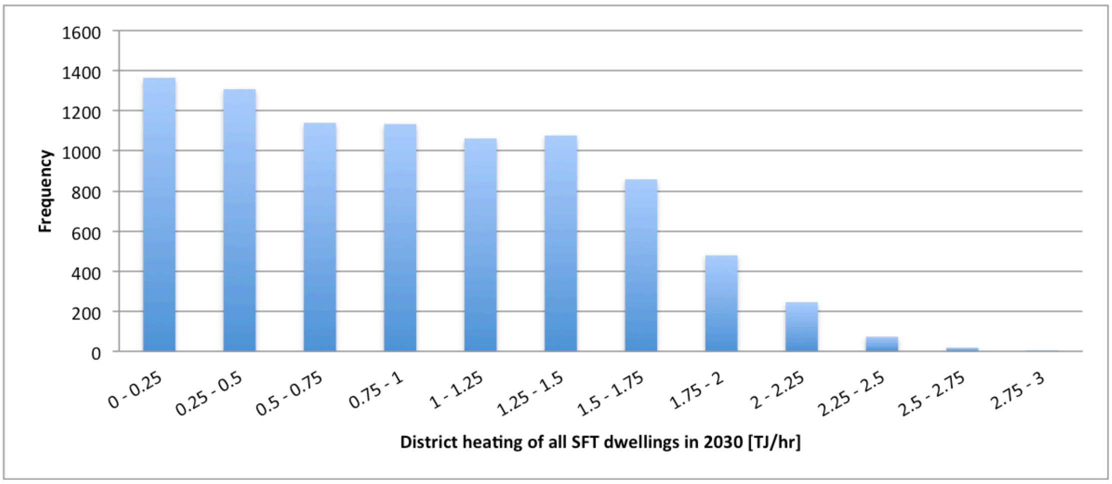

Figure 91: Histogram of the number of hours with a specific district heating demand of all SFT dwellings in 2030 in the low scenario

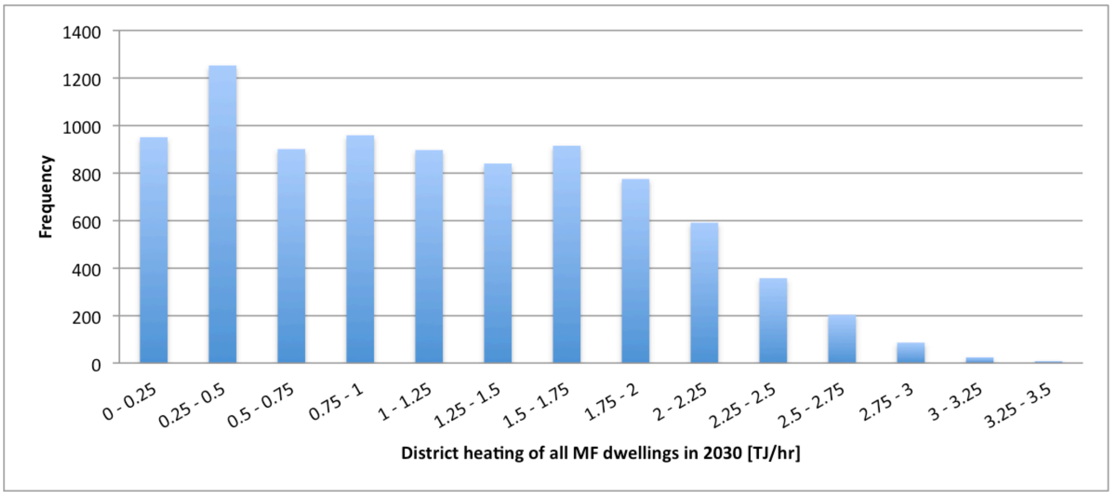

Figure 92: Histogram of the number of hours with a specific district heating demand of all MF dwellings in 2030 in the low scenario