A Heating Plan for Valsted

Master Thesis

Department of Planning at Aalborg University

Sustainable Energy Planning and Management

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Abstract:

Denmark and Aalborg Kommune have an aim of transforming the heating sector to become 100% dependent on renewable energies by 2035 and 2030 respectively. This aim is difficult to reach in areas without access to district heating, therefore a heating plan for Valsted, a town with this condition, is investigated and presented in this thesis.

First the potentials for different renewable heat sources are investigated before scenarios are created and modelled in energyPRO. The simulations show that the implementation of the most realistic scenario has the 2nd lowest socioeconomic costs but, when calculating the private economy the same scenario becomes the thrid-most expensive scenario. This is contradicting to Aalborg Kommune and Denmark's aims. During a policy analysis taxes, tariffs and fees are identified as the main barriers for the implementation of the most socioeconomically beneficial scenario. The taxes, tariffs and fees prevent private households from changing their current heating system to a renewable heating system. Recommendations are given on how these barriers can be minimised or removed.

PREFACE AND ACKNOWLEDGEMENTS

This thesis is carried out by two 10th semester students, studying Sustainable Energy Planning and Management at Aalborg University. The thesis is written from February 1st till June 2nd 2017.

The authors would like to thank the citizens of Valsted for participating in interviews and showing their heating systems. Moreover the authors would also like to thank the supervisor of this thesis, Anders N. Andersen, for very quick responses and consultancy. Furthermore also the company EMD International A/S deserves an acknowledgement and thank you for the consultancy related to energyPRO specific challenges.

Reading Instruction

Chapters, sections, figures, and tables are numbered chronologically according to the chapter. This means that e.g. the first figure in Chapter 3 is numbered 3.1 and so forth.

The Harvard Referencing System is used in this thesis. The references have a unique label of the type: (Author, year). If more sources of the same author published in the same year occur, the source is additionally labelled with a letter in alphabetical order. For references placed after a dot applies that the reference is made for the full section. References placed before the dot apply for the statement or sentence. All references are listed in the Bibliography at the end of the thesis.

The unit ton refers to the metric ton of 1,000 kg = 1 ton.

Summaries of interviews are attached in the Appendix.

INDEX OF ABBREVIATIONS

AAU	Aalborg University
BBR	Bygnings- og Boligregistret (Building and residence register)
CHP	Combined Heat and Power
DH	District Heating
DK	Denmark
DMI	Danmarks Meteorologiske Institut (Danish Meteorological Institute)
EU	European Union
COP	Coefficient Of Performance
GHG	Greenhouse Gasses
HP	Heat Pump
IEA	International Energy Agency
IPCC	International Panel on Climate Change
NPV	Net Present Value
O&M	Operation and Maintenance
PV	Photovoltaic
TSO	Transmission System Operator
USA	United Nations of America
VAT	Value-added Tax

Units

€	Euro
DKK	Danish Kroner

GJ	Gigajoule
kg	Kilogram
km	Kilometre
kWh	Kilowatt hour
l	Litre
m	Meter
MWh	Megawatt hour
TJ	Tera joule

Chemistry

CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Nitrous Oxide
SO_2	Sulphur Dioxide
NO_x	Nitric Oxides
$PM_{2,5}$	Particulate Matter

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INTRODUCTION

The global climate is changing, which has major impacts on the natural systems. This is caused by global warming, which has a wide range of impacts related to it, e.g. melting of snow and ice and hence an increase in sea level. Most of this temperature increase is caused by emissions of greenhouse gasses (GHG) which has drastically increased due to human activities, especially through economic growth. This growth has mainly been achieved through industrialisation. Climate change is a contemporary issue, as *"About half of the anthropogenic* CO_2 *emissions between 1750 and 2011 have occurred in the last 40 years"* according to IPCC. (IPCC, 2014, p. 4)

Climate change will progress with the continuous or increasing emission of GHGs and its impact on humans, and the ecosystems will become more severe or irreversible. The risks from climate change can be limited by reducing GHG emissions as well as by adaptation strategies. (IPCC, 2014)

According to the International Energy Agency (IEA) 42% of the global CO_2 emissions of the year 2013 were emitted by the electricity and heat production sector. Residential energy consumption amounted for 11% of it. (International Energy Agency, 2016)

Global efforts are made in regards to sustainable development, reducing GHG emissions and controlling the consequences of climate change. The Brundtland Plan officially called "Report of the World Commission on Environment and Development: Our Common Future" was published in 1987 and can be seen as the first international report which lead to political changes to take action against climate change. While the Brundtland Plan was vague in its formulations, it paved the way for future climate agreements. (United Nations Economic Commission for Europe, 2005) One of the agreements with further impacts was the United Nations Framework Convention on Climate Change treaty, which was signed in 1992 and is since 1997 followed by yearly conference of the parties conferences, some of which lead to famous agreements like the Kyoto protocol in 1997 as well as the Paris agreement in 2015. (United Nations Framework Convention on Climate Change, 2016)

One of the countries leading in counter climate change policies even beyond the international agreements is Denmark. (Burck, et al., 2015) There the aim for a low emission society by 2050 is set in the Danish climate law and the phase-out of fossil fuels until 2050 has been decided by a broad political majority in 2012. (Danish Energy Agency, 2016 c) Both aims have a big impact on the energy sector, the transportation sector, as well as the industry. In order to achieve these ambitious goals Danish municipalities have to create their own strategies. (Danish Energy Agency, 2016 c)

In this report Aalborg Kommune is taken as an example because of its plans to become fossil fuel free by 2030 in both the heating as well as the electricity sector. (Forsyningsvirksomhederne, 2011) A focus on possible problems showed, that the heating sector, in locations that are not connected to district heating systems are facing additional challenges when having to cope with the ambitious plans of the municipality. The focus of this thesis is therefore to investigate how a village in Aalborg Kommune without access to district heating can fulfil Aalborg Kommune’s goal of being fossil free in the heating sector by 2030. The village of Valsted meets these criteria and is hence chosen as study case.

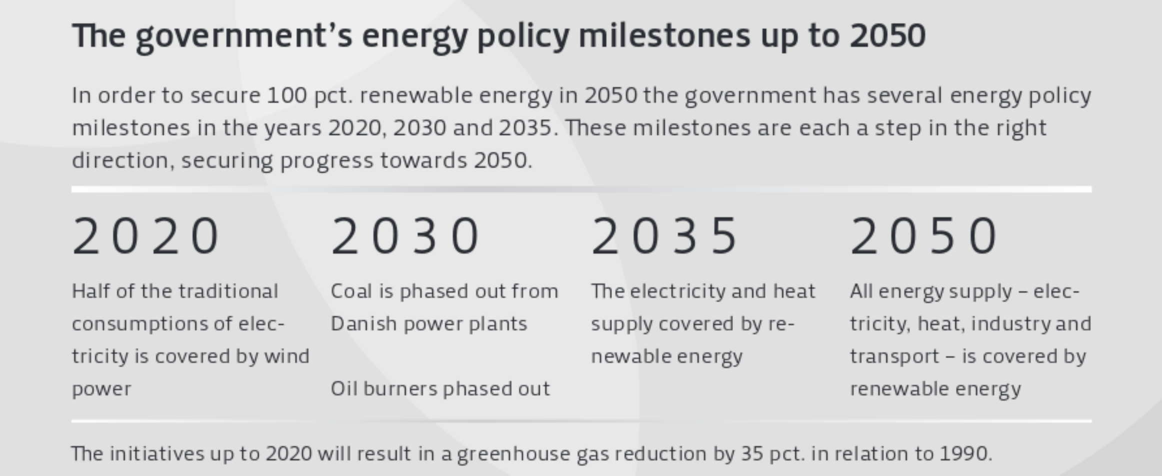
CHAPTER 1: PROBLEM ANALYSIS

This Chapter: Problem Analysis aims at describing the conditions surrounding the introduced problem more detailed. Therefore the Danish energy targets, on national as well as on municipal level are elaborated as well as a more in-depth introduction to Valsted is given.

1.1 Danish Energy Targets

As stated in the Introduction, Denmark has ambitious energy targets looking beyond the international agreements. The current energy targets were agreed upon in 2012 by a broad political majority of parties, and covers the period of 2012-2020. (Danish Energy Agency, 2016 c) The energy agreement supports the European Union's (EU) target, of *"20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables and 20% improvement in energy efficiency"* (European Commission, 2009), but is more ambitious.

The main Danish target is to phase out fossil fuels in the energy sector consisting of the electricity-, heating-, and transport sector by 2050. This should be done by supporting energy efficiency, thereby lowering the demand, and installing more renewable energy sources to cover the energy demand. (Socialdemokraterne, et al., 2012) In order to reach this target some milestones have been defined. These milestones are seen in Figure 1.1 below. (Danish Energy Agency, n.d. a)



The government's energy policy milestones up to 2050

In order to secure 100 pct. renewable energy in 2050 the government has several energy policy milestones in the years 2020, 2030 and 2035. These milestones are each a step in the right direction, securing progress towards 2050.

2020	2030	2035	2050
Half of the traditional consumptions of electricity is covered by wind power	Coal is phased out from Danish power plants Oil burners phased out	The electricity and heat supply covered by renewable energy	All energy supply – electricity, heat, industry and transport – is covered by renewable energy

The initiatives up to 2020 will result in a greenhouse gas reduction by 35 pct. in relation to 1990.

Figure 1.1: Milestones to reach the target of phasing out fossil fuels by 2050. (Danish Energy Agency, n.d. a)

As seen in Figure 1.1 the electricity and heating sectors should be renewable by 2035 targeting both district heating and individual heating. (Danish Energy Agency, n.d. a) This can cause difficulties in areas without access to district heating as each household has to invest in alternative heat sources. Therefore some rules making it illegal to install new oil boilers were made in the Energy Agreement of 2012, with the exception of areas without access to alternatives, such as natural gas or district heating. (Socialdemokraterne, et al., 2012) It is also required by law for every municipality in Denmark to make their own energy strategies. In the following different institutions' energy plans are presented.

1.1.1 Energinet.dk's Strategy Plan

As an extension to the national energy targets the Danish Transmission System Operator (TSO) energinet.dk, who is in charge of the electricity and gas distribution in Denmark, made a plan in 2014, with their suggestion on how to reach the Danish targets, called "Strategy Plan 2014" which is applicate for 2015-2017. This plan will be presented in the following.

The mission of energinet.dk is to provide secure energy to Denmark and their vision is to do that, using sustainable energy without compromising the security of supply. The energy system should be socioeconomically feasible. In order to keep it this way, while at the same time transforming it to be sustainable, a closer cooperation with the neighbouring countries must be made. This makes the electricity systems more integrated which is necessary in order to increase the amount of renewable electricity in the grid.

The transformation of the energy system is expected to increase the electricity share in the total energy production significantly. Therefore a closer integration of the electricity system with the rest of the energy sectors (heating, transport, and gas) is essential. This closer integration demands a good cross-sectoral cooperation. The transformation should be based on market solutions to promote flexibility and the cheapest solutions. Furthermore the transition of the energy system should not compromise the security of supply of electricity. In order to ensure security of supply Denmark will have to expand the import capacity of renewably generated electricity. In addition international cooperation about operation of the electricity markets should be accomplished. (Energinet.dk, 2014)

Energinet.dk is, however, not the only institution making its own renewable energy plan to fulfil the national targets. The following section will present the Danish Energy Agency's strategic framework for fulfilling the Danish energy targets.

1.1.2 Danish Energy Agency's Energy Strategy

The Danish Energy Agency has made a strategic framework for all utility services. The framework for energy will be presented below.

The utility companies' main focus should be to make prices as cheap as possible for the consumers, so that they only pay the actual costs. Efficiency measures should be made in order to reach lower prices.

For district heating a new taxation system is expected as it is stated by the Danish Energy Agency that the current taxation system does not support a socioeconomic development of the sector. Furthermore the Danish Energy Agency suggests to remove the connection obligation for district heating. This will give the consumers a free choice to choose the cheapest solution, which in some cases might be individual heating solutions. (Danish Energy Agency, 2015 c)

Lastly Aalborg Kommune has also made its own energy plan, which has more ambitious targets than the national targets. These are accounted for in the follow section.

1.1.3 Aalborg Kommune's Energy Vision and Strategy

Aalborg Kommune made an energy vision in 2010 in collaboration with Aalborg University. In this it is stated that Aalborg Kommune should to the biggest extent possible be independent of fossil fuels in the energy production. (Østergaard, et al., 2010) Two years later the Energy Agreement 2012 supported this vision and made it a national target for Denmark to be free of fossil fuels in the energy sector by 2050. (Danish Energy Agency, 2016 c)

According to Aalborg Kommune's Energy Vision 2010 Aalborg should gain a renewable energy system via several methods. An important one of these is energy efficiency, with an aim of reducing the accumulated energy demand (for electricity, heat and process energy excluding Aalborg Portland) by 17% between 2010 and 2013 (Forsyningsvirksomhederne, 2011). The transformation to a renewable electricity system should be met by increasing the installation of wind power, and biomass in cogeneration facilities. Renewable heating should be attained by using district heating where ever possible. The heat should be generated in combined heat and power (CHP) plants, waste incineration plants, through heat pumps, by using industrial excess heat as well as geothermal heat. (Forsyningsvirksomhederne, 2011) Individual heating should be provided by heat pumps as well as by solar thermal collectors. For transportation the vision is to lower the amount of people driving in cars by improving the public transportation and to make it more expensive to use cars. In 2050 the remaining transportation should be based on electricity or be hybrid transportation. (Østergaard, et al., 2010)

Aalborg Kommune also made plans targeting only the municipality's heating supply in the report "Energy Strategy for Aalborg Kommune until 2030" (Forsyningsvirksomhederne, 2011). Here it is stated that energy savings are a fundamental part of the strategy to reach a fossil free energy production, and Aalborg Kommune has a target of saving 40-50% from 2010 to 2050. Aalborg Kommune assesses the incentive to make heat efficiency investments to be greatest in areas without access to district heating, as the heating is typically more expensive in these areas. In the report it is stated that the district heating system should be expanded. But in some areas it is not economically feasible to expand an existing district heating system or to build a decentralised district heating system. These areas must continue to rely on individual heating. Since most of the individual heating is based on oil, a transformation of these systems must happen as well. Aalborg Kommune suggests alternative heat sources such as ground source heat pumps with a heat storage or the use of solar thermal energy for these areas. By connecting a heat storage to the heat pumps they can help even out periods of high or low penetration of wind power in the market. Biomass is not suggested for individual heating systems, as biomass can be used in cogeneration facilities, increasing the efficiency significantly. The future demand of biomass will be high as it can be used to produce power and heat as well as fuel for transportation. Aalborg Kommune set the aim to become independent of fossil fuels by the above described measures by 2030 in the heat and electricity sector. (Forsyningsvirksomhederne, 2011)

As established, a part of Aalborg Kommune's energy plan is for the heat sector to become renewable by 2030. This includes all areas from the district heating supplied in major cities down to the small individual supplied villages. The following section describes the relevance of Valsted as case.

1.2 Relevance of the Chosen Study Case

In order to investigate the relevance of the case studied in this thesis an analysis has been carried out. The analysis includes the identification of all towns in Aalborg Kommune as well as their number of inhabitants. Further it has been investigated if these places are connected to a district heating system or supplied by natural gas. For these areas where district heating and gas is available it is assumed that people use the available dominant heat source.

According to Aalborg Forsyning the actual percentage of people with a district heating connection is 98.6% in the area around Aalborg. (Aalborg Forsyning, 2012) Numbers are unavailable for areas with access to natural gas.

It is assumed that the size of the towns stays constant throughout the simulated time. This is a simplification. Therefore phenomena like urbanisation are disregarded for the sake of simplicity.

Aalborg Kommune consists of 81 towns with very different sizes, ranging from as few as 23 inhabitants in Egholm By (Aalborg Kommune, 2008 a) to Aalborg with 112,194 inhabitants. (Danmarks Statistik, 2016) Additionally there are approximately 4000 people living spread out in the country side. (Aalborg Kommune, 2008 b)

The most common heat source in Aalborg Kommune is district heating which will be available in 46 towns (55% of the towns) by 2030. Further there are 9 towns (11%) connected to the natural gas system. The remaining 37 towns (34%) are based on individual heating. An overview is seen in Figure 1.2. (Aalborg Forsyning, 2012) This makes the findings of this thesis directly relevant for 34% of the towns in Aalborg Kommune.

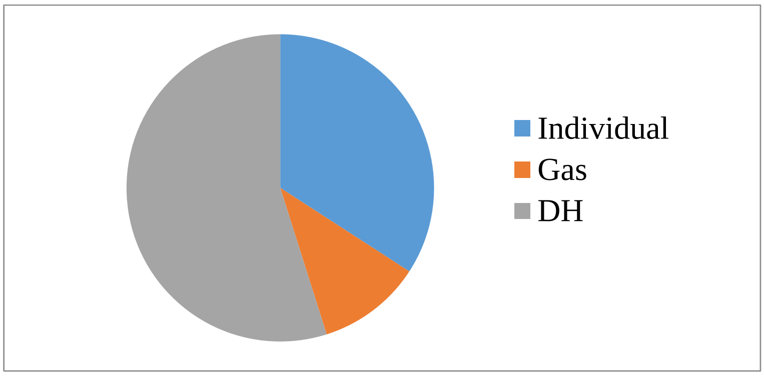


Figure 1.2 Towns with access to district heating in Aalborg Kommune based on (Aalborg Forsyning, 2012)

When looking at the amount of people involved in this change who have to transform their own heating system, this thesis is relevant for approximately 7,600 people in Aalborg Kommune, which is the population of the previously mentioned 34% of towns with individual heat sources. This is approximately 4% of the people living in the municipality. While this number is low, it is still an important group in the municipality as the Danish and municipal aim is to be 100% independent of fossil fuels and hence 96% of renewable heating is not sufficient. Further it is assumed that there are similar situations in most Danish municipalities. This thesis addresses an important component of Denmark's aim to become 100% renewable in the heating sector. It bridges the final 5% to achieve this goal.

In areas where no utility company is providing heat more personal initiative is needed in order to succeed in the transition of the heating system. According to the heating plan in Aalborg Kommune there are areas which in 2035 are not supplied by district heating and will continue to rely on individual solutions. (Aalborg Forsyning, 2012)

In Strategiplanlægning 2013-2024 (strategy plan 2013-2024), Aalborg Forsyning published the following Figure 1.3 of Aalborg Kommune and its planned heat supply. It illustrates Aalborg Kommune and the different forms of covering the heat demand. The colour blue represents decentral district heating, red stands for central district heating, green depicts a connection to the natural gas grid, and purple shows areas with individual heating solutions.

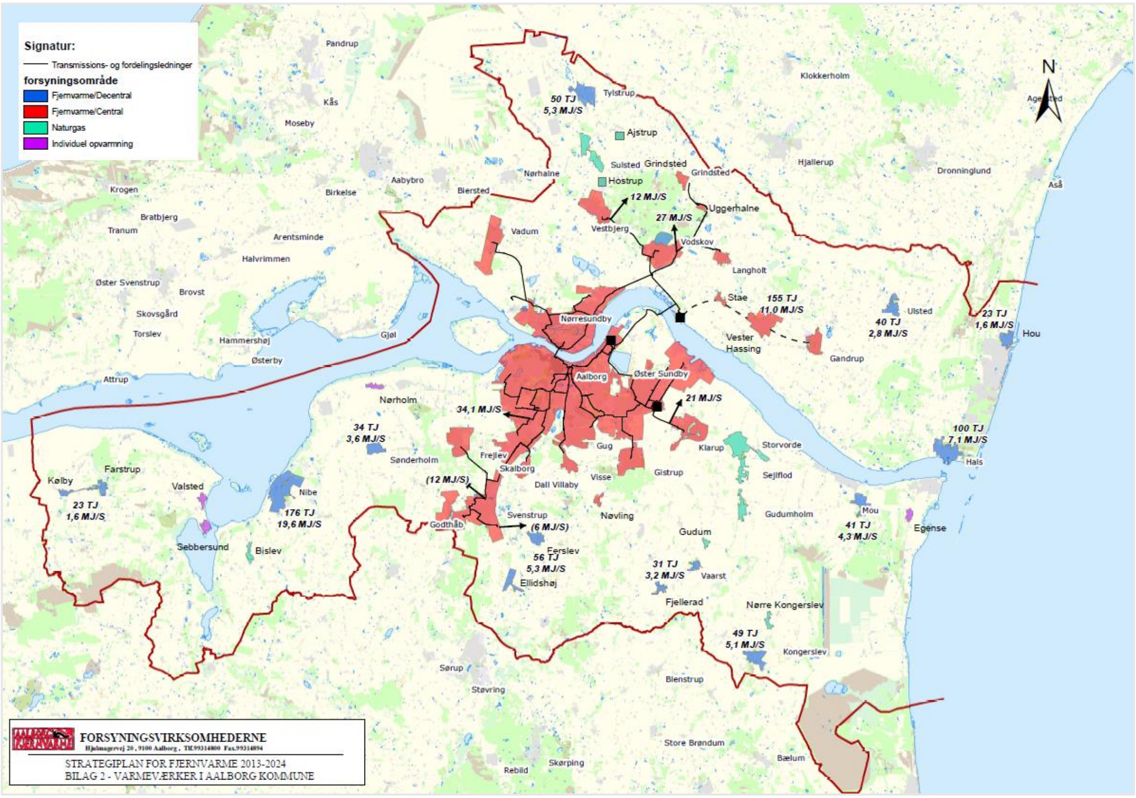


Figure 1.3 Strategy plan for district heating 2013-2024 (Aalborg Forsyning, 2012)

Obtained from Figure 1.3 one of the areas which will continue to rely on individual heating according to the plan is Valsted. Amongst villages without access to district heating Valsted was randomly chosen as case for this thesis. A further introduction is presented in the next section.

1.3 Introduction to Valsted

The village Valsted is located in Northern Jutland and is part of Aalborg Kommune. As seen in Figure 1.4 and 1.5, the village is located close to the Limfjord and approximately 30 km from the main city in the municipality, Aalborg. Valsted is a small village with 103 heated houses, including family houses and sheds (Aalborg Kommune, 2014) and a total of 234 inhabitants (Danmarks Statistik, 2016).

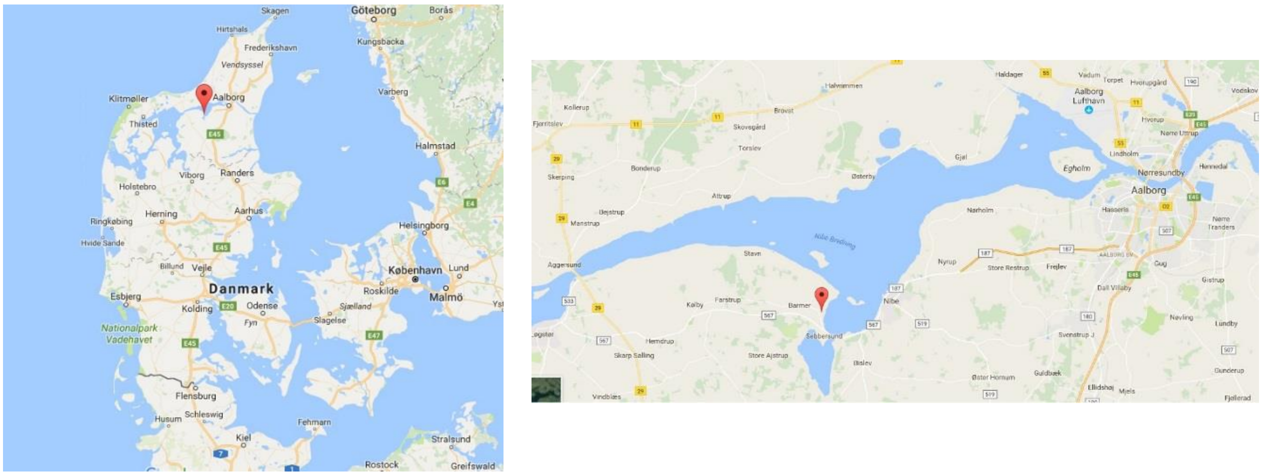


Figure 1.4 and 1.5 Valsted is located in the northern part of Jutland in Denmark (google.com/maps, 2017)

There are no shops or fuel stations in the village, and the biggest employer is the school, Sebber Skole, which in 2013 had 27 employees and approximately 100 pupils. (P4 Nordjylland, 2013) The village has one active farm. (Household 1, 2017)

The average age in Valsted is 44.6 years. This is 3.2 years older than the Danish average age. (Danmarks Statistik, 2017) The average space per household is 160 m^2 (Aalborg Kommune, 2014) which is about 50 m^2 more than the Danish average. (Statistics Denmark, 2015) In terms of the average number of people living in a household Valsted is very close to the Danish average of 2.1 persons per household. (Aalborg Kommune, 2014), (Statistics Denmark, 2015) Furthermore the education level as well as the average income of the people living in Valsted is above average (Aalborg Kommune, 2014).

CHAPTER 2: PROBLEM STATEMENT

In 2012 a broad political majority set the aim to change the energy sector from a mainly fossil fuel based energy system to a 100% renewable based energy system in the sectors electricity, heating and transportation, by 2050. (Socialdemokraterne, et al., 2012) Therefore radical technological changes are needed. The most abundant renewable energy resource in Denmark is wind and with an expansion of installed wind capacity as well as a better interconnection with other countries among improvements in the waste incineration as well as biomass based CHP production, and solar power, this aim can be achieved in the electricity sector. The heating and transportation sectors are more challenged in this change. For the heating sector an expansion of the existing district heating systems as well as more decentral small scale community heating systems should be implemented wherever possible. The rest of the heating sector should be electrified using electric heat pumps. In order to create a renewable transportation sector the Danish Government is aiming for more public transport, private electric vehicles as well as bio fuels. (Danish Energy Agency, n.d. a)

Following the pathway described by the Danish Government the electricity and heat sector are the first ones to accomplish these transformations by 2035. The transportation sector follows with a timeframe until 2050. (Danish Energy Agency, n.d. a) The heating sector is to be transformed before the transportation sector and it was found that besides a transformation of the district heating systems and their expansion plans few specific plans are in place. (Danish Energy Agency, 2015 d) In this thesis it has been chosen to carry out an in-depth analysis of an important upcoming problem in the heating sector. Therefore it is investigated how a 100% renewable heating system can be obtained for an area without access to district heating, using Valsted as case.

2.1 Research Question

This thesis will answer the following research question including two sub-questions.

How can Valsted reach a heating system entirely based on renewable energy?

1. How can this goal be achieved in a socioeconomic beneficial way, by planning and comparing different scenarios?
2. How can barriers in the current legislation be changed in favour of the most socioeconomic scenario?

The most socioeconomic beneficial scenario is in this thesis defined as the scenario which causes the least (financial) burden on society and where an implementation is realistic. This follows the definition presented in (Retsinformation.dk, 2011). Further explanation on how the socioeconomic analysis is carried out in this thesis is given in Section 5.3: The Process of Approving an Energy Project on page 38.

2.2 Limitations

Some forms of renewable fuels are not used or are not recommended for individual heating in this thesis. These are elaborated in the following.

Biogas is considered a renewable fuel as the CO_2 released through the burning process has previously been stored in the plants used to generate the biogas. This process is CO_2 neutral if the biomass is produced in a sustainable way, meaning that the biomass is regrown. (Wilkie, 2017) Nevertheless biogas is disregarded in this thesis, as there is currently no infrastructure available in Valsted. (Aalborg Kommune, 2014) Further it is not recommended to use biogas for heating only purposes as it can be used more efficiently in cogeneration of heat and electricity or as fuel in the transportation sector. (Forsyningsvirksomhederne, 2011)

Electrical heating is disregarded as renewable heat source. Even though the utility gird is assumed to be fed with 100% renewable electricity by 2035, energy efficiency measures are promoted in all sectors, making electrical heating an improper heat source as the efficiency of electric heaters is low compared to the efficiency of heat pumps. (Danish Energy Agency, 2014 a). Therefore electrical heating is disregarded as a heat source for Valsted.

Biomass is not recommended to be used in the heating system as it needs to be regrown sustainably in order to be considered a CO_2 neutral fuel as described in biogas. (Wilkie, 2017) Additionally biomass can also be used more efficiently in cogeneration of heat and electricity. Further it is assumed that the biomass demand will increase as it can also be used to CO_2 neutralise the transportation sector. Through the broad application possibilities Denmark is not able to cover its biomass demand if all sectors rely on biomass. However, biomass also has some characteristics making it desirable to use for larger plants such as district heating, as it is not a fluctuating heat source and it is easy to store. Aalborg Kommune gave out the aim not to use more biomass than it is able to generate within the municipality, therefore priorities need to be set and the available resource has to be used as efficiently as possible. Since it is considered a renewable heat source and it has the mentioned characteristics district heating plants can, in this thesis, be fuelled by biomass, however it is not recommended for individual heating solutions. (Forsyningsvirksomhederne, 2011)

CHAPTER 3: THEORIES

This Chapter describes the theories which are applied throughout the work on this thesis. The case study theory as well as strategic energy planning and public engagement are described. They are followed by a description of choice awareness theory and socioeconomic analysis.

3.1 Case Study of Valsted

This thesis investigates Valsted as a single example. Therefore the theoretical framework is a case study. Abercrombie, et al. (1994) defined a case study as *"The detailed examination of a single example of a class phenomena."* (Abercrombie, et al., 1994, p. 34) In this thesis Valsted is defined as the single example and villages of similar size without access to district heating as the class phenomena. Amongst the villages without access to district heating Valsted has been chosen as a random sample. The criteria for the village were: It should have more than 50 inhabitants, be located in Aalborg Kommune, and should not have access to district heating. By using these criteria Valsted was selected. The selection was random as other villages fulfilling these criteria were not considered.

The theoretical approach of a case study gives an *"understanding oriented and an action-oriented perspective"* (Flybjerg, 2006, p. 229) and when being energy planners an action oriented perspective is essential as this is a field that emphasises action. Furthermore understanding the cases and mind-set behind certain obstacles made by the local population is also important in order to be able to implement the energy plans. Case studies are furthermore useful for investigating a certain topic in real-life situations, which is supported by Flybjerg (2006, p. 235):*"The advantage of the case study is that it can "close in" on real-life situations and test views directly in relation to phenomena as they unfold in practice."*

Previously, case studies have been criticised and disregarded as a theory since concerns were raised that case studies are more likely to be biased by the authors' pre-conceived opinions and hypotheses. Therefore some scientists, such as Diamond (1996), consider case studies subjective. This is invalidated by Flybjerg who argues that in a case study the participants have the possibility to speak up and influence the outcome of the case study more than they can in other qualitative research methods. He argues that researchers, who did in-depth case study research are more likely to revise their hypotheses. Furthermore Flybjerg argues that all kinds of research are prone to be biased, case studies are no exception. (Flybjerg, 2006)

As part of this case study of Valsted's heating system, a strategic energy plan is used as an approach of creating the different simulated scenarios. Therefore the framework of strategic energy planning is presented in the following section.

3.2 Strategic Energy Planning

Strategic energy planning is a tool used by municipalities in Denmark to plan and prioritise energy projects. (Danish Energy Agency, 2015 a) It is a holistic approach that combines multiple perspectives of energy planning: Technical solutions, economics, political, and social perspectives. A strategic energy plan differs from a customary energy plan by also including an implementation aspect. The main focus for a strategic energy plan is therefore on technologies that support and improve an energy system model and implementation strategy. When conducting a strategic energy plan several considerations should be made. (Weijermars, et al., 2013)

Firstly, the scope, scale and perspective of the energy plan should be established. A strategic energy plan can be made on different scales. Those can vary from local to global level depending on the scope of the analysis. Various perspectives can be taken to a strategic energy plan. It can be made in a modelling perspective where various energy technologies are considered and modelled. The modelling perspective goes hand in hand with a strategic energy plan, which adds an aspect of practical application. Also national, corporate, and energy market perspectives can be chosen. (Weijermars, et al., 2013)

The strategic energy plan should direct the future energy system, meaning that the planning should evolve into the energy system and contain an implementation strategy. The implementation strategy should take financial conditions and regulations into account, considering future conditions by making policy regulation suggestions. (Weijermars, et al., 2013)

Making a strategic energy plan therefore consists of the following steps:

1. Determine scope, scale, and perspective of project
2. Make a model of the future energy system
3. Investigate implementation issues

4. Make suggestions for changes in policy regulations
5. Identify practical steps for implementation of the strategic energy plan

3.2.1 Strategic Energy Planning in Valsted

For this thesis strategic energy planning is used as a theoretical framework. Since the focus of this thesis is the heating sector, the strategic energy plan is limited to the heating sector as well. The scope of the energy plan is to find the cheapest renewable heating solutions for Valsted and therefore it is made on a local level including only the village of Valsted. The perspective used is a modelling perspective, where a resource assessment is carried out and relevant technologies are chosen to model several scenarios. Furthermore public engagement is carried out in the form of interviews of 11 dwellings as a part of the implementation strategy. Public engagement is important for the implementation as public resistance can cause renewable energy projects to be delayed or even cancelled (Devine-Wright, 2011). Involving the public is therefore a way to oblige their wishes, to the extent possible, and ease the implementation process. This is however not the only advantage encountered, when using public engagement. Therefore the next section elaborates more on public engagement.

3.3 Public Engagement

As stated above considering the public's opinions is important for the implementation process of an energy project. But easing the implementation is not the only reason for using public engagement. Public engagement can also be used as a method for the researcher to gain knowledge from as many relevant sources as possible. (Rowe & Frewer, 2005)

Public engagement or participation is by Rowe & Frewer (2005, p. 253) defined as *"the practice of involving members of the public in the agenda-setting, decision-making, and policy-forming activities of organisations/institutions"*. The public can, however, participate in many different ways, and therefore it is not enough to state that public engagement has taken place. The kind of public engagement needs to be specified. Rowe & Frewer identified three kinds of public engagement: Public communication, public consultation, and public participation as shown in Figure 3.1.

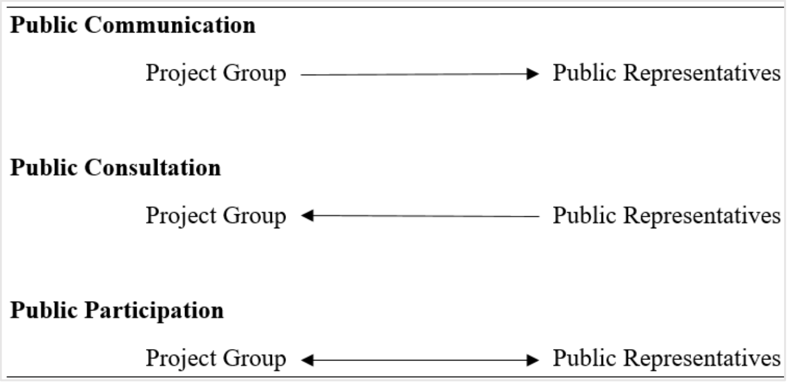


Figure 3.1: Types of public engagement (Rowe & Frewer, 2005)

The three types of public engagement are defined by how the information flows. In *public communication* the information flow one way where the project group communicates information to the public. Using this form of public engagement the communication is one-way from the project group to the public, feed-back from the public is not sought. If the public tries to inform or comment on the project, the information is not taken into consideration. For *public consultation* the flow of information is opposite of the flow in public communication, and information is given from the public to the project group, initiated by the project group. Real dialogue between the public and the project group does not exist in this form of public engagement. The information given by the public is regarded as the public's currently held opinions. In *public participation* the information flow goes both ways. The project group and the public exchange information and a dialogue takes place. Dialogue is not only a way to exchange knowledge, opinions, and ideas, but it also transforms opinions within both the project group and the public participating in the project. (Rowe & Frewer, 2005)

3.3.1 Public Engagement in Valsted

The public engagement used in Valsted consists of interviews with inhabitants with the purpose of gathering as much knowledge as possible from as many sources as possible. Therefore the public engagement used in this thesis consists of public consultation. The knowledge gained from the interviews is, however, not solely targeted at benefitting the authors of this thesis, but also for the public's benefit. Thereby the interviews are also conducted in order for the authors to be able to make a heating plan that takes the public's opinions into consideration, which also has the purpose of easing the implementation process.

When using public engagement one should be aware of not limiting options for the public but on the other hand make the public aware that they have more choices than often presented. Therefore the following section presents the theory of choice awareness.

3.4 Choice Awareness Theory

The choice awareness theory is developed by Henrik Lund from Aalborg University (AAU). It focusses on how to implement radical technology changes. It is explained that decision-making is strongly dependant on the presented choices. Knowing several options and having the choice between them is giving room for real decisions. In these cases the options with their side effects are presented to the decision makers and they can balance reasons as well as consequences and decide up on them. In many situations the presented choices are intentionally limited to give the decision makers a false impression of not having a choice. In these cases decision makers are often forced to decide between one option or non, which is called Hopson's choice. (Lund, 2014)

Lund therefore recommends raising awareness of the existing alternatives in order to allow a real choice. He proposes promotion on different levels: To include specific technological alternatives in the debates, to promote feasibility study methods such as relevant political analyses as well as specific public regulation measures. (Lund, 2014)

Lund's suggestion that political analyses should be carried out when radical technology changes are planned is valid and the aim of becoming 100% reliable on renewable energy in 2050 can be categorised as a radical technological change.

3.4.1 Choice Awareness in Valsted

In this thesis it is investigated which renewable energy system is the most feasible technology for providing heat to Valsted. The investigation will be based on different scenarios. The results presented in this thesis are recommendations which can be compared with other investigations. The relevant decision makers e.g. Aalborg Kommune or the individual households in Valsted can come to their own conclusions. Furthermore a political analysis is carried out in Chapter 10: Policy Recommendations in the form of identifying barriers, for implementing the most socioeconomically feasible scenario, in the current legislation.

In order to find the most socioeconomically feasible scenario, a socioeconomic analysis has to be carried out. The following section presents how a socioeconomic analysis is carried out according to the guidelines published by the Danish Energy Agency.

3.5 Socio Economic Analysis

This thesis presents a socioeconomic analysis of Valsted's heating system as a criterion when comparing different scenarios. A socioeconomic analysis is a tool to help make qualified priorities of the society's limited resources. The Danish Energy Agency has made a guideline on socioeconomic analyses in the energy area. As this is the official guideline on how to make socioeconomic calculations in energy projects in Denmark this will also be the guidance followed in this thesis. (Danish Energy Agency, 2007)

The first step in a socioeconomic analysis is to make a reference scenario, which other scenarios should be compared to. In the reference scenario a delimitation also takes place, as it presents what the other scenarios should be compared to. A reference scenario presents the energy system if no other changes than the natural changes are implemented. (Danish Energy Agency, 2007)

In this socioeconomic analysis the costs of the scenarios are calculated in order to identify the most beneficial scenario for society. These costs include: Investment, operation and maintenance (O&M), negative effects on the environment. The preferred project is the one causing the least costs for society. (Danish Energy Agency, 2007) Negative effects on environment are, however, not included in this analysis as all new scenarios are based on renewable heat sources.

Sensitivity analyses are also an important part of a socioeconomic analysis, as they investigate the insecurities or possible changing factors that affect the economic feasibility of the project. (Danish Energy Agency, 2007)

Furthermore the Danish Energy Agency's guide for socio economic analysis includes the elements: Tax distortion loss, net factor, and job creation. The last element, job creation, is not included in this analysis as the collected workforce in the long term is considered to be a limited resource. Therefore it is assumed that the workers, in the long term, will find jobs elsewhere (Danish Energy Agency, 2007, p. 19).

For reasons of simplicity the tax distortion loss and net factor are not included in this analysis either. The following paragraphs describe them.

The tax distortion loss is used to take expensive public projects' influence on the tax level into account, as some projects might result in a tax increase if the state has to support the project. The tax distortion is by the Ministry of Finance set to be 20% of the tax amount. (Danish Energy Agency, 2007, p. 14)

The net factor represents the state's lost income from unknown consumer goods or services that the consumers would buy instead of the energy investment. On average the Danish consumer goods and services are taxed with 17%, and the state therefore loses 17% of the investment. (Danish Energy Agency, 2007, p. 11)

CHAPTER 4: METHODS

The methods used in this thesis are based on the theories presented in the previous chapter. This chapter elaborates on stakeholder analysis, making the grounds for public engagement. Further the methods for choosing an appropriate simulation software are presented. The methods used for modelling the different scenarios are presented in Chapter 6: EnergyPRO Model, and to a small extend in Chapter 7: Scenarios as well.

4.1 Stakeholder Analysis

A stakeholder analysis is carried out in order to identify the relevant actors who have an influence on the heating system in Valsted or are affected by a change of it. This stakeholder analysis follows the definition of Varvasovszky & Brugha, according to whom a "*stakeholder analysis is an approach, a tool [...] for generating knowledge about actors - individuals and organisations - so as to understand their behaviour, intentions, interrelations and interests*". (Varvasovszky & Brugha, 2000, p. 338)

The stakeholder analysis carried out in this thesis uses the current situation as a starting point and focuses on the future, as the scenarios are future oriented. A medium timeframe is chosen, as the changes are expected to happen before 2035 in accordance with the Danish energy targets. This future oriented stakeholder analysis is a valid representation of the current situation, but the unpredictable nature of the future makes it prone to changes.

Interviews with the people of Valsted are the main source of information about the stakeholders, and therefore the methods used for public engagement are presented in the following section. Additionally legislation and further literature has been used to identify the relation between the individual stakeholders. A graph has been designed to present the stakeholders as well as the relations between them, which is presented in Section 5.4: Stakeholder Analysis on page 40.

4.2 Public Engagement

As stated in Section 3.3.1: Public Engagement in Valsted on page 18, the public engagement used in Valsted has been on the level of public consultation, in the form of interviews. In order to gain participants, half a page about the thesis with a statement that interviewees were needed was published on the civic association's web page and on the school's intranet. 11 households volunteered to participate and have been interviewed. All interviewees are to the biggest extend possible anonymised in this thesis and will thereby appear as numbered households. It was, however, made clear to the interviewees that a full anonymisation might not be possible for all, as some people will be able to recognise the households. An overview of the interviewees and their heat sources is seen in Table 4.1 below.

Interviewees	**Main heat source**	**Additional heat source**
Household 1	Cattle excess air-to-water heat pump	
Household 2	Wood pellets boiler	
Household 3	2×wood stove	2×air-to-air heat pump, electric radiators
Household 4	Wood stove	Electrical heating
Household 5	Air-to-water heat pump	PV panels, solar thermal collectors, wood stove
Household 6	Ground source heat pump	
Household 7	Ground source heat pump	
Household 8	Ground source heat pump	Wood stove
Household 9	Ground source heat pump	
Household 10	Oil boiler	
Household 11	Oil boiler	

Table 4.1: Overview of interviewed households and their heat sources

Compared to Valsted's overall distribution of heat sources, seen in Section 5.1: Valsted's Current Heating System on page 31 ground source heat pumps are over-represented amongst the interviewees, and oil boilers are under-represented. The optimum would have been to have the same distribution of heat sources among the participants as the actual distribution, however, since the interviewees are volunteers, a distribution of heat sources cannot be chosen by the authors.

The interviews were conducted as semi-structured interviews where interest areas and questions were prepared in advance, but the interviews were still open to follow new information given during the conversation. (Tanggaard & Brinkmann, 2010) The interviews were conducted in Danish as this gave the interviewees the chance to better express themselves as well as it would not be perceived as a barrier for participating in the interviews. The authors visited the interviewees in their homes and conducted the interviews there. This gave the chance to also see the heating system. Further the interviews were recorded in order to make the summaries more precise.

Summaries of each interview have been made and the participants were offered the opportunity to approve the summary and give corrections, 4 households took the offer and approved the summaries with minor corrections in subjects such as amount of heated m^2. The summaries of the interviews with the households can be found in Appendix 1. An analysis of the interviews has been carried out by using a pre-prepared answer sheet, which was created in order to quantify important data from the interviews.

Knowledge gained from the interviews is used for creating scenarios, where the opinions expressed in the interviews are taken into consideration in order to create realistic scenarios that increase the chances for not causing public resistance. For the authors to be able to analyse said scenarios a simulation of these must be made. Therefore the next section presents the method of choosing a simulation software.

4.3 Simulation Tool

The following section will describe the identification process of an appropriate simulation tool for simulating the current heating system of Valsted as well as possible future changes within the heating sector. First this section will specify the criteria used in the comparison of the simulation tools. Thereafter seven planning tools for local community energy systems are described individually and the compliance with the above mentioned characteristics is presented in Table 4.2 on page 29. The decision for an appropriate simulation tool is based on this comparison.

For the identification of an appropriate simulation tool several parameters have to be taken into account. The tool needs to be able to simulate the operation of a village size heating system with several, different energy conversion units. It has to be able to calculate different scenarios and present operational and economic characteristics in a comparable manner. Additionally it is important to choose a tool which is commonly used in the industry, as this is an indication, for the quality and the level of mistakes encountered throughout the simulations. It was chosen that the number of users/downloads has to exceed 1000 in order to fulfil this criterion. A software tool with a simple user-interface and short training duration is preferred. Short in this case is defined as training durations of 1 day or less. Moreover only tools which are up-to-date and available at AAU are considered further in the comparison.

The Department of Development and Planning at AAU recommends the following list of planning tools for local community or single project energy systems: BCHP Screening Tool, COMPOSE, energyPRO, ETEM, HOMER, MODEST, TRNSYS. (Department of Development and Planning Aalborg University, n.d. a) These tools are included in the comparison and will be described individually in order to investigate their compliance with the characteristics described at the beginning of this section. The tools are described in alphabetical order.

The BCHP Screening Tool, which was developed in 2003 by the Oak Ridge National Laboratory in USA *"is specifically designed for a single-project investigation"* (Department of Development and Planning Aalborg University, n.d. b) on building level, but experts in the tool are able to simulate several buildings up to company campuses. The tool is capable of performing simulations of different energy conversion units and their technical operation as well as economic features. (openEI, n.d.) The tool has been downloaded more than 2000 times. (Department of Development and Planning Aalborg University, n.d. b) but as it is no longer accessible via the links published at energyplan.eu. Therefore it is assumed that the simulation tool is not up to date any more. The BCHP Screening Tool has no focus on the heating sector. Further, the long training time of 7-14 days to complete a basic analysis is considered an obstacle. (Department of Development and Planning Aalborg University, n.d. b) The BCHP Screening Tool is therefore not suitable for the use in this project.

COMPOSE (Compare Options for Sustainable Energy) was designed at AAU in 2008 and since then only gained few users, the software was not updated since the autumn of 2015. (Energyinteractive.net, n.d.) It requires a relatively long training with a length of 3 days. COMPOSE has the ability to simulate several energy conversion units and their simultaneous operation. The program has amongst others a focus on heating systems and is capable of simulating both technical as well as economic characteristics. (Department of Development and Planning Aalborg University, n.d. c) Morten Boje Blarke who updated the software (Blarke, n.d.), and wrote most publications about it, changed positions in early 2016 (Blarke, 2017) and it is assumed that the work on the software has not been continued. COMPOSE is therefore disregarded as simulation tool.

energyPRO is a modelling software, which was developed by Henrik Lund at AAU in the late 1980es and is further developed and maintained by EMD International A/S in Denmark. (Aalborg University, n.d.) It is able to simulate district heating systems and similar projects with a wide range of parameters which can perform analyses on the operation of systems with several energy conversion units and provides reports on the simulations based on operation, financial and environmental criteria. It is used in the industry with over 1000 downloads in 16 countries as well as it has a user-friendly interface. Further the training required to use the software is relatively short with an estimation of 1 day of training. (Department of Development and Planning Aalborg University, n.d. d) energyPRO licences and introduction lectures are available to the students at the Department of Development and Planning at AAU. As energyPRO meets all evaluated criteria it is considered a suitable simulation tool for this project.

ETEM (Energy Technology Environment Model) is currently advanced by ORDECSYS (Operation Research Decisions and Systems) which is based in Switzerland. (Ordecsys, n.d.) ETEM is a simulation tool, with a strong focus on simulating the influence of policy changes on an energy system. The current update is called ETEM-SG which is specifically designed for the simulation of smart grids in cities and metropolitan areas. Additional features like the possibility for coupling the simulation with chemical simulations regarding emissions, are irrelevant for this project. ETEM does not have a focus on the heating system as well as it is unknown how detailed it simulates the technical operation of the simulated system. (Department of Development and Planning Aalborg University, n.d. e) The amount of users, the required training duration as well as the level of simplicity encountered at the user-interface are unspecified on the company’s website (Ordecsys, n.d.). Furthermore the tool is not available at AAU (Østergaard, 2017). On these grounds ETEM is disregarded.

The HOMER simulation tool was designed in 1992 by the National Renewable Energy Agency in USA and has since then been used by 32.000 people. The tool is mainly designed for the simulation of small scale electricity systems and was mostly used in publications about photovoltaic (PV) systems. While it has features for thermal energy usage it does not support the simulation of heat pumps. (Department of Development and Planning Aalborg University, n.d. f) Homer gives the possibility for comparing different scenarios but is primarily focused on the comparison of financial parameters. (Homer Energy LLC, 2015 a) HOMER is available online under homerenergy.com and has an estimated training duration of 3 hours; this is partly achieved through an intuitively designed user-interface. (Homer Energy LLC, 2015 b) HOMER is not considered a suitable simulation tool for this project, as it does not support all needed parts of heating systems.

MODEST was developed by Dag Henning at Lindköping University (Sweden) in the early 2000s and most publications about the simulation tool were written by him. (Henning, 2017) Since he left the University there are no new publications about the simulation tool and it is questionable if the software has recently been updated. Generally MODEST has a focus on the simulation of district heating systems with various energy conversion units. With this purpose it was used for over 50 cases in Sweden. While the tool is focused on district heating, it is theoretically able to simulate systems of any scale, but it needs to be taken into account that the bigger the model, the more complex it will be. MODEST offers the opportunity to simulate interactions between markets and calculate technical, economic as well as environmental characteristics. Based on the description of the tool and its mentioned use cases it is assumed that the tool is not having more than 1000 users. Neither the user-friendliness of the tool nor the expected training duration is mentioned in the program description. The program is currently not accessible online but the author can be contacted via mail. (Optensys Energianalys AB, n.d.) (Department of Development and Planning Aalborg University, n.d. g) For these reasons MODEST is not considered further in the comparison.

TRNSYS was first published in 1975 and has since continuously been updated. It is widely used although mainly by experts at Universities, as it is a vast and complex simulation tool. (Thermal Energy System Specialists LLC, 2008) It is capable of simulating the entire energy sector, *“by breaking it down to the individual components.”* (Department of Development and Planning Aalborg University, n.d. h) Through its complexity TRNSYS requires a long training time, before bigger models with not pre-defined modules can be simulated. Because the tool is capable of simulating very detailed processes it can be used at very different scales, ranging from individual parts, e.g. the heat transfer within a solar thermal collector to an entire energy system for a town. TRNSYS is designed to simulate flows by using open source code in a modular structure. Economic calculations could be carried out, but would require that the user creates own TRNSYS modules. The simulation tool is kept up to date by an international collaboration of institutions with focus on solar energy (Department of Development and Planning Aalborg University, n.d. h). TRNSYS is rarely used in the Department of Development and Planning at AAU but access to it could be gained via the Department of Energy Technology (Østergaard, 2017). TRNSYS is because of its level of complexity not considered further.

Table 4.2 summarises the findings of the comparison of the different simulation tools, and presents the compliance of the described simulation tools with the required characteristics. And therefore helps to identify the most suitable simulation tool.

	BCHP Screening Tool	COMPOSE	Energy PRO	ETEM	HOMER	MODEST	TRNSYS
Suitable for village size	Experts	✓	✓	✓	✓	✓	✓
Different scenarios	✓	✓	✓	✓	✓	✓	✓
Focus on heat sector	✗	✓	✓	✗	✗	✓	✓
Combination of energy conversion units	✓	✓	✓	✓	✓	✓	✓
Model technical operation	✓	✓	✓	N/A	✓	✓	✓
Model economic features	✓	✓	✓	✓	✓	✓	✗
More than 1000 user	✓ Buildings	✗	✓ DH/CHP/el	N/A	✓ PV	✗	✓ PV
Simple user-interface	N/A	N/A	✓	N/A	✓	N/A	✗
training duration ≤ 1 day	✗	✗	✓	N/A	✓	N/A	✗
Availability at AAU	✓	✓	✓	✗	✓	✗	✓ other Dep.
Up-to-dateness	✗	✗	✓	✓	✓	N/A	✓

Table 4.2: Comparison of simulation tools

The comparison of simulation tools, presented in Table 4.2, illustrates that only energyPRO meets all requirements. Therefore energyPRO is identified as the most appropriate simulation tool for the simulation of Valsted’s current and future heat sector.

CHAPTER 5: FRAMEWORK CONDITIONS

In this chapter Valsted's current heating system is presented in detail. Further the availability of heat sources is evaluated before the process of approving energy projects is described. This chapter closes by presenting a stakeholder analysis of the heating system in Valsted.

5.1 Valsted's Current Heating System

Valsted is supplied by individual heating systems as the village does not have access to district heating. The distribution of the individual heat sources in 2014 can be seen in Table 5.1 where the heat demands marked with a star (*) are estimated demands, and the distributed heat sources marked with a plus ($^{+}$) are not specified in (Aalborg Kommune, 2014) but assumed distribution.

Heat sources	Amount	Heat demand [MWh]
Oil boiler	50	885.0
Oil boilers + solar thermal collector	$^{+}$2	*36.2
Biomass Boiler	10	209.0
Heat Pump **(Ground source)** **(Air-to-water)** **(Air-to-air + electric heat)**	33 $^{+}$18 $^{+}$5 $^{+}$10 +$^{+}$10	657.0 $^{+}$403.0 $^{+}$115.0 $^{+}$139.0+*119.0
Air-to-water heat pump + solar thermal collector + wood stove	1	*18.1
Electrical heating	4	52.0
Cattle excess air-to-water heat pump	1	*18.1
Additional wood stove	21	*145.3
Total	132	2,139.7

Table 5.1: Distribution of heat sources and demand in Valsted. (Aalborg Kommune, 2014)

The heat demand for electrical back-up and additional wood-stoves are added to have a more correct estimation of consumption, since these consumptions are not included in (Aalborg Kommune, 2014).

Three heat sources were gathered in the same category ("Others") in (Aalborg Kommune, 2014), namely the heat demand for two wood stoves and a cattle excess air-to-water heat pump. The cattle excess air-to-water heat pump covers the whole heat demand of a house, whereas the wood stoves, in this case, are only used for heating sheds. Therefore it has been assumed that the farm (using the cattle excess air-to-water heat pump) has a heat demand corresponding to the national average annual heat demand of 18.1 MWh (PlanEnergi, 2015), and the remaining heat demand of 11.3 MWh has been divided equally between the two wood stoves. These are added to the additional wood stoves, as the heat demand is covered when installing the typical capacity of 4 kW (Danish Energy Agency, 2013 a). Wood stoves used for additional heating are common in Valsted and are used in 20 houses. It is assumed that they cover 1/3 of the 20 houses' space heating demand, leaving an annual demand of 145 MWh.

The national average heat demand has also been used to determine the heat demand of the houses supplied with combined heating systems: Solar thermal collectors and oil boilers, and air-to-water heat pump, solar thermal collectors and wood stove.

Aalborg Kommune (2014) provides Valsted's heat demand categorised by type of heat generation unit. For heat pumps the overall demand is specified but a distribution of different kinds of heat pumps is not specified. Therefore the presented distribution is based on the authors' impression from the interviews with the citizens of Valsted. For this reason it might not be the correct distribution, but it shows the tendency experienced by the authors. According to Energinet.dk and Danish Energy Agency (2016) air-to-air heat pumps are able to cover 60% of the space heat demand and 0% of the hot water demand. Therefore the remaining 40% of the average heat demand attributed to air-to-air heat pumps is distributed to the other types of heat pumps, in equal shares. A consumption of 119 MWh for electrical back-up covers both back-up for space heating and hot water. It is thereby assumed that the last 40% of the space heating demand as well as the hot water demand is covered by electrical back-up heating. The hot water demand is by Statens Byggeforskningsinsititut (The state's construction research institute) estimated to be between 30-40% of the total heat demand depending on the age and energy efficiency of the building. (Gram-Hanssen, 2003) Therefore it is assumed that 1/3 of the heat demand is used for hot water in Valsted.

Valsted's heat demand has to be covered by renewable heat sources in 2035 according to national regulations. Therefore the availability of heat sources in Valsted is investigated in the following section.

5.2 Availability of Heat Sources

The aim of this section is to investigate which resources are available in Valsted and could potentially be used for generating heat. Heat pumps, solar thermal collectors, terrestrial heat, as well as the utilisation of excess heat and the creation of a local district heating system are taken into consideration.

5.2.1 Heat Pump

Low-temperature heat e.g. from ambient air, ground or water can be used via heat pumps. When the power used in the heat pump is generated by renewable resources, heat pumps can be considered climate neutral. The different types of heat pumps are labelled by the input as well as output medium, e.g. air-to-air heat pump and water-to-water heat pump. (Quaschning, 2013)

Heat pumps work more efficient the higher the initial temperature level of the heat source. The required energy for operating the heat pump decreases the closer the initial temperature of the source is to the required temperature level of the heating system. This gives advantages to space heating systems, which require lower temperature levels. (Quaschning, 2013)

The advantage of heat pumps is that the amount of mechanical power input is smaller than the heat output. The heat output consists of the mechanical power input as well as the input from the heat source. The relation between output heat and input power is referred to as Coefficient Of Performance (COP). (Quaschning, 2013) Typical COP values for heat pumps are around 3. (Danish Energy Agency, 2014 b) This means that with 1 unit of electricity 3 units of heat can be generated.

In Valsted both ground as well as air temperature can be utilised as low temperature heat sources. Both sources are utilised in already existing heat pumps in private households as presented in Table 5.1 on page 31.

5.2.2 Terrestrial Heat

Terrestrial heat is usable for heating purposes in two different types, deep geothermal and near surface heat. The second is harvestable by placing heat absorbers in the upper layers of the ground, approximately 1-3 m under the surface and circulate a liquid, which is heated by the surrounding earth. This liquid is then used as the heat source for an electric heat pump which boosts the temperature to the level needed for heating. (Virén, et al., 2014)

Deep geothermal is harvested by drilling holes into the warm layers of the ground approximately 1,500 m. Through these holes water or air is circulated and heated from the earth's geothermal energy, before being boosted by a heat pump. (Quaschning, 2013) In Denmark the geothermal potential is located between 800 and 3000 m below the ground. There are different geothermal reservoirs in Denmark, which contain heat at varying temperatures and depths. These potentials are described in maps. (Hurter & Heanel, 2002) The geothermal potentials in Valsted are presented in Table 5.2

Name	Depth [m]	Thickness [m]	Temperature [°C]	Resources
Frederikshavn Formation	1300-1500	125-150	40 - 50	N/A
Gassum Formation	2500	150-175	90 -100	2.5
Haldager Formation	2000	50	60 - 70	0.5

Table 5.2: Geothermal potential in Valsted (Hurter & Heanel, 2002)

It can be seen in Table 5.2 that the geothermal potential in Valsted is located in great depths of around 2000 m. In order to utilise this energy huge initial investments would be necessary. This investment is only feasible for a plant with a big district heating network. As this is not the case for Valsted, geothermal heat is disregarded in the further analysis. The utilisation of near surface heat via ground source heat pumps is considered further in this thesis.

5.2.3 Solar Thermal Energy

Solar thermal energy can be used for heating purposes. A solar thermal collector absorbs the sunlight which heats a fluid inside the collector. The warm fluid is pumped through a heat exchanger, where it transfers the gained temperature difference to water, which is then stored in a thermal storage. The stored hot water can be used in the heating system, preferably surface heating, which requires lower temperatures, or it can be utilised for domestic use. Currently solar thermal heating systems are implemented together with a second heat source, e.g. a heat pump, or a sessional storage. (Quaschning, 2016)

The amount of heat generated is depending on the available sunlight. Therefore the conditions in Valsted have been investigated. In the area of Valsted global solar radiation on a horizontal surface amount to approximately 950 kWh/a, as presented in Figure 5.1 below. This energy can be utilised for the generation of heat via solar thermal collectors.

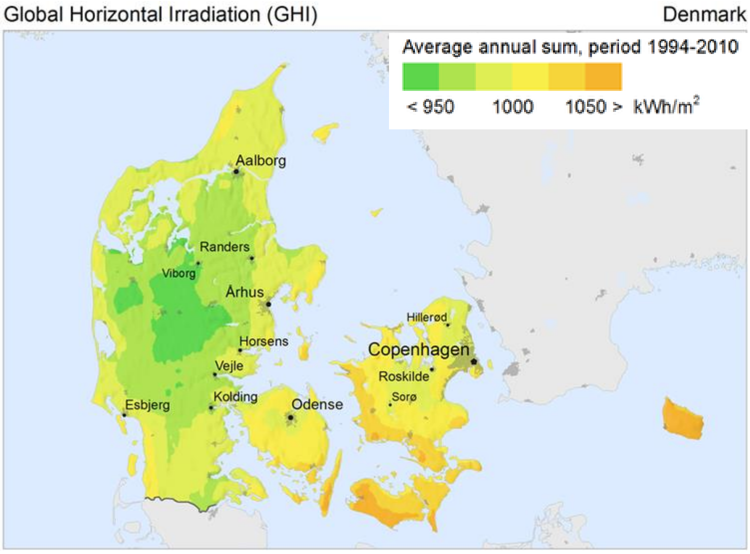


Figure 5.1: Global horizontal irradiation map for Denmark (solargis.info, 2014)

From a technical perspective solar thermal energy can be used for heating in Valsted. The highest temperatures/amount of heat can be achieved, when the collectors are positioned facing south, the orientations south-east and south-west only lead to minor reductions of yields. An inclination of 20-45° is favourable for solar thermal collectors. (Quaschning, 2016)

Solar thermal collectors are already used in Valsted. Further Aalborg Kommune specified the aim to drastically increase the existing amount of installed solar collectors until 2030. (Forsyningsvirksomhederne, 2011) Therefore solar thermal collectors are included in the further investigations.

5.2.4 Excess Heat

Industrial as well as agricultural excess heat can be used for heating purposes, either conventionally or by increasing the temperature via heat pumps. As there is no industry located in Valsted there is no excess heat which can be used from industry. (P4 Nordjylland, 2013) One active farm is located in Valsted and the farmer is currently using the heat of the animals via an air-to-water heat pump to heat the house. Since the farmer is looking to retire and is not interested in making a business of selling heat, it is not investigated further if there is potential to heat additional buildings (Household 1, 2017)

5.2.5 Biomass

Biomass is a collective term. It includes all organic matter which can be used as fuel. The most common forms of biomass used in the heating sector are straw, wood chips, firewood, wood pellets, waste wood, liquid biofuels, and renewable wastes (Danish Energy Agency, 2014 b).

Aalborg Kommune published strict guidelines on the permitted usage of biomass as it is an aim of the municipality to fulfil the biomass demand locally. According to Aalborg Kommune it is not considered sustainable to import biomass form other countries in order to reach its goals of having a fossil free energy system. Moreover individual wood stoves are not considered efficient use of the limited biomass resource; therefore Aalborg Kommune recommends decommissioning existing wood stoves and instead recommends the use of biomass in more efficient heat and cogeneration plants. Therefore biomass is only considered in the district heating scenarios. (Forsyningsvirksomhederne, 2011)

Further, when comparing the different heating values of straw (15.5 GJ/ton (Danish Energy Agency, 2014 c)) and wood pellets (17.5 GJ/ton (Danish Energy Agency, 2011)) it can be seen that wood pellets have a higher calorific value and therefore contain more energy per mass. This gives an advantage to wood based biomass. Additionally the emissions related to burning straw compared to burning wood and wood pellets are presented in Table 5.3 below.

Fuel	**CO_2 [kg/GJ]**	**CH_4 [g/GJ]**	**N_2O [g/GJ]**	**SO_2 [g/GJ]**	**NO_x [g/GJ]**	**$PM_{2,5}$ [g/GJ]**
Straw	0	30	4	130	90	12
Wood	0	11	4	11	90	10
Wood pellets	0	3	4	11	80	29

Table 5.3: Emissions of biomass fuels (Danish Energy Agency, 2016 b)

Table 5.3 presents that using wood pellets causes the least emissions of the compared biofuels. Therefore wood pellets are the only biofuel considered further in the different scenarios.

5.2.6 District Heating

In a district heating system heat is produced at centralised plants or a number of heat producing facilities and distributed to the consumers. This system supports cogeneration of electricity and heat at CHP plants. Cogenerating electricity and heat increases the energy efficiency significantly, utilising the scarce resources better. (Lund, et al., 2014) By cogeneration the GHG emissions are also lowered, as the otherwise unused heat is utilised in a district heating system. (Amiri, 2013) Furthermore district heating has proven to reduce costs, as some scenarios for Europe have been proposed to lower the GHG emissions, and the use of district heating has proven to reach the same results but at approximately 15% lower costs. (Connolly, et al., 2014)

For Valsted CHP plants are not recommended due to the rather small heat demand. District heating scenarios without cogeneration are, however, tested in this thesis to investigate the costs for such systems in Valsted. This is part of applying the choice awareness theory on the case of Valsted's heating system.

5.2.7 Summary of Availability of Heat Sources

In this section it has been presented that it is not economically feasible to use geothermal heating in the scale of Valsted. Further, excess heat has also been identified to not have potential for Valsted. These two heat sources are therefore disregarded in the further analysis. District heating is described in order to present a broader range of scenarios increasing choice awareness amongst the citizens of Valsted. Therefore this is considered in the further analysis. Also considered heat sources are: Heat pumps, solar thermal collectors, biomass boilers, and wood stoves. These heat sources are commonly used in Denmark, especially heat pumps have proven to increase efficiency (Energinet.dk & Danish Energy Agency, 2016).

There are certain requirements that need to be met before an energy project, such as installing a district heating system and some individual heat sources, can be approved. The required processes are described in the following section.

5.3 The Process of Approving an Energy Project

The process of approving an energy project is defined by the Danish law, which differs between individual energy projects and collective energy projects. These processes will be accounted for in the following. Since the processes have been established by the Danish law, they do not vary significantly between municipalities. However, the energy projects must be in line with the municipal plans, which differ. Therefore the following is based on the guidelines provided by Aalborg Kommune.

5.3.1 The Process of Approving Individual Heating Systems

Some individual heating systems need to be approved before implementation, these will be presented in the following. Furthermore there is a ban on installing electrical heating in new and existing dwellings in areas with a collective heating system or plans of one. (Miljø- og Energiforvaltningen, n.d.)

An individual heat source that needs approval from the municipality before its implementation is a ground source heat pump due to the burying of pipes. The pipes should not be buried within a distance of 50 m of the dwelling's own water catchment and not within 300 m. from public water catchment. Nor should the pipes interfere with protected nature or historical grounds or memories. (Miljø- og Energiforvaltningen, n.d.) Since other renewable heat sources have less impact on the land and grounds around them no approval from the municipality is needed for installation of those.

Since the aim of this thesis is to make several scenarios for the heating in Valsted and finding the most economically feasible scenario, the requirements for approval of a collective heating system will be followed.

The requirements of approving individual and collective heating systems differ, therefore the next section describes the process of approving a collective heating system.

5.3.2 The Process of Approving a Collective Heating System

The proposal of establishing a new collective heating plant can be done by multiple groups: A group of citizens, a district heating company, municipalities, natural gas companies, and electricity companies. An application of establishing a new collective heating plant and system should consist of a technical part, an economical part, and an environmental part. In the first part the technical aspects should be accounted for, and the current law requirements should be kept. (Miljø- og Energiforvaltningen, n.d.) This includes requirements such as the national law stating that all heating plants with a capacity of 1 MW or more should have a renewable fuelled co-generation of heat and electricity. Systems used for covering peak demands or back-up systems, are the only exceptions, where individual generation of heat is permitted as well as the use of fossil fuelled systems can be approved. (Retsinformation.dk, 2011) The second part consists of economical calculations, including socioeconomic calculations and the private economy for the user, and a business economic analysis calculating the costs for businesses. (Miljø- og Energiforvaltningen, n.d.) The municipality should approve the most socioeconomic feasible project, if the project has a worse socio economy than the current system, the project cannot be approved. (Retsinformation.dk, 2011)

The last part should cover the environmental and energy conditions. After the application has been sent to the municipality a hearing period of four weeks takes place, where the directly affected stakeholders have the opportunity to make objections towards the project. Thereafter the municipality and the applicant body have time to propose or implement changes in the application. The next step is for Aalborg City Council to approve or dismiss the project. Hereafter the directly affected stakeholders have the opportunity to appeal for four weeks. The last step is the implementation of the project. (Miljø- og Energiforvaltningen, n.d.), (Danish Energy Agency, et al., n.d.)

Whether or not dwellings are required to be connected to a collective heating system is decided by Aalborg Kommune. The requirement of connection means that the dwellings are required to pay either a one-time connection fee or a steady yearly fee. Even though there can be a requirement of connection there is no requirement of purchasing heat, and the dwelling can be supplied by alternative heat sources. (Miljø- og Energiforvaltningen, n.d.)

As presented above, stakeholders have the opportunity to make objections to a project, and further to appeal the decision of either approving or dismissing an energy project. Therefore it is important for energy projects to identify stakeholders, their role and their interests in order to evaluate their ability to influence the project. For these reasons a stakeholder analysis is carried out in the next section.

5.4 Stakeholder Analysis

This stakeholder analysis presents the stakeholders involved in the heating system of Valsted. The individual stakeholders are described and their importance on the project is explained. Furthermore the relationships between the different stakeholders are elaborated on. Figure 5.2 is used to illustrate these relationships.

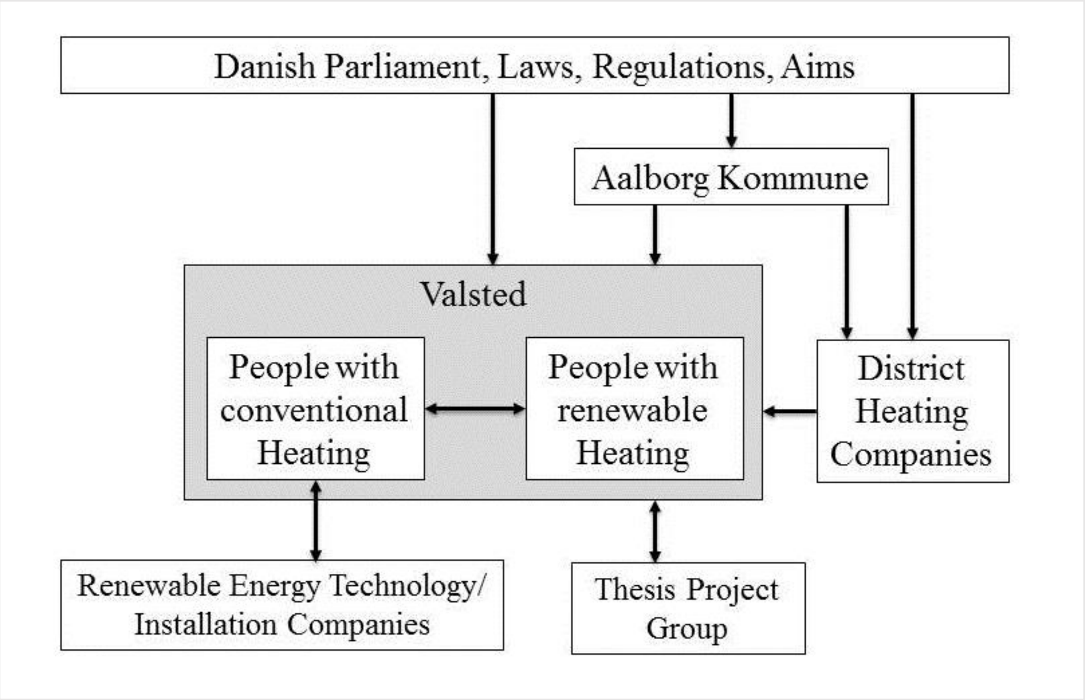


Figure 5.2: Stakeholder graph

5.4.1 The Danish Parliament

The Danish parliament plays a role in the heating system in Valsted because it is responsible for the legislation in Denmark. It was the parliament which gave out the aim of becoming 100% independent of fossil fuels by 2050 (Danish Energy Agency, 2016 c) and that affects the regulations in place for creating this change, which impact the municipalities as well as all people living in Denmark.

The people of Valsted have no direct influence on the decisions of the parliament other than through elections. This makes the citizens dependent on decisions which they cannot influence, and hence cause insecurities and worries in terms of not knowing if a future regulation that is discussed will have impact on their personal situation. Currently the people in Valsted are affected by an insecurity about new regulations regarding the emissions of wood stoves as the legislation in this field might change leading to restrictions for citizens using wood as their primary or secondary heat source (Household 3, 2017).

The parliament on the other hand has a big influence on Valsted like on all other locations in Denmark as the people have to follow the laws and regulations. Valsted as a small village has the disadvantage that regulations are usually focused on the majority and especially in the energy transition the solutions proposed by the government mainly disregard or just briefly touch upon how such small locations should reach the set goals. This increases the responsibilities for the individual households in smaller locations, whereas in bigger cities this responsibility is more put upon utility companies.

The Danish parliament as a stakeholder is able to influence the framework in which the other stakeholder operate in, therefore the parliament is considered the most powerful stakeholder, which can both be an opportunity for forcing certain changes as well as a threat to those who do not agree with them.

5.4.2 Aalborg Kommune

Valsted is located in Aalborg Kommune (Aalborg Kommune, 2014) and therefore is bound to the regulations and aims set within the municipality.

Aalborg Kommune is bound to follow national legislation and to follow national aims, but can introduce additional aims as well. In the field of renewable energy Aalborg Kommune decided to be more ambitious than the rest of the country, as Aalborg Kommune has a goal of having a fossil fuel free heating sector by 2030 (Forsyningsvirksomhederne, 2011) whereas the national aim is to reach a fossil fuel free heating sector by 2035 (Danish Energy Agency, n.d. a). As Valsted is a part of the municipality it has to follow this goal as well.

The citizens of Valsted are only to a limited extend able to influence decisions made on municipal level. The most powerful way is through elections, followed by raising awareness of their fears and worries. This is much easier on a municipal level than on national level, as a municipality is more reachable for the citizens. This on the other hand does not mean that the ability to influence decisions is higher, but it is easier to get access to information.

5.4.3 People of Valsted

The most relevant stakeholders in the case of the heating system in Valsted are the people living there. Therefore the people living in Valsted will be described. Further the insights on opinions held in the village, which were gained through the interviews are described. The opinions differ and therefore a categorisation was chosen. The households who have renewable heating and those with conventional heating are described separately.

The current heating system in Valsted consists of individual heating solutions. (Aalborg Kommune, 2014) The interviewed inhabitants are generally not interested in changing this. Further they believe that this is also the opinion of the rest of the inhabitants in Valsted. Many people prefer to be able to regulate their heating system individually or are striving towards self-sufficiency. Additionally most citizens are concerned about the costs of a district heating system, as other small villages which have invested in fossil fuelled district heating systems have to pay tremendous prices for the heat now. (Household 7, 2017)

The most common heat source in Valsted is oil boilers, which are installed in 52 of the 103 households. (Aalborg Kommune, 2014) This group is not represented properly in the group of interviewees, as only 18% of the interviewed people use oil boilers compared to 50% of the citizens who use them as their main heat source. This leads to the conclusion that the group of interviewees might have a more positive stance to renewables. As the sample of interviewees is of a representative size the gained information is assumed to be representative for the rest of the village.

The interviewed people showed an interest in renewable energies and energy efficiency which is estimated to be above average. Generally the interviewed citizens in Valsted are well aware of the possibility to reduce the heating expenses by insulating the house, including the walls and the roof, as well as changing doors and windows. Further most interviewed households have used thermography in order to identify thermal leaks on the outside of their house, which cause heat losses.

Most interviewed people were interested in investing in renewable energy technology but none of them planned specific measures, most of them because they had previously implemented energy efficiency measures as well as a renewable heating systems or there is a lack of financial possibilities to implement such changes at the moment. There is consent among the most of the interviewed people that new built houses should be heated by using renewable energy sources.

This section is complemented with two sub categories which are created in order to describe the differences between the people in Valsted who already use a renewable heating system and those who heat their house conventionally.

People of Valsted with Renewable Heating

Most of the interviewees have renewable heating systems installed. A trend for ground source heating can be seen for houses which are newly built or located on large premises. This heat resource is sufficiently available. Air-to-air heat pumps are used as additional heat sources, and air-to-water heat pumps are also used as primary heat source.

The interviewed people were very interested in the newest technology and to gain more insight in possibilities to renewably heat their homes in the most efficient, cheapest way possible. They are aware of the environment and interested in playing an active role in not further polluting it.

People of Valsted with Conventional Heating

The interviewed people who own an oil boiler explained that their decision for oil heating systems was mainly based on the fact that the technology is well known, the initial investment is relatively small and most houses in Valsted have the required pipe system already installed, which makes the installation time short and the installation cost rather cheap. The environmental drawbacks are known but only one parameter in the decision making process.

Another factor that leads to decisions against renewable heating systems is that the property bought is not suitable for implementing the preferred renewable heating system e.g. the property is not big enough for implementing pipes for a ground source heat pump, or the roof is not oriented south.

Generally there is an interest in the environment but the financial situation seems to be the most dominant reason for investing in an oil-based heating system, as it has a smaller initial investment compared to renewable heating systems.

Further the changes in the heating system are considered for the future but not before the end of the life time of the current heating system has exceeded. Using a small renewably fuelled district heating system is considered a good idea but it depends on the specific conditions and mainly the price if they would consider connecting to it.

5.4.4 District Heating Companies

District heating companies are a relevant stakeholder to the project of creating a renewable heating system in Valsted, even though Valsted is currently not connected to a district heating system.

From a technical point of view the connection to an existing district heating grid is not feasible, as the nearest district heating system is located in Nibe which is approximately 5 km away and the heat losses on the distribution line would not be in relation to the amount of heat needed in Valsted. (Aalborg Kommune, 2014)

Based on the information above district heating companies do not seem to be relevant stakeholders in the case of Valsted. However efforts are made that district heating companies are covering more of the Danish heat demand. Currently over 60% of Danish households are connected to district heating and this share is expected to increase. (Statistics Denmark, 2015) Even if households cannot be supplied with district heating a district heating company should be allowed to rent out heat pumps and hence create an efficient renewable heating system at lower costs than the households could themselves. This option was introduced to the people of Valsted during a meeting in the sports club (Household 11, 2017).

Further if a local district heating system would be introduced in Valsted there could be an obligation to connect to the system. This might cause problems with the citizens who prefer individual solutions and those who have just invested in an individual heating system. It also might cause problems for citizens whose heating system has not exceeded the planned lifetime.

Summarising the paragraphs above, district heating companies can present an opportunity for Valsted if they provide rental heat pumps but also a little threat in the case that a small district heating is introduced in Valsted for those households who do not want to connect to such kind of system.

5.4.5 Companies within the Field of Renewable Heating Systems

Companies in the field of producing and installing equipment for renewable heating systems benefit from the decision of the Danish government to become 100% renewable in the energy sectors. The specific case of Valsted will have minor impact on their economy as Valsted is consisting of only 103 houses of which 50% are already using a renewable heat sources. For the people of Valsted different companies offering equipment for renewable heating present an opportunity to choose between different options.

In the installation of these systems local installation companies are likely to benefit from further investments in the renewable heating sector. The citizens of Valsted might have a quite limited choice of installation companies but the interviewed citizens were satisfied with the installation done by local installation companies. Therefore all parties seem to benefit.

In the interviews it was mentioned that a ground source heat pump company used to be close by and that this increased the awareness of the opportunity to implement ground source heat pumps (Household 6, 2017). Also other successfully installed systems are a form of advertisement by word of mouth.

5.4.6 Thesis Project Group

The authors of this thesis have an interest in the implementation of renewable heating systems in Valsted and therefore can be seen as an opportunity for the people living in Valsted to gain more knowledge about the cheapest way to convert their existing heating system to a renewable one. As the authors are only creating a report as result of their project this leaves the citizens of Valsted the freedom to choose if they agree with the suggested solution or if they prefer another one. Therefore no pressure can be created between the authors and the citizens. If there were practices or circumstances which were violating the law in Valsted the authors would increase the risk that these circumstances would be made public and a conflict between citizens or a group of citizens and the municipality could occur.

The authors on the other hand benefit from the knowledge gained through the interviews to make the case study and later the suggestions more suitable for the specific conditions in Valsted.

As presented above there are many stakeholders affected by changing Valsted’s heating system. The ones affected the most are Valsted’s citizens. Therefore the citizens have been involved to get their opinions heard through interviews. The institution with the biggest power to change conditions for the transformation of Valsted’s heating system is the Danish parliament as it is able to change laws and regulations. Also Aalborg Kommune has the power to approve or dismiss certain energy projects as stated in Section 5.3: The Process of Approving an Energy Project. The authors of this thesis do not identify other stakeholders having similar big influences on the implementation of a new heating system in Valsted.

CHAPTER 6: ENERGYPRO MODEL

This chapter describes the assumptions and values the scenarios are based upon. First the parameters that are relevant for all scenarios are described, e.g. the inflation rates and currency exchange rates used. This section is followed by assumptions for the individual heating scenarios as well as assumptions for the district heating scenarios. In those sections an overview over the used values is given in Table 6.2 and 6.3. Fossil fuelled heat sources are presented in Table 6.2 as a Reference Scenario is simulated, presenting Valsted's current heating system without changes. This is done as a part of the socioeconomic analysis in order to be able to compare the different scenarios with the current system.

In Table 6.2 and 6.3 several numbers may occur in one field. This is the case when the scenarios use different capacities or performances of one heat source. If stated values are based on further assumptions these are explained after the table in the order of their appearance, using separate paragraphs for each value. Further the future electricity and fuel prices, used in the simulations, are presented.

In all scenarios, except the Reference Scenario, heat savings are applied. The level of heat savings applied is 20%, as calculations, elaborated in Section 7.1: Heat Savings on page 57, showed that this level is the most feasible level of heat savings in the case of Valsted. This means that the heat demand is lowered from 2,139.7 MWh/year to 1,711.8 MWh/year. A graph showing the heat demand is seen in Figure 7.3 on page 59.

As presented in Table 4.2 on page 29 energyPRO is the only simulation program fulfilling the requirements for modelling the heating system in Valsted. In energyPRO different simulation modes can be chosen. All scenarios, presented in Chapter 7: Scenarios, are modelled in finance-mode, allowing simulations for several years (EMD International A/S, 2016). A timeframe of 19 years (2017-2035) is simulated, as transforming the heating system by 2035 fulfils the national energy targets. The authors are aware that Aalborg Kommune set more ambitious aims with achieving that by 2030, but in order to increase the transferability of Valsted as a case to the Danish context, the 19 year timeframe has been chosen. Further when modelling in energyPRO, different input has to be inserted. As energyPRO does not contain financial data, it has to be found via other sources and put in manually for the program to make the calculations. The forecasted financial data is based on assumptions and forecasts, which have mainly been published by the Danish Energy

Agency in “Forudsætninger for samfundsøkonomiske analyser på energiområdet” (Conditions for socioeconomic analyses in the field of energy) and in the technology catalogues published by the Danish Energy Agency. Technical and financial assumptions for the scenarios are presented in tables in the following, divided into heat sources used for individual heating and heat sources used for district heating. Forecasted fuel prices for both heating forms are presented as well in Figure 6.2. All prices are presented in 2017 prices, using the inflation rates presented in Table 6.1 (Danish Energy Agency, 2016 a, p. 8) as well as the currency conversion factors presented below Table 6.1.

Inflation rates	[%]
2012	2.40
2013	1.70
2014	0.59
2015	1.05
2016	1.52
2017	1.55

Table 6.1: Inflation rates used to calculate 2017 prices. (Danish Energy Agency, 2016 a, p. 8)

Danish Energy Agency technology catalogues present prices in Euro (€). For the Technology Catalogue published in 2016 an exchange rate of 7.45 DKK per € is applied (Energinet.dk & Danish Energy Agency, 2016, p. 14). For prices from 2011 and 2013 an exchange rate of 7.42 DKK per € is used in accordance to the particular technology catalogues (Danish Energy Agency, 2013 a, p. 9).

For investments a discount rate of 6% without inflation has been used, as recommended by the Danish Energy Agency (2007, p. 13). Investment costs have all been adjusted to be the price for 19 years, which covers the simulation period (1/1 2017- 31/12 2035).

6.1 Assumptions for Individual Heating

A number of different heat sources have been used for modelling the scenarios with individual heating. These are presented in Table 6.2 together with the technical and economic data used for each heat source in energyPRO. Investment costs include all costs for installing a heat source at a consumer. (Energinet.dk & Danish Energy Agency, 2016), (Danish Energy Agency, 2013 a) For each heat source the same capacity is assumed to be installed in all houses which are supplied by this technology.

	Share of space heating covered [%]	Share of hot tap water covered [%]	Capacity [kW]	COP	Investment cost [1000 DKK]	Yearly O&M costs [1000 DKK]	Technical lifetime [years]
Ground source HP	100	100	10	3.95	123	1.6	20
Air-to-water HP	100	100	10 (3.8)	3.55	77 (29)	1.6	15
			8		61		
Air-to-air HP	60	0	5	5	17	1.5	10
			4		14		
Electric heating (back-up)	40	100	4	1	26	0.3	30
Solar thermal collector	10	65	4.2 ($6\ m^2$)	N/A	44	0.5	20
Heat storage	N/A	N/A	$1\ m^3$ (1000 l)	0.95	30	N/A	20
Additional wood stove	50	0	4	0.65 (0.50)	21	0.0	24
Biomass boiler	100	100	10	0.75	36	0.2	20
Oil boiler	100	100	15	1	53	2.2	20
Electric heating	100	100	10	1	65	0.8	30

Table 6.2: Technical and economic assumptions used for modelling individual heating in 2017 prices. (Energinet.dk & Danish Energy Agency, 2016), (Danish Energy Agency, 2013 a), (Danish Energy Agency, 2012)

The COP of a heat pump is dependent on several parameters. The following paragraph describes the determining factors for defining the COP values for the different scenarios. First the input and output temperatures are described, followed by the assumptions for different types of heating systems which are supplied. All values are for heat pumps installed at existing one family houses as this is the most common housing type in Valsted.

The COP of heat pumps varies significantly depending on input temperature and output temperature. For ground source heat pumps it is assumed that the pipes are buried in 1 m depth. (Energinet.dk & Danish Energy Agency, 2016). And the input temperature is assumed to vary between 2.7°C and 15.2°C, an estimation made by the authors of this thesis, inspired by Energinet.dk and the Danish Energy Agency (2016, p. 31). For the ground source heat pump an output temperature of 55°C is assumed. The same output temperature is assumed for air-to-water heat pumps, where the input temperature is assumed to follow the Danish outdoor temperature, which has been obtained from DMI (DMI, 2013), in form of hourly temperature values from the Danish Reference Year for central Jutland. For air-to-air heat pumps the input temperature also follows the Danish outdoor temperature and the output temperature is set to 25°C.

The COP of heat pumps is determined under defined temperature conditions, as the COP varies depending on the in- and outlet temperatures. For ground source heat pumps the standard temperatures that the COP is determined in is an inlet temperature of 0°C and an outlet temperature of 45°C. For both air-to-water and air-to-air heat pumps the standard temperatures for determining the COP is an inlet temperature of 7°C, and for air-to-water heat pump an outlet temperature of 45°C, whereas the outlet temperature for air-to-air heat pumps under the standard conditions is 20°C. (Varmepumpefakta.dk, 2013) This means that when setting the outlet temperature higher than described in the standard conditions, as it is done in this thesis, the actual COP is lowered compared to the COP stated in the data sheet. Also when varying the inlet temperature, the COP is affected either by being lowered when the temperature is lower than the standard of 0°C or 7°C or higher when the temperature exceed the standards. As the temperatures used in energyPRO vary on an hourly basis, also the COPs of the heat pumps vary, and therefore the COPs for heat pumps stated in Table 6.2 and Table 6.3 are describing the simulated heat pumps under standard conditions but throughout the simulation the COP is dependent on the temperatures and varies therefore according to the temperatures from hour to hour.

The COP further varies depending on whether the house has floor heating or if the heat is distributed by radiators. As data on which kind of heating is used is unavailable, it is assumed that half of the houses have floor heating, and the other half is heated via radiators. The stated COPs present the arithmetic mean of the COPs stated in the Technology Catalogue for the different types of heating (Energinet.dk & Danish Energy Agency, 2016).

Air-to-water and air-to-air heat pumps are presented in split cells, as they are used with different capacities in the scenarios. The lower values are used for modelling the individual heating scenarios, where the smallest capacity still covering the demand is installed. Furthermore two capacities are presented in the top part of the split cell as it is known from the interview with Household 5 that the installed capacity is 3.8 kW. (Household 5, 2017) 10 kW are installed in the other houses as the heat pumps there are assumed to cover the total demand.

In the Technology Catalogue (Danish Energy Agency, 2013 a) biomass boilers are presented with both the option of manual and automatic stocking. Table 6.2 presents prices for biomass boilers with manual stocking, as the only interviewed household with a biomass boiler (Household 2) has manual stocking. It is assumed that Household 2 is representative for biomass boilers in Valsted.

Wood stoves are presented with two COPs in Table 6.2 as the COP of 0.65 stated by (Danish Energy Agency, 2013 a) is for new wood stoves. All the wood stoves in the interviewed households were of an older date, and therefore assumed lower efficiency. In order to get a more precise result when modelling, these wood stoves' COP is lowered to 0.50. Furthermore the share of space heating covered by the wood stoves differs, as it is known that in two occasions wood stoves are used for heating sheds. In these cases the full heat demand is covered.

The COP of biomass and oil boilers differs according to the load, the lower the load, the lower is the COP. Therefore load curves (Indoor Comfort Marketing, 2012) have been inserted in energyPRO. The load curves used in the model are presented in Figure 6.1 below.

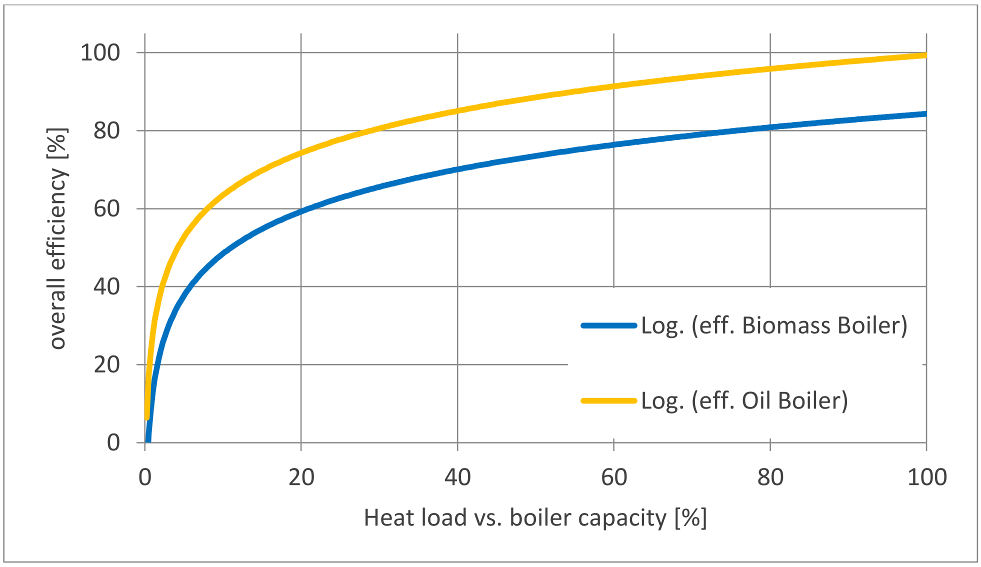


Figure 6.1: Load curves, adapted from (Indoor Comfort Marketing, 2012)

Both types of boilers are assumed to follow the same load curve function, but with an offset, which is obtained from the Technology Catalogue through given COP values of 0.85 and 1 for operation in full load for biomass and oil boilers respectively. (Danish Energy Agency, 2013 a)

Fuel prices are needed in order to calculate operation expenditures. Since the development of fuel prices is not known, forecasted fuel prices have been used for modelling. Forecasted prices for electricity, wood pellets, and gasoil have been obtained from (Danish Energy Agency, 2016 a) and are presented in the following.

6.2 Fuel Prices

Different kinds of fuels are used for the different heat sources. The used fuels are electricity, wood pellets, and gasoil. Prices for these fuels in DKK/MWh are presented in Figure 6.2. The forecasted electricity prices for district heating plants differ from the individual consumer electricity prices as district heating plants are able to purchase electricity at spot market prices. Wood pellet prices are differentiated as well, as district heating plants can buy wood pellets at a cheaper price too (Danish Energy Agency, 2016 c).

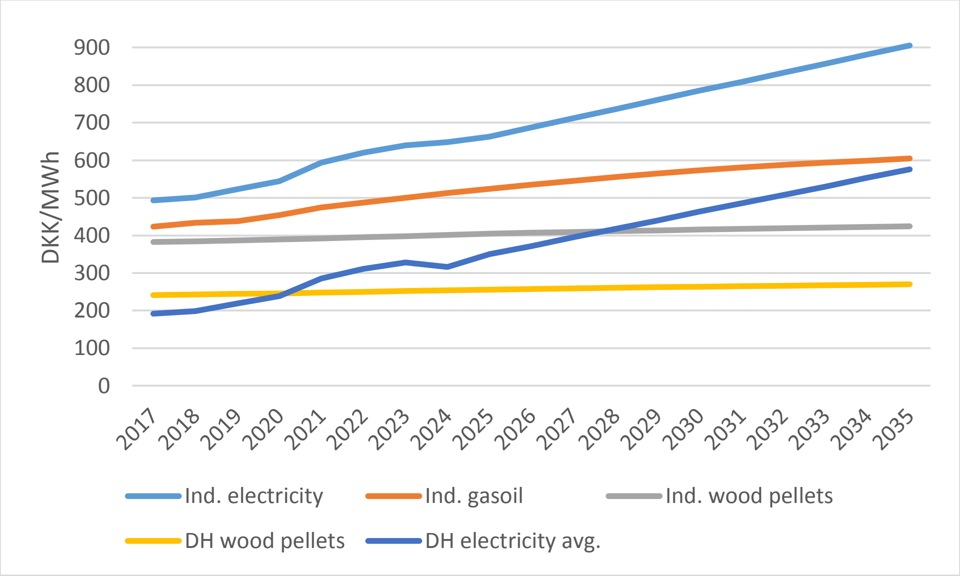


Figure 6.2: Fuel prices presented in DKK/MWh in 2017 prices. (Danish Energy Agency, 2016 a)

The tendency of electricity prices seen in Figure 6.2 is based on estimated average production costs. (Danish Energy Agency, 2016 a) Individual households are assumed to purchase electricity at a stable price. Therefore the yearly electricity price for households are the ones shown in Figure 6.2. District heating plants, on the other hand, buy electricity on the spot market to an hourly price. Therefore an hourly time series of the forecasted electricity prices has been created. This has been done by calculating the mean value of the hourly distribution for the DK west spot market prices in 2016 (Energinet.dk, 2017 a) and the difference of every value to the mean value. This gives the applied distribution, which has then been multiplied with the forecasted electricity prices. The values of all simulated years are created in one time series.

6.3 Assumptions for District Heating

This section describes the data used in the district heating scenarios. It follows the same structure as the previous section. First the technical and economic assumptions are presented in Table 6.3, which is followed by an explanation of further assumptions to explain why these values were chosen.

Two different district heating scenarios are modelled, one scenario with a ground source heat pump and one scenario with solar thermal collectors. In both scenarios these heat sources are combined with differently sized biomass boilers and thermal storages.

Table 6.3 below presents the technical and economic data used for each district heating scenario in energyPRO. Black horizontal lines symbolize separations between scenarios. The simulated district heating systems are designed to cover all heat demands; therefore shares of space heating and hot tap water are not included in this table.

The presented values differ from the ones presented in the individual scenarios as the size of the heat source influences both the performance as well as the economy. The presented investment prices include purchase and installation cost. The yearly O&M costs are calculated by summing up fixed as well as variable O&M costs. The values presented are all based on the technology catalogues from the Danish Energy Agency which are stated below the table. The sizes of the heat sources are estimated by using the heat demand, requiring that the heat demand has to be met in all hours of the year with an installed capacity as low as possible. As the capacities of most of the components are rather small compared to the numbers given for district heating systems it has been chosen to use data for existing apartment complexes form the Technology Catalogue. The heat sources simulated in the scenarios, namely ground source heat pump and biomass boiler as well as solar thermal collectors and biomass boiler are chosen in a preliminary assessment of the available renewable heat sources with potential for covering Valsted’s heat demand as stated in Section 5.2.7: Summary of Availability of Heat Sources. Therefore no other district heating scenarios are taken into consideration.

	Capacity	COP	Investment cost [Mio DKK]	Yearly O&M cost [1,000 DKK/year]	Technical lifetime [years]
Ground source HP	350 kW	3.50	4.07	46.90	20
Biomass boiler	300 kW	0.85	2.62	83.51	20
Heat storage	600 m^3	0.95	4.24	-	30
Solar thermal collector	400 m^2	N/A	4.01	7.23	30
Biomass boiler	575 kW	0.85	5.01	160.06	20
Heat storage	26 m^3	0.95	0.18	-	30
DH Network	8.77 TJ	0.80	8.53	96.93	40

Table 6.3: Technical and economic assumptions used for modelling district heating in 2017 prices. (Danish Energy Agency, 2016 b), (Danish Energy Agency, 2012), (Danish Energy Agency, 2014 b)

Values used for the ground source heat pump are obtained form (Danish Energy Agency, 2016 b). The COP is assumed to be 3.5. This assumption is influenced by the fact that the COP is depending on the type of heating used in the individual households. The arithmetic mean has been calculated as described in Section 6.1: Assumptions for Individual Heating. Further it is found that the COP varies significantly between new and existing buildings, therefore the previously described arithmetic mean values are used to calculate another arithmetic mean out of data sheets for existing and new buildings. This resulted in a COP of 3.5. Further the lifetime of the heat pump is set to 20 years. As this is the average lifetime of heat pumps when comparing the heat pumps in the technology catalogues with lifetimes specified between 15 and 25 years.

The data for biomass boilers is obtained from (Danish Energy Agency, 2013 a), specifically the data sheet for biomass boiler with automatic stoking and for existing apartment complexes. Automatic stocking is chosen as this is the standard for district heating plants. In the investment cost a specific investment per installed kW capacity is given and has been used for calculating the specific investment. Further a possible additional specific investment is given in a range of 0.22–1.10 Mio DKK. These numbers and the range of heat production capacity of 100-1000 kW have been used to generate a function, in which the simulated capacity is entered. This results in an additional specific investment of 0.31 Mio DKK which is added to the specific investment. The sum of both specific investments is stated in Table 6.3.

For thermal storages the lowest specific investment cost out of the given range has been chosen as the storage capacity in the simulation is smaller than the ones specified in the Technology

Catalogue. (Danish Energy Agency, 2014 b) This applies for both thermal storages specified in Table 6.3.

Solar thermal district heating data is obtained from the Technology Catalogue (Danish Energy Agency, 2014 b). For the financial data two ways of calculating the initial investment are presented. Both have been compared and the more expensive one is chosen in order to be more conservative with the calculations.

General costs for setting up a district heating network in existing building areas are presented in (Danish Energy Agency, 2013 a). The data sheet specifies a net loss of 15% but heat losses in the range of 15 to 20% are also suggested (Danish Energy Agency, 2013 a, p. 116). As the distances in Valsted are long a high net loss of 20% is assumed. Further the Technology Catalogue specifies a technical lifetime of the district heating network of 30 to 50 years. In this case it is chosen to use the arithmetic mean of 40 years. Investment costs are presented in DKK/TJ/year and as the heat demand is specified in MWh the conversion is based on the conversion factor that 1 TJ = 278 MWh (International Energy Agency, 2017). Further a price range is presented for the initial investment and it has been chosen to use the upper end of the range with 0.97 Mio DKK/TJ for the calculation of the total initial investment. This is done in order to achieve more conservative results when comparing the different scenarios.

CHAPTER 7: SCENARIOS

The economic and technical data used for modelling in energyPRO has been presented for the different types of heating systems in the previous Chapter 6: EnergyPRO Model. In the following potential heat savings are accounted for and the heating scenarios: Reference Scenario, Individual Heat Pump Scenario, Individual Combination Scenario, DH Heat Pump Scenario, and DH Solar Thermal and Biomass Scenario, are presented. Moreover the results of simulation are briefly described. A further elaboration of results is found in Chapter 8: Comparison of Results.

7.1 Heat Savings

As presented in Section 1.1: Danish Energy Targets, making energy savings is an important step in the transition towards a renewable energy sector. Energy savings are prioritised above changes on the supply side and therefore making energy savings is the first step in the transition. (Danish Energy Agency, n.d. a) Since this thesis focuses on making a heating plan, only heat savings are taken into consideration for Valsted.

The investigation has been made for existing single-family houses, and only considers savings made by reducing the demand with insulation measures. Other measures such as changes in user behaviour have not been taken into account. Figure 7.1 shows the cost curve of heat savings made in existing buildings in Denmark (Thellufsen, 2017), using Valsted's annual heat consumption of 2,139.7 MWh as case.

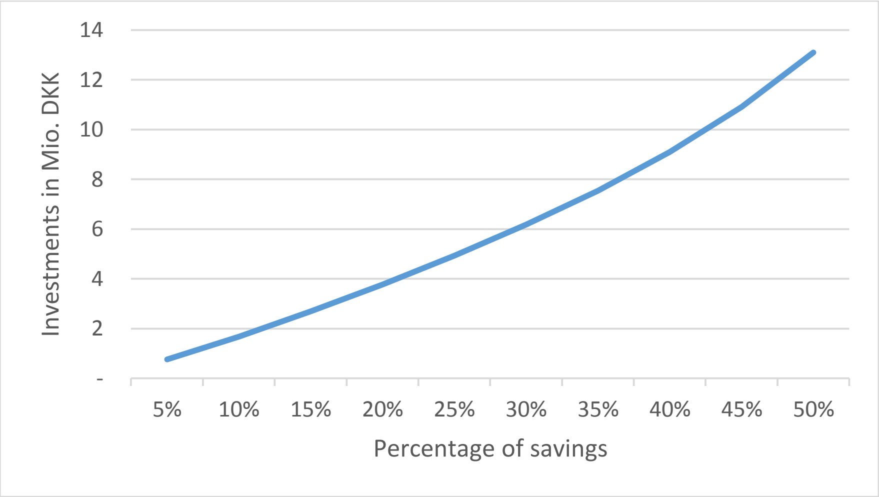


Figure 7.2: Cost curve for heat savings in existing buildings in Denmark. (Thellufsen, 2017)

The extent of recommended heat savings is dependent on the heat production price for the building. This is making it more beneficial to invest in saving measures in houses with high heat production prices. In connection with Figure 7.1 it is important to state that the percentage level of savings are for existing single-family houses being fully renovated. The heat saving function is based on the full housing stock in Denmark, from which the housing stock in Valsted might vary. It is, however, assumed to be the best available basis for the development of a heating scenario which includes heat savings.

The heat saving cost curve presented in Figure 7.1 is used to calculate the NPV of the different levels of heat savings in Valsted, using a discount rate of 6%. The Reference Scenario, with a heat production price (incl. investment) of 774 DKK/MWh in 2035, is used as basis for the heat saving calculations. It is assumed that all investments are made in the same year, and the economic benefits from the investments are experienced throughout the whole economic lifetime of 30 years. All prices are socioeconomic. The heat price is based on the socioeconomic forecasts on fuel prices, O&M costs and investment prices presented in Chapter 6: EnergyPRO Model and the distribution of heat sources presented in Section 5.1: Valsted’s Current Heating System on page 31.

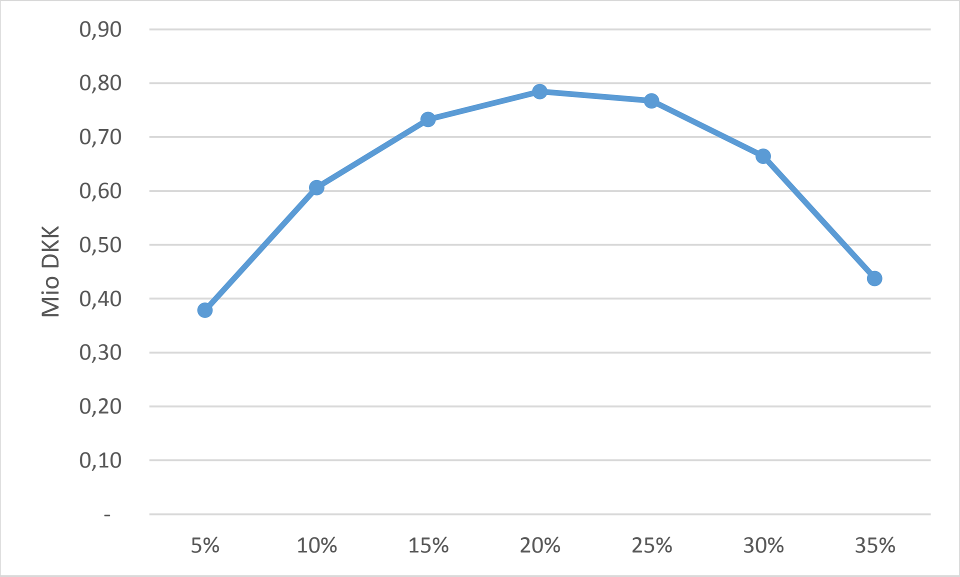


Figure 7.3: NPV at different levels of heat savings in Valsted

From Figure 7.2 it is evident that heat savings are most beneficial at a level of 20%, where the profit is approximately 0.78 Mio DKK after the lifetime of 30 years, giving an annual heat consumption of 1,711.8 MWh, which is used for the future scenarios. The heat demand is dependent on outdoor temperatures, and the distribution is illustrated in Figure 7.3.

Figure 7.3: Collective heat demand, including heat savings of 20% for Valsted

As seen in Figure 7.3 the demand for the scenarios is varying depending on the outdoor temperature. In the summer the heat demand only consists of the demand for hot water. As stated in Section 5.1: Valsted's Current Heating System, 1/3 of the heat demand is used for hot water, based on estimations from Statens Byggeforskningsinsititut. (Gram-Hanssen, 2003)

The scenarios, using the illustrated heat demand, are presented in the following, starting with the Reference Scenario where no heat savings are applied as this scenario should present the current situation.

7.2 Reference Scenario

In the reference scenario it is assumed that the current heat system will be used until 2035 without applying any changes to the heating system. Only the fuel prices change, as presented in Section 6.2: Fuel Prices on page 52. Table 7.1 shows the relevant figures of the reference scenario.

	Number of installed heat sources	Installed capacity [kW]	Heat demand [MWh]
Ground source HP	18	180	403.0
Air-to-water HP	5	50	115.0
Air-to-air HP and electrical boiler	10 10	60 40	258.0
Cattle excess air-to-water HP	1	10	18.1
Biomass boiler	10	100	209.0
Additional wood stove	21	84	145.3
Oil boiler	50	750	885.0
Electric heating	4	40	52.0
Air-to-water HP, solar thermal collector, and wood stove	1 heat pump 1 solar thermal 1 wood stove	3.8 6 m^2 4	18.1
Oil boiler and solar thermal collector	2 oil boiler 2 solar thermal	30 12 m^2	36.2
Total	135	1,359.8 18 m^2	2,139.7

Table 7.1: Relevant figures for the reference scenario (Aalborg Kommune, 2014)

7.2.1 Assumptions for the Reference Scenario

For modelling the Reference Scenario the technical assumptions presented in Section 6.1: Assumptions for Individual Heating have been used. There are, however, a few special cases that need elaboration.

The cattle excess heat air-to-water heat pump is modelled like the other air-to-water heat pumps with an output temperature of 55°C and the input temperature following the Danish outdoor temperature, but 5°C warmer than the actual outdoor temperature. A 5°C warmer temperature is chosen as the stall is not insulated, and contains a small stock. The warmer input temperature increases the heat production of the heat pump, which makes the cattle excess air-to-water heat pump production cost cheaper.

Solar thermal collectors have been modelled together with other heat sources as they cannot cover the full heat demand of a house. Therefore it is more realistic to model solar thermal collectors with another primary heat source. It is known that in one of the installations, solar thermal collectors are installed in combination with an air-to-water heat pump and a wood stove (Household 5, 2017), this is modelled in the Reference Scenario. The combination of heat sources is not known for the other two households using solar thermal collectors. It has been assumed that they are combined with oil boilers.

Air-to-air heat pumps will always run together with another heat source as the air-to-air heat pump only covers 60% of the space heating demand and does not cover any of the hot water demand. (Energinet.dk & Danish Energy Agency, 2016) Therefore air-to-air heat pumps and electric heating are modelled as a combination.

Wood stoves are modelled separately. This is done as the heat demand covered by wood stoves is an additional estimated heat demand for which no actual numbers exist. Furthermore, since energyPRO is modelling the cheapest heating solution, wood stoves will have a low priority amongst the heat sources, as it is an expensive heating solution due to the low efficiency, and will only be used to cover peak demands that other heat sources cannot cover. The wood stoves' small part of covering the heat demand modelled in energyPRO does not reflect reality, as many people in Valsted prefer the heat from wood stoves over heat delivered through radiators or floor heating. This is confirmed in the interview with Household 3, in which it was said, that they use their wood stoves as primary heat source as the heat provided by wood stoves, in their opinion, is a nicer form of heat. (Household 3, 2017) In addition to this another interviewed household also told that they use their wood stoves as the primary heat source. (Household 4, 2017)

7.2.2 Results of Reference Scenario

Based on the inputs presented in Chapter 6: EnergyPRO Model and Table 7.1, economic results of the Reference Scenario have been generated by energyPRO. Costs for both fuel and O&M are presented in Table 7.2 as well as total costs, which also include investment costs, using a discount rate of 6%.

	Fuel + O&M costs [1,000 DKK]	Fuel + O&M costs [DKK/MWh]	Total cost of heating system [Mio DKK]	Accumulated heat demand [MWh]	DKK/ MWh
Ground source HP	124	308	5.51	7,657.0	720
Air-to-water HP	46	400	1.54	2,185.0	705
Air-to-air HP and electrical boiler	176	682	3.60	4,902.0	734
Cattle excess air-to-water HP	7	387	0.27	343.9	785
Biomass boiler	143	684	3.35	3,971.0	844
Additional wood stove	125	860	2.87	2,760.7	1,040
Oil boiler	469	530	12.35	16,815.0	734
Electric heating	49	942	1.02	988.0	1,032
Air-to-water HP, solar thermal, and wood stove	8	442	0.34	343.9	989
Oil boiler and solar thermal	16	442	0.69	687.8	1,003
Total of scenario after 19 years			31.54		

Table 7.2: Economic results of the Reference Scenario in 2017 prices

Although the investments are already made, the total cost of the heating system is regarded as the true cost in order to not give preference to the Reference Scenario when comparing results. Costs excluding investments are, however, also presented in Table 7.2 in order to show the heat generation costs for each heat source.

From Table 7.2 it is seen that the cheapest heat source is the air-to-water heat pump, with a price of 705 DKK/MWh, including investment. The most expensive heat source has shown to be wood stoves, closely followed by electrical heating.

7.3 Individual Heat Pump Scenario

The results from the Reference Scenario presented above in Table 7.2 are used for creating the second scenario for individual heating. This scenario presents the cheapest system for individual heating in Valsted. From the results of the Reference Scenario it is evident that the cheapest heat source are air-to-water heat pumps, with a heat production price of 705 DKK/MWh, including investment. Therefore the second scenario will investigate the economy of air-to-water heat pumps covering the whole demand, with the exception of electricity based heating system, where a conversion to water based heating systems would increase the costs by approximately 1 million DKK compared to heating the houses with air-to-air heat pumps and electrical back up. The distribution of heat sources is presented in Table 7.3 below.

Heat savings of 20%, as accounted for in Section 7.1: Heat Savings, are included, lowering the total annual demand to 1,711.8 MWh. As the cheapest heating option is aimed for in this scenario, the heat demand should be just covered. By installing a heat source capacity of 8.0 kW in each house, this requirement is met. The average annual heat demand for a household (incl. heat savings) is 16.6 MWh. This is distributed evenly for all houses.

	Number of installed heat sources	Installed capacity [kW]	Heat demand [MWh]
Air-to-air HP + electrical back-up	14 14	56 56	232.6
Air-to-water HP	89	712	1,479.2
Total	103	824	1,711.8

Table 7.3: Relevant figures for the Individual Air-to-Water Heat Pump Scenario

7.3.1 Results of the Individual Heat Pump Scenario

Based on the inputs presented in the section above and in Section 6.1: Assumptions for Individual Heating, energyPRO has generated economic results for the Individual Heat Pump Scenario, which are presented in Table 7.4 below.

	Fuel + O&M costs [1,000 DKK]	Fuel + O&M costs [DKK/MWh]	Total cost of heating system [Mio DKK]	Accumulated heat demand [MWh]	DKK/ MWh
Air-to-air HP + electrical back-up	159	684	3.50	4,419.4	792
Air-to-water HP	632	427	21.59	28,104.8	768
Total of scenario after 19 years			25,09		

Table 7.4: Economic results of the Individual Air-to-Water Heat Pump Scenario in 2017 prices

Table 7.4 shows that the costs per MWh increases compared to the Reference Scenario, but the total cost of the scenario decreases. The small change of 2 DKK/MWh in the fuel and O&M costs for air-to-air heat pumps can be caused by rounding the gained numbers. This also affects the air-to-water heat pumps. The differences for air-to-water heat pumps are in a range of 36 DKK/MWh. An explanation for this can be found in the changed conditions by lowering the heat demand, and adapting the installed heat pump capacity. The installed capacities are sized differently between the Reference Scenario where the capacities are based on the Technology Catalogue's recommendations, and the other scenarios where the capacities just cover the heat demand. This affects the heat production cost. The effects are however considered minor compared to the scale of the project.

7.4 Individual Combination Scenario

The third individual heating scenario targets a more realistic heating solution than the Individual Heat Pump Scenario, as it is not realistic for all houses to change their heat source to an air-to-water heat pump or an air-to-air heat pump and disregard their current heat source. The 20% heat savings are also included in this scenario.

It is assumed that all houses heated by a ground source heat pump keep this heat source, as the investment is already made, it is a renewable heat source, and cost per MWh is only 15 DKK more than the cheapest heat source, making ground source heat pumps the second cheapest option.

All oil and biomass boilers are changed to air-to-water heat pumps. Biomass boilers are also changed despite the fact, that biomass is a CO_2 neutral fuel, but as presented in Section 2.2: Limitations on page 12 biomass is in this thesis disregarded as a fuel used for individual heating.

Even though the cattle excess air-to-water heat pump is a renewable heat source, it is assumed to be replaced by an air-to-water heat pump. This is done as the farmer is looking to retire, but has not retired yet, due to their heating system being reliant on the cattle (Household 1, 2017).

All systems heated by air-to-air heat pumps and electric heating are kept, and houses using electrical heating only are converted into using air-to-air heat pumps. This is done, as Table 7.2 shows that electric heating is the second most expensive form of heating. Furthermore electric heating is not considered an efficient use of available resources due to its low efficiency compared to heat pumps.

Wood stoves are kept in the heating system as it is the authors' impression from the interviews that wood stove owners are not willing to replace their wood stoves, as also presented in Section 7.2: Reference Scenario. For the economy of the heating system, the optimal solution is to disregard wood stoves as they have an expensive MWh price of 1,040 DKK. But since this scenario targets a realistic heating solution wood stoves are kept, disregarding the costs. Furthermore solar thermal panels are also kept since the only cost connected to the heat produced by the solar thermal collectors is the investment and O&M costs. Since the investment is already made the solar thermal panels are kept.

Table 7.5 shows the relevant figures of the Individual Combination Scenario.

	Number of installed heat sources	Installed capacity [kW]	Heat demand [MWh]
Ground source HP	18	180	316.6
Air-to-water HP	66	528	1,003.0
Air-to-air HP + electrical back-up	14	56	232.6
Additional wood stove	21	84	116.0
Air-to-water heat pump, solar thermal, and wood stove	1 heat pump 1 solar thermal 1 wood stove	3.8 6 m^2 4	14.6
Air-to-water HP and solar thermal	2 heat pumps 2 solar thermal	16 12 m^2	29.0
Total	122	923.8 18 m^2	1,711.8

Table 7.5: Relevant figures of the Individual Combination Scenario

7.4.1 Results of the Individual Combination Scenario

Modelling the data presented in Table 7.5 above by using the technical and economic specifications presented in Section 6.1: Assumptions for Individual Heating, energyPRO has generated economic results, which are presented in Table 7.6.

	Fuel + O&M costs [1,000 DKK]	Fuel + O&M costs [DKK/MWh]	Total cost of heating system [Mio DKK]	Accumulated heat demand [MWh]	DKK/ MWh
Ground source HP	104	328	5.21	6,015.4	866
Air-to-water HP	437	436	15.55	19,057.0	816
Air-to-air HP + electrical back-up	159	684	3.50	4,419.4	792
Additional wood stove	100	862	2.40	2,204.0	1,089
Air-to-water HP, solar thermal, and wood stove	6	411	0.31	277.4	1,363
Air-to-water HP and solar thermal	11	379	0.68	551.0	1,234
Total of scenario after 19 years			27.65		

Table 7.6: Economic results of the Individual Combination Scenario in 2017 prices

In Table 7.6 it is seen that air-to-air heat pumps and electrical back-up boilers are now the cheapest heat source. This is caused by the low initial investment price, and the better COP of the air-to-air heat pump compared to the other heat pumps. When having to cover a lower demand the electrical back-up boiler works less, making the air-to-air heat pump cover more of the heat demand, resulting in a lower price.

Scenarios for individual heating have been presented in this chapter, further scenarios for a small district heating system are made, as it needs to be investigates whether or not a collective system could be cheaper for Valsted. In the interviews with citizens of Valsted there were divided opinions about having a district heating system, but most citizens were expressing the opinion that a small district heating system would not be welcomed by the majority of the citizens in Valsted. Scenarios for small districts heating plants are, however, made in order to investigate the cheapest heating system. Furthermore as a part of the choice awareness theory it is the authors' obligation to present options that the citizens are not aware of.

7.5 DH Heat Pump Scenario

In the DH Heat Pump Scenario the total heat demand of Valsted is supplied by a central district heating system. As described in Section 7.1: Heat Savings implementing 20% heat savings is recommended. Therefore 20% heat savings are applied on Valsted's total heat demand. Further as specified in Section 6.3: Assumptions for District Heating, system losses are taken into account with 20% losses between generation and the consumers. These losses are added to the calculations after the heat savings were applied. This results in an annual heat demand of 2,055 MWh.

The focus of this scenario is to have the heat pump cover the majority of the heat demand and the biomass boiler is used as a back-up. This is difficult to identify in Table 7.7 when comparing the installed capacities but becomes evident when comparing the column covered heat demand in MWh.

The covered heat demand specified in Table 7.7 and 7.9 varies between the scenarios because of differing losses of the thermal storages, which need to be covered by the systems.

Table 7.7 shows the relevant figures of the DH Heat Pump Scenario.

	Installed capacity [kW]	Covered heat demand [MWh]
Ground source HP	325	1,838
Biomass boiler	234	274
Thermal storage	600m^3	-
Total	559 600m^3	2,112

Table 7.7: Relevant figures of the DH Heat Pump Scenario

7.5.1 Results of DH Heat Pump Scenario

This section presents the economic results of the DH Heat Pump Scenario which are obtained through simulation in energyPRO. The accumulated costs of generating Valsted's heat demand in this scenario are stated in Table 7.8 below.

	Fuel + O&M costs [1,000 DKK]	Fuel + O&M costs [DKK/MWh]	Total cost of heating system [Mio DKK]	DKK/MWh
Total of scenario after 19 years	920	538	34.05	1,047

Table 7.8: Economic results of the DH Heat Pump Scenario in 2017 prices

As presented in Table 7.8 the heat cost in DKK per MWh is 1,047 DKK/MWh for supplying the heat to Valsted's households. These numbers are calculated by dividing the total cost of the presented heating system through the MWh that are actually sold to customers to supply their heat demand. The number presented is higher than for the individual scenarios.

7.6 DH Solar Thermal and Biomass Scenario

In the DH Solar Thermal and Biomass Scenario a combination of solar thermal collectors, a biomass boiler as well as a thermal storage is simulated in energyPRO. The solar thermal collectors were sized in a way that they can contribute to the heat supply in the summer months. Excess heat produced by the solar thermal collectors is stored in a thermal storage. Due to the natural distribution of sunshine hours in Denmark, solar thermal collectors are not feasible as the only heat source for a district heating system. Therefore they are accompanied by a biomass boiler which is supplying the majority of the heat demand in this scenario.

The heat demand is assumed to be the same as in the DH Heat Pump Scenario with applying 20% heat savings as well as 20% losses of the district heating system, as described in Section 7.5: DH Heat Pump Scenario.

Table 7.9 shows the relevant figures of the DH Solar Thermal and Biomass Scenario.

	Installed capacity [kW]	**Covered heat demand [MWh]**
Solar thermal collectors	400 m^2	287
Biomass boiler	553	1,770
Thermal storage	26 m^3	
Total	- 26 m^3	2,057

Table 7.9: Relevant figures of the DH Solar Thermal and Biomass Scenario

Table 7.9 shows that the biomass boiler is supplying the majority of the heat needed in this scenario. The thermal storage is of a rather small size as it is only used to store excess heat produced by the solar thermal collectors during the summer months.

7.6.1 Results of the DH Solar Thermal and Biomass Scenario

After the simulation of the DH Solar Thermal and Biomass Scenario in energyPRO the following economic results are obtained and presented in Table 7.10.

	Fuel + O&M costs [1,000 DKK]	**Fuel + O&M costs [DKK/MWh]**	**Total cost of heating system [Mio DKK]**	**DKK/MWh**
Total of scenario after 19 years	816	477	34.08	1,048

Table 7.10: Economic results of the DH Solar Thermal and Biomass Scenario in 2017 prices

Table 7.10 shows that the price per MWh of heat produced by a combination of solar thermal collector and biomass boiler is 1,048 DKK. This is almost the same price which was obtained in the DH Heat Pump Scenario and is still higher than the heat prices in the individual scenarios.

The results for all scenarios are further compared and analysed in sensitivity analyses in the following chapter, where one scenario is recommended.

CHAPTER 8: COMPARISON OF RESULTS

Based on the inputs presented in Chapter 6: EnergyPRO Model and Chapter 7: Scenarios some economic outputs are generated by energyPRO and presented in the previous chapter. In order to be able to find the most socioeconomic beneficial scenario the economic data is compared and analysed for sensitivities in this chapter.

8.1 Simulation Results

The socioeconomic costs of the scenarios are presented in Figure 8.1 below. The costs include all costs for the heating systems in the full period of 2017-2035.

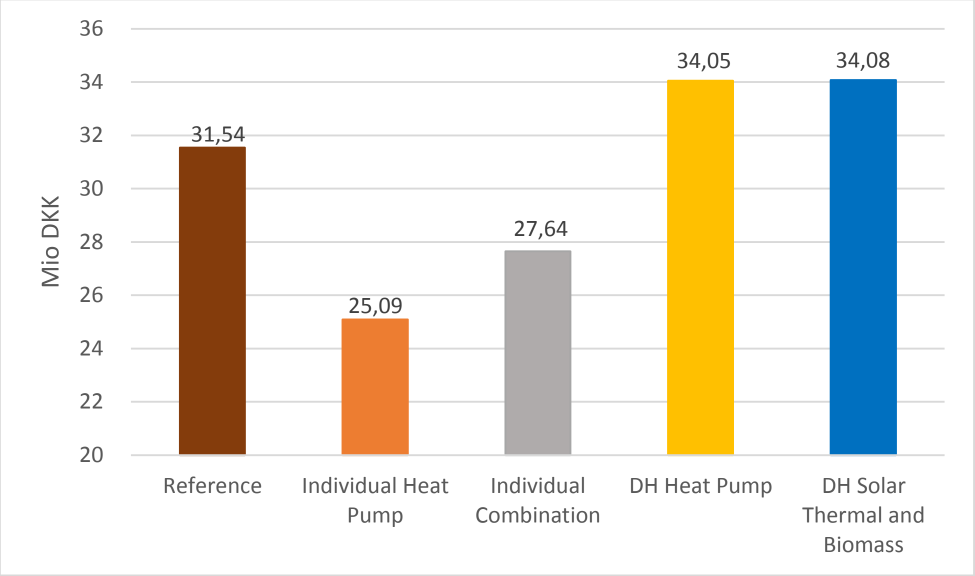


Figure 8.4: Costs of the scenarios in 2017 prices

Figure 8.1 illustrates that the cheapest scenario is the Individual Heat Pump Scenario (orange) by being approximately 2.6 million DKK cheaper than the Individual Combination Scenario (grey). The most expensive scenarios are the two district heating scenarios, with the DH Solar Thermal and Biomass Scenario (blue) being the most expensive with a price of 34.08 Mio DKK, the DH Heat Pump Scenario (yellow) follows with a price of 34.05 Mio DKK. In the middle is the Reference Scenario (red), being approximately 3.9 Mio DKK more expensive than the Individual Combination Scenario (grey).

In order to get an overview of the distribution of the overall costs presented in Figure 8.1, Figure 8.2 has been made dividing the total costs into O&M costs, fuel costs, and investment costs.

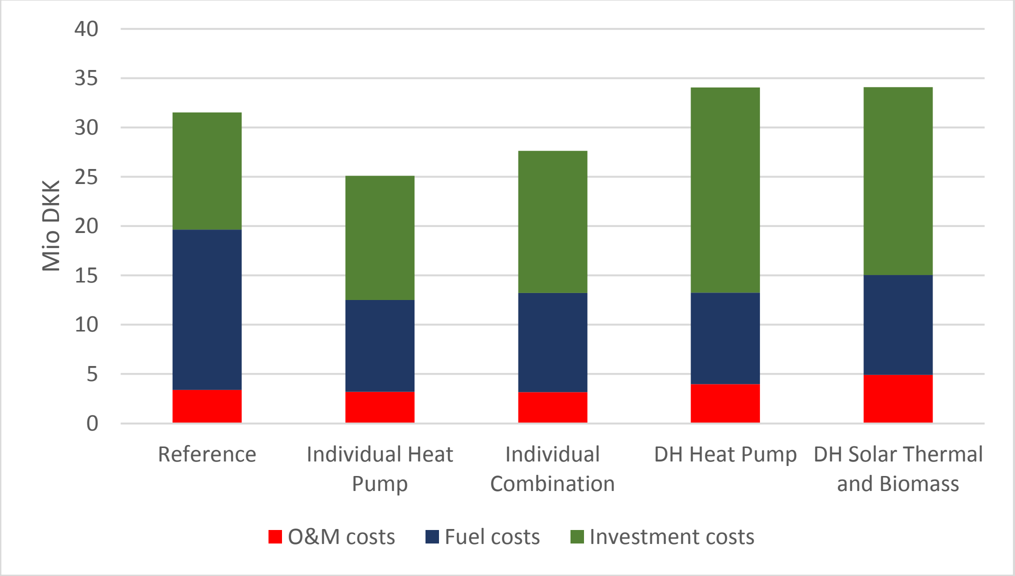


Figure 8.5: Distribution of costs in scenarios in 2017 prices

In Figure 8.2 it is seen that the two district heating scenarios have the highest O&M costs, and the Individual Combination Scenario and the Individual Heat Pump Scenario have the lowest O&M costs. The Reference Scenario has the highest fuel costs, making this scenario more sensitive to changes in fuel prices than the other scenarios. Whereas the two district heating scenarios are more sensitive towards changes in investment costs and discount rate, as these two scenarios have the highest investment costs.

Before recommending a scenario, sensitivities have to be investigated as the feasibility of a scenario can vary significantly due to changes in different parameters. A sensitivity analysis is therefore conducted in the following section.

8.2 Sensitivity Analyses

Sensitivity analyses of each scenario are carried out and presented in order to investigate how economic insecurities can affect the scenarios, in order to determine the stability of the results. This is done as the economic data is based on prognoses and assumptions which could differ from reality (Danish Energy Agency, 2007). Different factors are investigated in this sensitivity analysis. These are the discount rate (ranging from 0 to 8%), fuel prices (± 20%), investment prices (± 20%), and price with and without heat savings.

8.2.1 Sensitivity to Discount Rate

The discount rate is a factor that has a great impact on the economy of an energy project. As stated in Chapter 6: EnergyPRO Model on page 47 a socioeconomic discount rate of 6% has been used in this thesis. However, different discount rates can apply in reality for different projects, and the Danish Ministry of Finance for instance recommends a discount rate of 4% for public investments, such as district heating plants (Danish Ministry of Finance, 2013). In order to demonstrate the influence of the discount rate on the simulation results a sensitivity analysis of the discount rate is shown in Figure 8.3.

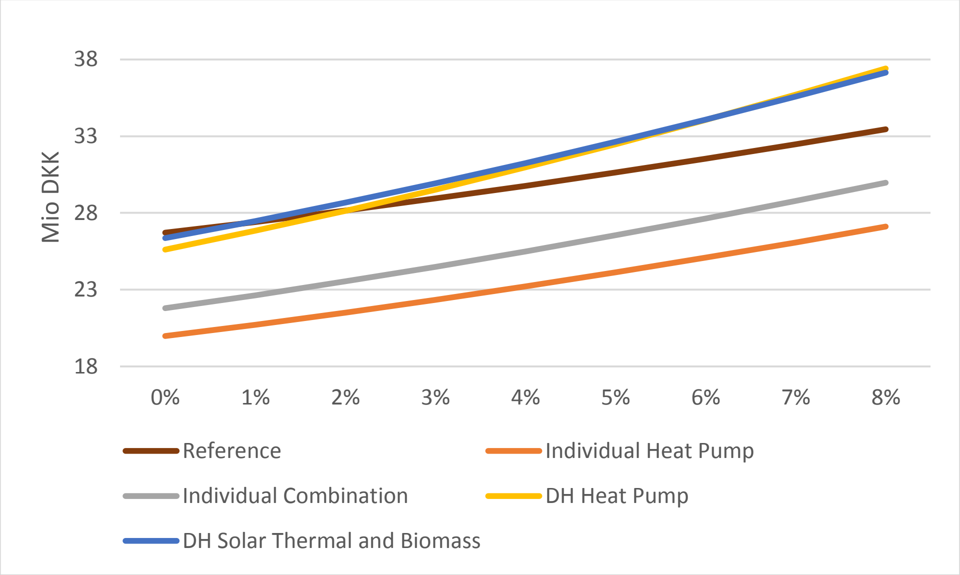


Figure 8.6: Sensitivity towards discount rate in 2017 prices

Derived from Figure 8.3 the discount rate has a big influence on the projects, causing DH Heat Pump Scenario (blue) to become cheaper than the DH Solar Thermal and Biomass Scenario (yellow) at a discount rate of 7 and 8%. This is caused by the DH Heat Pump Scenario having a higher investment price than the DH Solar Thermal and Biomass Scenario, and therefore it is affected more by a change in discount rate. At a discount rate of 0% the Reference Scenario (red) is the most expensive scenario. Amongst the two other individual heating scenarios the order of feasibility of the scenarios are kept. The Individual Heat Pump Scenario (orange) is the cheapest scenario at any discount rate, followed by the Individual Combination Scenario (grey).

8.2.2 Sensitivity to Electricity Prices

The economy of all scenarios is dependent on fuel prices. Since the used fuel prices are prognoses, they are subject for insecurities as it is not known how the fuel prices will develop in the future. One of these fuels is electricity, as electricity is used as fuel for heat pumps and electric heating. All scenarios except the DH Solar Thermal and Biomass Scenario (blue) are affected by changes in electricity prices. Therefore the scenarios' sensitivity towards electricity prices have been investigated presented in Figure 8.4, using a price variation of ±20% from the prognoses.

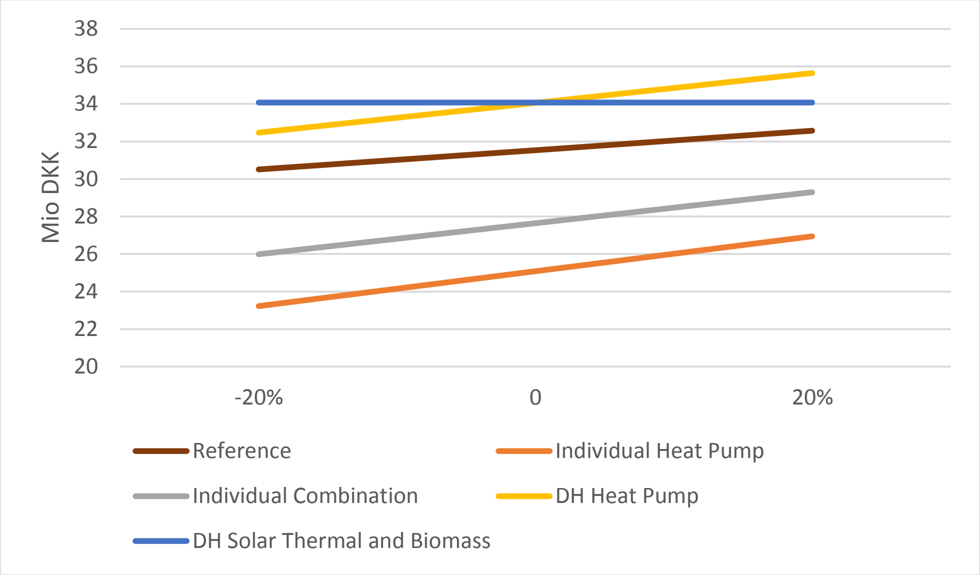


Figure 8.7: Sensitivity towards electricity prices in 2017 prices

Figure 8.4 shows that the scenarios affected most by a change in the electricity prices are the Individual Heat Pump Scenario (orange), the Individual Combination Scenario (grey) and the DH Heat Pump Scenario (yellow), as these three scenarios are mainly fuelled by electricity. Also the Reference Scenario (red) is affected by in- or decreasing electricity prices, but since the scenario is less reliant on electricity a smaller affect is experienced. The DH Solar Thermal and Biomass Scenario (blue) is not affected by electricity prices, as electricity is not used as a fuel in this scenario. This results in the DH Solar Thermal and Biomass Scenario becoming cheaper than the DH Heat Pump Scenario when increasing electricity prices. The individual heating scenarios keep their order of feasibility.

8.2.3 Sensitivity to Wood Pellet Prices

Wood pellets are used as fuel in all scenarios, except the Individual Heat Pump Scenario (orange). Wood pellet prices have, as all fuel prices, been based on prognoses, and the insecurities of that is investigated in Figure 8.5 using a price variation of ±20%.

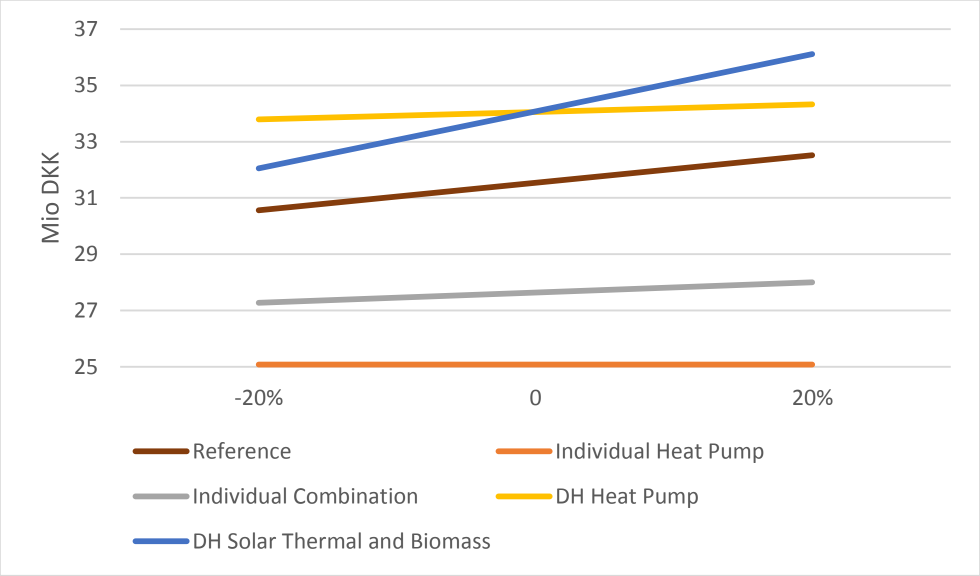


Figure 8.8: Sensitivity towards wood pellets prices in 2017 prices

Figure 8.5 illustrates that the scenario most affected by the wood pellets prices is the DH Solar Thermal and Biomass Scenario (blue), which has the highest consumption of biomass. By increasing the wood pellets price with 20% the DH Solar Thermal and Biomass Scenario is approximately 1.8 Mio DKK more expensive than the DH Heat Pump Scenario (yellow).

The Individual Combination Scenario (grey) is affected slightly, due to the additional wood stoves, if they were replaced with air-to-water heat pumps, the scenario would not be affected by an in- or decrease of wood pellet prices, like the Individual Air-to-Water Heat Pump Scenario (orange). By decreasing the wood pellet price with 20% the Reference Scenario (red) is approximately 3.3 Mio DKK more expensive than the Individual Combination Scenario.

8.2.4 Sensitivity to Oil Prices

Oil is only used as a fuel in the Reference Scenario. Oil prices have, as the other fuel prices, been based on prognoses, and the insecurity of that is investigated in Figure 8.6 below varying the prices with ±20%.

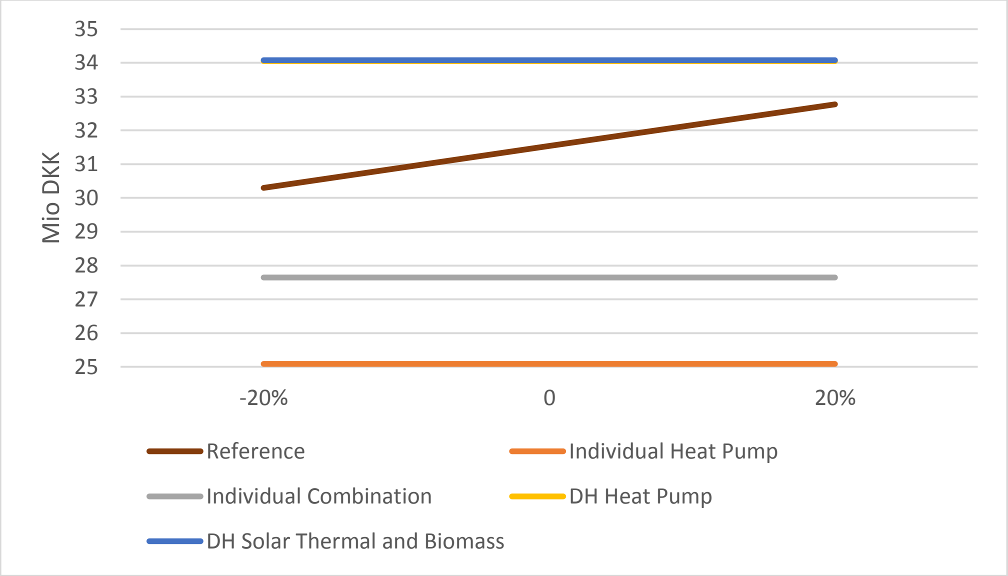


Figure 8.9: Sensitivity towards oil prices in 2017 prices

As seen in Figure 8.6 the only scenario affected by the oil price is the Reference Scenario (red), as this is the only scenario using oil as a fuel. Neither in- nor decreasing the oil prices with 20% have any impact on the order of feasibility of the scenarios. The DH Heat Pump Scenario (yellow) is almost not visible in Figure 8.6, as it is placed under the DH Solar Thermal and Biomass Scenario (blue), due to the prices being very similar.

8.2.5 Sensitivity to Investment Prices

Investment prices are also an important aspect of the economy of the scenarios as some scenarios, such as the two district heating scenarios, have a high investment price affecting the feasibility of these scenarios throughout the investigated period of 19 years. A variation of investment prices could have a high impact on the economic feasibility of the scenarios, and since real investment prices could vary from the prices obtained from the technology catalogues, the scenarios' sensitivity towards investment prices are investigated in Figure 8.7, using a variation of ±20%.

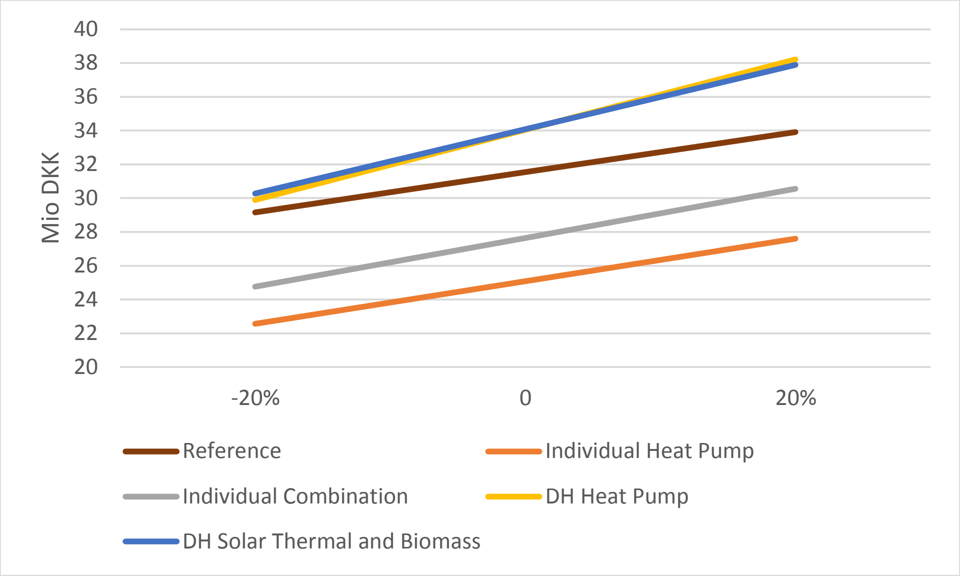


Figure 8.10: Sensitivity towards investment prices in 2017 prices

Figure 8.7 shows that for the individual heating scenarios the order of feasibility is not affected by varying the investment prices with ±20%. The district heating scenarios are, however, affected by varying the investment prices. By increasing the investment price with 20%, the DH Solar Thermal Solar and Biomass Scenario (blue) becomes cheaper than the DH Heat Pump Scenario (yellow) with approximately 0.3 Mio DKK, and by decreasing the investment price, the DH Heat Pump Scenario gets approximately 0.4 Mio DKK cheaper than the DH Solar Thermal and Biomass Scenario.

For the individual heating scenarios increasing investment prices 20% decreases the gap between the Reference Scenario (red) and the Individual Combination Scenario (grey), making the Individual Combination Scenario approximately 3.4 Mio DKK cheaper than the Reference Scenario.

8.2.6 Sensitivity to Heat Savings

All scenarios, except the Reference Scenario, include 20% heat savings, which was found most beneficial for Valsted in Section 7.1: Heat Savings on page 57. Heat savings affect the prices of the scenarios and therefore the sensitivity towards heat savings is investigated in Figure 8.8.

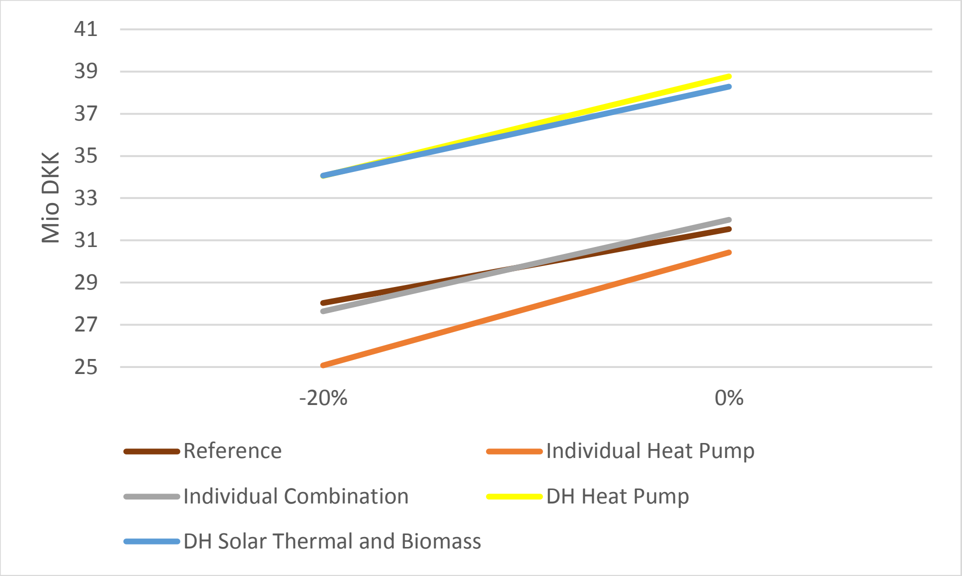


Figure 8.11: Sensitivity towards heat savings in 2017 prices

As shown in Figure 8.8 the scenario most affected by heat savings is the Individual Heat Pump Scenario (orange), where an increase of price if no heat savings are made of approximately 5.3 million DKK is seen. Furthermore, it is also seen that increasing the heat demand could potentially affect the individual heating scenarios, and make the Reference Scenario (red) cheaper than the Individual Combination Scenario (grey) if no heat savings were made in the Individual Combination Scenario.

Figure 8.8 also illustrates that not making the heat savings of 20% affects the order of feasibility of the two district heating scenarios making the DH Heat Pump Scenario (yellow) more expensive than the DH Solar Thermal and Biomass Scenario (blue).

8.3 Recommendation of Scenario

It is seen in Figure 8.1 that the individual heating scenarios are the most socioeconomic feasible heating systems for Valsted, with the Individual Heat Pump Scenario being the cheapest scenario, followed by the Individual Combination Scenario, making the Reference Scenario the third most feasible scenario, only outdone by the district heating scenarios, out of which the DH Heat Pump Scenario is the more feasible, leaving the DH Solar Thermal and Biomass Scenario to be the most expensive heating solution for Valsted.

The sensitivity analyses have shown that the individual heating scenarios are stable systems where the order of feasibility have only been affected by lowering the discount rate and implementing heat savings. The district heating scenarios are on the other hand unstable systems where the order of feasibility is affected by changes in the investigated ranges. Based on the socioeconomic investigations, where the district heating scenarios have proven to be both the most expensive scenarios and unstable investments, it is not recommended to introduce district heating in Valsted. This is also in line with the public opinion in Valsted experienced through the interviews. However, a private economic analysis is made in Chapter 9: Private Economic Analysis, testing economic results when implementing current taxes and subsidies.

Based on the socioeconomic results the most feasible heating system for Valsted is the Individual Heat Pump Scenario, a system solely based on heat pumps. Since it is not realistic that all houses will change their heating system to be based on air-to-water/air-to-air heat pumps, the Individual Combination Scenario is, based on the socioeconomic investigation, recommended for Valsted. It is by the authors of this thesis assessment more likely that the residences of Valsted will keep their additional wood stoves, their ground source heat pumps, and the solar thermal collectors than replacing them all with air-to-water heat pumps. It is also recommendable to keep the ground source heat pumps and solar thermal panels. However, the authors of this thesis also recommend the citizens of Valsted to replace the additional wood stoves with air-to-water heat pumps, doing so makes the Individual Combination Scenario 1.6 Mio DKK cheaper, giving a total price of 26 Mio DKK. When applying taxes and subsidies the result might, however, change. Therefore a private economic analysis is presented in Chapter 9: Private Economic Analysis.

CHAPTER 9: PRIVATE ECONOMIC ANALYSIS

As mentioned in the previous chapter, applying taxes and subsidies might change the feasibility of the different scenarios. Therefore a private economic analysis, applying fuel taxes and subsidies is presented in this chapter, is conducted in order to investigate if the order of feasibility of the scenarios is affected.

9.1 Investment Taxes

For all investments made by private households the value-added tax (VAT), which has a level of 25% in Denmark, must be added. (Skatteministeriet, 2016) For supply companies applies that the investments of heat sources are VAT free as these are technologies used in the companies' production (Retsinformation.dk, 2016). However, since the heat bought by consumers is taxed with VAT, this does not affect the private economy. As the VAT influences all scenarios the same way it does not change the order of the scenario's feasibility, and therefore it is not included in this private economic analysis.

Investments in district heating plants were subsidised by the government in 1979. These subsidies were reduced and then transformed into surcharges on the consumer energy prices in 2003. It is therefore assumed that there are currently no investment subsidies for district heating applicable. (Danish Energy Agency, 2015 b)

9.2 Fuel Taxes

Most fuels are taxed in Denmark. These taxes need to be applied in order to calculate the private economic analysis of the scenarios. In the following section the taxes for the individual fuels will be presented.

9.2.1 Electricity Taxes

Different taxes and rules can apply for electricity used for heating in individual households and in a district heating plant. The different rules are accounted for in the following sections. Further, the taxes and tariffs applicant for individual households and for the modelled types of district heating plants are presented in Table 9.1.

Private households having an electricity based heating system, including the various kinds of heat pumps and electrical heating, get a deduction in electricity taxes after a consumption of 4,000 kWh. (SKAT, 2017) The yearly average electricity consumption of a single family house was 4,090 kWh in 2010. This is excluding electricity consumption for electric heating. (Danish Energy Agency, 2013 b) Therefore it is assumed that all electricity used for heating in Valsted has deducted taxes. Taxes and tariffs applicant for electricity used for heating in private household are presented in Table 9.1.

District heating plants can be taxed differently than private households. There is an act (Elpatronloven) reducing electricity taxes for cogenerating district heating plants or heat-only plants delivering heat to a district heating network where most heat is produced by cogenerating units. But since the district heating scenarios do not consist of cogenerating plants and there are no cogenerating units in the district heating system, this act does not apply for the case of Valsted. (Retsinformation.dk, 2005) Based on the recommendation of the supervisor of this thesis electricity taxes that are applicant for a district heating plant are presented in Table 9.1 below. (Andersen, 2017)

Tariffs and taxes	Individual households [DKK/MWh]	District heating plant [DKK/MWh]
Electricity fee	412	412
PSO tariff	144	144
Transmission net tariff	59	59
System tariff	24	24
Net tariff to local grid	125	125
Total	764	764

Table 9.1: Fees and tariffs of electricity used in respectively private households and for a district heating plant in 2017 prices. (SKAT, 2017), (Energinet.dk, 2017 b), (Andersen, 2017)

9.2.2 Wood Pellets Taxes

Wood pellets are not taxed in Denmark, neither for private consumers nor public consumers (Danish Energy Agency, n.d. b) (Danish Energy Agency, 2017 a). Therefore no changes from the socioeconomic scenarios are applicant for wood pellets.

9.2.3 Oil Taxes

Oil as a fuel is only used in the reference scenario, where it is used for individual heating. Therefore only the oil taxes applicable for private consumers are presented in Table 9.2 below.

Taxes on gasoil	DKK/1000 l
NO_x tax	9
CO_2 tax	457
Energy tax	1,982
Energy conservation contribution	85
Total	2,536

Table 9.2: Taxes on gasoil in 2017 prices (OK, 2017)

9.3 Subsidies for Private Households

It is possible for private households to get subsidies for energy efficiency measures such as converting the heating system to be based on renewable heat sources e.g. replacing an oil boiler by an air-to-water heat pump. Further it is possible to get subsidies for insulation measures. (Energihjem.dk, 2016) Subsidies for insulation measures are, however, not included in this thesis as the calculation on the beneficial degree of heat savings already includes these costs.

The amount of subsidies granted is dependent on the amount of saved energy in kWh for the first year, where the average amount per saved kWh is 0.30 DKK. This amount is also used in the case of Valsted. Some standards have been made for the amount of saved energy when applying different energy conservation measures. (Energihjem.dk, 2016) The ones relevant for the individual scenarios in Valsted are described in Table 9.3.

Energy conservation subsidies per household	Saved energy [kWh]	Subsidy granted [1,000 DKK]
Oil boiler → Air-to-water HP	18,032	5.41
Electrical heating → Air-to-air HP	6,504	1.95
Old air-to-water HP → Air-to-water HP	2,031	0.61
Solar thermal collectors w. air-to-water HP	1,002	0.30

Table 9.3: Subsidies given for changing heat source in 2017 prices (Danish Energy Agency, 2017 b)

In connection with the energy conservation subsidy it needs to be stated that there also is a subsidy for changing biomass boilers installed before 1990 with an amount of 6,100 DKK. This subsidy is not included in this private economic analysis, as it is assumed that all biomass boilers in Valsted are installed after 1990.

Apart from the energy conservation subsidy there is also a craftsmen deduction that can be used when installing a renewable heat source. The deduction covers costs for payrolls, and occurs as a deduction in the personal tax report. A deduction of 12,000 DKK is granted for every person, above 18 years, who is living in the household. For the individual scenarios it is assumed that there are two adults living in each house and the payroll cost for installing most renewable heat sources is 24,000 DKK or more. This results in a tax deduction and hence reduces the investment price by 7,680 DKK. This assumption will be used for all renewable heat sources, except for air-to-air heat pumps. These have a simple installation procedure. A payment of 8,000 DKK to payrolls is assumed, and the craftsmen deduction therefore amounts to 1,280 DKK. (Haandvaerkerfradrag.dk, 2016)

9.4 Private Economic Analysis of Scenarios

This section analyses the effects of applying a private economic analysis on the different Scenarios. As opposed to the socioeconomic analysis the private economic analysis takes taxes and subsidies into account. In accordance to the process of approving an energy project, which is presented in Section 5.3: The Process of Approving an Energy Project, the socio economy is a crucial criteria for getting an energy project approved but as most individual heating scenarios do not need approval and have to consider private economic prices both economic analyses are of relevance. Further this private economic analysis is carried out according to the theory of strategic energy planning described in Section 3.2: Strategic Energy Planning, in order to be able to compare multiple perspectives of the different scenarios and hence give strategic recommendations.

The private economic analysis is carried out for each scenario and the results are described in individual sub-sections.

9.4.1 Private Economic Analysis of Reference Scenario

In the private economic analysis of the Reference Scenario the energy conservation subsidy is not included, as the old heat sources for households with renewable heat sources are not known.

Therefore the Energy conservation subsidy cannot be used, as this subsidy is dependent on the old heat source. The craftsmen deduction is however applied for the renewable heat sources, which include the heat pumps, biomass boilers, and solar thermal collectors. The results are presented in Table 9.4.

	Total cost of heating system [Mio DKK]
Ground source HP	6.86
Air-to-water HP	2.08
Air-to-air HP and electrical boiler	6.13
Cattle excess air-to-water HP	0.35
Biomass boilers	3.34
Additional wood stove	2.87
Oil boiler	14.64
Electric heating	1.78
Air-to-water HP, solar thermal, and wood stove	0.39
Oil boiler and solar thermal	0.73
Total of scenario after 19 years	39.17

Table 9.4: Results of private economic analysis of Reference Scenario in 2017 prices

9.4.2 Private Economic Analysis of Individual Heat Pump Scenario

For the Individual Heat Pump Scenario the tariffs, fees and taxes for fuel prices are applied. Further, also including subsidies for the households which are changing their heat source from a conventional heat source to respectively air-to-air heat pumps and air-to-water heat pumps. The subsidies have been scaled according to the modelled timeframe of 19 years. Moreover, the craftsmen deduction has been applied and scaled. The results of the private economic analysis of the Individual Heat Pump Scenario is presented in Table 9.5.

	Total cost of heating system [Mio DKK]
Air-to-water HP	27.69
Air-to-air HP and electrical boiler	5.63
Total of scenario after 19 years	33.32

Table 9.5: Results of private economic analysis of Individual Combination Scenario in 2017 prices

9.4.3 Private Economic Analysis of Individual Combination Scenario

Taxes, tariffs and fees applied to fuel prices been applied for the Individual Combination Scenario. Moreover have the subsidies and the craftsmen deduction been applied as well. The subsidies are applied in the way as described in the previous section. The results of the private economic analysis of the Individual Combination Scenario are presented in Table 9.6.

	Total cost of heating system [Mio DKK]
Ground source HP	6.22
Air-to-water HP	19.47
Air-to-air HP and electrical boiler	5.63
Additional wood stove	2.40
Air-to-water HP, solar thermal, and wood stove	0.35
Air-to-water HP and solar thermal	0.75
Total cost in 19 years of scenario	34.82

Table 9.6: Results of the private economic analysis for the Individual Combination Scenario in 2017 prices

9.4.4 Private Economic Analysis of DH Heat Pump Scenario

In the private economic analysis of the DH Heat Pump Scenario no subsidies apply directly to the investment required for building and installing a district heating network, as described in Section 9.1: Investment Taxes. Therefore the only difference to the socio-economic analysis is in the electricity price which has to be increased by 764 DKK/MWh as described in Table 9.1 on page 82. This leads to the private economic result presented in Table 9.7 below.

	Total cost of heating system [Mio DKK]
Total cost of DH Heat Pump Scenario after 19 years	42.72

Table 9.7: Private economic result of the DH Heat Pump Scenario in 2017 prices

9.4.5 Private Economic Analysis of DH Solar Thermal and Biomass Scenario

A private economic analysis of the DH Solar Thermal and Biomass Scenario is carried out in order to identify differences to the socioeconomic analysis. As described in Section 9.1: Investment Taxes there are no direct or indirect subsidies applicable for building the system required in this scenario. Moreover biomass is not taxed in Denmark in order to create an incentive for the implementation of renewable energy into the energy system. These assumptions lead to the private economic result presented in Table 9.8 below.

	Total cost of heating system [Mio DKK]
Total cost of DH Solar Thermal and Biomass Scenario after 19 years	34.08

Table 9.8: Private economic result of the DH Solar Thermal and Biomass Scenario in 2017 prices

As there are no taxes, subsidies or other benefits applicant for the socio economic analysis of the DH Solar Thermal and Biomass Scenario its results are identical with the results presented in the socioeconomic scenario presented in Section 7.6. Further analysis of the results will be carried out in the following section.

9.5 Comparison of Scenarios

As presented in Section 9.4: Private Economic Analysis of Scenarios, the total costs of the scenarios increases in all scenarios, except of the DH Solar Thermal and Biomass Scenario. There the costs are not affected by applying taxes and subsidies. The private economic prices for the scenarios are presented in Figure 9.9 below.

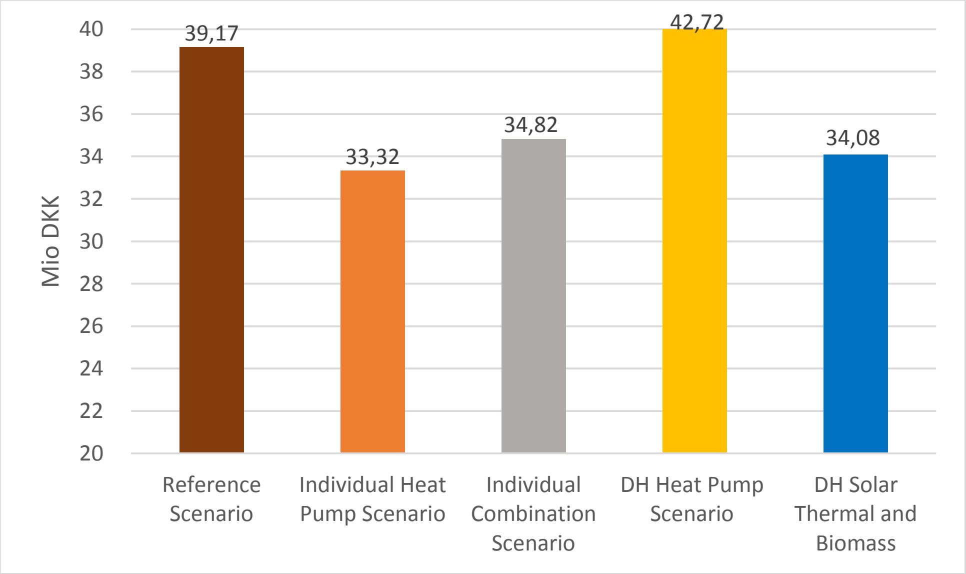


Figure 9.9: Private economic comparison of scenarios in 2017 prices

In Figure 9.9 it can be seen that the most expensive scenario after applying taxes and subsidies is the DH Heat Pump Scenario and the second-most expensive scenario is the Reference Scenario.

The cheapest private economic scenario is the Individual Heat Pump Scenario. A comparison of the socioeconomic results and the private economic results is illustrated in Figure 9.10.

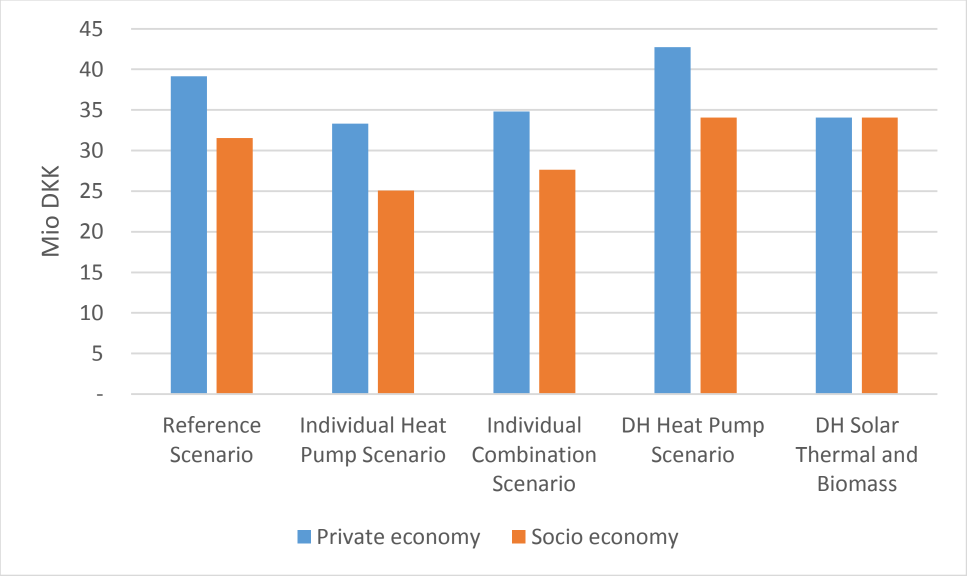


Figure 9.120: Comparison of private- and socioeconomic analyses in 2017 prices

In Figure 9.10 it is seen that the scenarios experiencing the largest increase in price are the DH Heat Pump Scenario and the Individual Heat Pump Scenario. These big increases are caused by the scenarios primarily/only being based on electricity, where the biggest price increase is seen due to tariffs and fees. Also the Reference Scenario and the Individual Combination Scenario are largely affected by applying taxes and subsidies as well, making the DH Solar Thermal and Biomass Scenario the cheaper than the Individual Combination Scenario. These increases are also caused by the increase in fuel prices. As seen in Figure 9.10 no change in price is experienced for the DH Solar Thermal and Biomass Scenario. This is caused by biomass not being taxed.

As stated in Section 5.3: The Process of Approving an Energy Project the approved heating system should be the most socioeconomic beneficial heating system. The current tax system is not supporting the implementation of the recommended system based on the socioeconomic analysis. Here the Individual Heat Pump Scenario is the cheapest scenario, but since it is not realistic for all households in Valsted to change to air-to-water heat pumps or air-to-air heat pumps the Individual Combination Scenario is recommended. The private economic analysis presented in this chapter reveals that from a private economic perspective the previously recommended scenario became the third-most expensive scenario. In order to be able to implement the most socioeconomic beneficial and realistic scenario: the Individual Combination Scenario, the tax regulation system must face changes. In the next chapter recommendations on changing the tax system in order for it to become more supportive of the most socio economically beneficial scenario are given.

CHAPTER 10: POLICY RECOMMENDATIONS

This chapter focuses at giving policy recommendations on how to change the current policy and taxation system in order for creating an economic environment which allows the implementation of the socio economically most beneficial heating system in Valsted.

If a new heating system has to be implemented it should be the one which is most beneficial for society. The most beneficial is in this case considered to be the system with the best socio economy. (Retsinformation.dk, 2011) For the case of Valsted taxes, tariffs, and fees are blocking the most socioeconomic beneficial and realistic scenario from being implemented, as it in the private economic analysis becomes the most expensive scenario. The change from being the second-cheapest socioeconomic scenario to being the third-most expensive private economic scenario is caused by taxes and fees on electricity. Therefore policies and taxes need to change in order to support the systems most beneficial for society.

Taxes, tariffs and fees applied to electricity have an additional function of regulating customer behaviour in order to secure a low consumption of electricity. (Ölander & Thøgersen, 1995) These measures should not be changed as long as they do not interfere with implementing the socio economically best heating scenario. It is therefore recommended to introduce an additional tax deduction on electricity used for heating purposes in areas without access to district heating networks. This could be implemented similar to the already existing reduction of electricity fees when a consumption of 4000 kWh/year is exceeded. The current electricity fees amount to 412 DKK/MWh (SKAT, 2017) as described in Table 9.1 on page 82. The electricity fee is currently the biggest individual expense added to the electricity price. For the case of areas without access to district heating it is recommended to disestablish the electricity fees for consumption exceeding 4,000 kWh/year. In the case of Valsted that would mean that the electricity price would stay the same as it is now for the first 4,000 kWh used in each household. All electricity used additionally (for heating) is recommended to be sold at a deducted price where the electricity fee is set to zero. This would drastically improve the socio economic feasibility of the Individual Combination Scenario.

From Chapter 9: Private Economic Analysis is it clear that the taxing of fuels is not providing equal conditions for different types of fuels. The current taxation system discriminates in favour of renewable fuels such as biomass, which is not taxed, whereas the tariffs and fees for electricity, also produced through an increasing share of renewable sources, exceed the actual price for electricity. (Danish Energy Agency, 2015 a) As Denmark is increasing the share of renewably produced power in the electricity mix and aims at generating 100% of its electricity by using renewable sources it is a discrimination of a renewable fuel if the electricity produced by renewable sources is taxed as if it was produced by a fossil fuelled source. This seems contradicting to the plans of achieving 100% renewable electricity as well as heat generation by 2035 (Danish Energy Agency, n.d. a), especially since an expansion of district heating networks as well as electrification of the heating sector are the proposed measures to reach these goals in the heating sector. (Energy Comission, 2017) If the Danish ,private economically feasible. One way of increasing the private economic feasibility of projects in the heating sector is to introduce equal taxation conditions for all renewable fuels which are available in abundance in Denmark. This is seen as a crucial step forward to reach more feasible business and private economic scenarios. It is acknowledged that a preference is given to renewable fuels over fossil fuels in order to incentivise the use of renewable fuels. And hence work towards the goals of 100% renewable generation of electricity and heat. (Danish Energy Agency, n.d. a) This is however difficult to apply to electricity before it is generated 100% renewably, in 2035, as electricity is currently produced through a mixture of fossil and renewable fuels. (Energinet.dk, 2016) One solution is to introduce a yearly changing tax level, which is taking the share of renewably generated electricity from the total amount of generated electricity into account. This could continuously decrease the tax rate until it reaches zero when all electricity will be generated by renewable sources, presumably in 2035.

As described previously taxes can be used to regulate consumer behaviour (Ölander & Thøgersen, 1995) and therefore are an important regulation measure. In the case of Denmark biomass is considered renewable and heavily incentivised by currently being tax-free. This is however creating problems in the long run as it is not recommended for Denmark to base its 100% renewable energy system on imported biomass. (Mathiesen, et al., 2015) It is therefore included in national plans to only use biomass which can be generated in Denmark. As the Danish capacities of growing biomass are limited also the availability of biomass is limited and it therefore has to be used in the most efficient way possible. (Danish Energy Agency, 2014 c) A way to steer this process is to introduce taxes on biomass. It is therefore recommended to introduce taxes on renewable fuels with a limited capacity (such as biomass) similar to the taxes that are in place for fossil fuels, exempting cogenerating district heating plants from this tax. These taxes should take the availability of the resource as well as the efficient use of it into account when defining the taxation levels for the heating sector.

Introducing taxes on biomass also will change the private economic feasibility of the different scenarios as it would make both district heating scenarios more expensive.

Another way to incentivise investments in the heating sectors in areas without access to district heating systems is that parts of the initial investment could be made tax deductible for private households. The tax deduction could be introduced in a similar way as the craftsmen deduction, where instead of the payroll a share of the initial investment can be deducted from the personal tax.

The implementation of these measures is however seen as a challenge as there is currently too little awareness of the problems faced in areas without access to district heating, like Valsted.

For the citizens of Valsted the private economy of a suggested heating system will play the most important role as they will have to finance changes in their heating system themselves. The recommended scenario is only the second cheapest based on socio economic costs, but the third-most expensive one in a private economic analysis. It is therefore recommended for the citizens of Valsted to try to increase awareness of their situation.

This can be done by approaching politicians in the field of energy, both on municipal as well as on national level. It would also be possible to reach out to Aalborg Kommune to present the special situation of Valsted and the challenges in changing the heating system according to municipal plans. It might be possible to negotiate special conditions or exceptions for changing the current heating systems in areas without access to district heating.

Further it would also be possible that one or more of the citizens of Valsted get actively involved in politics and try to introduce change themselves. This process might, however, be too slow and contains a lot of uncertainties.

The authors believe that it would be beneficial to implement the policy recommendations on national level, in order to remove disadvantages of implementing the socio economically most feasible heating system in areas without district heating systems. This could help Aalborg Kommune and Denmark to reach their goals in the heating sector, in areas where they are dependent on the cooperation of private households.

Summary of recommendations:

Disestablishment of the electricity fees of 412 DKK/MWh for consumption exceeding 4,000 kWh/year in areas without district heating access

Introduction of reduced electricity tax levels (yearly changing, depending on the previous years' share of renewably generated electricity, until 100% is reached)

Introduction of taxes on biomass (taxes should depend on availability of the resource and efficient use)

Incentivise investments in the heating sectors in areas without access to district heating (tax deduction on share of initial investment)

The implementation of the above mentioned measures would increase the private economic feasibility of the Individual Combination Scenario and hence strongly align the private economic as well as socioeconomic results. The suggested measures can lead to a reduction in barriers that the current legislation poses onto the implementation of the most socioeconomic scenario.

CHAPTER 11: DISCUSSION

In this chapter the sources of information, the methods used in this thesis, and the results are discussed. This is presented in order to identify limitations and consequences of using these sources of information and methods. Furthermore the results of the analysis are discussed.

11.1 Discussion of Sources of Information

For modelling the presented scenarios many assumptions have been used. The sources of information making the basis for the assumptions are presented and discussed in this section. This specifically includes sources for establishing heat demand, the Danish outdoor temperature used in energyPRO, and technical and economic assumptions used when modelling.

11.1.1 Discussion of Heat Demand

The heat demand in Valsted has been obtained from (Aalborg Kommune, 2014). The information on heat demand and distribution of heat sources has by Aalborg Kommune been obtained from Bygnings- og Boligregistret (BBR) (the building and residence register). The data from the BBR register is connected with a certain degree of uncertainty, as it consists of data entered by the house owners (BBR, 2012). This means that the data might not be up-to-date, as it is a possibility that house owners are not aware of the obligation to keep the information about their heating system up to date or refrain from updating heat sources in BBR. Furthermore heat demands from additional heat sources are not included in the given heat demands. Therefore the authors had to make an estimation of heat demand covered by the additional heat sources. Moreover the data used is from 2014. By having more specific and newer data a more correct heat demand would have been obtained. However, since the heating system in Valsted consists of individual heat sources no other data than the used data could be obtained. This data was considered to be more Valsted-specific than the Danish average even when being slightly outdated. Therefore the data from BBR was used. Further the authors added their estimation of the heat demand covered by additional wood stoves. However, it should be kept in mind that the actual distribution of heat sources and heat demand might vary in reality.

For estimating the heat demand covered by additional wood stoves, the authors assumed that an additional wood stove covers 1/3 of the space heat demand in a household as accounted for in Section 5.1: Valsted's Current Heating System on page 31. This assumption is based on the authors' impression from the interviews, where households with additional wood stoves expressed that the wood stoves cover a high share of the total space heat demand. (Household 3, 2017), (Household 5, 2017), (Household 8, 2017) The heat demand covered by the additional wood stoves most likely varies from the assumed share.

The heat demand affects the economic results presented in the analyses. Therefore the results of this thesis are affected by the presented insecurities from obtaining heating data from the BBR. However, as presented this has turned out to be the most case-specific data which was by the authors preferred over using a national average. This lead to more case specific results, which is of advantage to the citizens of Valsted and it was therefore chosen to prioritise the usability of this case study for the examined case over the transferability to other cases.

11.1.2 Discussion of Danish Outdoor Temperature

The Danish outdoor temperature used for modelling in energyPRO is obtained in form of hourly temperatures from the Danish Reference Year (DRY) for central Jutland. This data is based on weather data from 2001-2010, presenting the outdoor temperatures of an average year on an hourly basis. Furthermore the DRY is area specific for different locations in Denmark. For Jutland temperatures are available in three different areas, Jutland west-coast, Jutland east-coast and central Jutland. (DMI, 2013) As Valsted is not located on the coast central Jutland was chosen. Using the outdoor temperature from the DRY for modelling gives the best currently available representation of outdoor temperatures in Denmark. Another advantage is that the data is area specific and therefore more accurate than nationwide data. But it should be kept in mind that the costs of the different scenarios vary depending on the temperatures. Further the used data presents average temperatures which give a likely overall result for the simulated timeframe but the individual years and especially days will vary greatly depending on the actual weather conditions.

11.1.3 Discussion of Technical and Economic Assumptions

For technical assumptions the technology catalogues provided by the Danish Energy Agency have been used as main source of information for the simulated technologies in terms of financial and technological assumptions. The source is considered appropriate as it is the official guidelines of the Danish Energy Agency for energy related projects. The technology catalogues present important technology specifications including technical and financial parameters of energy technologies of different scales under Danish conditions. Furthermore the technology catalogues are created in a cooperation of the Danish Energy Agency as well as COWI with Teknologisk Institut and Dansk Gasteknisk Center which are prominent and experienced consultancy as well as research institutions. The fact that the catalogues are developed in a knowledgeable and trustworthy cooperation of institutions and companies as well as the fact that they present comprehensive data about energy technologies and are regularly updated, makes them the most appropriate source for Danish case studies in the energy sector.

11.2 Discussion of Methods

In this section the methods used in this thesis are discussed. Moreover, also the usage of the presented theories is discussed. The thesis has an overall framework of a strategic energy plan with a modelling perspective of a local scaled heating system. Strategic energy plans are used to investigate the socio economy of different scenarios, but also contain an implementation perspective where implementation barriers are identified and policy recommendations are given in order to overcome these barriers. Further, public participation has been used in order to identify and overcome implementation barriers and is therefore discussed in this section.

11.2.1 Discussion of Strategic Energy Planning

As presented in Section 3.2: Strategic Energy Planning on page 16 the approach consists of 5 steps: Determining scope and perspective, modelling scenarios, investigating implementation issues, policy recommendations, and identification of practical implementation steps. The first four steps have been completed in this thesis. The fifth step has, however, not been covered. This is due to major obstacles found in the current legislation. It is therefore recommended to implement policy changes before identifying practical steps.

11.2.2 Discussion of Socioeconomic Study

In line with both the strategic energy planning theory and the process of approving an energy system on a municipal level, a socioeconomic study has been conducted in this thesis. The socioeconomic analysis does, however, lack certain elements, specifically the tax distortion loss, net factor, and job creation. As stated in Section 3.5: Socioeconomic Analysis the tax distortion loss and the net factor are not included for reasons of simplicity. Moreover, the tax distortion loss only applies for large public projects and the scenarios presented in this thesis are not considered to be in the scale of “large public projects”. The scenarios are considered rather small-scale as three of the simulated scenarios are based on individual heating and the district heating scenarios are not considered large public projects due to the small size of the heating system. Further, the job creation element is not included, as the collective workforce in the long term is considered a limited resource (Danish Energy Agency, 2007, p. 19).

Including these elements would have affected the socioeconomic results presented in this thesis, by making the costs higher. However, since the tax distortion loss and job creation are elements that would not affect the economy of presented scenarios, the increase in costs is not expected to have a big influence. Therefore the only experienced increase in socioeconomic costs when including the exempted elements will be caused by the net factor. The net factor would affect the investment prices and since the district heating scenarios have the highest investment costs (as seen in Figure 8.2 on page 71), these scenarios would be affected the most, but the order of feasibility would not be affected as the most expensive scenario would also be the one effected the most, as it has the highest investment price. For the individual scenarios the investment prices are close to the same level, and the experienced difference from including the net factor are therefore not expected to vary the order of feasibility.

11.2.3 Discussion of Economic Analysis and Results

The economies of the scenarios are presented as socio economy and private economy. According to the municipal guideline, three economies of project proposals should be given: Socio, business, and private (Miljø- og Energiforvaltningen, n.d.). However, the business and private economies are combined in this thesis and presented in the private economic analysis. This is done as in these cases the two economies are the same as the citizens of Valsted are expected to own the district heating plant if one of these scenarios would be implemented.

Socioeconomic and private economic results are compared and make the grounds for the policy recommendations given in this thesis. By using this method economic barriers for implementing the most socioeconomic beneficial scenario are identified. This makes the policy recommendations purely oriented towards economic measures. Other barriers for implementation can occur, but these are not investigated in this thesis, as the economy for projects often is determining for a project's implementation. However, it should be kept in mind that other implementation barriers should be investigated if an implementation of one of the scenarios is sought.

11.2.4 Discussion of Public Engagement

Public engagement has been used in the form of interviews to gain knowledge and to be able to create scenarios that can be accepted by the local public. The chosen form of public participation is public consultation using interviews. A reason for using public engagement is to ensure implementation, however implementation has not been ensured at this level of public participation, as no feedback for the scenarios from the citizens in Valsted has been sought or given. In order to ensure implementation the authors of this thesis should have created a form of public engagement including all citizens in Valsted with a two-way information flow, with regular dialogues between the authors of this thesis and the citizens in Valsted. This would change the level of public engagement to be in the level of public participation. By ensuring an opinion transforming dialogue with the citizens in Valsted a possible implementation would have been ensured. This has, however, not been done as this process would be very time consuming, and not fit within the timeframe of the thesis.

Regarding public participation also the distribution of heat sources amongst the interviewees can be discussed, as many interviewees already implemented renewable heat sources. A distribution in accordance with the actual distribution of heat sources in Valsted would have been preferred. However, since participation in student projects are based on volunteers it was not possible for the authors to choose the distribution of heat sources. The fact that a majority of interviewees already had renewable heat sources most likely has affected the authors' sense of willingness to change heat sources in Valsted. Implementation might therefore be a bigger challenge than just on a policy level, as otherwise assumed in this thesis.

11.2.5 Discussion of the Model

When using models, it is important that one is aware of the fact that a model is a simplification of reality and that its' results present how a future scenario might look like but they do not give a certainty that the future will be as simulated in the model.

Further it is important to be aware of the abilities and limitations of the simulation tool. As described in Section 4.3: Simulation Tool energyPRO is the only simulation tool that met the criteria set by the authors. A simulation tool with the additional ability to size the heat generation unit based on a given demand would have been preferred but was not available in combination with the other criteria. Further it would have been an advantage if different heat sources could have been simulated in one site. Meaning that it would be possible to define which heat demand has to be covered by which heat source instead of creating different sites, for the different heat sources in order to ensure that individual systems do not cooperate in order to supply the demand.

The methods used for modelling are described extensively in Chapter 6: EnergyPRO Model as well as in Chapter 7: Scenarios where the relevant assumptions are presented. These sections aim at putting the reader in the position of being able to follow the procedures and assumptions that lead to the results of this thesis. These chapters should also provide the base for reproducing the results obtained in this thesis. As it was chosen to present rounded numbers in order to improve legibility, it is difficult to obtain the precise numbers the authors obtained, in reproductions of the model. However the results will present the same outcome as presented in this thesis.

11.3 Discussion of Results

As presented in Chapter 8: Comparison of Results, the cheapest socioeconomic scenario is the Individual Heat Pump Scenario, where all water-based heating systems are to be heated by air-to-water heat pumps, and all electricity-based systems are to be heated by air-to-air heat pumps and electrical back-up boilers. This scenario is, however, not recommended as it is considered unlikely that the people of Valsted will replace their already renewable heat sources, such as ground source heat pumps, with air-to-water heat pumps. Therefore the second cheapest scenario in terms of socioeconomic costs, the Individual Combination Scenario, is recommended as the most feasible heating system. This scenario represents a more realistic solution where only biomass boilers and fossil fuelled heat sources (incl. electrical heating) are replaced with air-to-water heat pumps or air-to-air heat pumps and electrical back-up boilers. Already installed renewable heat sources are kept. However, including taxes and subsidies changes the economy drastically, making the Individual Combination Scenario the third-most expensive scenario. This makes the economy of the heating system unstable, and therefore not recommendable to implement before the given policy recommendations are implemented. An additional challenge that the recommended scenario has to face is the fact that the financing of the systems depends on the individual households and it is unlikely that all households would change to the recommended heat sources. It is expected that some households have concerns about the recommended heat sources and prefer to invest in other heat sources. This would lead to a more expensive overall solution for Valsted. The influence on the neighbours is however limited as it is the households themselves who have to cover the higher costs.

11.3.1 Relevance of the Results

As stated in Section 1.2: Relevance of the chosen Study Case and Section 3.1: Case Study of Valsted this thesis presents a case study for the case of Valsted. It is in some aspects very case specific. The most accurate data available has been used when investigating the heat demand and the distribution of heat sources. Further the interviews have been used to estimate additional heat demand and create the Individual Combination Scenario. This however does not mean that the case modelled specifically for Valsted is only encountered in Valsted. The results found through the model can be transferred to all other towns without access to district heating in Aalborg Kommune. The overall results can also be transferred to similar locations in the rest of Denmark but it has to be kept in mind that the local weather conditions as well as heat demands might vary slightly depending on the location and the building stock. Further the barriers encountered are not only encountered by the citizens of Valsted but by people all over Denmark who live in areas where district heating systems are not feasible. Therefore the policy recommendations are not limited to improve the situation only in Valsted but the recommendations would improve the situation Denmark wide.

CHAPTER 12: CONCLUSION

The research question of this report is: *How can Valsted reach a heating system entirely based on renewable energy?* This is investigated by answering the two sub questions of the research question. First the potentials for different renewable heat sources were investigated before scenarios for the heat sources with sufficient potential were created. The simulations showed that the implementation of the Individual Combination Scenario is the scenario with the second lowest socioeconomic costs. It is given preference over the cheapest scenario as it is adapted in a way that it is more likely to be installed in Valsted according to the interviews conducted in Valsted. When calculating the private economy of the different scenarios the Individual Combination Scenario turned out to become the third-most expensive one. Fees and taxes make it non beneficial for private households to change their current heating system to a renewable heating system under these conditions.

This was found to be contradicting, with Aalborg Kommune’s and Denmark’s aim to change the heating sector to be 100% dependant on renewable energy by 2030 and 2035 respectively. The policy analysis showed that the main barriers are: the taxes, tariffs and fees which are added to the fuel prices as well as to the initial investment. These barriers can be minimised or removed by disestablishing the electricity fees for consumption exceeding 4,000 kWh/year in areas without district heating access. Moreover reducing the electricity tax level depending on the share of renewably generated electricity would decrease private economic costs. Further introducing taxes on biomass and incentivising investments in the heating sectors in areas without access to district heating would minimise the main barriers. The implementation of these measures is however seen as a challenge as there is currently too little awareness of the problems faced in areas without access to district heating, like Valsted.

For the citizens of Valsted the private economy of a suggested heating system will play the most important role as they will have to finance changes in their heating system themselves. The recommended scenario is only the second cheapest based on socioeconomic costs, but the third-most expensive one in a private economic analysis. It is therefore recommended for the citizens of Valsted to try to increase awareness of their situation.

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APPENDIX 1

Interview with Household 1

Has stall-heating, a heat pump where the heating source is the heat from the cattle. There are pipes above the cattle to take in the heat. They think there is potential to heat at least one more house. They used to live 6 people in the house and there was always enough hot water for all of them. The heating system is approximately 30 years old, and they heat 170 m^2.

They have never thought about heating other houses than their own, but they never thought about that and they also have concerns about the money issue between neighbours, so they rather just heat their own houses. Sees practical issues with pipes as well.

In 1986 when they built the house the price was the same for an oil boiler + chimney as for the heat pump, and the heat pump was tax deductible, therefore they chose that option. Last year they paid 12,000 kr. for the private use (including heating). But for their heating system they are dependent on having cattle, which is also why he has not retired yet. They have thought about getting a geothermal heating system instead when that becomes an issue. Thinks a geothermal heating system is cheaper than an air-to-air heat pump in electricity. But would like to have a wind turbine to produce power to the whole village, but knows that some environmental people are worried about the safety of birds.

For the tax system 8733 kWh has been set to be the private consumption. Combined, they in 2015 used 25,809 kWh.

They do not expect to make energy efficiency measures. They cannot really see what they should do. They tried signing up for a free energy check, but nothing ever happened, but since the house is warm enough and they have a sustainable heating source they do not see a reason for making energy savings. But if they were to do something it should probably be insulating, which is the energy efficiency measure they know about. They are however optimizing the use of their milk-cooler by tapping hot water from it.

Requirements for heating system: Should cover their demand, should work without issues, and sees it as huge advantage that it is emission free.

Other potentials for heating: Geothermal, wind turbine, solar thermal.

Technologies that are not a potentials: Oil boiler, wood stove, straw boiler (too much work).

The only concern they had about installing the heat pump was whether or not it could cover their hot water demand. Ruth was worried that the heat pump could not produce enough heat.

Attitude towards Nærvarme: When that was a debate they had just installed their heating system and were not interested in a DH system, and do not think people are interested in having their own system, unless it financially makes sense, if it is more expensive than HP people would not be interested. Does not know about a common place to have it, but are willing to sell some land for it. Would not be a member due to their system, and thinks it is easy to make it a geothermal system. Likes the idea about having a common geothermal system.

Would be willing to have solar thermal panels on the barn (but would prefer PV panels) where they have approximately at least 200 m^2 roof with a South orientation. But likes a system where they only need one technology to cover the demand all year round. Do not like the aesthetics of having it on their house. If there is a profit they would like to have PV panels. Are willing to make the investment if it is profitable in the long run.

Would be willing to pay more for renewable heating to avoid having an oil boiler.

Did not consider the property value when making the heating system. But are aware that it would be decreased if the new buyer has to install their own heating system.

Incentive for installing their heating system: could be deducted from the taxes, price was the same for installing an oil boiler + chimney, got more room in the house.

Sense of community in Valsted: Pretty good, but could be better. The Borgerforening helps a lot.

The size of the village has changed a bit, in average one new house is built every year.

Interview with Household 2

Have a wood pellets boiler (25 W) and have used that for 15 years, are not worried about the extra work and feels that it is earned back by being cheaper than oil. Are heating 180 m2 and two people living there. Annual heating price is approximately 17,000 kr. They burn 11-12 ton of wood pellets annually. The space heating is turned off from May to the end of September.

They are not expecting to make energy savings in future as the house is on sale. But they know that the efficiency can be improved by changing the windows, and insulating more, but they have it checked out and their current insulation is slanted which makes the process of insulating right very expensive.

Requirements to the heating system: Has to cover the demand. Does not mind the work.

Potential heating sources: Geothermal, brændeoven (but does not like this option), solar thermal panels (would make sense for them, has 80 m2 in a West orientation).

Technologies that are not an option: Brændeoven.

Are willing to have solar thermal panels on the roof.

Did not have any concerns about changing the system. The incentive for changing from oil was the price. Did not get any subsidies.

Attitude towards Nærvarme: Do not want to be part of a nærvarme system, due to experiences from other small places. Do not think it is possible to have an economical feasible nærvarme system in Valsted. Does not think the village are willing to have it, maybe the younger people who are new in the village and used to a DH system would be willing to be a part of a nærvarme system. Do not know about a common area where such a system could be placed, but it has earlier been suggested to have close to the school.

Incentive for making the investment in wood pellets boiler: Better economy in the long run.

Sees all other fuels than fossil fuels as cheaper in the long run so would be willing to pay more for having a renewable heating system. Did not consider that the current heating system would affect the property value.

Uses around 8000-9000 kWh electricity annually.

Sense of community in Valsted: Good, not as good as previously, since the sports union is experiencing less members (previously this was the rallying point). The borgerforening makes a good effort in gathering the village.

The size of the village has changed a bit, the area has gotten bigger, but the amount of people living in the village has dropped by 6 (they think) since last year. Are keeping an eye on whether or not new citizens in the village have kids. The house has been for sale for a year now, 10 years ago the houses were often sold within a week.

Interview with Household 3

Have two air-to-air HP (10 & 5 years old, one of them is combined with a ventilation system), two wood stoves (uses them as main heating, they run only in winter), and electrical heating. Electrical floor heating in the bathroom. Are heating 180 m2, 2 people living there. Has their annual electricity consumption (I assume we have a note on that?). 8500 kr. on fuel for the wood stoves. Months with HP running: turns it off April, turns it on again in October. Changed to LED light bulbs to use less electricity. Likes the heat from the wood stoves best, they feel it is a better form of heating. Spends 22,000 – 23,000 kr. on heating and electricity annual.

They are annoyed by the noises from the HP, they don't have them turned on during the night (except for on the coldest days) due to the noise.

Are not expecting to reduce energy demand by energy efficiency measures. They cannot see any opportunities for making energy efficiency measures. They are happy about what they have, so therefore it is not a consideration.

For energy efficiency measures they know about: HP, got a thermography of the house which did not show any insulation problems, changed their windows to double glasses.

Are open for ideas, but are confident that there will never be DH in Valsted, as a group some years ago tried to implement it, but the suggestion did not meet support, and from other places it has shown to be too expensive.

Requirement to heating system: should provide enough heat, and should keep 20-21° during the day and 24° in the evening. Does not mind the work with having wood stoves.

Possible RE technologies: House wind turbine (if they lived at the country side), solar thermal panels (but not on their roof, maybe on garage roof or on the ground). Has one roof with a South-orientation, but that is shadowed in the winter. Likes the new thing with built on PV panels in the roof. Their house is worthy of preservation (a lot of houses are in Valsted), so that restricts them. Geothermal heating could also be an option, but is too big a project for them.

RE technologies that are not an option: Wind turbine due to regulations.

Issues with changing the heating system: Geothermal: the mess with rebuilding the house and the ground and the matter of having to move out while it is installed. Are dredging taxes on wood stoves, they would only use the HP if that was the case.

Did not ask whether or not they were allowed to install the HP, so had no problems with doing that in a worthy of preservation house.

Attitude towards nærvarme: Hard for them to be connected as they have no radiators or floor heating (except for bathroom), but if it could be induced by air they are positive towards it. Would be positive about a small nuclear power plant in Valsted as well. If they could make common RE electricity form common WT they would join. Does not think the citizens in Valsted would be willing to have nærvarme as it has increased the heating price for other small villages. Also many of the houses have their own renewable heating system. Are sure they would find a place to have the heating plant if that was the case, and there is a place close to the school that is only used for the village’s Christmas tree, which could be a possibility.

They made investment in HP for their own benefit, so they are willing to make the investments, and are interested in investing in more efficient wood stoves. They invested in the HP due to economic reasons, and easy regulated and you are able to set a timer, and also to reduce the electricity consumption. They got no other subsidies than the craftsmen deduction. Did not consider how the investments would affect property value.

They do not agree on whether or not they would be willing to pay more for RE. The wife can accept a small price increase for a more automatic system.

Thinks there is a good sense of community in Valsted, they work together on different project. The size of the village has changed as a new neighborhood has been made, which made the average property value increase.

Interview with Household 4

Uses Electricity/Wood heating (used a lot), also has a defect heat pump (is at least 10 years, worked for 7 years) was an expensive HP approximately 20,000 kr. when it was bought. Heats 90m^2.

Electricity Consumption:

From 1/4-30/6-2016: 2141 kWh

From 1/7-30/9-2016: 2165 kWh

- ➔ Annual demand of approximately 12,000 kWh (our estimation)

Used electrical heating on two radiators (in bathroom and hall), floor heating in living room, but never uses that. She closes the radiators in the summer, but it is different when she stops using them.

Her house is from 1897 and is not insulated so when it is warm outside it is cold inside.

For energy savings she is expecting to insulate the gable on the roof, and is planning to change some windows. Besides insulation and exchange of windows also the addition of an electricity generation via PV is a possibility. She was planning to build an annex and would planned to install PV panels on the roof there, but the bank did not allow it, so she built an entrance hall instead. She also thought about replacing the wood heating stove, not because it is working badly, but because there might be more efficient ones one, which are better in distributing the heat.

Her requirements for a heating system are that it should work. She doesn't have a preference of automatic or manual operation.

For renewable potentials she thinks geothermal is a good heating source for bigger buildings. But she decided for an air to air heat pump, because the house is rather small. She still thinks that and considers buying a new air-to-air HP. She thinks that all renewable technologies are fine, but she doesn't like skifer gas. Wind turbines have both advantages and disadvantages. But she likes them as alternative energy resource.

The concerns about changing her heating system for her, would, if she would invest in geothermal, be that she would have to change the entire heating system in the house, e.g. building a new pipe system. So she doesn´t think that is a current option for her as that would be expensive for her.

When she invested in the air-to-air heat pump she did so because she wanted to reduce her electricity consumption (from el. heating to heat pump) and thought it is smart to use the air for heating up the house. She didn’t get any subsidies for buying the heat pump.

Her attitude towards a nærvarme system is that she thinks it is brilliant if people can go together in neighbourhoods and have a common renewable heating system. Having a common heating system instead of individual is a great idea. She is sure that the inhabitants of Valsted would be interested in a district heating system if they can see the advantages of it. Many of her neighbours are heating by using pellet ovens, delivery of pellets is a little burdensome. For them it might be an advantage to have a nærvarme system. She doesn’t know if there is a specific place in Valsted for a common heating system. It depends on the size, and the people participating in the project, but she definitely sees a possibility for finding a common space. If she did not have to change the pipes etc. in her house she would be a member of a nærvarme system.

Is positive about having solar panels on the roof. Roof is East/West oriented, but she does not know the size.

She is willing to invest in a renewable heating system, but financing it might be a problem as she is retiring in the fall and that is limiting her possibilities to make investments. When she invested in the heat pump, she didn’t think about the property value.

She is member of the board of the inhabitants association in Valsted and thinks that there is a very good connection between the people in Valsted.

The size of Valsted changes a little. There are a few new houses but the family sizes are shrinking.

If electricity is cheaper that would be a consideration to change to el. But right now she is using the wood heating as her primary heat source.

Interview Household 5

Current heating system: Air-to-Water Heat pump (3.8 kW, 4 year), solar thermal (partly) (8-10 year), and PV panels (8 kW, also 4 years old), and have a wood stove for the first floor. Are heating 252m^2, and two to three people living in the house.

Electricity 5000 kWh/year including heat pump doesn´t know it that includes electricity from PV or not. The HP is closed in June, July, and August but in other months they use some heating. (Are spending 10,000 annually on heating and electricity)

In April – October the PV panels generate more electricity than they consume.

Energy reductions difficult, as they already use many different technologies. But if they were to do anything they would insulate more.

For energy savings they know about: Insulation, solar thermal, PV panels, geothermal heating, air-to-air heat pumps, and small wind turbines.

Heat pump works perfectly, and they are very happy about it.

Requirements for the heating system: Easy to use and effective, should work automatically, cover a space heating demand of around 20°C.

Other potential technologies for heating the house: Geothermal heating, solar thermal panels has gotten more effective, something to store the hot water in and also store electricity, and air-to-water heat pump is good. All renewable technologies are possibilities for him.

They did not have any concerns about changing the heating system to be renewable. The incentive for changing the system was the fact that the oil boiler was old and needed to be changed, and the unstable oil prices. They did not get any subsidies for making the investments but get a deduction on electricity taxes for the consumption above 4000 kWh. (Afskrive PV panel med 25% hvert år)

Attitude towards a nærvarme system: If it is supported it is a good idea, but it should have a stable price level. Good idea to have local DH utilising renewable energy. Generally a positive opinion towards DH in Valsted expected. Does not know of an area to have a common heating system. Since they are self-sufficient with heating and electricity they would not be a member, not if that were not the case they would be interested.

Willingness to pay more for renewable energy is given.

The energy efficiency measures and change of heating system are part of the increasing property value but it is not much, when breaking it down to the individual measures.

Community feeling in Valsted is fine, much contact with neighbours. But thinks it is important for the village to think about how to make it attractive in order to keep it.

Does not know if the size of Valsted changed but thinks it is quite constant. Thinks there is a general concern that the village dies out, and people are worried about their property value. The fjord is, however, a big plus so there is people moving to Valsted as well.

Interview with Household 6

Geothermal heating source, combined with an el-patron and ventilation system. Furthermore they have Danfoss Link to control the heating and the ventilation system. Moved in December 4th 2016, so does not know the annual heating demand, estimated use for the geothermal heat pump is 3000-4000 kWh. They expect the total electricity consumption to be around 8000-9000 kWh. They pay lower electricity taxes after 4000 kWh. The house is 230 m^2. 4 people living in the house. Heating has been regulated automatically at their old house as well, as they also had Danfoss Link there.

Since it is a completely new house (they tore down the old house on the property (with an oil boiler)) with all approved energy and insulation measures, they do expect to make any kind of energy efficiency measures. Are speculating in producing own electricity by either PV panels or house wind turbine. PV panels should, however, not be placed on the roof, but at "shack".

Requirements to heating system: Should be able to cover the demand, future-proof (Danfoss Link – should be cheap to update), should not have other big expenses than the investment, should work automatically, and reduce the demand.

If there had been district heating available and a connection obligation, they probably would not have the investment in geothermal heating as that would not have been economically feasible.

Got subsidies from: The smith did it on the geothermal system, they got 12,000 kr to replace the oil boiler, the energy saving subsidy (10,000 – 20,000 kr), and the "håndværkerfradrag" (workmans deduction). Combined 40,000 – 50,000 kr subsidies. Thinks it is a good idea to have advisement on energy investments.

Renewable technologies that are not an option for heating the house: The house wind turbine, as it is probably not allowed to have in a village. But no other than that.

Issues with the renewable energy investment: System only runs on electricity, but that does not concern them much.

Thinks it is hard to start a district heating system as all houses have their demand covered individually, but sees it as a benefit that the production would be bigger, and there would be less maintenance for the individual citizens. Thinks it is a good idea to have small CHP plants, but at they are too reliant on subsidies and old technologies. Thinks it is a good idea for district heating systems to be reliant on multiple technologies, preferably renewable. Thinks that the citizens in

Valsted might be willing to have a district heating system, as there are still some oil boilers, and brændeovne. Thinks the majority would like it, but it should be able to cover the demand. Would be a member of a local district heating system, to support the community. Does not know about a common place to have a district heating plant.

It is his impression that people in Valsted trust geothermal heating a lot, due to having DVI (Dansk Varmepumpe Industri) close by, and some people working there.

Would not be willing to have solar cells on the roof due to aesthetics. Would not compromise the aesthetics to have a cheaper electricity/heating system.

Are willing to pay more for a renewable heating system. It was not a part of their consideration that the geothermal heating system would increase the property value (and knows that not all renewable energy investments are increasing the property value). They build the house to live in and are not considering selling anytime soon, and choose the geothermal heating due to the automatic system and renewable energy.

The village has 4 less citizens than last year, but knows people are “on the look” for decrease in size.

Interview with Household 7

Has geothermal heating (360 m pipes), elpatron as back-up (and brændeovn). Built the house (147m2, 2 people living) in 2007 and had the heating system from the beginning. Runs all year around but consumption is higher in the winter months. They do not expect to reduce the heating demand by energy efficiency measure in the future, as it is a new house. Furthermore they do not want to have solar panels on the roof, as they do not like the aesthetics of it.

For energy efficiency measures they know about: producing power and selling it.

Requirements for heating system: Familiar with it (from a trustable provider), should cover the heating demand, environmental aspect, price, automatic. Had no worries about installing geothermal heating.

Possible RE: geothermal, solar thermal, HP (but does not like the noise disturbances).

Not possible RE: Oil boiler, house wind turbine.

Nærvarme: Was very active in the initiative made in 1993 that was not backed up by the locals. But are happy that it did not succeed, as the price has turned out to be very expensive. The problems with it is also that the village is not used to have common solutions, which was a big bump in the way. People wants to have individual solutions. It should be a really good project if it is to gain public support. – maybe a renewable solution could help it, but it all depends on the economy. Depending on the conditions they would be a member of the DH. For them to be a member the price should be guaranteed and so should the heating. Does not know a place close to Valsted to place a heating plant.

Roof is East-West oriented. But they do not want solar panels on the roof.

Reason for investing: They needed a heating system, which they wanted to be secure in future as well, familiar and trustworthy. Did consider the property value when making the investment. Did not get any subsidies. Pays less taxes after 4000 kWh.

Cannot really answer whether or not they are willing to pay more for RE. It is their experience that RE is cheaper.

Heating is set at a certain degree all year round.

The sense of community is good in Valsted is good, even though they miss the young people engaging more. A lot of people know each other and you talk to everyone. But there some people who are not interested in participating in the community. The community has gotten better than 40 years ago where two group dominated the village.

The size of the village has changed as new houses have been built, in the past 10 years 24 building grounds have been made, most have been sold.

Interview with Household 8

Started off with having an oil boiler, but due to high prices she changed to a biomass boiler, but it was too much work and there was always problems with the boiler and especial one reoccurring error was troubling her, since she did not have the physical strength to fix it, so she had to call for help every time it happened. In 2013 she changed the heating system to be geothermal heating (300 m pipes). The house is 120+67 m^2. 4 people living in the house. Has an electrical boiler for heating water (except for floor heating), and when it is the coldest she needs her wood stove as well. Turns the geothermal heating off from May or later and turns it on again mid-October approximately. Renovated the whole house when moving in, so is not expecting to make more energy efficiency investments. If she were to do anything she would like to have PV panels to fuel the geothermal heating (as an energy efficiency initiative) to become self-sufficient (but not on her wooden roof, but on her annex roof – west oriented (63 m^2 45 degrees).

Yearly electricity consumption of approximately 10,000 kWh. (which is also used for heating)

Requirements for heating system: maintenance free, likes the idea of being self-sufficient, likes that she does not have DH, as she has more possibilities for covering her demand.

Possible technologies for heating the house: solar thermal, geothermal.

NOT possibilities: air-to-air heat pumps (due to the noise), oil boiler, gas.

Had no issues with changing the heating system. Had a lot of help from her brother, which she took much trust in. Did not get any subsidies, but gets lower electricity prices after 4000 kWh.

Does not like the idea about a DH system, and would not be a member. Thinks people have gotten used to be able to control the heating systems themselves, if it was to happen, it should be some kind of common project where the citizens could participate, like joint wind turbines. There should be some public engagement, also in the idea phase, so people feel ownership. Or where there could be some joint owned sheep. If a DH system were to be combined with the above, she could see it happen. But not if it is an ordinary DH station. Does not know of any places where the DH system could be.

She would be willing to pay more for a renewable heating system – to a certain degree.

When renovating the house she thought about the property value, but does not plan to sell and therefore that has not been the priority.

Sense of community is very good. There are many projects that happened because of people working together, and they have different (children-friendly) parties together. People do a lot to keep the village alive. The size of village have not changed much, there are a few new houses.

Interview with Household 9

Has geothermal heating ((Queen VV9DC Combi ST) 8.9 kW and no back-up) and a ventilation system which also reuses the heating, and 156 m^2 house + 30 m^2 basement. The geothermal heating is from July 2013. Before they had an oil boiler. Has an excel file with data over consumption, which had been sent to Rikke.

The space heating is running all year round with 23-24̊. Gets a deduction in electricity taxes after 4000 kWh.

Are not expecting to make any energy savings (as it is a quite new house, built in 1999), but are considering putting up PV panels, but do not like the aesthetics of having them on the roof but are willing to have them on the garage roof. ←Is East oriented and approximately 40 m^2. If they were to make some energy savings they would insulate the roof more.

For energy efficiency measures they know about: LED light bulbs, insulating, and PV panels combined with batteries to store the electricity.

Requirements for the heating system: Reliable, should cover their heating demand, work automatically, and environmentally friendly.

Potential renewable heating technologies: Geothermal heating, PV panels, in theory: WT.

Technologies they do not want: Oil boilers and biomass boilers.

Incentive for changing system: Oil boiler was getting too old, but wanted to secure the heating system for the future as well, and since they had enough space for the pipes they choose a geothermal heating system. The better economy of the geothermal heating system was also an incentive for changing the system. Got a small subsidy from the energy savings pool (energitilskud) (around 3000 kr.) and had the craftsmen deduction as well. After 4000 kWh they get a deduction in electricity taxes.

Concerns about changing the system: Were a bit worried if the system could cover the demand. But has no such issues with the system.

Attitude towards Nærvarme: Thinks it is a good idea to have more houses making heat and electricity together (in the scale of 3-4 houses). But the current tax system does not support these kinds of systems. Do not think the citizens in Valsted would be willing to have a Nærvarme system, based on previous experiences. Maybe some groups of houses could do it. But many knows what they have, but does not know what they are going to get, so therefore a lot would stick to the known solution. Such a system could be placed in the part of the village where there are some building grounds. Would consider being part of such a system, depending on the structure of it.

Would be willing to make new investments in the heating system if it is economically beneficial.

It is their experience that the renewable heating system is cheaper than the old fossil fuelled system. But they did not consider the heating system’s influence on the property value when they made the investment, as they are not expecting to move anytime soon.

The sense of community is good in Valsted, but is affected by the fact that there are less children and the sports club is not as active as it used to be anymore, which is also due to iPads and such electronics. The size of the village has changed due to the expansion of new houses.

Interview with Household 10

Heating system: Oil boiler from 2009. Area of house is 101 m^2, one person living there. Those oil boiler as it is not a possibility to get district heating. Yearly heating demand: used 690 L of oil. Price 8074 for 1090 L (cheap year). Yearly electricity consumption: 1724 kWh.

Floor heating: close it down mid-April, turns it on again in the beginning of October. In the summer the heating from the sun is enough.

Does not expect to reduce heating demand in the future. For heating efficiency she knows about: insulation, new windows and doors, new roof, getting a thermography done to check for leakages. Which has been done for her house (build in 2009). Invest in a new heating system if you have an old inefficient heating system.

In 2009 when she built the house was oil boiler the cheapest option, which is why she chose that as heating source. She heard from people who work with oil boilers that environmentally it is okay due to high efficiency, even though they pollute. She have thought about getting a heat pump, but economically it is not feasible.

Demands for heating system: putting fuel in the system should work automatically, and be maintenance free.

Possible renewable heating technologies: Heat pump as a realistic option for her house, geothermal heating (but her house is close to being too small for that to be feasible). Renewable heating technologies that are NOT a possibility: Wind turbine in the backyard due to aesthetics and noise, solar cells (house does not have the right orientation).

Issues about changing the heating system: Economically (oil is cheapest option for her), RE technologies need to become cheaper for her to consider it. Also, lacking knowledge, she would need some advisors.

Nærvarme: Pro and con. Based on previous experience the small DH systems have proved to be very expensive, due to increases in gas prices. Therefore she would have issues with a local DH system in Valsted. If they were to something it should be geothermal or something like that – a secure investment. Does not think the population in Valsted would have one, as some does not like changes in the small village. Does not think there is a place for a nærvarme station in Valsted, but it can be made. It depends on the heating sources and the price whether or not she would be a member of the DH.

Willing to make the investment: If it is feasible in the long run, compare it to current system. But will also have the environmental aspect in mind. Not sure if she would be willing to pay more for renewable heating.

The property value was kept in mind when making the investment in an oil boiler, even though she does not plan to sell the house anytime soon. What could make her change her system is the economical aspect, but she is also conscious about the environment. If the oil boiler broke, she would invest in something renewable.

In Valsted it is legal to install oil boilers in existing houses (no access to DH or gas). If she were to build a new house today she would not choose an oil boiler. But when she built the house she did not give the heating system enough attention. Would like for Nibe or Farstrup to expand the DH system to include Valsted.

Sense of community in Valsted: Very big, they try to protect the sense of community and keep the village alive, and take care of each other. The size of the village have not changed when you look at population. There are no shops or industry in Valsted. There are a couple of craftsmen companies (2-3), and an agriculture.

Interview with Household 11

He has an oil boiler from 2007. Heating 170m^2 and garage is heated as well with a radiator, with one person living in the house every other week, and every second week four people are living in the house. Has floor heating in 2 rooms, the bathroom as well as the living room.

Oil Consumption: In the past three years he have approximately used 6200 l oil. (Approximately 2000 l/year to 16,800 kr. (approximately 15,000 kr/year)). Indoor temperature varies as the kids like it warmer (23°) than him (21°). Due to low oil prices he does not keep close track to what he uses. During the summer he does not need space heating (estimates: beginning of May to beginning of September/end of August), he can program the oil boiler to only heat water.

He does not think he will reduce his heat consumption in the future. He bought the house in 2007 and changed the insulation on the roof and changed the windows and doors. Furthermore he made energy efficiency measures in the garage. Therefore he thinks he has already done a lot. He insulated the house because he wanted to reduce his heating expense, and electricity expense, and for the case of the windows is was also about the aesthetics. There are also problems with condensing humidity on the window, which cause mold if the rooms are not ventilated. That is a problem with very well insulated windows.

Has no specific requirements to his heating system, besides it has to warm up the house.

When he moved in an Oil boiler was already installed and it would have been a big change to change the entire heating system, so in order to be able to move in rather quickly he decided to just replace the old oil boiler by a more efficient one and not invest in geothermal, since he also did not have the space for the pipes, at that point.

Incentive for changing the heating system: Should be cheaper.

If he would build a new house now, he would build a zero energy house including air-to-water HP and solar cells on the roof in order to be able to be self-sufficient.

RE technologies that are not an option: Solar thermal, as he heard that is some problems with the sun heating the water too much causing problems for the storage tanks. This and the economical aspect would be the only concern for him when changing the system.

About a DH system in Valsted he has no concrete feeling. He is working at Aalborg DH and whether or not he supports the ides depends on the heat source used for the heating system. In

Aalborg there is the massive advantage that excess heat can be used for DH. But he doesn´t know which resource could be utilised in Valsted. But it all depends on the price. Especially the initial investments required are hard to finance with the share that the people of Valsted would have to pay, especially, since Valsted is quite small and people are comparing the prices to their current heat price. He is not sure if the people in the village would support it, as a lot of people found some renewable individual solutions. If the heat plant is in the centre it is a good idea to decrease heat losses.

Would he be interested in being a member of a nærvarme system?: His oil heating is 10 years so he wants to use it for at least 10 more years before he wants to reconsider the heating system.

He likes the idea of solar, but it is again an economic consideration, and his roof has east/west orientation.

Is willing to invest in efficiency measures and new technologies, (especially) if building a new house.

Thinks, that the value of the house might change with a change of the heating system, but did not speculate on the house price, because he bought it to live in it.

He does not see the advantage of a DH system, which sometimes needs to be coal fired, over an individual oil boiler in terms of the environmental effects (CO2).

The sense of community in Valsted is not as strong as it has been in the past, but that is normal. E.g. in the football club they are missing young members, who moved away for their education. It is common that the youth from 18-20 up until 35 move away before some of them return to Valsted and built a house. Generally the community feeling is fine.

Valsted is becoming a little bigger, maybe 1 or 2 houses are new every year. There are more houses but the number of inhabitants is almost constant. A big influence on that is the school, if the school would be closed he thinks that also the size of Valsted would decrease as families would reconsider to move there.

The Oil boiler has a capacity of 20 kW (Vitopuls300 by Vissmann)