Impact Assessment from a Complete Repeal of the Consumer Obligations in the Danish District Heating

Master Thesis

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The report is written in LaTeX according to the standards of the document class "report". The references in LaTeX is made using bibtex and JabRef. Figures and illustrations are made in Microsoft Excel and edited in Inkscape. For data analysis, statistics and models ArcGIS, Microsoft Excel and EnergyPRO has been used.

AALBORG UNIVERSITY
STUDENT REPORT

Sustainable Energy Planning and Management
Aalborg University
http://www.aau.dk

Title:
Impact assessment from a complete repeal of the consumer obligations in the Danish district heating

Theme:
Master thesis

Project Period:
1. February, 2019 - 7. June, 2019
4. semester

Participant(s):
Mathias Vestergaard Steenstrup

Supervisor(s):
Steffen Nielsen

Copies: 1

Pages: 73

Date of Completion:
7. June, 2019

Abstract:

An aim of liberalising the DH sector has been politically stated. This liberalisation and market-based regulation potentially involve a repeal of the obligation for consumers to remain financially connected to the DH. From a multiple case study, only 14 DH plants of the 393 DH plants registered are estimated to be considerably affected from a complete repeal of the consumer obligations. A closure of these is not assumed to affect the cross-sector interplay and security of supply. Depending on the future regulations, fuel prices and actual acts of consumers, this may in worst case increase to up to 47 DH plants. The most adequate and long-term solution to minimise the economic consequences while assisting the market-based regulations of DH is found to be an ease of the current fuel- and CHP commitment. A socioeconomic evaluation of the affected DH plants should be carried out individually to state whether it is feasible to continue operation.

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Preface

This master's thesis is the final project of the Master's programme of Sustainable Energy Planning and Management at Aalborg University. The basis of this research stems from my acquired interest in district heating from studying it in various perspectives. I would like to express my gratitude to my supervisor, Steffen Nielsen for proper guidance and well-thought inputs throughout the project.

Reading Guide

Figures, equations and tables are numbered according to the chapter of their appearance. For example, the third figure in Chapter 1, will be numbered 1.3. Same applies for equations and tables throughout the project. Every figure and table is provided with a caption explaining its content. The first time an abbreviation is introduced, it will be written in full, followed by the abbreviation presented in parenthesis whereas it will subsequently be referred to as the abbreviation. References are made using the Harvard method, signifying that any source is marked with the surname of the author followed by the year of publication; [Author, Year]. If the source is added before a full stop it implies that it belongs to the contents of that sentence. However, if the source is added after a full stop, it covers the contents of the entire previous paragraph. The full reference list can be found starting on page 60.

Aalborg University, June 6, 2019

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1 | Introduction

The industrial development in Denmark was in the late 1800s and early 1900s enhanced by the cooperative movement which caused farmers, manufacturers, and suppliers of various services to join together in respective groups and partnerships in order to minimise overall costs. This also applied for the energy sector where district heating (DH) began to replace individual heating in dense urban areas. [Skov and Petersen, 2007]. In line with the cooperative thinking, DH was and still is, essentially centralising and streamlining the production of heat while partitioning expenses among consumers.

1.1 The foundation of Danish DH

The gradual transition from individual heating to DH made large investments possible which allowed investing in large production capacities of which the investment cost was cheaper per increased capacity. The large capacity production units were not only cheaper per capacity, but were also more efficient [Skov and Petersen, 2007]. In this way, economic savings were achieved in both investment and production. Apart from the economic savings, another benefit was the minimisation of manual work from fuelling the individual boilers. Hence, the initial benefits of DH were primarily economic savings and comfort. The disadvantage of DH is the grid losses induced from distributing heat in particularly over longer distances. With time, pre-insulated pipes and lower supply temperatures have decreased this loss. However, the average overall DH grid loss is still noticeable at around 23% [Dansk Fjernvarme, 2018a]. This exemplifies the fact that DH is most advantageous in dense areas where grid losses can be minimised. A further potential of decreasing this average grid loss is present and can be achieved from decreasing supply temperatures, optimise dimensions of pipes and increase the insulation thickness. DH started to dominate the Danish heat supply in dense cities around 1950 and 1960, where 250 new plants were established [Skov and Petersen, 2007]. The share of DH has increased since its beginning and is today the most common type of heating based on installations, with 63.9% of all heat installations in Denmark being DH [Energistyrelsen, 2018].

1.2 The versatility of DH in the Danish energy sector

The constant increase in the number of DH consumers is a result of the political and technological development that DH has gone through. During recent decades, DH has become an important part of the Danish energy sector. From primarily serving as a cheap and convenient alternative to individual heating, DH has developed to also assist the electricity sector and claim a key role in the green transition of phasing out fossil fuels in favour of renewable and sustainable alternatives [Danish Government, 2018a]. An outline of the versatile operation of DH in the Danish energy system is given in Figure 1.1.

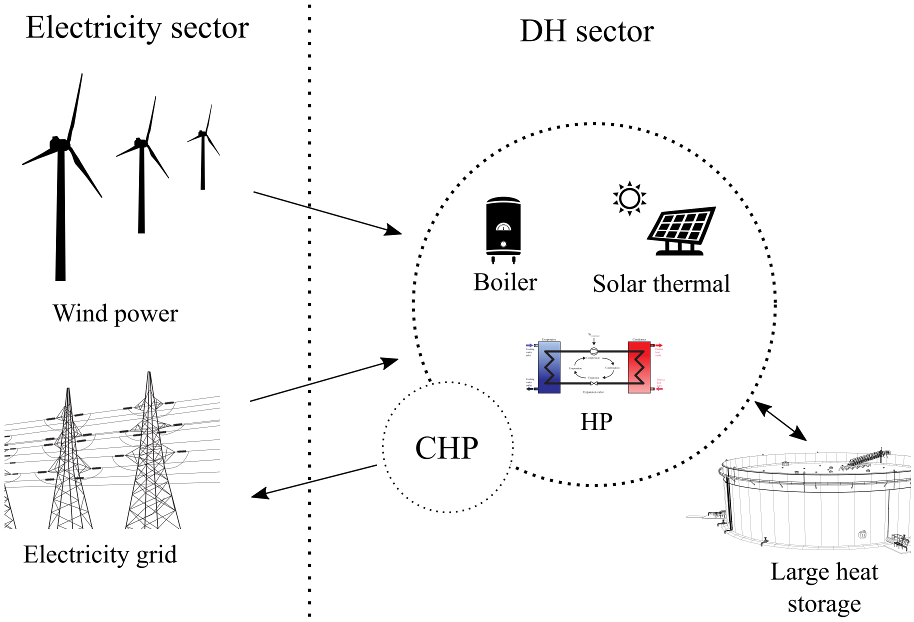

Figure 1.1: An outline of the versatile operation of DH in the Danish energy system. DH both assists the electricity sector and utilises renewable energy.

The assistance of the electricity sector to maintain a high security of supply is a result of the production of combined heat and power (CHP) and consumption of electricity at times of excess electricity production. By producing electricity when there is no wind or solar power production, the DH can maintain the electricity supply and by consuming electricity at times of excess production, energy can be stored in terms of heat. Storing energy in the form of heat can be done at a low cost compared to storing energy in e.g. batteries [Lund et al., 2016]. The DH sector has contributed as a versatile producer and consumer which seems to also have a great potential in the future, given that the capacity of intermittent energy supply such as wind power is projected to increase as a result of the aim of being fossil free in Denmark by 2050 [Danish Ministry of Energy, Utilities and Climate, 2018].

1.2.1 DH in regards to the green transition

The DH sector directly contributes to the phase-out of fossil fuels and reduction in CO_2-emissions. This can be confirmed by comparing the fuel supply for DH with fuel supply for individual heating. Most capacity of oil boilers in the DH sector are today either replaced or do only serve as emergency backup units [Energistyrelsen, 2018]. Thus, oil boilers were only primary production units for 0.5% of all DH plants in 2017, whereas 26.3% of the individually heated households (excluding households supplied by DH) were still supplied by heat produced from oil boilers. Also, primary production units supplied from NG made up only 15.7% in the DH and 42% of individual heating installations. [Energistyrelsen, 2018] One of the reasons for this is that fuels for DH are more easily converted to renewable and sustainable fuels due to the unified production and continuously revised regulations. Furthermore, the obligation to meet the EU requirements of CO_2-quotas which DH companies of more than 20 MW input capacity must meet, indirectly enhances the transition for utilising renewable and sustainable fuels and minimise consumption of fossil fuels [Danish Government, 2012a].

Besides utilising renewable and sustainable fuels such as biomass, solar thermal energy, biofuels and electricity, DH also has the benefit over individual heating to utilise excess heat from production facilities. With the integration of large heat pumps (HP), low-temperature sources from both excess heat recovery and natural heat sources can be utilised.

Currently, the DH sector is essential to the Danish energy system in terms of both security of supply and sustainability. Also in the future DH is projected to have a key role due to its possibilities from versatile operation [Danish Ministry of Energy, Utilities and Climate, 2018]. In the aim of Denmark to be fossil free by 2050, the DH sector has already proven to be a progressive shareholder of which a further potential is projected in e.g. excess heat recovery and in the utilisation of excess electricity production from intermittent energy sources. In 2017, DH produced from oil, coal and NG made up 28.3% of the total heat production [Energistyrelsen, 2018]. According to the energy agreement of 2018, by 2030, 90% of all heat produced for DH is to be produced from other energy sources than oil, coal and gas [Danish Ministry of Energy, Utilities and Climate, 2018]. Hence, production of heat based on oil, coal and gas needs to be reduced by 18.3% in 13 years. It is furthermore the objective that the remaining 10% of fossil fuel based heat production is phased out by 2050 to accomplish the aims of reducing greenhouse gas emissions according to the Paris agreement and EU energy strategy [United Nations, 2015] [European Union, 2012].

1.3 Future challenges to the DH

Due to the technological and legislative development since the beginning of DH, certain types of individual heating has gained competitiveness to DH during recent years both in terms of costs and sustainability. In particular biomass boilers of higher efficiency and HPs of higher coefficient of performance (COP), have proven ability to financially compete with DH while potentially being sustainable. The degree of sustainability both for DH and individual, depends on the specific fuel supply which can be questioned for both biomass in terms of reforestation [Sørensen et al., 2018] and electricity in terms of renewable production such as the wind penetration rate [Fraile and Mbistrova, 2018].

1.3.1 Individual heating

In 2018 the tax on producing heat from electricity was reduced for HPs to be implemented both in individual heating and DH. As a result of this reduction, an estimate was made that the price of heating a standard single-family house from a HP, would be approximately 15,000 DKK/year [Lilleholt, 2018]. For comparison, in January 2019 the average price of a standard single-family house supplied from DH was 14,164 DKK/year. The distribution of prices from all Danish DH plants can be seen in Figure 1.2. It can also be seen that the highest price of DH in January 2019 was 25,659 DKK/year. [Forsyningstilsynet, 2019a]

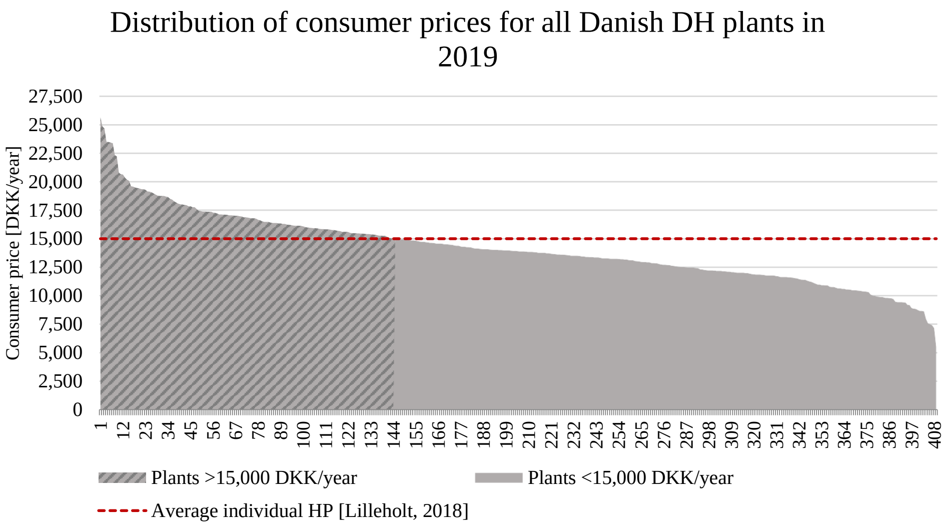

Figure 1.2: Distribution of all Danish DH consumer prices of a standard single-family house and average estimated price of an individual HP [Lilleholt, 2018]. The marked area represents the DH plants of higher price level than the estimated price of an individual HP.

Statistically, this means that 35% of DH plants have a price that is higher than the estimated price of 15,000 DKK/year for heating by an individual HP. Compared to the average price of DH in 2018, this is an increase of 8%, which among other things is a result of the phase-out of the capacity payment.

1.3.2 Consumer obligations

The spread of- and support to DH in Denmark led to a definite legislation in 1983, applicable to the collective natural gas (NG) and DH supply. This legislation is known as the Heat Supply Act (HSA) [Danish Government, 2019]. The HSA intends to ensure the most socioeconomic and environmentally sustainable heat supply and considers the collective basis that DH is built upon. A definite example of the considerations toward the collective heat supply is the consumer obligations which tie consumers to the collective heat supply to ensure the profitability of investments. [Danish Government, 2019]

However, the consumer obligations is also what currently prevents consumers with expensive DH installations from replacing it with cheaper individual alternatives without still being bound to pay a share to the DH. The consumer obligations applicable in the Danish DH was implemented by law to ensure the profitability of large investments made, but has later appeared to also be advantageous in heat planning and expansions of DH grids where it has ensured socioeconomic investments further advancing the green transition. [KTC and KER, 2017] The consumer obligations can be divided into two governing obligations; *the obligation of connecting* and *the obligation of remaining connected*. These obligations are applicable according to the HSA [Danish Government, 2019] and law of consumer obligations for collective heat supply [Danish Government, 2016]. By January 2019, the consumer obligations were eased as the obligation of connecting was cancelled from the HSA [Danish Government, 2019]. The obligation of connecting was stated as:

> "A commitment for a property to connect to the collective heat supply i the area, which e.g. implies that the owner of the property needs to contribute financially to the collective heat supply as stated in § 7 of the HSA."
>
> [Danish Government, 2016]

This means that the municipality is no longer allowed to compel newly built houses and houses of potential DH connection, to connect and financially contribute to the collective heat supply. Hence new connections are now based solely on the free will of the consumers. This liberalisation and thinking is part of the regulative and legislative consideration that is made in terms of DH and indicates the governments' proposed future economic regulations for the DH sector [Danish Ministry of Energy, Utilities and Climate, 2017a]. Generally, the DH sector is proposed to transition from being regulated on special terms and operate on separate market conditions to be based on equal conditions to other sectors and consumer groups.

It is assumed that this transition will also be applied for the obligation of remaining connected.[Danish Ministry of Energy, Utilities and Climate, 2017a] The obligation of remaining connected is currently stated as:

> "A commitment for a property that is already connected to the collective heat supply in the area to remain connected, which e.g. implies the owner of the property to contribute financially to the collective heat supply as stated in § 7 of the HSA."
>
> [Danish Government, 2016]

Consequently, consumers who are already connected to a collective heat supply are not allowed to change for individual heating without still financially contributing to the collective heat supply. That is unless the building meets certain requirements of exception. Exceptions from the consumer obligations have so far only applied for certain circumstances and buildings, including buildings already heated from renewable energy sources and buildings, declared as low energy buildings at the time of building approval [Danish Government, 2016]. With only a fraction of the DH consumers already excluded from the consumer obligations, several operators of DH plants has expressed their concern towards the governmental propose for a complete repeal of the consumer obligations [Dansk Fjernvarme et al., 2018]. Thus it has been suggested that the government conduct a thorough analysis, covering the consequences that a complete repeal may entail. In this regard, the municipal technical head association (KTC) and professional group for climate, energy and resources (KER), has stated their highest concerns towards a complete repeal of the consumer obligations [KTC and KER, 2017]. Concerns are specifically made in regards to smaller DH grids, new-built areas and the heating sector in relation to the green transition. A repeal of the obligation of remaining will ultimately result in a reduction in the number of consumers. As the DH is built upon the principle of financially breaking even, a decrease in the number of consumers will increase the price of heat for the remaining consumers. Additionally, DH plants with a consumer price above average, have a significantly higher risk of losing consumers, as individual heating technologies are more likely to be competitive. [KTC and KER, 2017]

Potential consequences of a complete repeal

The potential consequence of a repeal of the remaining consumer obligation is consumers changing from DH to individual heating. Derived consequences of this are business economic and socioeconomic losses which at worst case is a result of a bankruptcy. The business economic losses for the DH plants is a result of losing income in means of consumers while still having to amortise loans and maintain the operation of the existing production units. A lower production due to fewer consumers may cause less efficient operation of the plant and higher cost of maintenance per consumer. These losses of income and additional expenses would have to be accommodated by increasing the price of heating which then again could result in even more consumers leaving the collective heat supply. The socioeconomic losses are potential losses of scrap values from pipes and increased socioeconomic costs of heat. Also, in case that some consumers remain, the plant would still be obliged to supply heat due to its universal service obligation stated in the HSA [Danish Government, 2019].

Hence, plants producing and distributing heat at a noncompeting price compared to individual heating may face consumer losses and in the extreme face bankruptcy, if a sufficient number of consumers resign from the collective heat supply.

2 Problem statement

DH has played a central role in both cross-sector electricity production and in the transition for implementing more renewable energy. Also in the future, DH is projected to have a central role in further utilising renewable and sustainable energy sources such as solar thermals and electricity with the additional benefit of large scale heat storage. Both legally and financially, DH is established with specific considerations to its consumers. Up till today, the consumer obligations has protected DH from the direct competition and potential consumer losses. However, by 2019 the consumer obligations were partly withdrawn and are potentially facing a complete repeal according to a governmental consultation which suggests a liberated heat supply further based on market conditions [Danish Ministry of Energy, Utilities and Climate, 2017a]. The consequences of this may be comprehensive and several plant operators have expressed their concern towards it, leading to considerable consumer losses and potential bankruptcies. [Dansk Fjernvarme et al., 2018] Hence, it is requested to evaluate if the obligation of remaining can be phased out, what consequences it may induce and what parameters are decisive in this regard. This study is delimited to investigate this on a general sector level where specifically chosen DH plants are investigated to demonstrate how many and which DH plants are exposed to consumer losses. Finally, it is investigated how the derived consequences can be evaded or minimised.

Research question

To what extent are Danish DH plants affected by a complete repeal of the consumer obligations?

Sub questions

- Which Danish DH plants would be most affected by a complete repeal of the consumer obligations?
- What consequences can a complete repeal of the consumer obligations induce?
- What parameters are decisive in assessing whether consumers want to change for individual heating?
- How can consequences from a complete repeal of the consumer obligations be minimised?

3 Methodology and Theoretical Framework

This chapter aims at describing the methods and theoretical framework applied for this study. Approaches to the problem are described through applied methods and underlying knowledge in the investigation is described through theories. Due to the coherence of the two, this chapter does not further distinguish between the two.

3.1 Basis of the thesis

Chapter 1 described the foundation of DH and its importance to the Danish energy system along with the future challenges it may face in terms of consumer obligations. From a more subjective point of view, the study is based on a concern expressed by operators of Danish DH plants at the national fair of DH 2018. It was here stated by the minister of energy, utilities and climate, Lars Chr. Lilleholt, that the obligation of connection was to be phased out by 2019 and that the obligation of remaining would be maintained for now. This raised questions of what investigations had been made in this regard and the minister ensured that a more thorough analysis would be carried out before a complete repeal of the consumer obligations. Currently, several investigations have been made regarding competition between individual heating and DH. [Hansen and Gudmundsson, 2018] [Dansk Fjernvarme, 2018c] [Ea Energianalyse et al., 2017] However, common to all of these studies is that they do not account for the dynamics at consumer level within each DH grid and nor do they quantify the possible consequences of a complete removal.

Hence, the hypothesis for this study is that a complete repeal of the consumer obligations will cause consumers to leave the DH and put DH plants in an economically infeasible situation. To test this hypothesis and include considerations towards specific consumers, the study will investigate basic assumptions of DH and individual heating and compare the resulting prices on a consumer level.

The theoretical framework of the study is built around technical, economic and regulatory measures. The technical measures are used in regards to heat production and the estimations hereof. Economic measures are used through evaluation and comparison of prices. Regulatory measures are used for evaluating energy policies. Furthermore, sociological and environmental measures are used through subanalysis and in general considerations throughout the study. Hence, the study is a mix of various measures, which together constitute the socio-technical problem.

3.2 Case study

All measures are essentially embedded through the cases of this study. The case study is conducted by investigating multiple DH plants of which each case represents a DH plant. Hence, a *multiple case study* is conducted [de Vaus, 2001]. The other type of case study and possibly the most used is a *single case study*. A single case study would for this investigation be insufficient as the data i.e. prices of heat and composition of prices differ greatly from plant to plant. The advantage of conducting a multiple case study rather than a single case study is the compelling and powerful insight it provides. From investigating multiple cases, a tougher test of a theory can be made as it is tested under which conditions a theory may or may not hold. However, the robustness of the multiple case study relies on a sufficient number of cases and a cautious selection of cases. [de Vaus, 2001] The slection of cases will be elaborated on in section 4.3.2.

By investigating actual cases, the reality is represented directly through results. Due to the complexity and the time-consuming data gathering of data of all Danish DH plants, the multiple case study is based on specifically selected cases. The selection of cases is based solely on the price of heat for every single DH plant. Hence, the choosing of cases is based on behalf of the price rather than be chosen randomly from a statistic representation. Thus, it is not the aim to make a statistic generalisation, but rather a theoretical generalisation where each case is contributing to support or dismiss the hypothesis that there is a correlation between the price of DH and resulting consumer loss from a complete repeal of the consumer obligations. Initially, a DH plant for every thousands DKK/year in annual price is investigated to specify which range of DH plants are more affected. From this, the number of cases was increased for the range of plants of interest.

From the multiple cases, a general tendency and correlation between prices of DH plants and consumer losses is sought. The aim of this is to predict consumer losses of cases which are not investigated through the case study. Results are averaged across ranges in prices which inevitable causes deviations from the individual cases. However, for investigating the overall consequences this is assumed sufficient. From a such theoretical generalisation, the number of cases and spread of cases is crucial to the accuracy of the results.

3.3 Report structure

In Figure 3.1 the formal report structure is given. To the right of the figure, the governing question to the respective chapter is stated and to the left, the theories, methods, and acts to answer these questions are listed.

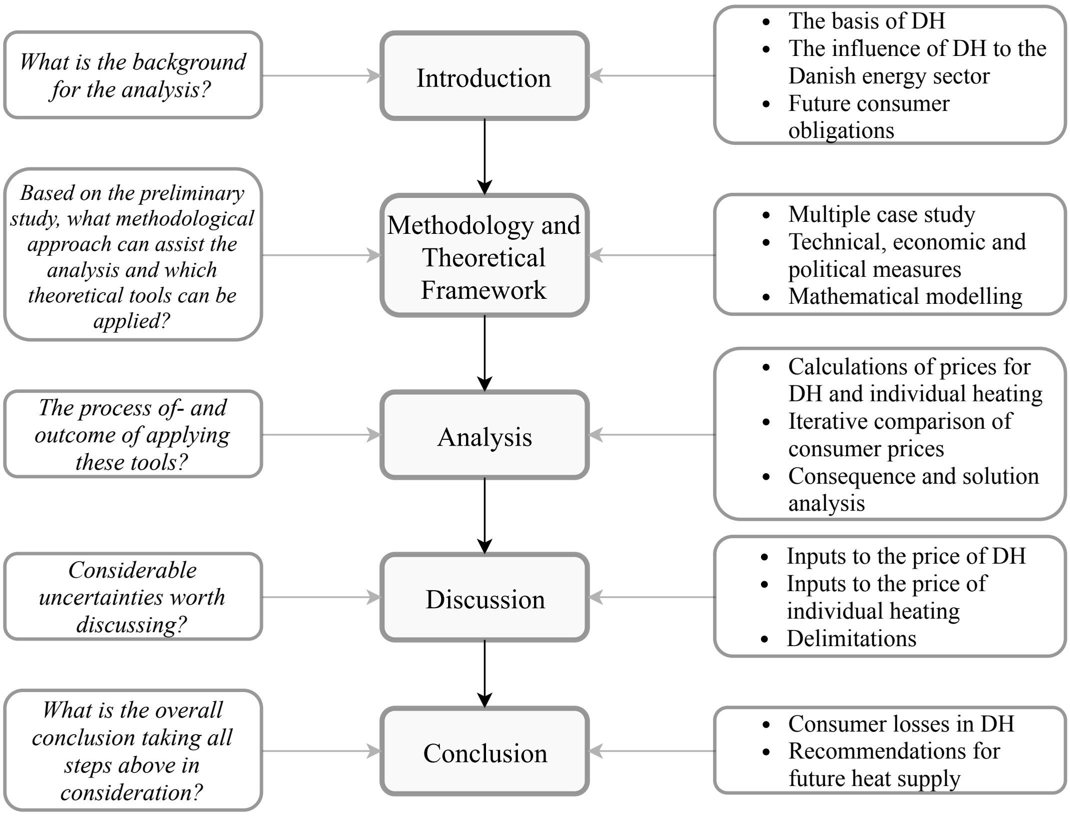

Figure 3.1: Report structure with chapters and description of chapter content.

The structure of the report is structured to initially state the problem and its underlying causes and then describe the approach and tools for solving the problem. The first, second and fourth sub question of of the study are addressed through the analysis. The aim of these sub questions is to outline the DH plants most affected from a phase-out of the obligation of remaining and quantify consequences as well as describe how these can be evaded to minimise consequences. The third sub question is addressed through the sensitivity analysis in the discussion and aims to answer which parameters are causing the evaluated consequences. Lastly, the conclusion will sum up on results and recommendations from the study.

3.4 Data and data gathering

The various measures of the study mean that the data gathered for the study are both quantitative and qualitative data. The quantitative data is primarily used for the model of calculations and comprises consumer data and building specifications such as heated areas and derived heat demands. Furthermore, the specifications for the production of heat and distribution of heat are quantitative data. These comprise efficiencies and the cost of fixed and variable character.

Qualitative data mainly concern statements and considerations regarding the legislation. Another type of qualitative data used, is the considerations towards consumers' affiliation to DH described by Danish Competition and Consumer Authority [2017]. Hence, the consumers' awareness towards prices of heating and willingness to change for individual heating. Problems of such qualitative measure are often referred to as wicked problems as they cannot be definitively described. Consumer behaviour might as well be affected by environmental awareness, trust and economic factors. To wicked problems there are no true or false and the result may very likely vary from each inquiry. Thus, the same definition applies for policy problems. [Rittel and Webber, 1973]

All data gathered for the study are evaluated in terms of validity and reliability. An approach for this is distinguishing between primary and secondary sources. Of these, primary sources are preferred in terms of validity and reliability as possibilities of misinterpretations, misunderstandings, etc. are reduced. Legislation data are gathered through www.retsinformation.dk which is a governmental database regulated by the Danish Department of Civil Affairs under the Danish Ministry of Justice. Hence, data refer to official documents of legal agreements. For fuel prices, taxes and subsidies, data have been gathered through Danish authorities such as Energinet, the Danish Energy Agency and the Danish Tax Affairs. For certain data, the authorities are secondary sources. However, as a governmental instance, these sources are assumed to have no intention of spreading misinformation. A secondary source used, is the data gathered for Danish buildings. These data origins from the Danish building and household register (BBR), but have been pre-processed to analyse the potential of DH in Denmark [Grundahl, 2017]. The reason that this secondary source is considered valid, is that it is processed with an objective approach that incentives no interest in manipulating data for any given outcome. Also, the BBR data can be considered as a tertiary source as the exact data is essentially only known to the consumer of a specific building.

Another method for ensuring validity of results is through validation of data. However, for certain research validation is not possible due to lack of comparable data and computations. For this study, validation is complicated from the large amounts of data and the fact that no study is found to use data in the specific configuration of this study.

3.5 Analytical approach and tools

The analytical approach for this study is governed by the large amounts of data and the multiple measures involved. The BBR data initially contain 2,554,280 data points each representing a building with information of the geographic location, type of heat supply, year of construction of the building, etc. To handle the large amounts of data and to geographically define the data points of interest, the geographical information software, ArcGIS has been used. Microsoft Excel is simply limited to a certain amount of data and visually defining buildings within each DH grid is more practical and time efficient. Buildings are initially sorted by type of heating supply. Then from an outline of cities, buildings within each DH grid are defined. Hence, a data set of buildings within each DH grid is made.

The pre-processed data of buildings also contains estimated heat demands based on every single building [Grundahl, 2017]. However, average heat demands based on the year of construction have been made for this study. The reason for this is to ensure that heat demands represent the concurrent stage of insulation standards etc. The assessment of heat demands is further elaborated in section 4.2.3.

Large amounts of data are also gathered in terms of DH plants and corresponding prices of heat. In the statistics made by Forsyningstilsynet [2019a], 393 DH plants are listed with corresponding variable prices and total prices of heat for a standard single-family house of 130 m^2. Based on the listed DH plants 39 DH grids were selected in a circumspectly way aiming at covering the full price spectre as well as thoroughly analyse the DH plants with the highest prices of heat. Specific fixed and variable prices of the 39 DH plants were gathered from the tariffs of each DH plant.

By combining the sets of data, the price of heating for every single building can be estimated. The combining of data and the main analysis is made in Microsoft Excel. Through the embedded functions of Excel, a matrix is made indicating the area of each building as well as the heat demands based on the year of construction. By multiplying the matrix with the variable price of the specific DH plant and individual heating, the variable cost for every building can be calculated and added to the fixed costs. The capacity payment of DH is furthermore multiplied with the heated areas. A more in-depth clarification and overview of calculations are given in section 4.3.1.

When calculating the consumer losses induced by prior consumer losses, an iterative calculation is conducted. Essentially it means that calculations are recalculated in iterations until the result converge or a convergence criterion is fulfilled. For each iteration, the inputs are updated which in this case means that the fixed price of heat is updated according to the number of consumers who choose to leave the DH according to the previous iteration. A convergence criterion is for these calculations a minimum of change allowed for the price of heating.

Besides ArcGIS and Microsoft Excel, EnergyPRO has been used for estimating variable costs of DH. The reason for using EnergyPRO and not simply adding up costs and taxes for each technology is its efficient setup of model inputs for evaluating changes hereof. Furthermore, the visualisation of spot price dependency has been used for estimating ranges of variable costs in a present context.

4 Analysis

In order to conduct the analysis, investigating consequences of a complete repeal of the consumer obligations, a series of preliminary sub analysis needs to be conducted. Initially, it is evaluated how the price of heat is distributed for all Danish DH plants. The aim of this is to obtain an overview of how groups of DH plants differentiate in terms of price and to possibly narrow down the field of plants for the analysis based on prior knowledge. Following, parameters decisive to the economic vulnerability of plants are derived and specified. These parameters link the price of heat to the investigated necessity of the consumer obligations. The specified parameters are used as inputs for the governing analysis, investigating the competitiveness of DH to individual heating. From this analysis, it is feasible to quantify how likely plants are to suffer economically from a repeal of the consumer obligations by estimates of how many consumers will leave the DH grid.

4.1 Danish DH plants

Several divisions are made within the Danish DH sector. Division of plants can be made, based on parameters such as capacity, number of consumers, type of supply etc. A common division often referred to, is the division in *centralised plants*, *decentralised plants* and *only heat-producing plants*. This division is primarily based on the type of supply as it distinguishes between electricity producing plants and non-electricity producing plants. However, it also considers capacity and number of consumers to some extent, as the centralised plants are defined among the largest plants of more than 25 MW electric capacity [Danish Ministry of Energy, Utilities and Climate, 2017b] [Danish Government, 2014].

4.1.1 Centralised-, decentralised- and only heat producing DH plants

As centralised and decentralised plants are both groups of DH plants with CHP production, the income of selling electricity on the spot market is contributing to a lower price of heat. However, it is only favourable to produce electricity in circumstances where the spot price is higher than the production costs including taxes. Hence, CHP plants are in most cases also capable of only producing heat from a secondary production unit. Depending on the spot price and fuel costs etc., an only heat-producing plant may be cheaper in operation for certain hours. However, this heavily depends on fuel costs, spot prices and operation and maintenance (O&M) costs. During the recent years the spot price has been decreasing and as a result, the number of full load hours of CHP production has decreased from more than 3,000 hours/year in 2010 to approximately 1,000 hours/year in 2017 [Boes, 2018]

Price statistics have been gathered annually by Forsyningstilsynet [2019a] since 2007. By applying the aforementioned division of DH plants, these statistics show that the price of heat does depend on the type of plant. However, the most significant distinction is made from the capacity and number of consumers. As shown in Figure 4.1, during the most recent 5 years, prices of heat has been rather stable, but centralised plants have statistically been 10%-31% cheaper than the average price of heating. Also, the difference between decentralised plants and only heat-producing plants have only differed 1%-11% and has equalled by 2019. One of the reasons for this is the phase-out of the capacity payment which caused an increase in the price of heat for decentralised plants.

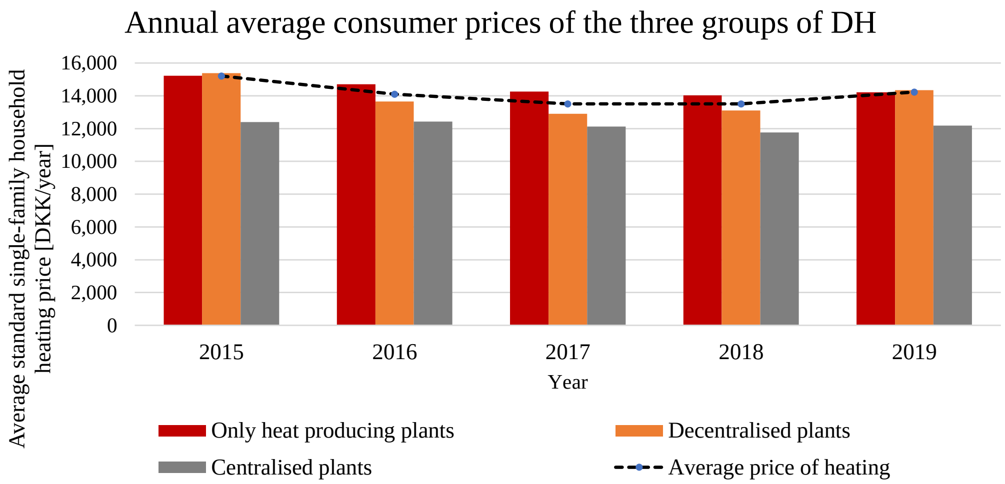

Figure 4.1: The average price of heating based on the division of centralised-, decentralised- and only heat producing plants.

The price of heat which is referred to and compared is based on a widely used estimate of a standard single-family house. This estimate is based on an annual heat consumption of 18.1 MWh in a 130 m^2 house, including both space heating and domestic hot water use. Annual heating prices will henceforth refer to the annual price of heating a such standard house if not stated otherwise.

From the 393 DH companies assessed by [Forsyningstilsynet, 2019a] in 2019, 9 plants have been assigned as centralised plants, 197 as decentralised plants and 187 as only heat-producing plants. Due to the price of heating from centralised plants being 2,153 DKK/year and 2,025 DKK/year lower on average than for the decentralised and only heat-producing plants respectively, the centralised plants are not considered to be influenced by the potential repeal of the consumer obligations. Furthermore, the centralised plants supply heat to more than 30,000 consumers on average [Dansk Fjernvarme, 2018b] and are decisive to the electricity sector. Hence the relatively low price of heating combined with the relatively high number of consumers and cross-sector importance excludes the centralised plants from the further analysis.

4.1.2 Spread of DH prices

Compared to other services and products, the DH sector is characterised by having a large spread in prices. As described in the previous section, the average difference between only heat-producing plants and decentralised plants is not currently considerably large, however, the price range across the individual DH plants is. The difference in annual cost from the cheapest to the most expensive is 20,801 DKK for a standard single-family house.

The distribution of DH plants based on the annual cost of heat can be seen in Table 4.1. The number of DH plants are given in price intervals along with the percentage that they represent from all DH plants. Notable is that 57% of Danish DH plants lie within the range of 10,000 to 15,000 DKK/year for heating a standard single-family house. Also, the vast majority of DH plants have a price of heat below 20,000 DKK/year.

$C_{B,DH}$ [DKK/year]	**Number of DH plants**	
25,000-	1	(0.3%)
20,000-24,999	13	(3.3%)
15,000-19,999	126	(32.1%)
10,000-14,999	224	(57.0%)
-10,000	29	(7.4%)

Table 4.1: Numbers of DH plants within each range of DH prices.

From the spread of prices in Table 4.1, plants are covered in intervals of 5,000 DKK. By doing this, intervals cover the most expensive, the average priced and the cheapest DH plants. As a distinct correlation between the DH price and potential consumer losses are found, results are henceforth represented from a subdivision similar to Table 4.1.

4.2 Preliminary studies

As clarified in Chapter 1, the possible repeal of the consumer obligations is generally affecting the plants with a high price of heating and a low number of consumers. This is due to the competitiveness that individual heating solutions have gained and the increased risk of bankruptcy in case that few consumers opt out of DH. However, additional parameters affect the price of heat and the choice between DH and individual heating. Of these parameters, the following has been investigated:

- The price of DH
- The price of individual heating
- Building stock based heat demand
- Consumer affiliation to DH
- Terms and conditions for consumer withdrawals

4.2.1 The price of DH

According to the HSA, DH companies are restricted to only charge money for production related expenses [Danish Government, 2019]. Hence the principle of breaking even is compulsory to the DH sector. However, the distribution of costs vary from plant to plant due to the expenses that they cover and so does fees for the DH. Generally, the total plant costs and the total consumer fees can be divided into *fixed* and *variable* costs and fees.

The fixed fees comprise all costs which do not specifically vary with production. Being; staff salaries, administration and sale, costs of public obligations etc. For the consumers, these costs are usually assigned as fixed fees as well, based on the number of meters in the household and area of heated household. These costs are also known as the consumer subscription fee and consumer capacity fee. Unlike the variable fees, fixed fees are directly dependent on the number of consumers,

Plant costs	**Fixed costs**	**Variable costs**	**Other costs**
	• Staff salary • Administration & sale • Consultancy • Public obligation • Grid maintenance	• Production • O&M • Taxes	• Grid expansion
Consumer fees	**Fixed fees**	**Variable fees**	**Other fees**
	• Subscription • Capacity	• Consumption	• Connection

Figure 4.2: An overview of plant costs and corresponding consumer fees.

as the plant costs of which the fixed fees make up are rather constant and equally divided between consumers. The reason for the fixed costs and fixed fees to not be definitely constant in the case of a consumer decrease is the fact that a sufficient decrease might have an impact on staffing due to less need of manpower, grid maintenance due to more unused grid etc. For this study, however, the fixed fees are assumed to increase according to a decrease in consumers. Thus, a 5% decrease in consumers yields a 5% increase in fixed consumer fees.

Variable costs and fees, on the other hand, vary with production and depends on the demand of heat. The variable fee is directly linked to the costs of production and is paid per consumed MWh or m^3. Hence it greatly depends on the type of heat production specific to the plant. When comparing plants, this cost of production is often used as a parameter to weigh technology and efficiency between plants. The fee is also referred to as the consumption fee. A decrease in consumers is assumed to only have a minor impact on the variable plant costs and variable consumer fee. This is due to the fact that production of heat would simply be less, only affected by the efficiency and transmission losses. The efficiency of the heat production unit is dependent on the load at which it produces, thus a lower demand would eventually cause the efficiency to decrease. The transmission heat loss, on the other hand, would increase per consumer, if consumers on the same transmission or distribution line disconnected from it. For this study, the variable consumer fees are kept constant, unconditioned by the decrease in the number of

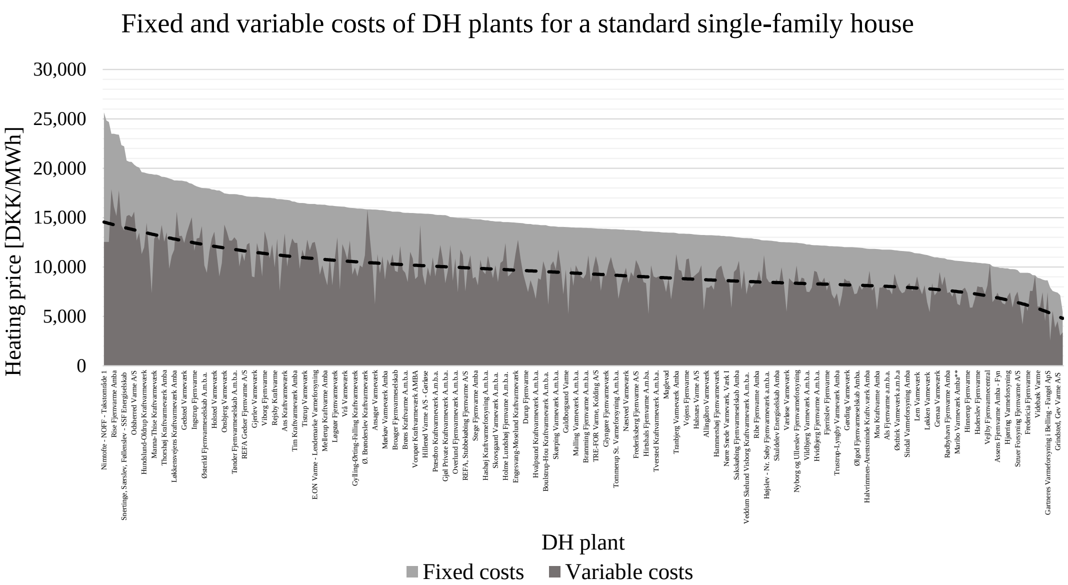

Figure 4.3: Fixed and variable production costs of all investigated DH plants ranged from most to least expensive plant based on the total annual price of heating. [Forsyningstilsynet, 2019a] Tendency line of the variable costs is given by the dotted line.

consumers.

Besides fixed and variable fees, grid expansions and new connections to the DH grid are financed from installation or connection fees. However, as only the decrease in the number of consumers is investigated, these costs are not included in the further analysis. An overview of plant costs and consumer fees can be found in Figure 4.2.

Statistics by Forsyningstilsynet [2019a], show that the average variable production cost in 2019 was 526 DKK/MWh with an upper and a lower price of 988 DKK/MWh and 141 DKK/MWh respectively. There is a general tendency between the variable production cost and the total price of heat as can be seen from the dotted tendency line in figure 4.3. However, the fluctuations in variable production costs indicate that the relation between the total price of heat and consumer dependency is not consistent. Due to the dependency between the fixed fees and the number of consumers, a plant of higher total heat price may be less influenced by a decrease in consumers than one of lower total heat price and vice versa.

To sum up, in the case of a decrease in consumers, variable consumer fees are assumed to remain constant while fixed fees are assumed to increase according to the decrease in consumers. Also, a high total price of heating is not necessarily implying that a plant is more vulnerable to loss of consumers, as the ratio between variable and fixed fees vary from plant to plant with some dependency to the total price of heat.

4.2.2 The price of individual heating

A dismiss of DH in favour of an individual alternative is presumed to take place only if the price of heat is lower and practical circumstances are comparable to DH. Thus, the cheapest and most comparable alternative to DH is sought through this subanalysis. Of comparable aspects besides the price of heat, the degree of sustainability and comfort will be taken into account and compared as these are considered to have an impact on the choice. For the degree of sustainability, it is evaluated whether the legislation approves the specific change for a potentially less sustainable source of heat. For the comparison of comfort, manual work and space requirements are evaluated. The individual heating technologies investigated are; oil boilers, NG boilers, biomass boilers and HPs. Evaluation and comparison of each technology of individual heating will be made considering the price of heat, sustainability and degree of comfort.

Oil boiler

In case of a complete repeal of the consumer obligations, the choice of alternative individual heating is to some extent limited by the energy agreement of 2012. Accordingly, individual oil boilers are no longer allowed to be installed and old oil boilers are no longer allowed to be replaced by new oil boilers. [Danish Government, 2012b] The installation of an oil boiler fuelled by fuel oil would furthermore be a retrograde step in terms of sustainability and in terms of comfort by means of manual fuelling. The average fuel price of 2018 was 11.22 DKK/litre (1.2 DKK/kWh) of which taxes accounted for 41% [Agency, 2019]. The high fuel price and legislative framework conclude the fact that oil boilers are not assumed to be an option for replacing DH.

NG boiler

A widely used fuel in the Danish heating sector and technology for individual heat supply is NG and NG boilers. In 2017, 15.3% of all Danish households were heated by individual natural boilers, making it the second most common type of heating installation [Energistyrelsen, 2018]. For a house to be heated by a NG boiler, it is first and foremost required that NG is supplied in the area. In 2009 the Ministry of Climate and Energy urged municipalities to consider converting individual NG supply for DH Hedegaard [2009]. Thus, areas where NG has previously been

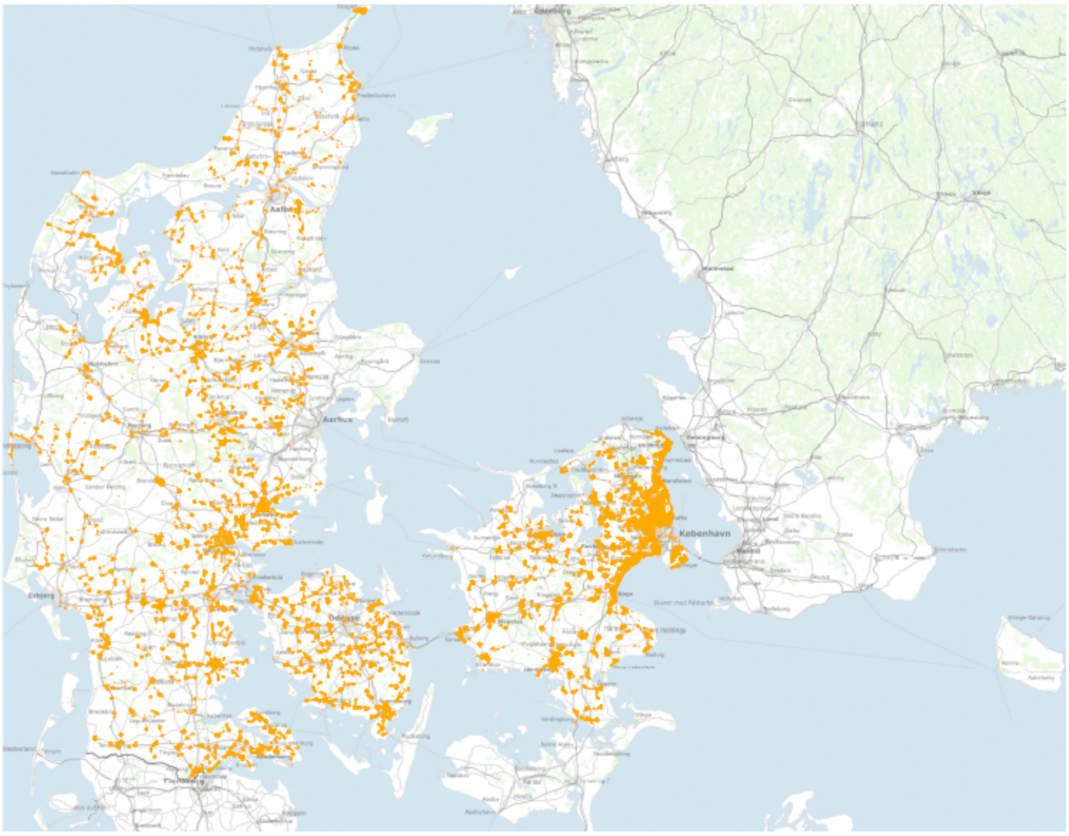

Figure 4.4: Map of Denmark showing consumers supplied by NG. [Grundahl, 2017].

distributed for heat supply and where the NG grid is maintained gives opportunity for yet again installing a NG boiler instead of DH. In Figure 4.4 the consumers from the heat atlas assigned with NG as heat supply is marked. From this figure, it can be seen that NG is distributed widely across the country.

NG boilers of today's standard have proven to have efficiencies of up to 98.7% [Schweitzer et al., 2015]. The high efficiency and relatively low gross fuel price at around 7-8 DKK/m^3 [Danish Utility Regulator, 2019] in 2018, partly explains the continual recognition of NG boilers. The other main strength of NG boilers is the comfort which is more or less comparable to DH, as no manual work for fuel supply is required. However, NG boilers do take up physical space for the boiler and due to the risk of a gas leak and potential poisoning, the boiler needs service and maintenance frequently. It is expected that some consumers will maintain their supply of DH for this reason alone.

Besides the limited supply to Danish households, NG and NG boilers also fall short, considering their current degree of sustainability. As NG is considered a fossil fuel, plans of minimising the use of NG has already been made. These plans consider expanding biogas production to replace NG to the extent possible and replacing NG supplied production units with renewable and sustainable alternatives [Danish Ministry of Energy, Utilities and Climate, 2018]. In 2018, the share of upgraded biogas in the NG supply was 9% [Energinet, 2018]. Hence, it is not assumed achievable for biogas to completely replace NG within the time frame of a repeal of the obligation of remaining.

Biomass boiler

Biomass boilers are primarily installed in the outskirts of dense cities where DH and NG is not distributed. The reason for this is primarily because of the required space for the boiler and for storing fuel. The solid biomass fuels most commonly used, are wood logs, wood chips and wood pellets. The type of fuel also complicates the fuel supply as it requires frequently manual work to supply the boiler with biomass. Supposedly, because of these requirements, in 2017 biomass boilers only made up 11.3% of all heating installations together with HPs and electric heaters [Energistyrelsen, 2018].

Apart from the inconvenient demand for space and required manual work, biomass boilers are relatively cheap in production. One of the reasons for this is the exemption from taxes. Because of this, the price per MWh of heat is the lowest of all investigated types of individual heating at only 610 DKK/MWh [Energianalyse, 2017]. However, the relatively low efficiency of 90.1% on average [Teknologisk institut, 2019], increases the actual cost of heat.

The sustainability of solid biomass is a well-debated topic. Generally, the sustainability of biomass depends on the ratio between foresting and reforesting [Sørensen et al., 2018]. Hence, the sustainability of biomass is limited by the growth of new biomass. Additionally, in Denmark biomass is a limited resource and 43% of the biomass consumed in Denmark is imported [Sørensen et al., 2018]. By importing biomass the emissions caused by transportation also needs to be overcome in order to minimise the carbon footprint. From a national economic perspective, the import of biomass reduces the national balance of payment. Suggestions to put equal taxes on biomass as to other fuels have been made by Sørensen et al. [2018], in an attempt to avoid overconsumption of biomass.

Due to the complications regarding practicality and comfort, biomass boilers are not considered a typical alternative to DH.

HP

From the political agreement of 2018, it is clear that a strategy is made to promote electricity in the entire energy sector. The agreement also contributed to an electrification of the heating sector by removing the PSO (public service obligation) tax and lowering the electricity to heat tax. A distinct and defined aim was to increase the national capacity of HPs. [Danish Ministry of Energy, Utilities and Climate, 2018]

With the lowered taxes, HPs are now more competitive to other individual technologies and DH. However, an important criterion for the HP to be competitive is the efficiency. Opposite to boilers, the efficiency of a HP is not given by a percentage of the fuel input, but by a coefficient of performance (COP). The COP indicates the ratio of heat output per unit of electricity input. Hence a COP of 2 means that e.g. 1 MW of electricity input capacity equals 2 MW of heat output capacity. Basically, this is achieved by evaporating a refrigerant obtaining energy from a low-temperature source. Thus, the COP is very dependent on the low-temperature source in order to gain a high COP. Also, the output temperature is determining the COP as a high output temperature requires a higher energy input, hence lowering the COP. From a practical perspective, this means that the higher indoor temperature, the lower the COP.

For individual heating two types of HPs are governing. These differ by having either ambient air (air-to-water or air-to-air) or geothermal heat (water-to-water or water-to-air) as the low-temperature source. To compare DH to the most efficient type of HP and most comparable type to DH, the water-to-water HP has been chosen for further investigation. The higher efficiency is because the low-temperature source is geothermal which means that the temperature changes less during the year. An air-to-water HP is known for being for noisy, making it less comparable to DH in means of comfort.

The seasonal temperature change of the low-temperature source changes the energy absorbed from the ambient source of heat and thereby the COP. To account for this seasonal dependency of the COP, a seasonal coefficient of performance (SCOP) is specified by the European Union (EU). The SCOP is calculated from an average annual ambient temperature profile and indicates the seasonal average COP of a HP [Danish Energy Agency, 2011]. The Danish Energy Agency (DEA), has performed test of HPs and provided a list of HPs and corresponding SCOPs [Danish Energy Agency, 2019]. Of the listed HPs, the SCOP ranges from 3.3 to 4.3, with an average SCOP of 3.74. With a gross electricity price of 2.2 DKK/kWh, the price per MWh of heat amounts to 588 DKK/MWh$_{heat}$.

As for the biomass boiler, the sustainability of HPs depends on the origin of the fuel. Electricity production in Denmark and neighbouring countries of which electricity is imported vary from being fossil fuel-based to being almost entirely renewable [EMD International A/S, 2019]. However, fossil fuel based electricity production is gradually being replaced with wind turbines, solar thermals and other renewable energy sources as also outlined in the most recent energy agreement of 2018 [Danish Ministry of Energy, Utilities and Climate, 2018]. In comparison to DH, electricity production is currently being produced at centralised and decentralised plants which presumably makes the two equally sustainable.

Summary

A summary comprising fundamental variables and costs of the investigated alternatives to DH, are listed in Table 4.2. From an energy efficiency perspective, the HP is, in particular, the most efficient alternative to DH with a COP of 3.74. The alternative of the lowest efficiency is the biomass boiler. However, due to the low fuel price, it is the cheapest alternative investigated regarding the specific price of heat. The specific price of heat, specified as the variable cost, includes the cost of fuel and taxes. Fixed costs of individual heating comprise subscription fees and investment costs and are included in the given price of a standard single-family house of 130 m^2 and annual heat demand of 18.1 MWh.

	Efficiency [-]	**Variable cost [DKK/MWh$_{heat}$]**	**Std. house heating price [DKK/year]**	**Investment cost [DKK]**	**Price incl. investment [DKK/year]**
DH	-	526	14,164	-	14,164
NG boiler	98.7%	(696) 705	12,756	48,000	15,156
Biomass boiler	90.1%	(610) 677	12,248	80,000	16,248
Oil boiler	95.0%	(1,200) 1,264	22,870	56,000	25,670
HP	3.74*	(2,198) 588	11,132	149,000	18,582

Table 4.2: Key values comparing NG boilers, biomass boilers, oil boilers and HPs to the averaged DH. [Hansen and Gudmundson, 2018] [Danish Energy Agency, 2019] [Schweitzer et al., 2015] *) COP

To account for the investment, that is required in terms of the change for individual heating, investment costs for all investigated individual technologies have been gathered. For comparability, investment costs are spread over the expected lifetime of each technology. All individual alternatives are found to have an expected lifetime of 20 years in accordance with Danish Energy Agency [2018c]. Investment costs are estimates based on estimates from Danish Energy Agency [2018c] and Hansen and Gudmundson [2018], and do not include any subsidies in this regard. By spreading the investment with no rate of interest, it is assumed that investments can be made with no need for a loan.

By comparison, the biomass boiler shows to be the cheapest individual alternative from mere fuel costs. However, by including efficiency, the HP is found to be the cheapest next after DH. Based on the heat demand for a standard single-family house every individual technology investigated, proves to be cheaper than DH when excluding investment costs. By including investment costs spread across the expected lifetime, similar to the fixed costs of DH, none of the investigated individual alternatives are found to be competitive from the specific inputs. As the oil boiler and biomass boiler do not meet criteria to substitute DH, these are not further considered. The annual costs of a NG boiler only differ 992 DKK/year from the costs of DH and the HP differs 4,418 DKK/year. Figure 4.5 shows how the annual cost of each individual heating alternative varies from increasing heat demand.

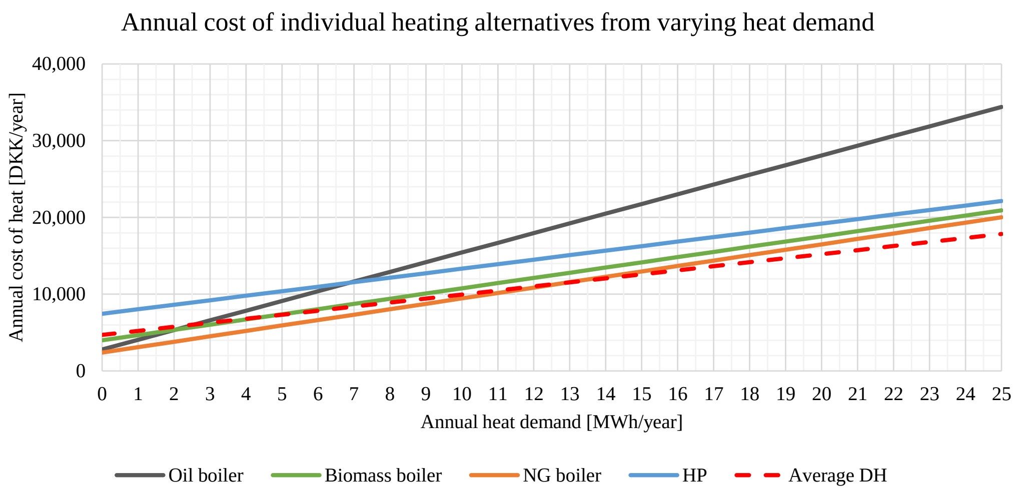

Figure 4.5: Annual individual heating prices of varying heat demand.

Although the NG boiler is the cheapest of the two, its complication in terms of the distribution of gas requires a far more thorough study. This limits the general opportunities of individual heating alternatives for this study, down to the HP. As an electrification of the heating sector is also an objective according to the energy agreement of 2018 [Danish Ministry of Energy, Utilities and Climate, 2018], the choice of comparing DH to HPs is considered both reasonable and far-sighted.

Consideration towards the potential consequences of including NG boilers are exemplified in Chapter 5.

4.2.3 Building stock based heat demand

In addition to the fixed and variable fees of DH, the heat demand of the building stock also affects whether or not DH is competitive to individual heating as the heat demand is determinative for the total cost of the variable fee of DH. A house of low heat demand will have a corresponding low variable cost and in the case that the fixed fee is high, DH might not be able to compete with individual heating. From prices gathered by Forsyningstilsynet [2019a], the span from the lowest to the highest price of DH is illustrated in Figure 4.6. Compared to a HP, fixed fees of DH are found to commonly be lower which is indicated by the point of origin on the y-axis. This basically makes DH cheaper than a HP. However, by changing the variable cost, the slope is changed and thus an increasing heat demand may result in a higher annual cost.

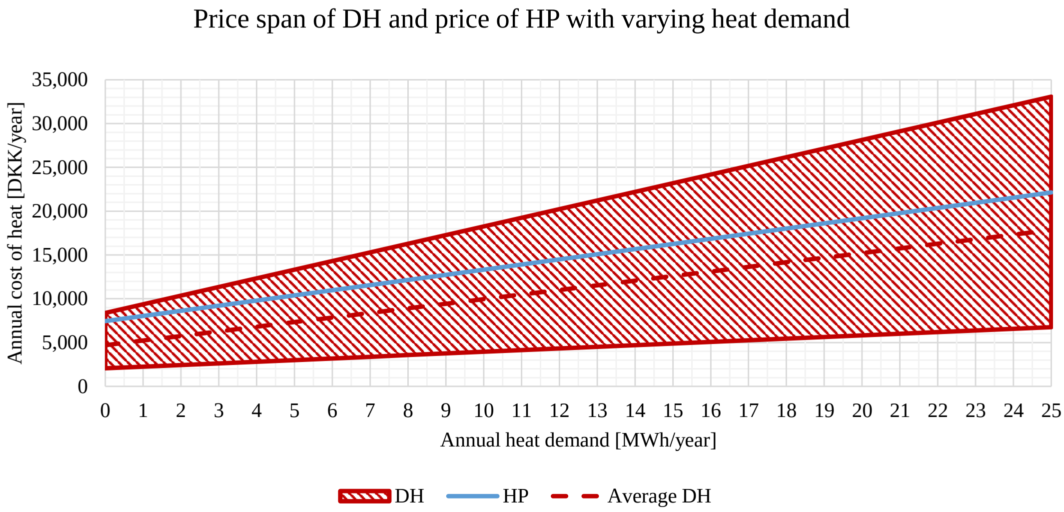

Figure 4.6: Annual cost span of DH and annual cost of a HP from varying heat demand.

Due to the high investment cost of a HP, this breaks with the general perception, that DH as heat supply is too expensive for low energy buildings due to high fixed fees. As a fact, before the obligation of connection were phased out, a consequence of this was that exceptions from this obligation could be made. Hence, a newly built house which met the standards of low energy houses at the time of building approval was allowed to opt out of DH in favour of an individual heating alternative [Danish Government, 2016].

A low heat demand can generally be achieved by houses acquiring less area to be heated or houses improve insulation and thus being more energy efficient. The further study will investigate the heat demand of each individual household in each DH grid, considering energy efficiency and heated area. The Danish building regulation is for every revision updated with a new framework of boundaries for energy use for heating purposes including domestic hot water use. Since 1961, this regulation has been updated 11 times up till today where the building regulations of 2018 (BR18) applies [Danish Transport, Construction and Housing Authority, 2018]. As an example in 2008, according to the BR08, buildings were constructed to have an estimated annual heat demand of 11.3 MWh. According to the most recent BR18, buildings are now constructed to have an annual heat demand of only 4.9 MWh. Thus, the heat demand has been regulated to be more than halved during the past century. Besides regulations of new buildings, buildings built according to earlier building regulations have gained higher insulation standards and energy renovations have gained more attention, making it difficult to determine the actual heat demand based on the year of construction.

Furthermore, while buildings and insulation standards have improved, there is no restrictions for the actual heat demand of buildings. Hence, through measuring heat demands of houses, the actual heat demand has shown to be larger than estimated for buildings of higher insulation standards and lower for buildings of lower insulation standards [Gram-Hanssen and Rhiger Hansen, 2016]. The higher heat demand of newly built houses is explained by higher indoor temperatures than estimated and aberrant behaviour. The lower heat demand of older buildings, however, is due to later energy renovations.

Building regulation	**Year of construction**	**Heat demand [kWh/m^2]**	**Annual heat demand [MWh]**
BR61	- 1965	183	23.8
BR66	1966 - 1971	153	19.9
BR72	1972 - 1976	136	17.6
BR77	1977 - 1981	131	17.0
BR82	1982 - 1984	125	16.3
BR85	1985 - 1994	120	15.6
BR95	1995 - 1997	115	15.0
BR98	1998 - 2007	105	13.6
BR08	2008 - 2009	92	12.0
BR10	2010 - 2014	69	9.0
BR15	2015 - 2017	39	5.1
BR18	2018 - 2019	38	4.9

Table 4.3: Computed heat demands based on building regulations [Ministry of Transport and Housing, 2018], estimates [Grundahl, 2017] [Andersen et al., 2016] and measures [Hvenegaard et al., 2008]. Annual heat demands corresponds to a house of 130 m^2.

By comparing estimates of heat demands [Andersen et al., 2016], building regulations [Ministry of Transport and Housing, 2018], measures of heat demands [Hvenegaard et al., 2008] and estimates for the Danish heat atlas [Grundahl, 2017], the listed heat demands in Table 4.3 has been computed. These are the average heat demands of a standard single-family house.

According to statistics by Statistics Denmark and Lubson [2019], most residential area of household was built from the late 1960s and early 1970s up to the early 1990s. As indicated by the standard of heating prices [Forsyningstilsynet, 2019a], the standard annual heat demand of Danish households is assumed to be 18.1 MWh which is coherent to range between 19.9-15.6 MWh given in Table 4.3.

The heated area of each household in each DH grid is obtained from the Danish building and household register (BBR). Based on the year of construction and corresponding heat demand of Table 4.3, the heat demand of every single house can be calculated. By doing this it is assumed that all BBR data are updated and correct. However, the responsibility of updating BBR data of a house solely belongs to its resident owner. Thus, the registered areas may vary from actual areas,

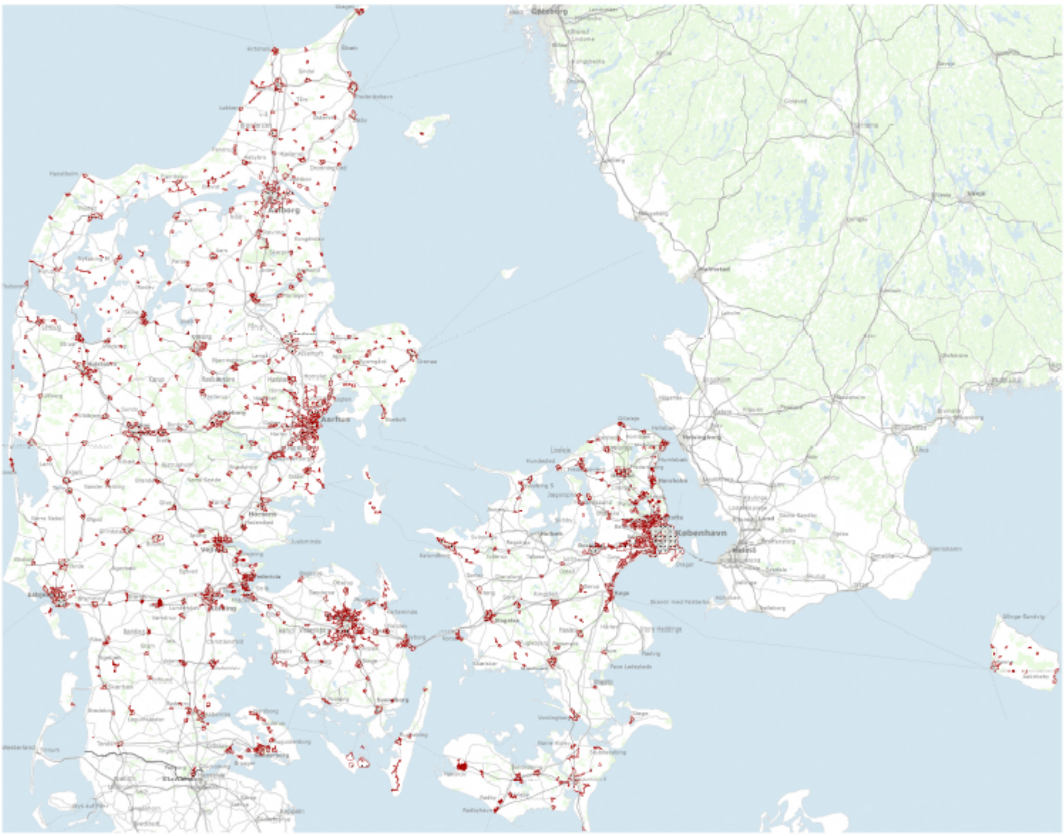

Figure 4.7: Map of Denmark showing the areas where DH is distributed (red) [Grundahl, 2017].

but for this study, it is assumed that registered areas correspond to actual heated areas.

As the BBR data do not clarify to which DH grid a specific building is connected, a geographical representation is needed. Pre-processed data used for the creation of the Danish heat atlas [Grundahl, 2017] has been obtained for this reason. Through the Geographical Information System (GIS) tool, ArcGIS, consumers within each DH grid are located. A map outlining all Danish DH grids is given in Figure 4.7.

4.2.4 Consumer affiliation to DH

An important determinant to the act of consumers changing from DH to individual heating is the consumers' awareness towards the heating market. Hence, the consumers' affiliation to DH. In 2017, Ea Energianalyse et al. [2017] investigated the competitive conditions within the DH sector, concluding that two main groups of consumers were found in the DH sector. One being inattentive and unaware of the price of heating and the other being extraordinary aware. However, the former approach to heating prices was found to be the far most widespread among consumers.

This is supported by the consumer affiliation index, annually investigated by the Danish competition and consumer authority [Danish Competition and Consumer Authority, 2017]. If assuming that the heating sector is comparable to the other utility sectors and services such as the water-, electricity- and gas supply, DH is considered to be one of the least transparent markets. A less transparent market is an expression of a market of which comparison to alternatives seems complex which reduces incentives for change. The consumers' trust and fulfilment of expectations are furthermore among the highest regarding utility markets, insinuating that consumers are happily ignorant to the market. All these studies need to be put in relation to the market conditions which currently maintain consumers through the obligation of remaining. Possibly due to this, the general impression among consumers towards the utility markets is that the price of heating is given very little awareness if any at all. Besides the awareness of the heating market, some consumers actively chose DH over individual alternatives. Reasons for this could be visuals, as DH only requires a heat exchanger or small heat storage of household installation. Also, the comfort of DH could be a factor, as no particular maintenance at the consumer site is required.

To include the consumers' awareness of the heating market, consumers are assumed to change in favour of a HP, based on the difference in price between the two. This means that a marginal price difference will determine if a consumer will change from DH to a HP or not. The marginal price difference varies with demand, assuming that consumers of lower and higher annual costs of heat are not willing to pay the same. It is thus assumed that consumers are either willing to pay extra or unaware of the price until it reaches 20% additionally before changing for a HP. For the average heating price, this equals a marginal price difference of 2,833 DKK/year.

As this is a very complex measure that would rely on a comprehensive consumer survey to be fully covered, variations in the marginal price difference are investigated as part of the sensitivity analysis in section 5.3.

4.2.5 Terms and conditions for consumer withdrawals

Each individual DH plant has its own terms and conditions for the supply of heat. These terms state the obligations that the DH plants have in regards to its consumer and vice versa. A template for guidance to these terms and conditions has been provided by the Danish DH Association and the Danish Utility Regulator, but not all DH plants have applied these. From the current legislation, it would seem unnecessary for a DH plant to have terms stated for consumers resigning from the DH grid as the obligation of remaining prevents this from happening. As a result, some DH plants do not have terms specified for such cases. If the aforementioned terms from the Danish DH Association are applied for a given DH plant, the plant has the authority to charge debt according to investments made until 2 years from the date of resigning along with expenses related to the administrative and physical disconnection. [Danish Utility Regulator, 2009] As the aim of the study is not to investigate consequences on a case-specific level these have been neglected for the further analysis. Also, for these specific costs to be included for each consumer estimated to leave the DH grid, an in-depth review of expenses for each individual DH plants is required. Furthermore, it is not known how many DH plant have adopted these exact general terms provided by the Danish DH Association. Also, this exact situation has not occurred yet, so it is unknown if the terms accepted in a given case. This decision is imposed on the Danish Utility Regulator. [Danish Utility Regulator, 2009]

When adding these extra expenses of resigning from the DH grid to the costs of individual heating, it is assumed economically infeasible to resign from the DH. Hence, the consumers are tied to the DH and it is rather likely that consumers will continue to pay the fixed costs of DH in addition to the costs of individual heating. The primary aim of this study is to investigate the consequences of consumers leaving the DH grid with no consideration towards extra expenses from the general terms of supply. However, the consequences of consumers being tied to the DH and forced to maintain payments of the fixed costs of DH are evaluated in section 4.3.3. In this event, it is assumed that the consumers belong to the group of consumers that are very aware of the price of heat and thus the marginal price difference is neglected in this case.

4.3 Danish DH plants in competition with individual HPs

From the preliminary analysis, all inputs for calculating the potential decrease in consumers for each DH grid are defined. The calculation can be divided into four steps.

4.3.1 Calculation of consumer losses

The first step is estimating the current price of DH for every single building ($C_{B,DH}$) in each single DH grid. This can be estimated from knowing the fixed and variable fees denoted $C_{subscription}$, $C_{capacity}$ and $C_{consumption}$, the general heat demand based on the year of construction ($Q_B(Y_B)$) and the heated area of the building (A_B). The fixed and variable fees are specific to each grid and are obtained from each individual DH company. The fixed capacity fee is like the heat demand, depend on the heated area of the building. From the BBR data processed through the heat atlas and GIS, areas of buildings listed as heated can be obtained. Hence the price of heat by DH can be estimated from equation 4.1.

$$C_{B,DH} = C_{subscription} + C_{capacity} \cdot A_B + C_{consumption} \cdot Q_B(Y_B) \cdot A_B \tag{4.1}$$

The second step is calculating the price of heating from an individual HP. To determine how the price of DH compares to the price of heat from an individual HP, this price of heat also needs to be calculated for every single building in each single DH grid. The price of heat is determined from the same heat demand as for DH, the investment cost (C_i) spread across its expected lifetime (Y_i), the price of electricity (C_e) and the COP. The price of electricity is dependent on the tax levels and the hourly spot price. The electricity price used in the calculations is based on the average spot price of 2018 and taxes levels of 2019. The reason for this is that the price of electricity can be seasonal dependent due to renewable production from wind turbines and photovoltaics etc. The price of electricity thus amounts to 2,198 DKK/kWh [Forsyningstilsynet, 2018] [Forsyningstilsynet, 2019b]. The equation for calculating the price of heat from a HP is given in equation 4.2.

$$C_{B,HP} = \frac{Q_B(Y_B) \cdot A_B}{COP} \cdot C_e + \frac{C_i}{Y_i} \tag{4.2}$$

Assuming that the general terms of supply apply and it is not economically feasible to withdraw from the DH grid, the fixed costs of DH needs to be added to the price of heat from a HP as stated in equation 4.3.

$$C_{B,HP} = \frac{Q_B(Y_B) \cdot A_B}{COP} \cdot C_e + \frac{C_i}{Y_i} + C_{subscription} + C_{capacity} \cdot A_B \tag{4.3}$$

Knowing the two competitive prices of heat leads to the third step in the calculation which is determining if a consumer is likely to change for a HP. As earlier stated, the difference in price determines whether a consumer wants to remain connected to the DH or change heat supply in favour of a HP. The change of heat supply is not considered to take place unless the difference in price exceeds the marginal price difference (ΔC_B) of 20%.

$$\Delta C_B = \frac{C_{B,DH} - C_{B,HP}}{C_{B,HP}} \tag{4.4}$$

The fourth step is calculating how many consumers potentially change the supply of heat in each DH grid. From this step, an iterative calculation is required. This is because the number of consumers who choose to change for a HP, induces higher fixed fees to the remaining consumers of DH. The increased price of DH

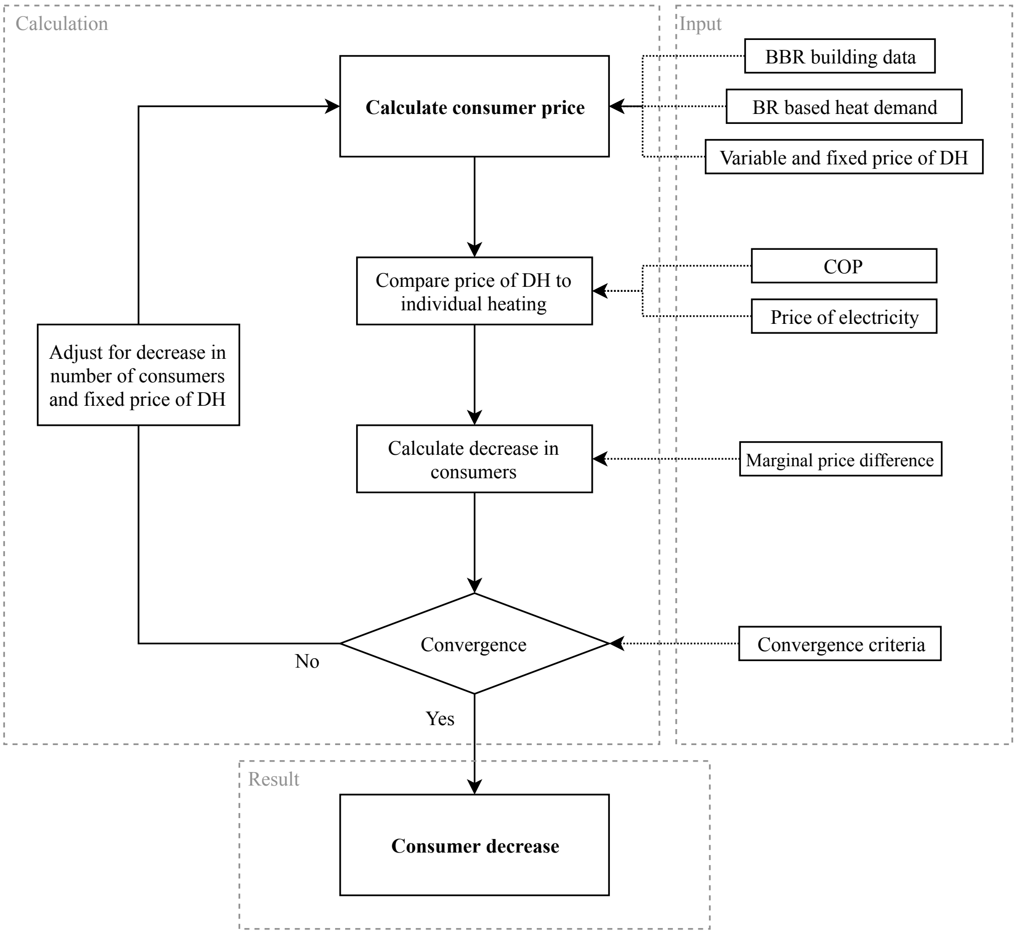

Figure 4.8: Flow chart describing the iterative calculation of consumer loss.

then again needs to be compared to the alternative of a HP in a new iteration. Iterations proceed for as long as the change in the price of DH induces a loss of consumers. To avoid minimal and impractical continuous loss of consumers a convergence criterion is set for the iterative change of the DH price. This criterion is set as 50 DKK/year, meaning that if the annual change in the price of DH changes less than 50 DKK/year between iterations, the iterative calculation is considered to converge. A flow chart of the iterative process and associated inputs can be seen in Figure 4.8.

4.3.2 Spread of cases

Generally, the DH grids of most concern are the ones with the highest prices of heating. However, to investigate at what price DH plants are being affected, several DH plants in a given price range need to be investigated. The annual costs for a HP, estimated in section 4.2.2, indicates that affection might occur around an annual cost of 18,000-19,000 DKK/year for DH. However, this cannot solely be based on the average cost of a standard single-family house as not all buildings are so. Hence, a wider range of DH plants needs to be investigated. Also, as indicated by Figure 4.3, the fixed and variable fees differ from each plant which affects the price for a given building. Thus, several DH grids covering a wider range of the price spectre needs to be investigated.

For the study, 39 plants have thus been selected, ensuring variance in price levels and numbers of consumers. A complete list of the 39 plants investigated can be found in Appendix A. In continuation of the price statistics made by Forsyningstilsynet [2019a], the investigated plants spread as illustrated in Figure 4.9.

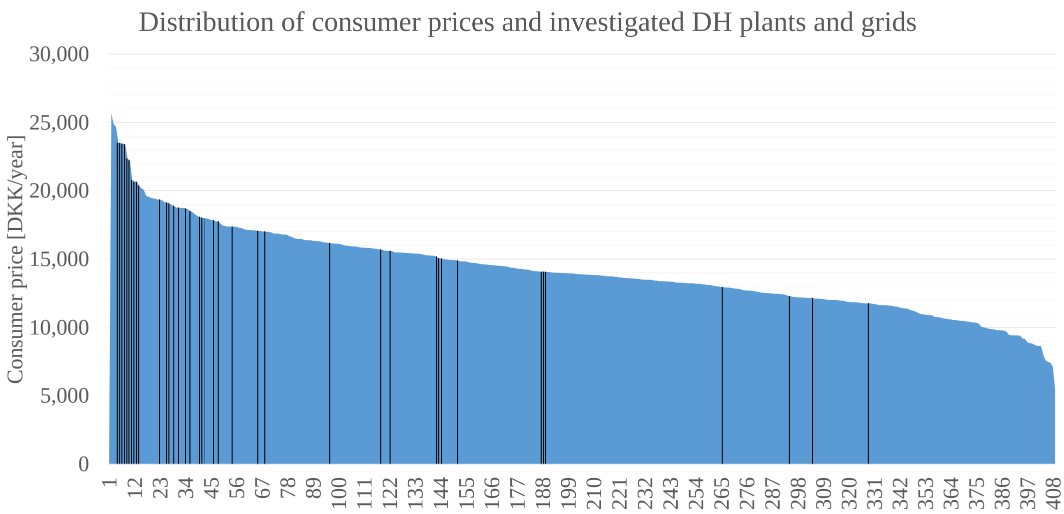

Figure 4.9: Distribution of consumer prices for each Danish DH plant, where the investigated DH plants marked are marked.

Of the investigated DH plants, 22 are categorised as decentralised DH plants and 17 as only heat-producing DH plants. Hence, the distribution of DH plants based on the type is more or less even and the slight majority of decentralised DH plants are not assumed to have a considerable impact on the outcome of the study.

4.3.3 Resulting consumer losses

Calculations based on the listed inputs show that there is a general tendency between the average price of heat and the estimated decrease in consumers. In Appendix B, a review can be found, exemplifying how consumer losses are calculated. Table 4.4 shows intervals of DH prices and corresponding estimated average consumer losses. The averaged consumer loss means that within this range some plants will have higher and some will have lower consumer losses. The span of which consumer losses were estimated for the given price intervals is illustrated in Figure 4.10.

From the table, it can be seen that significant consumer losses take place from consumer prices exceeding 20,000 DKK/year. In total, there are 14 plants of which the heating price exceeds 20,000 DKK/year and out of those, 9 have been investigated. Four of the investigated plants are estimated to lose all of its consumers, as the price of heat cannot compete with the individual alternative of a HP. By applying results of these four plants to the full list of DH plants, it is estimated that all plants with a price of heating above 22,500 DKK/year and thus being six plants are estimated to lose all consumers. The remaining eight DH plants of prices between 20,000 and 22,500 DKK/year are estimated to on average encounter partial consumer losses which do not lead to a complete consumer loss.

DH grids with a price below 15,000 DKK/year shows to be notably cheaper than an individual HP across all types of buildings as no decrease in consumers are estimated. Also for the DH grids with a price between 15,000 and 20,000, an

Consumer price [DKK/year]	Avg. consumer loss	Investigated plants/ total number of plants
25,000 -	100%	1/1
22,500 - 24,999	61%	2/5
20,000 - 22,499	41%	6/8
17,500 - 19,999	2%	10/33
15,000 - 17,499	1%	9/94
12,500 - 14,999	0%	7/137
10,000 - 12,499	0%	3/86
- 10,000	0%	1/29

Table 4.4: Average consumers loss for price intervals along with degree of coverage in each interval.

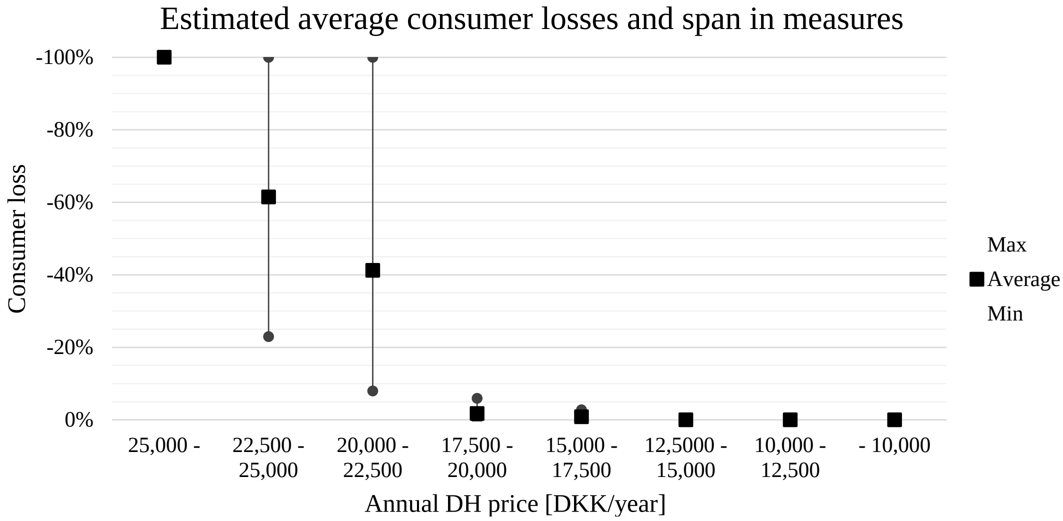

Figure 4.10: Estimated consumer losses with maximum and minimum measures in the given price intervals.

average decrease of only 1-2% is calculated based on the total of 19 DH plants investigated within this price range. Decreases in consumers are primarily calculated from heating prices exceeding 20,000 DKK/year, where an average decrease of 41% is calculated. The sudden increase from almost no consumer loss in the price range of 15,000-20,000 DKK/year to 41% in the range of 20,000-22,500 DKK/year and 61% in the range of 22,500-25,000, is due to the DH price exceeding the average competitive price of 18,582 DKK/year for heating a standard single-family house by a HP.

Even though there is an overall correlation between the price of heat and the decrease in consumers, plants with a high consumer price might also be less influenced as can be seen from Figure 4.10. This is e.g. the case for plants with high variable costs and low fixed costs. As an example, Lørslev Fjernvarmeforsyning Amba is the third most expensive DH grid, but the estimated decrease in consumers is only 23%, whereas all other four of the five most expensive DH plants investigated, has an estimated decrease in consumers of 100%. These plants are Øland Kraftvarmeværk Amba, Rise Fjernvarme Amba, Svebølle-Viskinge Fjernvarmeselskab Amba and SSF Energiselskab. Common to all of these plants, is that fixed costs amount to more than 7,000 and 8,000 DKK/year for a 130 m^2 house, whereas the average plant has fixed costs at around 4,000-5,000 DKK/year. Reasons for Lørslev Fjernvarmeforsyning Amba being less influenced by consumer losses are both the composition of fixed costs and building areas, as described in Appendix B.

If considering that all DH plants make use of the general terms of supply mentioned in section 4.2.5, the fixed costs of DH are added to the total cost of individual heating and the marginal price difference is neglected. By doing this, it is found that consumer losses generally decrease from the initial result of Table 4.4 to the result of Table 4.5. The minor increase in consumer losses for DH plants with prices below 20,000 DKK/year is due to the neglecting of the marginal price difference, which means that consumers will change as soon as the HP is cheaper than DH.

Consumer price [DKK/year]	**Avg. consumer loss**
25,000 -	100%
22,500 - 24,999	56%
20,000 - 22,499	26%
17,500 - 19,999	5%
15,000 - 17,499	3%
12,500 - 14,999	0%
10,000 - 12,499	0%
- 10,000	0%

Table 4.5: Average consumer losses from consumers paying both individual costs and fixed costs of DH.

If accounting for the general terms of supply and assuming that a withdraw from DH is economically infeasible, the number of DH plants estimated to encounter a complete consumer loss is still assumed to be approximately six plants. However, DH plants of prices between 20,000 and 22,500 DKK/year are found to be significantly less affected and the average consumer loss is found to be reduced by 15%.

4.3.4 Decisive parameters

From comparing results, the main reasons for large consumer losses are found to be:

- New building stock (low heat demand) and high fixed costs (can be aggravated by large building areas)
- Low number of consumers in particularly for plants with high fixed fees
- Old building stock (large heat demand) and high variable fees

A plant that has a heating price just over 20,000 DKK/year is Odsherred Varme A/S. With a heating price of 20,361 DKK/year and a fixed fee of only 4,750 DKK/year for a 130 m^2 house, no significant consumer loss is to be expected. However, the loss of consumers is estimated to be 18%. For the case of Odsherred

Varme A/S, it is a combination of a low number of consumers, a high variable fee and old building stock, that results in the high loss of consumers relative to the annual cost of DH. The low number of consumers causes a correspondingly high increase in fixed fees per consumer. The high variable fee and old building stock increases the overall cost of DH and thereby decreasing the competitiveness towards individual heating.

The reason that new building stock can cause an increase in consumer losses is as previously mentioned, due to the low heat demand and potentially high fixed costs of DH compared to the fixed costs of individual heating. As new building stock is primarily located near large cities, a hypothesis would be that consumer losses are higher near such cities. However, from the investigated DH plants mapped in Figure 4.11, no distinct relation between geographic placement and consumer loss seems to be evident. This is backed up by Energitilsynet [2012], which concludes that only the small plants of only heat production in the outskirts of Denmark are generally characterised by higher heating prices. However, this is rather due to a low number of consumers spread across a large populated area which increases fixed costs for investments and maintenance and variable costs

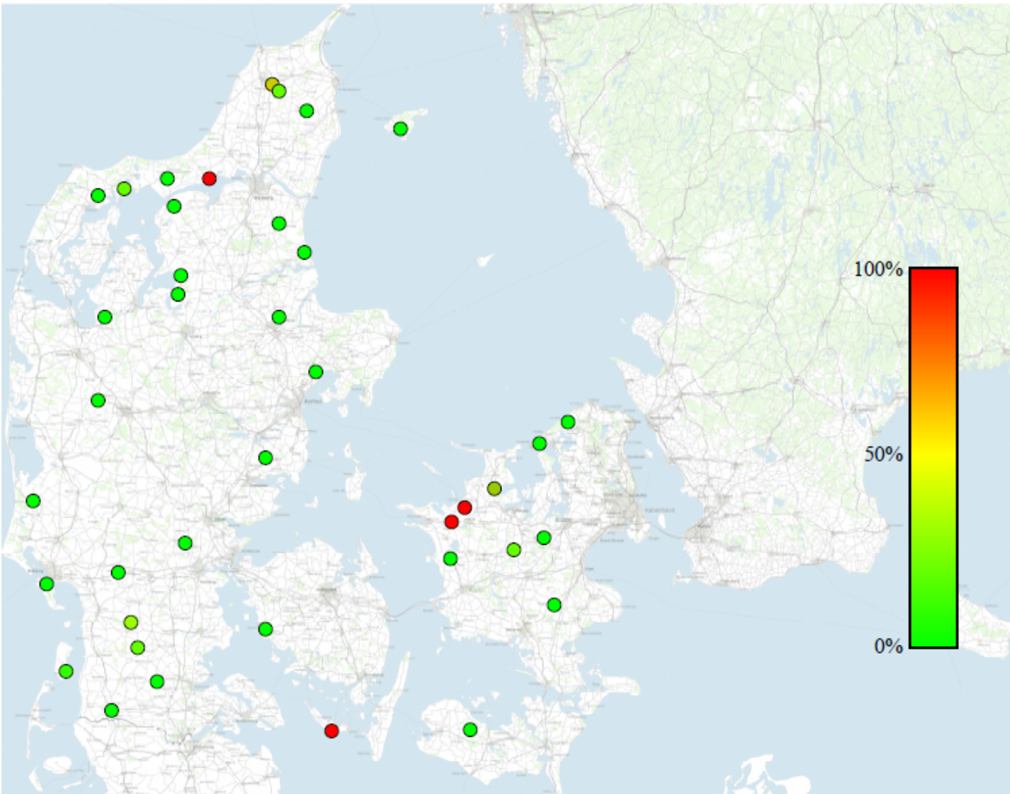

Figure 4.11: Map of investigated DH plants with gradient indicating the calculated consumer loss.

due to grid losses [Energitilsynet, 2012].

All four investigated DH plant which are estimated to lose all consumers, are all small DH plants of 124-524 consumers, located fairly distant from larger cities. Two of the DH plants are only heat-producing plants which may be comprised by the aforementioned generalisation, of DH plants in the outskirts generally being more expensive. However, the other two are decentralised DH plants. An explanation to this could be that CHP production from these plants is outcompeted by renewable electricity production from wind power etc. Hence the high variable fees of these two DH plants.

With only 14 out of 393 plants estimated to encounter a partial or complete consumer loss, the repeal of the obligation of remaining does not appear to be decisive to the prevail of the DH. However, the consequences for a DH grid losing its consumers needs to be evaluated before such a conclusion can be made.

4.4 Consequences of consumer losses

Consumer losses of any degree will inevitably have economic consequences for a given DH plant. The degree at which a plant is affected depends on the specific consumer loss and economic situation of the plant.

Throughout this study, consumer losses are given as a percentage of the total number of consumers. By doing this, the DH plants are evaluated on equal terms regardless of how many consumers each grid contains. It is assumed that every DH plant can withstand losing a certain percentage of its consumers and that at a certain point the number of consumers will be too low for the DH grid to actually be economically justifiable.

From a theoretical and impractical point of view, a complete consumer loss and resulting bankruptcy will not occur until a consumer loss of 100% is reached. However, at a certain point, production units might not be capable of producing heat at a sufficient efficiency which this study does not account for. Furthermore, grid losses might be unreasonable high and maintenance of a large DH grid may not be economically feasible in regards to the number of remaining consumers. For DH plants with a relatively high price of heat and few consumers, it is found that consumer losses increase exponentially with consumers leaving. Hence, it is impractical that a such DH plant is found to avoid bankruptcy with only very few consumers left. From the analysis, it is found that for most DH plants a consumer loss of up to approximately 60% is plausible based on the number of remaining consumers and resulting price. Consumer losses above 75% are rarely estimated, as such a loss would in most cases result in a complete consumer loss. This indicates a point in consumer loss at which bankruptcy is expected to occur.

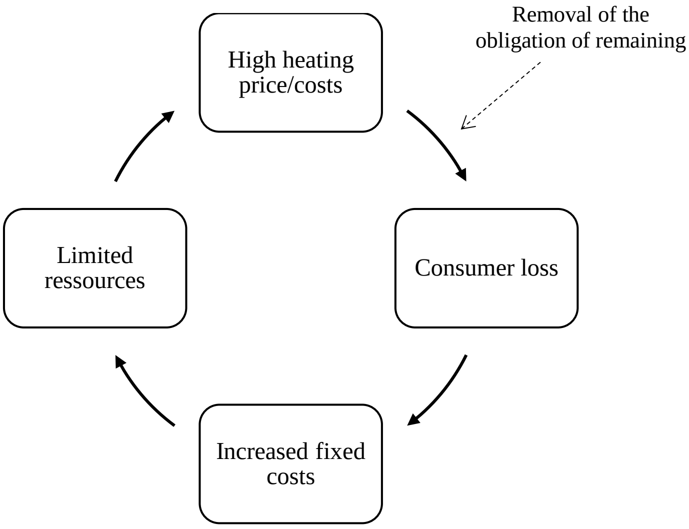

Figure 4.12: Vicious circle of consequences from high costs of heat and resulting consumer losses.

A DH plant which has already build up high fixed costs will have less opportunity to make new investments for lowering the variable cost of heating as it will further increase the fixed costs. Hence, they may be caught in a vicious circle, unable to lower costs and eventually unable to pay their debt. This is illustrated in Figure 4.12. In case a DH plant goes bankrupt, the municipality is according to §6.4 of the HSA, obliged to take over the DH company independent from the current ownership [Danish Government, 2019] [Danish Ministry of Energy and Climate]. The municipality then takes over any given debt depending on the specific lender. Many loans made within the DH sector are municipal loans made through Kommunekredit. The municipal loans ensure that loans can be made by even small DH plants of which private lenders would potentially reject. Furthermore, the municipal loans ensure a low discount rate and a municipal guarantee. [Danish Ministry of Energy and Climate]

Based on this analysis, approximately six Danish DH plants are estimated to encounter a complete consumer loss and at least eight DH plants are estimated to encounter partial consumer losses in the range of 2-60%. In 2016, municipal loans amounted to almost 22 bn DKK equivalent to an average debt of 54 m DKK per DH plant. There is presumably a correlation between the size of DH plants and the amount that they make up of this debt. However, the considerable total debt indicates the debt that needs to be covered in the event that DH plants go bankrupt. In contrast, the consumer economic gain from consumers saving money on heat can be calculated from the price difference of each consumer. This gain is calculated to be 1.5, 1.1, 2.3 and 2.6 m DKK/year in total for the four DH plants investigated to lose all of its consumers. Hence, the debt is presumably larger than the consumer economic gain.

According to §3 of the Project Declaration, the closure of a DH plant also needs to meet certain criteria. One of the governing criteria from the Project Declaration is the requirement of initiating the project of most socioeconomic benefit. [Danish Government, 2018b] By excluding taxes and subsidies from costs and gains related to the project, the socioeconomic benefit or loss can be calculated. [Danish Energy agency, 2018] As this is not specified during this study, a thorough socioeconomic evaluation cannot be carried out. However, the considerable debt and material value in DH plants compared to the consumer savings on heat indicates that the closure may likely result in a socioeconomic loss and depend on an exemption from the Project Declaration.

4.5 Possible solutions

In order to provide solutions on how to comply with the possible complete repeal of the consumer obligations, it is investigated how the links between consequences in Figure 4.12 can be broken. This is illustrated in Figure 4.13.

Breaking the first link involves methods of evading consumer losses. This can be accomplished by either legally forcing consumers to stay connected as it is done today, or by lowering costs of heat. By maintaining the currently employed obligation of remaining socioeconomic losses may be introduced. Furthermore, the liberal market conditions requested, will not be introduced. If maintaining the obligation of remaining other market regulations such as the currently implemented

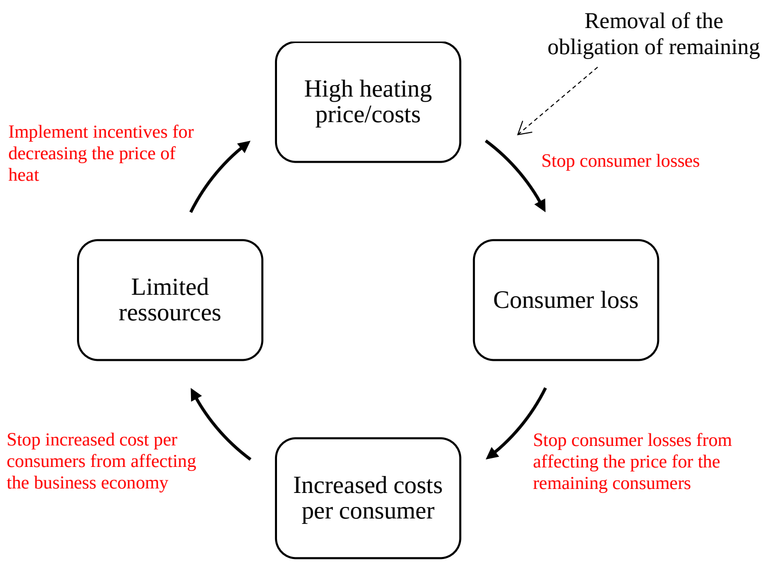

Figure 4.13: Solutions based on the vicious circle of consequences from high costs of heat and resulting consumer losses.

benchmarking can be used to undue the motive for changing for individual heating. Lowering the costs of DH for a given consumer also reduces incentives for changing for individual heating. As has been shown through this analysis, in cases where the variable cost of DH is higher than the variable cost of individual heating, it can benefit the competitiveness of DH to lower the heat demand of buildings. However, this only applies if the fixed costs of DH are lower than the fixed costs of individual heating. In such case, an additional subsidy for energy renovations may benefit economically both for the DH plant and the consumers. Effects and circumstances where this applies are however estimated to be minimal and in some cases, it may even have a negative effect towards DH and consumer losses. To not directly affect the DH plant, subsidies should be governmental.

After identifying consumer losses, the aim should be to not make these affect the remaining consumer of the DH grid. The simplest way to accomplish this is by ensuring economic coverage of debt upon withdrawing from the DH grid. Legally this can be achieved by stating it in the terms of supply. Hence, the general terms of supply should be applied.

If the debt of consumers leaving the DH grid is not covered, a higher price of heat is first of all induced. Secondly, the larger debt per consumer will complicate and even hinder new investments and loans for a DH plant. To overcome this, economic support of various kinds can be granted. These economic supports comprises production grants, investment grants to lower the variable cost while the current debt is paid back. This is however not recommended as it is only a temporary solution. Lastly, there is the possibility that the plant can apply for governmental debt relief. As for all kinds of economic support, this should be compared to the economic consequences of declaring a DH plant bankrupt.

The last and most crucial consequence to avoid is the currently high heating prices compared to individual heating. To avoid such high heating prices in the first place, the market should naturally force prices down. As the market of DH is rather closed due to the obligation of remaining, other market regulations are needed. As previously mentioned, benchmarking is one of these. However, as this study indicates, it does not consider all DH plants to the degree necessary. Another solution that has previously been implemented to a certain degree is easing of the legislation. This solution is specifically aimed at providing opportunities for DH plants to produce heat from cheaper fuel or technology. By easing the HSA it is possible to evade the fuel- and CHP commitment enabling cheaper heat production. Especially for small decentralised DH plants with expensive NG engines and expensive secondary production, an ease of the legislation could help by e.g. allowing installation of biomass capacity. Production costs of various types of production units are discussed in section 5.2 where also effects from lowering the variable cost of DH is evaluated. As only a few DH plants are found to be affected by a repeal of the obligation of remaining, the change in production is not assumed to affect the security of supply. A practical example of how this does not affect the security of supply is the considerable decrease in full load hours of CHP in the DH sector [Boes, 2018]. This solution is assumed to be the most suitable as it provides the potential of decreasing the price of heating which causes the problems in the first place. Furthermore, it follows the aim of liberalising the heating sector.

5 | Discussion

This chapter focuses on discussing general assumptions and clarifying uncertainties regarding the inputs of variables used throughout the study. Effects of practical and theoretical changes to these variables are investigated through a sensitivity analysis, which furthermore serves to investigate solutions to the complications of removing the consumer obligations. As several variables are used throughout the analysis, only certain variables are chosen to be investigated through the sensitivity analysis. The sensitivity analysis is conducted to investigate variables considering individual heating, DH and consumers separately. Lastly, delimitations made during the study are clarified and discussed.

5.1 The price of individual heating

The variable costs of individual heating are solely dependent on fuel prices (including taxes) and efficiency. Hence, conducting a sensitivity analysis on one of these parameters also indicates effects of doing it on another technology of individual heating.

Specifically for the HP, the price of electricity varies and can change the outcome by either lowering or increasing the variable cost of individual heating. Changes in the price of electricity can be caused by changes in both taxes and the net cost of electricity. Disregarding changes taxes, the net electricity cost is represented by the spot price. According to Forsyningstilsynet [2019b], in 2019 the spot price of electricity represented 21% of the total cost of electricity while the rest included taxes, VAT etc. In the case that the obligation of remaining is postponed several years into the future, the spot price of electricity may have increased steadily according to several projections. However, these projections have earlier showed to be incorrect. In Figure 5.1 the actual spot prices over the years are given along with various projections. From varying the spot price in accordance to earlier spot prices and future projected price levels, the resulting price of heating is found to be between 17,000-20,000 DKK/year.

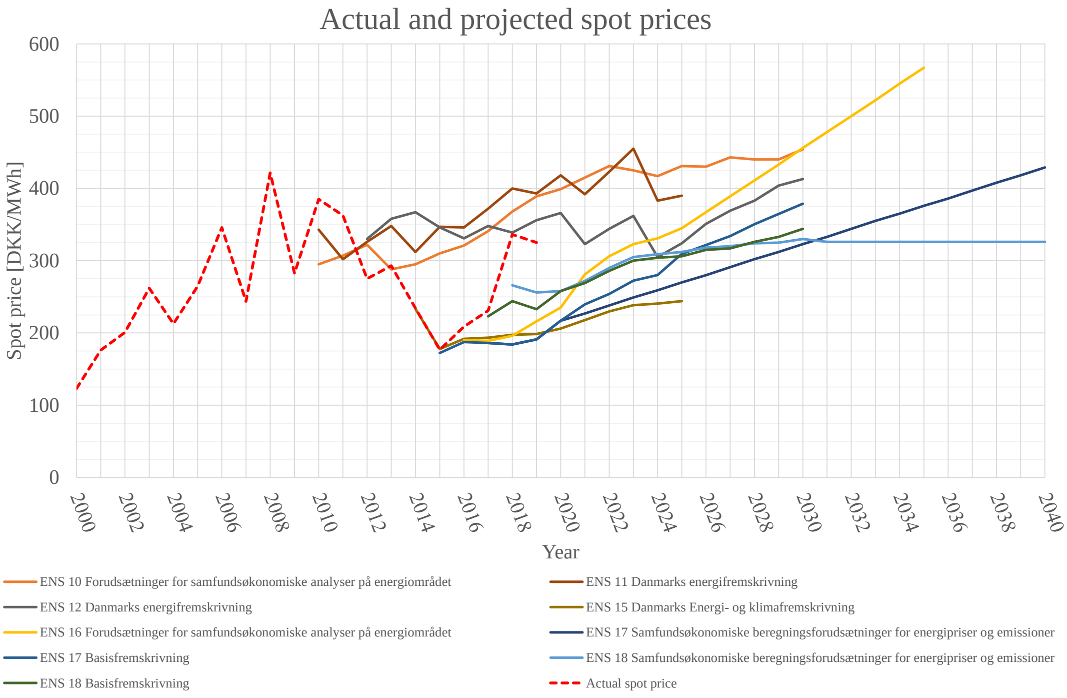

Figure 5.1: Actual spot price development (dashed red) and projected spot prices. [Danish Energy Agency, 2016] [Danish Energy Agency, 2010] [Danish Energy Agency, 2012] [Danish Energy Agency, 2015] [Danish Energy Agency, 2018a] [Danish Energy Agency, 2017a] [Danish Energy Agency, 2017b] [Danish Energy Agency, 2018b]

As spot prices only account for 21% of the gross fuel cost, minor changes do not affect the result much. A more effective way of investigating changes in variable costs is through efficiency as it directly changes the variable cost by a given factor.

For the HP, changes in efficiency mean varying the COP. Table 5.1 shows how changes in COP and thus changes in variable costs of individual heat is affecting the result. Annual costs of heat are given for a standard single-family house of 130 m^2. Changes in COP is investigated in the span of 2-5.5. According to the list of tested HPs made by Danish Energy Agency [2019], the SCOP is in the range of 3.6 and 5.2. However, if operated otherwise than the conditions stated for the standard of calculating the SCOP [Danish Energy Agency, 2011], the actual SCOP would differ from this range.

COP	$C_{B,HP}$ [DKK/year]	$C_{B,DH}$ [DKK/year]	Average consumer loss
2	27,342	25,000-	0%
		20,000-24,999	0%
		15,000-19,999	0%
		10,000-14,999	0%
		-9,999	0%
2.5	23,364	25,000-	0%
		20,000-24,999	0%
		15,000-19,999	0%
		10,000-14,999	0%
		-9,999	0%
3	20,711	25,000-	100%
		20,000-24,999	1%
		15,000-19,999	0%
		10,000-14,999	0%
		-9,999	0%
3.74 (*reference*)	18,087	25,000-	100%
		20,000-24,999	45%
		15,000-19,999	1%
		10,000-14,999	0%
		-9,999	0%
4.5	16,291	25,000-	100%
		20,000-24,999	64%
		15,000-19,999	23%
		10,000-14,999	0%
		-9,999	0%
5	15,407	25,000-	100%
		20,000-24,999	67%
		15,000-19,999	32%
		10,000-14,999	1%
		-9,999	0%
5.5	14,683	25,000-	100%
		20,000-24,999	72%
		15,000-19,999	50%
		10,000-14,999	2%
		-9,999	0%

Table 5.1: Average estimated consumer losses from various prices of individual heating.

Based on the projected spot prices in Figure 5.1, a higher variable cost of individual heating is to be expected. From the table, it can be seen that a corresponding lower COP, is generally resulting in DH being the cheapest type of heating installation. Even for DH plants with prices exceeding 20,000 DKK/year, consumer losses are minimal of only 1% on average. The only exception is Øland Kraftvarmeværk Amba, being the only DH plant with a price above 25,000 DKK/year. For this specific DH plant, an individual heating price of less than 23,000 DKK/year will result in a condition at which the DH plant can no longer compete with individual heating and will thus cause a complete consumer loss.

From investigating lower variable costs in terms of a higher COP, specific concern is aimed at DH plants in the range between 15,000 and 20,000 as they make up 32.1% of all DH plants. The average consumer loss is for this range increased from 1% with a COP of 3.74 to 50% with a COP of 5.5. Also, the 126 DH plants within this range are estimated to lose 23% on average if the COP is increased to 4.5 or the variable cost is increased by 1,796 DKK/year. As this is an average across a range in price, the most expensive DH plants is assumed to be most affected whereas the cheapest within the range is assumed to be less affected.

Conclusively, an increase in variable costs of the HP is not estimated to affect the Danish DH plants, but an increase in variable costs can be decisive to the DH plants with a heating price above 15,000 DKK/year which makes up more than one-third of all Danish DH plants. However, based on the current and projected spot price development, such substantial increases seems unreasonable. Furthermore, the conditions or technological development of HPs for a higher SCOP than 4-4.5 is assumed impracticable for average household HPs at the moment.

A central question to individual heating is how the opportunity of installing a different heating installation than a HP would change the result. As previously mentioned, NG boilers showed to be a cheaper alternative than a HP. Certain consumers may also be applicable to biomass boilers which for annual heat demands above 5 MWh/year showed to be even cheaper. Table 5.2 shows how average consumer losses spread across alternatives to DH if all consumers change for the

	HP	**NG boiler**	**Biomass boiler**	**Oil boiler**
25,000 -	-100%	-100%	-100%	0%
22,500 - 24,999	-61%	-70%	-62%	0%
20,000 - 22,499	-41%	-64%	-1%	0%
17,500 - 19,999	-2%	-31%	-0%	0%
15,000 - 17,499	-1%	0%	-0%	0%
12,500 - 14,999	0%	0%	-0%	0%
10,000 - 12,499	0%	0%	-0%	0%
- 10,000	0%	0%	0%	0%

Table 5.2: Consumer losses from different individual alternatives assuming all consumer change for the respective individual alternative.

respective individual alternative. From this investigation, both changes in fixed costs and variable costs are included. The variable costs of the HP and NG boiler are similar, only differing 80 DKK/MWh. Thus, the difference between the two is primarily caused by different fixed costs i.e. investment costs.

The lower investment costs of a NG boiler results in a generally higher consumer loss. However, DH plants with heating prices of below 17,500 DKK/year shows not to be affected. It is expected that for the certain areas where NG is still distributed or can yet again be distributed, the consumer loss should be expected to increase 20-30% additionally for DH plants of prices above 17,500 DKK/year. From an environmental point of view, this would most probably have a negative effect unless the NG supply is converted to biogas. In circumstances where a biomass boiler is applicable and desired, DH cannot compete. However, this is assumed only to be the case of very few consumers.

For DH plants with a price of heat between 10,000 and 12,500 DKK/year, the consumer loss in competition with HPs is 1% whereas it is 0% in competition with NG boilers. This is feasible as HPs can still be cheaper in the case of high heat demand. Also for the biomass boiler, consumer losses of DH plants ranging in annual prices of 17,500-22,499 DKK/year seem inconsistent to the other result. However, this exemplifies the economic difference between DH plants caused by the different ratios of fixed and variable costs.

To avoid the repeal of the obligation of remaining from affecting the DH sector it is from this sensitivity analysis shown that the price of heat should be below 15,000 DKK/year. Even in areas where NG can be distributed, the DH prices below 15,000 DKK/year shows to outcompete NG boilers.

5.2 The price of DH heating

A solution to reduce prices of DH is to lower production costs. Focus through the analysis has mainly been on the fixed costs of DH as these are the ones mainly affected by consumers losses. However, decreasing variable costs can also help increase the competitiveness of DH towards individual heating alternatives.

The variable costs of DH plants comprise all costs, directly related to the production of heat. Thus, reducing fuel costs, taxes or O&M will result in a lower variable cost. To noticeably reduce fuel costs and O&M it is in most cases required that the actual production unit is changed or optimised. Most DH plants are currently bound by the fuel commitment and CHP commitment, limiting them to produce heat from NG engines. Thus a regulatory change would in most cases be needed. Also for the taxes to change, a political and regulatory transition needs to take place.

In 2014 the HSA was revised to help the most expensive DH plants. Thus the 30 most expensive plants of that year and the 30 most expensive plants over the past

3 years were allowed to evade the fuel commitment and install a biomass boiler of up to 1 MW capacity [Danish Government, 2019]. Furthermore, from 2019 it was implemented by law, that DH plants with an annual heat production of less than 139 GWh/year, are allowed to install biomass capacity in combination with a HP. Only if installing a HP additionally to the biomass boiler increases the price by more than 1,500 DKK/year for a standard single-family house, it is allowed to only install biomass capacity. [Danish Government, 2019] Hence, lowering the variable cost of a DH plant is currently limited by capacity restrictions or additional large HP investments which will further increase the fixed costs and thus not necessarily decrease the total cost.

The average variable cost of all Danish DH plants is 525 DKK/MWh with the lowest and highest being 141 and 988 DKK/MWh, respectively [Forsyningstilsynet, 2019a]. Because the price of DH depends on both the fixed and variable costs, it is difficult to determine a certain criterion for the variable cost, in order for the DH plants to be spared from consumers leaving the DH. However, from previous investigations, it has been found that in worst case, the repeal of the obligation of remaining affects the DH plants with a price of more than 15,000 DKK/year. By comparing the variable cost of DH plants in the range of this total price, a recommendation would be that the variable cost is kept under 650 DKK/MWh depending on the fixed costs of the specific plant. By varying the variable cost of the most expensive DH plants, it is found that a reduction of 15-30% will eliminate consumer losses hereof. Thus, the aforementioned solution of allowing other production units for the most expensive DH plants should aim at a reduction of up to 30% of the variable cost.

For comparison, variable costs have been estimated for various production units by including current fuel costs, costs of O&M, taxes, subsidies and efficiency. From this, a NG boiler is estimated to have a variable cost of approximately 400 DKK/MWh depending on its efficiency, the given price of NG and the specific type of plant. Regarding a NG fuelled CHP engine, it is further dependent on the spot price, but for the average spot price, the variable production cost is estimated to vary from 300-600 DKK/MWh. Depending on whether a biomass boiler is fuelled by wood pellets or wood chips, it is estimated that the variable cost is 200-300 DKK/MWh. As for the NG fuelled CHP engine, the variable production cost of a HP is dependent on the spot price, but furthermore heavily dependent on the COP. From the average SCOP also used for individual HPs, the variable production cost is estimated to be approximately 350 DKK/MWh.

Additionally to this variable production cost, the respective grid loss needs to be accounted for. According to the average grid loss referred to in Chapter 1, the average grid loss is 23%. To account for this, a 23% increase needs to be added to the variable production cost. From the listed variable production costs, only the NG engine in low spot price situations are found to have a variable production

	Variable cost [DKK/MWh]	Variable cost incl. avg. grid loss [DKK/MWh]
NG engine		
- High spot price	600	738
- Low spot price	300	369
NG boiler		
	400	492
Biomass boiler		
- Wood chips	200	246
- Wood pellets	300	369
HP		
- COP 3.74	350	431

Table 5.3: Estimated variable costs of DH from various production units.

cost exceeding the recommended variable cost of 650 DKK/year. A list of estimated variable costs with and without consideration of grid losses is given in Table 5.3. Currently, there are only few HPs installed in the Danish DH sector which is partly due to the limited possibilities from the HSA [Energistyrelsen, 2018]. Hence, for the DH plants of highest variable costs, it is most likely either substantial grid losses, inefficient boilers, inexpedient operation of plants or the CHP commitment that prevents the plant from being competitive to individual heating.

5.3 Consumer conditions

On a consumer level, a governing variable that is subject for discussion is the heat demand of buildings, gathered and estimated from various sources. First of all, the measure of heated area of buildings and type of heat supply gathered through the BBR data can be questioned in terms of validity as they rest upon revision from the individual owner. Furthermore, the year of construction that is used for estimating the heat demand, can be incorrect in case that energy renovations have been made. Also for new buildings, the heat demand typically shows to be higher than estimated due to individual comfort and behaviour. In an attempt to account for this, measured heat demands have also been used in the estimation of the heat demand. However, the exact heat demand of each building is required for the analysis to be accurate. Since this would require a far more detailed and comprehensive data gathering than is currently available, a such study is left for future studies.

Based on this known source of error, a sensitivity analysis is made to investigate what impact variations in heat demand would have in terms of consumers leaving the DH. As heated areas of buildings are most likely increased in case that the BBR data is incorrect, this would cause a larger heat demand. Larger heat demands can also be caused by e.g. additions to buildings, individual comfort levels and conversions of non-residential area for residential area. On the other hand, an energy renovation would cause the heat demand to decrease. This is simply due to less heat loss from the building. It is assumed that the most likely instances are older buildings being renovated causing a lower heat demand and new buildings having an increased heat demand due to comfort related behaviour. According to Tommerup and Svendsen [2006], the largest potential of energy renovations exists for buildings built before 1979 as demands regarding energy performance were yet not implemented before then. Correspondingly, for new buildings, the largest deviation from the estimated heat demand is found to be for buildings of EU energy label A [Gram-Hanssen and Rhiger Hansen, 2016]. Buildings meeting the energy label A are assumed to be built from 2010 and forth. Hence, buildings from 2010 and forth are estimated to have a larger heat demand than estimated.

To implement energy renovations for buildings built before 1979, the 17.0 MWh (131 kWh/m^2) heat demand of buildings built between 1977 and 1981 is applied for all older buildings. An even more ambitious scenario is made where the heat demand between 1982 and 1984 of 16.3 MWh (125 kWh/m^2) is applied for all older buildings. Also, the heat demand for new buildings is altered by increasing demand by 10% and 20%. The resulting heat demands are given in Table 5.4.

Results from implementing the above-mentioned heat demands show that deviations in consumer losses are minimal of only 1-2%. Due to the high investment costs of individual heating, the lower heat demand of buildings from before 1979

Year	**Reference** $\left[\frac{kWh}{m^2}\right]$	**<1977: 17.0 MWh, >2010: +10%** $\left[\frac{kWh}{m^2}\right]$	**<1982: 16.3 MWh, >2010: +20%** $\left[\frac{kWh}{m^2}\right]$
-1965	183	131	125
1966-1971	153	131	125
1972-1976	136	131	125
1977-1981	131	131	125
1982-1984	125	125	125
1985-1994	120	120	120
1995-1997	115	115	115
1998-2007	105	105	105
2008-2009	92	92	92
2010-2014	69	76	83
2015-2017	39	43	47
2018-2019	38	42	46

Table 5.4: Resulting heat demands based on increased heat demand of buildings from before 1979 and lower heat demands of buildings from 2010 and forth.

decreases consumer losses. The higher heat demand of newly built houses, on the other hand, increases economic incentives for individual heating. However, newly built houses only make up 1.5% of the building stock which makes effects minimal. Another primary reason for the heat demand to have low influence is the marginal price difference which describes at which point consumers are willing to change for a HP. The marginal price difference is initially defined as 20% additionally to the price of DH. Based on the preliminary studies of section 4.2.3, the heat demand needs to change substantially for the difference between DH and individual heating to be more than 20%.

Investigated separately, decreasing the heat demand of older buildings lowered consumer losses mostly in DH grids of prices between 20,000-22,500 DKK/year by 2%. Likewise, increasing the heat demand of new buildings increases the average consumer loss of DH plants in the same price range by 1%.

The marginal price difference differs from the variables concerning technical specifications and technical uncertainties, due to its human behavioural aspect. This parameter is key to consumer losses, as it describes the willingness of consumers to change for individual heating. Attention towards DH prices has increased during the past year due to the phase-out of the capacity payment. Notably the medias has often referred to the most expensive DH plants which however make up a rather small fraction of the Danish DH plants as can be seen from this study. However, this increased awareness toward prices of DH can have an influence on the marginal price difference set for this study. The effects of an increased awareness towards prices of DH will be that consumers will change sooner which corresponds to a lower marginal price difference. The results from varying the marginal price difference can be found in Table 5.5

Consumer price [DKK/year]	ΔC_B **= 20%**	ΔC_B **= 15%**	ΔC_B **= 10%**	ΔC_B **= 5%**	**Investigated/total**
25,000 -	100%	100%	100%	100%	1/1
22,500 - 24,999	61%	69%	69%	70%	2/5
20,000 - 22,499	41%	59%	63%	66%	6/8
17,500 - 19,999	2%	4%	42%	46%	10/33
15,000 - 17,499	1%	2%	4%	7%	9/94
12,500 - 14,999	0%	0%	0%	0%	7/137
10,000 - 12,499	0%	0%	0%	0%	3/86
- 10,000	0%	0%	0%	0%	1/29

Table 5.5: Sensitivity analysis investigating variations in the marginal price difference.

As it can be seen from the table, the majority of Danish DH plants are resistant to changes in consumer obligations and thus competition towards individual heating. The most concerning result from changing the marginal price difference occurs for DH plants with prices of 17,500-19,999 DKK/year for a standard single-family house. By decreasing the marginal price difference, a sudden increase in average consumer losses takes place as it approaches the price of a HP. In general, changes in the marginal price difference are only affecting the aforementioned most expensive DH plants which make up under 7% of all DH plants. Even at a marginal price difference of 5-10%, only 24 DH plants in total are assumed to be subject to consumer losses which threaten the economic stability.

5.4 Delimitation

During the study, certain delimitations have been made in order to simplify the governing question of what impact a complete repeal of the consumer obligations would have. As the question is very complex due to its influence of several technical and human aspects, delimitations have been necessary for this study. Some of the most influencing delimitations will be elaborated on here.

The comparison of DH and individual heating is primarily based on the price of heating. Sustainability was a parameter in selection from individual alternatives, but is not further investigated. The price of heat does take sustainability into account as taxes are imposed on CO_2-emitting fuels etc. However, the delimitation to only investigate consumer economics cannot fully clarify the sustainable effects from changing from DH to individual heating. In order to do so, emissions of the respective plants would have to be hold up against individual heating.

Also in accordance to delimitations of not investigating DH plants on a more definite level, the actual effects of specific consumers leaving the DH grid are not investigated. As an example, the grid loss per consumer can vary depending on the specific consumer leaving the grid. Assuming that grid losses are highest closest to the DH plant due to large pipes of higher heat losses, consumers located closest to the grid will result in a higher grid loss per consumer. This is exemplified in

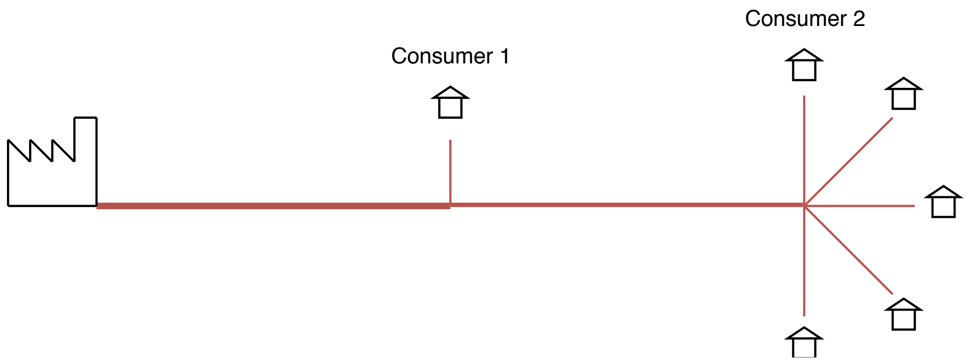

Figure 5.2: Example of how the grid loss per consumer increases in the event that consumer 1 leaves the DH grid.

Figure 5.2, where a loss of consumer 1 would result in a higher grid loss than a loss of consumer 2.

As a result of this, the variable cost would not decrease linearly with consumers leaving the grid.

A delimitation throughout this study also concerning consumers is the BBR data. The BBR data available for this study was gathered in 2016. Thus the study is delimited from investigating buildings from 2017 and forth. Based on the study carried out for this report, the vast majority of buildings was built from the 1990s and back. From this, it is assumed that buildings from the last two years will have minimal influence on the result.

Lastly, the selection of investigated DH plants may influence the result. The selection of DH plants is based on the price of heat for a standard single-family house. Plants are chosen to cover all price ranges with a main field of research for the plants of highest prices. Coverage in each range of prices has been calculated, but still, results may vary if other plants were chosen. For a more thorough analysis, calculations need to be made for each single DH plant.

6 | Conclusion

Based on the preliminary studies, it is found that a ground source HP is the most comparable type of individual heating to DH and also politically supported for the future of heat supply. Conclusively, the competitiveness of DH and consequences of a complete repeal of the consumer obligations is investigated by comparing DH plants to a ground source HP. The investigation rest on the fact that both DH and individual heating consists of a fixed and variable cost and that the cheapest supply of heat varies from building specifications. For the consumers' affiliation to DH, it is evaluated that attention towards prices of heating is limited and it is assumed that a change for individual heating will only occur at an extra cost of 20% compared to individual heating.

From the assumptions and inputs of the preliminary study, it is concluded that predominately DH plants with a heating price of more than 20,000 DKK/year for a standard single-family house of 130 m^2 are in risk of losing a critical number of their consumers. A critical point in consumer losses is found to be around 60% as consumer losses are found to escalate from here. The largest and cheapest DH plants, categorised as the centralised plants, are not assumed to be affected by a repeal of the obligation of remaining due to their relatively low price, large number of consumers and dependency in terms of electricity production. Out of the remaining 384 DH plants, the DH plants of considerable risk, only make up 14 plants. Of these, 6 plants are estimated to lose all of its consumers and 8 plants are estimated to lose a considerable part of their consumers of minimum 8%. For DH plants with a price of heat below 20,000 DKK/year, it is estimated that consumer losses only reach 0-2%. The affected DH plants are both decentralised CHP plants and only heat-producing DH plants. In continuation of the fact that full load hours of decentralised CHP plants have decreased by approximately two thirds during the last decade, consequences are not expected to affect the security of supply in regards to the electricity sector [Boes, 2018]. Also, no correlation between geographical location of the DH plants and the potential consumer losses is found.

The total consumer economic gain from consumers changing for a HP of a lower cost of heat is in the most expensive DH grids calculated to be 1.1-2.6 M DKK. However, these consumer economic gains are generally assumed to be low compared to the business economic losses from debt and scrap value of components in the DH plants and DH grids. A closure of a plant is thus expected to result in a socioeconomic loss of which the magnitude depends on the economy of the specific DH plant. Solutions to overcome a closure are found to depend on either economic support or ease of legislation. An ease of the CHP- and fuel commitment is found to be the most appropriate and long-term solution for DH plants to regain competitiveness towards individual heating. This is mainly because economic support is only considered a temporary solution and because an ease of the CHP- and fuel commitment would be in line with the liberalisation of the DH sector. From comparing variable costs of different production units for DH, it is assumed that the variable price of the most expensive DH plants can be brought down to a competitive level depending on the specific grid losses. From decreasing the variable costs of the most expensive DH plants by 15-30%, it is found that no consumer losses occur.

From the sensitivity analysis, it is concluded that a decrease in variable costs of individual heating increases the consumer loss particularly for DH plants within the price range of 15,000 to 20,000 DKK/year. A corresponding increase in variable costs of individual heating is on the contrary showing a distinct superiority of DH in terms of competitiveness. Sensitivity analysis furthermore shows that a re-implementation of individual NG boilers can cause an increased consumer loss of up to 29% for DH plants with prices of 17,500-20,000 DKK/year and 23% for DH plants with prices of 20,000-22,500 DKK/year. In regards to the individual consumers, it is investigated what impact changes in heat demand and changes in affiliations towards the DH make. It is calculated that an improvement in isolation standards and increased heat demand in new buildings only causes minor changes of 1-2% in the average consumer losses. The consumer loss is, on the other hand, found to be noticeably depended on the affiliation of consumers towards DH. A consequence of the recent publicity of DH prices from the recent phase-out of the capacity payment, might be an increased awareness towards prices and possible change for individual heating at a lesser extra cost. It is investigated that a change for individual heating at an extra cost of 15% and 10% would cause an increase in consumer losses of 8% for DH plants of heating prices from 22,500-25,000 DKK/year and 18-22% for DH plants of heating prices from 20,000-22,500DKK/year respectively. From having consumers change for individual heating at an extra cost of 10%, the consumer losses of DH plants with a price between 17,500-20,000 DKK/year would moreover increase by 40% from the reference. If the terms of heat supply for a DH plant includes it, economic losses can potentially be minimised in case a consumer leaves the DH grid.

From an environmental perspective consumers are prevented from changing for fossil fuel based heating technologies. However, a re-implementation of NG boilers may be a possible in certain areas. This would possibly not increase sustainability in the heat supply depending on the fuel supply of the former connected DH plant and depending on the progress of increasing the use of biogas. A change for a HP would likewise depend on the progress of increasing renewable electricity production from e.g. wind power to be sustainable. This also applies for the DH which is politically urged to utilise electricity as fuel for producing heat with HPs.

As a final conclusion, the complete repeal of the consumer obligations does not appear to have considerable consequences to the DH as only few plants are affected. To specify the exact business- and socioeconomic consequences, it is required that the economy of each DH plant is further investigated. This further study should be aimed at investigating the 14 DH plants with a price of heating exceeding 20,000 DKK/year as these show to be most affected. To avoid potential economic consequences, it is suggested that the CHP- and fuel commitment is eased or removed for at least these DH plants.

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A | List of investigated DH grids

A complete list of the 39 investigated DH grids.

DH grid	Price of heat (18,1 MWh, 130 m^2) [DKK/year] [Forsyningstilsynet, 2019a]	Number of consumers
Øland Kraftvarmeværk A.m.b.a	23,499	149
Rise Fjernvarme Amba	23,484	124
Lørslev Fjernvarmeforsyning Amba	23,434	109
Vejby-Tisvilde Fjernvarme A.m.b.a.	23,386	600
Svebølle-Viskinge Fjernvarmeselskab Amba	22,343	522
Snertinge, Særslev, Føllenslev - SSF Energiselskab	22,213	333
Gram Fjernvarme	20,784	1,053
Havneby Varmeværk A.m.b.a.	20,652	113
Taars Varmeværk Amba	20,643	741
Odsherred Varme A/S	20,361	288
Ejsing Fjernvarmeforsyning A.m.b.a.	19,349	132
Thorshøj Kraftvarmeværk Amba	19,127	103
Hundested Varmeværk A.m.b.a.	19,070	1,194
Vesløs Fjernvarme Amba	18,882	127
Gedsted Varmeværk	18,694	380
Nordby Varmeværk Amba	18,504	907
St. Merløse Varme A/S	18,078	321
Toftlund Fjernvarme Amba	18,016	878
Østerild Fjernvarmeselskab A.m.b.a.	17,994	251
Mejlby Fjernvarmeværk AMBA	17,950	200
Holsted Varmeværk	17,838	896
Stokkemarke Fjernvarme	17,756	136
Tønder Fjernvarmeselskab A.m.b.a.	17,372	2,410
Læsø Varme A/S	17,060	192
Egtved Varmeværk	17,010	858
Løgstør Fjernvarmeværk	16,166	1,645
Haslev Fjernvarme Imba	15,687	2,022
Hovedgård Fjernvarmeværk amba	15,596	491
Ulbjerg Kraftvarme Amba	15,178	170
Hvalsø Kraftvarmeværk a.m.b.a.	15,068	1,010
Assens Fjernvarme Amba - Jylland	15,035	3,002
Høng Varmeværk	14,888	1,410
Hornslet Fjernvarmeselskab Amba	14,073	1,740
Kongerslev Fjernvarme	14,068	480
Genner-Hellevad-Hovslund Forenede Kraftvarmeværker	14,065	180
Nørre Nebel Fjernvarme	12,943	630
Vildbjerg Varmeværk A.m.b.a.	12,287	1,380
Fjerritslev Fjernvarme	12,150	1,725
Als Fjernvarme a.m.b.a.	11,755	430

Table A.1: All investigated DH plants.

B Example of consumer loss calculation

To exemplify the substantial number of calculations made for each DH grid, an excerpt of the calculation made for the DH plant of Lørslev Fjernvarmeforsyning Amba is here presented. The reason for choosing Lørslev Fjernvarmeforsyning, is because of its noticeable, but not complete estimated consumer loss.

In Figure B.1, an excerpt of the initial BBR data of consumers in Lørslev is given. The data has already been filtered to only show buildings supplied from DH. The two other main data are the year of construction (opf_aar) and total heated area (tot_area).

OBJECTID	opf_aar	muni	tot_area	anvendelse	forsyning	y	x
241226	1967	860	125	Parcelhus	Fjernvarme	6365419,98	565099,92
241227	1970	860	148	Parcelhus	Fjernvarme	6365364,98	565187,63
241230	1930	860	76	Parcelhus	Fjernvarme	6365569,97	564935,58
241274	1961	860	145	Parcelhus	Fjernvarme	6365575,48	565193,98
241275	1951	860	50	Parcelhus	Fjernvarme	6365579,6	565227,93
241276	1877	860	174	Parcelhus	Fjernvarme	6365544,05	564981,14
241277	1953	860	68	Parcelhus	Fjernvarme	6365489,37	564996,71
241278	1969	860	113	Parcelhus	Fjernvarme	6365470,74	565142,67
241279	1900	860	109	Parcelhus	Fjernvarme	6365533,47	564907,5
241282	1945	860	70	Parcelhus	Fjernvarme	6365489,53	564892,87
241283	1925	860	81	Parcelhus	Fjernvarme	6365453,9	564901,03
241286	1910	860	170	Parcelhus	Fjernvarme	6365403,64	564941,04
241908	1974	860	138	Parcelhus	Fjernvarme	6365555,36	565310,35
241909	1974	860	159	Parcelhus	Fjernvarme	6365449,64	565313,87
241910	1973	860	140	Parcelhus	Fjernvarme	6365453,14	565261,16
241911	1973	860	144	Parcelhus	Fjernvarme	6365484,13	565277,79
241917	1975	860	108	Parcelhus	Fjernvarme	6365526,9	565231,53
241918	1974	860	135	Parcelhus	Fjernvarme	6365494,22	565231,98
241921	1960	860	335	Undervisning og forskning	Fjernvarme	6365519,69	564980,92
241922	1954	860	316	Undervisning og forskning	Fjernvarme	6365519,19	564981,78
241990	1977	860	155	Parcelhus	Fjernvarme	6365379,77	565291,11
[illegible]	1988	860	[illegible]	[illegible]	[illegible]	6365564,53	[illegible]
[illegible]	[illegible]	860	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure B.1: Excerpt from BBR data of buildings in Lørslev.

Based on the total heated area and year of building, a matrix indicating the total heated area of each building within the associated group of building is made. This is shown in Figure B.2, where also the resulting annual heat demands are estimated using the area-based heat demands of Table 4.3. Again, this is calculated for all buildings.

OBJECTID	-1965	1966-1971	1972-1976	1977-1981	1982-1984	1985-1994	1995-1997	1998-2007	2008-2009	2010-2014	2015-2017	2018-2019	$Q_B(Y_B)$ [MWh]
241226	0	125	0	0	0	0	0	0	0	0	0	0	19
241227	0	148	0	0	0	0	0	0	0	0	0	0	23
241230	76	0	0	0	0	0	0	0	0	0	0	0	14
241274	145	0	0	0	0	0	0	0	0	0	0	0	27
241275	50	0	0	0	0	0	0	0	0	0	0	0	9
241276	174	0	0	0	0	0	0	0	0	0	0	0	32
241277	68	0	0	0	0	0	0	0	0	0	0	0	12
241278	0	113	0	0	0	0	0	0	0	0	0	0	17
241279	109	0	0	0	0	0	0	0	0	0	0	0	20
241282	70	0	0	0	0	0	0	0	0	0	0	0	13
241283	81	0	0	0	0	0	0	0	0	0	0	0	15
241286	170	0	0	0	0	0	0	0	0	0	0	0	31
241908	0	0	138	0	0	0	0	0	0	0	0	0	19
241909	0	0	159	0	0	0	0	0	0	0	0	0	22
241910	0	0	140	0	0	0	0	0	0	0	0	0	19
241911	0	0	144	0	0	0	0	0	0	0	0	0	20
241917	0	0	108	0	0	0	0	0	0	0	0	0	15
241918	0	0	135	0	0	0	0	0	0	0	0	0	18
241921	335	0	0	0	0	0	0	0	0	0	0	0	61
241922	316	0	0	0	0	0	0	0	0	0	0	0	58
[illegible]	0	0	0	[illegible]	0	0	0	[illegible]	0	0	0	0	20
[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	146	0	[illegible]	[illegible]	0	0	[illegible]	18
[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure B.2: Table showing the matrix of heated area and resulting heat demand.

Lørslev is a relatively small city and DH grid with only 109 consumers. The prices of heat are listed below [Lørslev Fjernvarme a.m.b.a., 2018]:

$C_{consumption}$: 837.5 DKK/MWh
$C_{subscription}$: 1,125 DKK/meter
$C_{capacity}$: 55 DKK/m^2

Compared to other DH plants, the capacity price is rather high and the subscription price rather low. This can benefit consumers of low heated area. The average heated area of buildings in Lørslev is 24% less than the average of all the investigated DH grids. Hence, this might be the reason for the lower consumer loss compared to DH plants of similar prices for a standard single-family house.

For calculating the price of individual heating produced by a HP, the following costs and specifications are used:

COP: 3.74
C_e: 2,198 DKK/MWh
C_i/Y_i: 7,450 DKK/year

From knowing the heat demand, heated area and costs of DH and individual heating, the price of both can be calculated for each building. The price difference can then be estimated to evaluate if a consumer is leaving the DH grid in favour of individual heating based on the marginal price difference.

The consumers estimated to leave in the first iteration will not be accounted for in the second iteration. Hence, the fixed costs of DH are increased corresponding to the consumers leaving the grid. The fixed costs of DH and remaining consumers for each iteration are given in Table B.1.

Iteration	$C_{subscription}$ **[DKK/meter]**	$C_{capacity}$ **[DKK/m^2]**	**Consumers left**
1	1,125	55	109
2	1,301	64	92
3	1,414	69	84
4	1,414	69	84
5	1,414	69	84

Table B.1: Results of increased fixed prices and remaining consumer in the DH grid.

Iterations are converging already at the third iteration due to the increase in fixed costs of DH, not being sufficient enough to make HPs economically feasible for the remaining 84 consumers. The resulting increase in fixed prices corresponds to an increase of 2,109 DKK/year for a standard single-family house. Based on the remaining consumers, a decrease of 23% in consumers is estimated for Lørslev Fjernvarmeforsyning Amba. This exact procedure is carried out for all 39 investigated DH plants and 29,321 consumers.