AALBORG UNIVERSITY
STUDENT REPORT

ENERGY EFFICIENCY IMPROVEMENTS IN BUILDINGS

A Study of Private Economic Benefits for Homeowners in the Municipality of Greve

AALBORG UNIVERSITET – MASTER THESIS

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Summary

This thesis takes its point of departure in the current energy transition that Denmark and other European countries are currently facing as many European countries seek to become independent of natural gas imports from Russia, our energy system and building stock need to undergo drastic changes. Natural gas prices have been drastically increasing, which is reflected in homeowners' energy bills. This study focuses on the building stock in the Municipality of Greve and how energy efficiency improvements can affect the use of natural gas, and how it can result in private economic rewards. At the moment, the Municipality of Greve and Greve Fjernvarme are primarily focusing on expanding Greve's existing district heating grid and less on how changes can be implemented on the consumer side of the energy system to reduce consumption of natural gas. By investigating this issue further from the consumer side, this study aims to fill a regional knowledge gap. This is addressed through the following research question and sub-question:

How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit homeowners' private economy, and how do the private economic benefits correlate with socio-economic benefits?

- *Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*

The private economic assessment is based on a method created by BUILD that uses building data from The Danish Heat Atlas to assess selected building stock in the Municipality of Greve. The analysis compares different energy efficiency improvement scenarios for the selected building types with the marginal differences in heat costs when implementing energy efficiency improvements. The results demonstrate the private economic optimal degree of energy efficiency improvement to be about 30 percent depending on the building and heat supply type. The further analysis assessed the discrepancy between the private and socio-economic benefits of implementing energy efficiency improvements. The analysis uses the theoretical framework feasibility studies to assess the discrepancies between the private and socio-economic benefits. The more significant socio-economic potential is a combination of different spillover effects and includes factors such as less need for new heat supply expansion. To some extent, the identified discrepancy can be offset by public funds such as Byggepujlen offering subsidies for energy efficiency investments.

In this study, both a private and socio-economic potential for energy efficiency improvements is found. However, homeowners' behavior towards energy efficiency improvements is found to be irrational as they are not utilizing the evident potential. The last sub-analysis assesses some of the factors that contribute to the irrational behavior of the homeowners. Theoretical terms such as the power of social norms and discarding the future are used to assess how the homeowner's willingness to implement energy efficiency improvements can be influenced. Here, examples from the Municipality of Helsingør are used to assess how they are raising awareness of energy efficiency improvements and the potential benefits it can have. In this regard, different initiatives carried out by the Municipality of Helsingør are found to be applicable for the Municipality of Greve to implement. The discussion dive into the potential consequences of the current labor shortage and lack of materials in the building and construction sector. Moreover, it is discussed how multiple benefits can affect the prevalence of energy efficiency improvements.

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INTRODUCTION

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1. Introduction

1.1. Problem analysis

The chapter seeks to give an overview of the background and current and historical contextual factors that led to this study's research question and purpose.

1.1.1. Introduction

Natural gas has played an essential role in the European energy sector and industry since the first oil crisis in the 1970s'. As a result of the oil crises, energy policy formed the basis for natural gas investments to reduce the reliance on imported oil. In addition, natural gas was a cheaper alternative to oil and a less pollutant fuel than oil which favored investments in natural gas infrastructure throughout Europe (Mathiesen & Hagedorn-Rasmussen, 2022). In February 2022, the European Commission agreed on the classification system, "*Taxonomy of environmentally sustainable economic activities,*" which under specific circumstances consider investments in natural gas sustainable. However, natural gas is still considered a transition fuel and a "better" alternative than investments in more pollutant fossil fuels such as oil (European Commission, 2022).

On a national and international level, the political views on natural gas investments and usage have radically changed after Russia's invasion of Ukraine. This was among other things expressed by the German Chancellor, Olaf Scholz, who decided to shut down the newly finished natural gas pipeline, North Stream 2, which runs from Russia to Germany through The Baltic Sea (Florin & Wang, 2022). As a result, the influence of the events in Ukraine was immediately visible in natural gas prices in Europe. These changes in the natural gas prices are illustrated in figure 1.

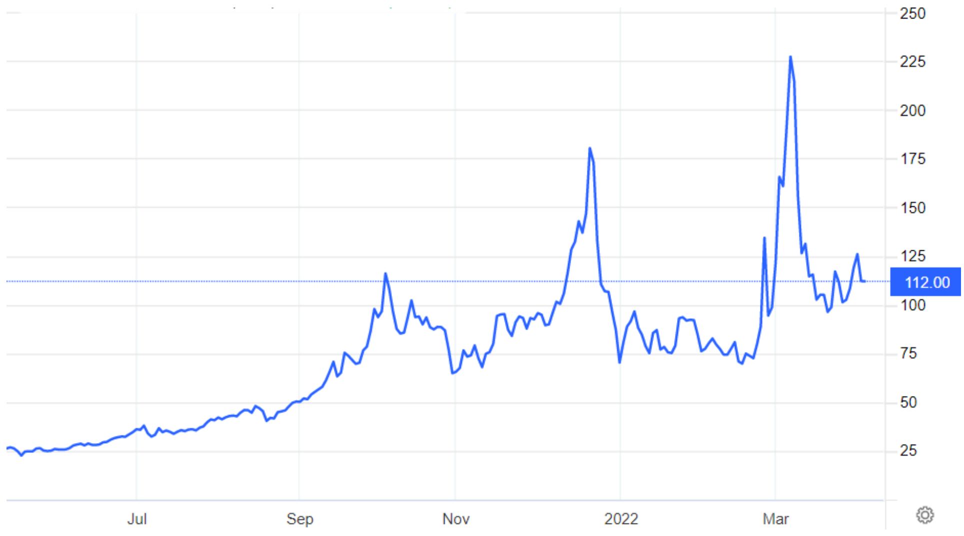

Figure 1: Natural gas price development on EU marked (Trading Economics, 2022).

EU countries are highly reliant on natural gas imports from Russia, constituting 38 percent of the imported natural gas to EU countries in 2020. In total, EU countries imported 84 percent of their natural gas comsumed in 2020 (Eurostat, 2022). The International Energy Agency (IEA) has presented 10 initiatives to minimize and phase out the dependency on imported natural gas. Some of the initiatives are (IEA, 2022):

- *Acceleration of new solar and wind projects.*
- *Improve energy efficiency in households and industry.*
- *Replace natural gas boilers with heat pumps.*
- *Lower temperature by 1°C in buildings.*

1.1.2. Danish natural gas overview

Until 2020, Denmark has been in a profitable position due to our production of natural gas surpassing our use of natural gas (Energistyrelsen, 2021) – presented in figure 2.

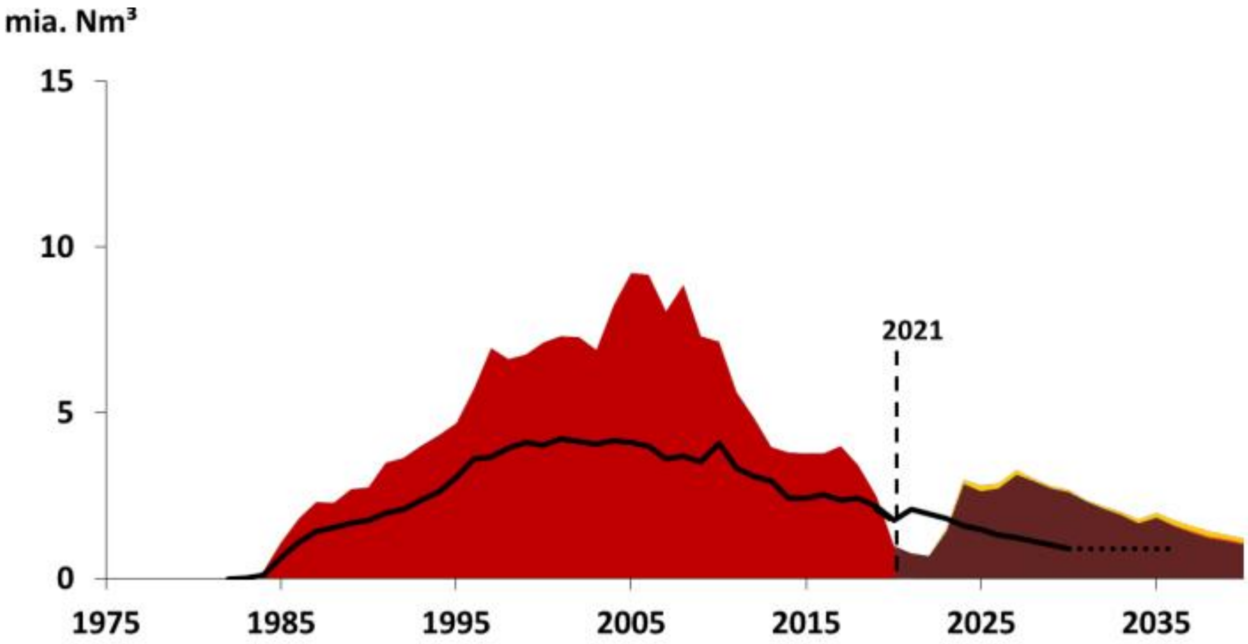

Figure 2. Natural gas production and consumption in Denmark and the extrapolation for the future. The red area is production, dark red is extrapolated production, and the black line is consumption (Energistyrelsen, 2021).

The rapid reduction in Denmark's natural gas production is a consequence of a shutdown of the most extensive natural gas extraction area Tyrafeltet due to renovation. The renovation of Tyrafeltet resulted in the need for imported natural gas for the first time since the 1980s. As a result, as seen in figure 2, the extrapolated natural gas production is surpassing the consumption in 2023 when Tyrafeltet is scheduled to reopen again (Energistyrelsen, 2021).

Natural gas consumption in Denmark covers four fields of usage, electricity production (10 percent), district heating (14 percent), industry (36 percent), and heating for buildings (40 percent) see table 1. The heating of buildings in this context consists of companies, single-family houses, and apartment buildings that are not connected to a district heating system but have individual gas boilers.

Sector	Natural gas consumption (PJ)	Share
Electricity production	7	10 %
District heating	10	14 %
Industry	25	36 %
Heating of buildings	28	40 %
Total	70	100 %

Table 1: Natural gas consumption in Denmark 2020 – own production with data from (Energistyrelsen, 2020).

The political will to phase out natural gas for heating has been prevailing since the latest energy agreement from 2020. The energy agreement states that Denmark must phase out natural gas for heating before 2030. In addition, the agreement allocates substantial funds for conversion to district heat and abandonment of natural gas boilers (Regeringen, 2020). The enormous increase in prices of natural gas was also present prior to the war in Ukraine, affecting private households' energy bills, as seen in figure 3.

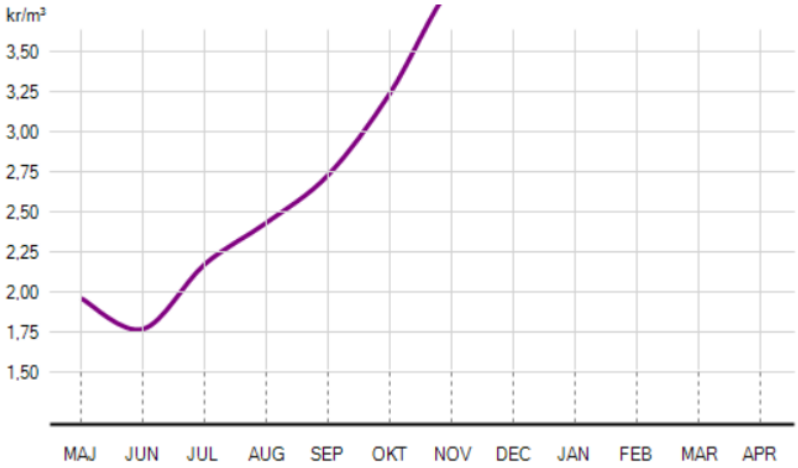

Figure 3. Development in Danish natural gas prices without rate, tax, and levies for the second half of 2021 (Gasguiden, 2022).

Due to the increase in natural gas prices, several political parties in the Danish parliament recently agreed on a new energy agreement. That allocates heat checks of DKK 6000 for low-income households affected by the increasing natural gas prices. Additionally, the agreement allocates funds for new district heating expansion at the expense of natural gas. More importantly, the agreement also prescribes the intention to initiate a dialog with the EU Commission on the possibility of banning new installation of gas boilers. Furthermore, the agreement also contains a proposal for a more detailed plan for phasing out natural gas from heating in a new energy and utility agreement that will be presented later this year (Ministry of Climate, Energy, and Utility, 2022a). However, several political parties declined the heat check agreement as some of them perceived the heat checks as an extension of natural gas dependency (EnergiWatch, 2022).

In addition to the political agreements on phasing out natural gas, Aalborg University, and IDA (Engineers Association) have issued a publication on how to accelerate the phasing out of natural gas on a European and national scale. The publication prescribes how Denmark can reduce its natural gas consumption by around 79 percent before 2028 by following the recommendations presented in the publication. The recommendations are divided into immediate, short-term, medium-term, and long-term actions. The recommendations emphasize the importance of energy savings and energy efficiency improvements in line with IEA's recommendations. Furthermore, the need for collaboration between stakeholders such as utility companies, municipalities, and knowledge institutions is mentioned as an important factor (Mathiesen & Hagedorn-Rasmussen, 2022). This collaboration must preferably be put into practice as soon as possible and paired with updated municipal heat plans inspired by results from Heat Plan Denmark 2021 (Mathiesen et. al., 2021). Municipal heat plans are an essential part of a cost-efficient transition of the natural gas areas, as they enlighten citizens with information about future heat supply at the building level. (Mathiesen & Hagedorn-Rasmussen, 2022).

Heat Plan Denmark 2021 distinguishes between densely populated areas or cities that optimally could transition their heat supply to district heating and less densely populated areas that preferably should change their heat supply to individual heat pumps. Another key conclusion from Heat Plan Denmark 2021 is made in relation to energy efficiency improvements in buildings. In this regard, it was found that the total heat demand for buildings in Denmark can be lowered by 36 percent. The 36 percent represents the socio-economic break-even point where costs of further energy efficiency improvements surpass the fuel costs for heating (Mathiesen et al., 2021).

1.1.3. Heat and climate planning in the Municipality of Greve

As the political as well as the public interest in phasing out natural gas for heating increases, many municipalities and utility companies urge to plan and implement cheaper and more sustainable alternatives. An example of that can be seen in the Municipality of Greve which will be examined more in-depth throughout this study.

The Municipality of Greve is located south of Copenhagen in the Zealand Region. The Municipality of Greve is a medium-sized municipality with around 50.000 inhabitants (DST, 2022). The municipality’s heat demand is primarily designated for natural gas for heating, as seen in figure 4.

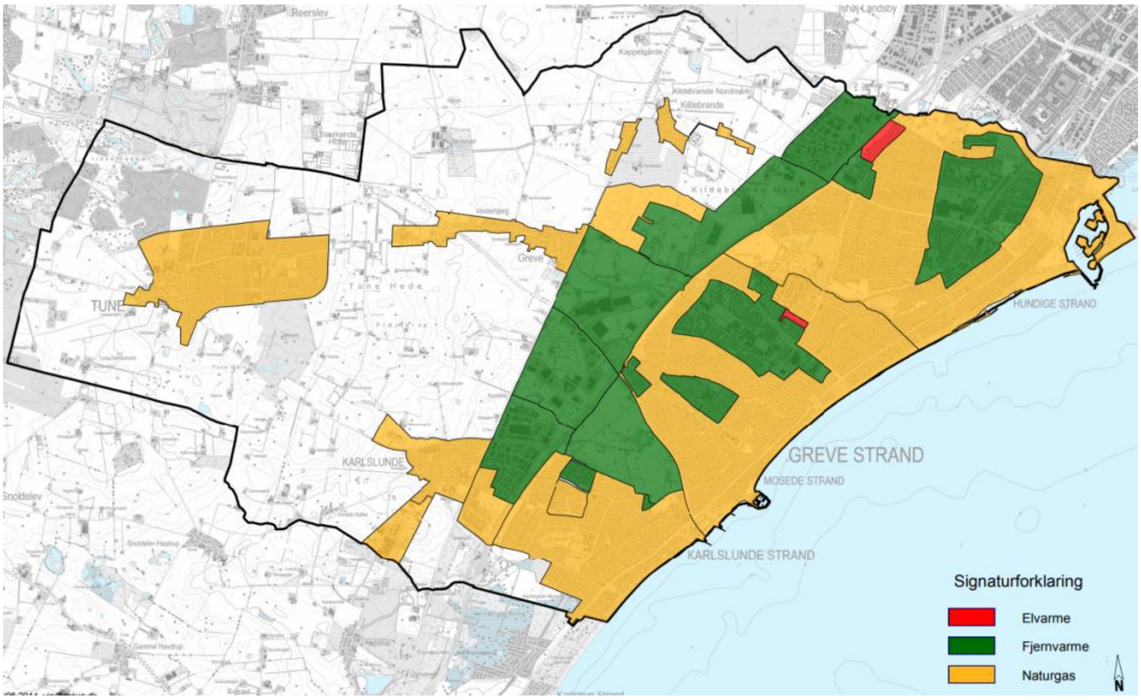

Figure 4. Heat map boundaries in The Municipality of Greve – Electric heating is the red area; district heating is green, and natural gas is yellow (The Municipality of Greve, 2014).

Table 2 shows the heat consumption in the Municipality of Greve in 2019 for different types of heat supply. As seen in table 2, most of the heat consumption in Greve is made up by district heating and natural gas boilers.

Heat supply	Quantity households	Heat consumption [MWh/year]
District Heating	2,156	106,647
Natural gas	10,190	236,654
Oil	987	30,530
Biomass	55	1,178
Heat pumps	614	9,690
Other	2,541	24,584
Sum	16,543	409,283

Table 2. Heat consumption in the Municipality of Greve in 2019 (The Danish Heat Atlas, 2019).

1.1.3.1. DK2020 climate plan

In 2021, the Municipality of Greve decided to become a part of the national climate partnership DK2020. The DK2020 partnership means that the municipality is currently developing a climate plan that must be finished before the end of 2023 (Realdania, 2021). DK2020 meets the international C40 standards, and the guidelines of the climate plan are presented in The Climate Action Planning Framework (CAPF) (C40 Cities, 2020). CAPF dictates how the set climate targets must comply with the Paris Agreement and aim for net-zero emissions in 2050. The set climate targets take their point of departure in the municipality's baseline, which is an overview that works as a point of reference for future reduction scenarios. The DK2020 plan is not only a matter of CO2 emission accounting, but it also includes mapping the consequences of climate change in the municipality and how the municipality can adapt to those. Citizen and stakeholder involvement is also a required part of the participation in the DK2020 partnership as they play an instrumental role in a successful transition. Finally, it is required that the municipality set ambitious subsidiary targets, which will be monitored continuously (C40, 2020). The Municipality of Greve's participation in DK2020 will naturally involve initiatives that decrease their dependence on natural gas. However, they are also working with concurrent projects until they initiate the implementation of the DK2020 targets.

1.1.3.2. Heat planning in the Municipality of Greve

The Municipality of Greve does not have a municipal plan for heating solely. However, their latest strategic energy plan from 2011 it is described what future heat supply is presumably going to look like in the municipality.

"In comparison to the rest of the country, the big share of one-family houses characterizes the Municipality of Greve (…) This particularly impacts the municipality's heat supply structure as it is relatively uneconomic to expand the district heating to one-family house areas. Consequently, the future heat supply is and will be dominated by more individual solutions which is the most cost-effective in one-family house neighborhoods. This currently applies to individual natural gas boilers which in the future most likely will be replaced by individual heat pumps and solar heat"

(The Municipality of Greve, 2011, p. 6).

The excerpt from the municipality's latest strategic energy plan predicts a significant discrepancy from the current plans in Greve (Appendix 2). The Municipality of Greve is currently working on a new heat plan (Appendix 2) that will designate way more district heating than what is seen in figure 4. There are several reasons for this change; where one primary reason is a change in *Projektbekendtgørelsen,* which means that new district heating project proposals no longer need to be compared with fossil fuel alternatives (BEK nr 1794 af 02/12/2020 § 18,4). The fact that the city council in the past should choose the cheapest alternative available when approving new district heating project proposals often meant that district heating projects were rejected because individual natural gas boilers were a cheaper alternative. The legislative changes and the previously described political will to phase out natural gas as heating has made cost-effective conditions for district heating expansion.

Greve is connected to the district heating network in the capital region, as seen in figure 5. The transmission pipeline seen with black going south in figure xx supplies Greve Fjernvarme with heat which is then distributed within their distribution area. Greve Fjernvarme's supply area is located east of the transmission pipeline, whereas Tranekilde Fjernvarme supply area is located west of the transmission pipeline (Appendix 1).

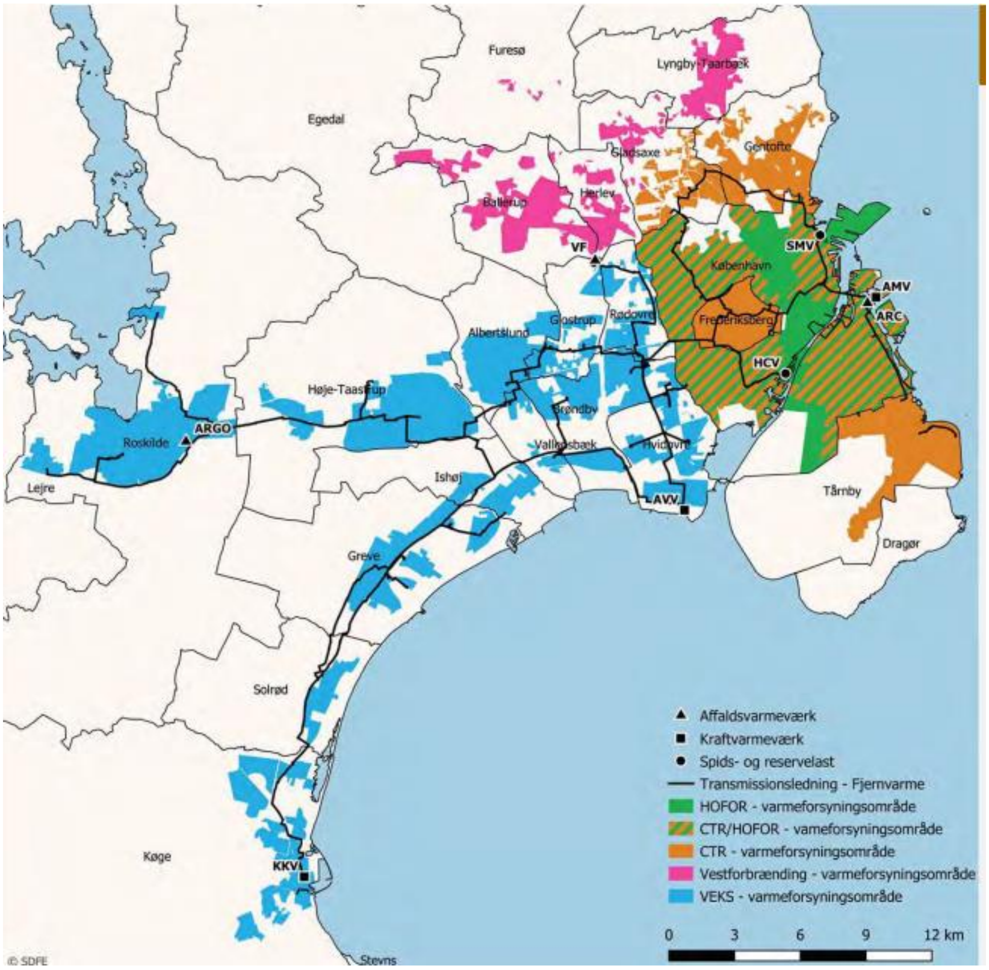

Figure 5. District heating network in the capital region. (FFH50, 2022)

Greve Fjernvarme is planning to expand its supply area substantially in the years to come. The expansion involves 9,000 households (Greve Fjernvarme n.d.) in the colored areas shown in figure 6, which according to the Government, must be converted into district heating before 2028 (Regeringen, 2022a). The district heat expansion in Greve will happen in stages where the first stage offers the conversion of 2,000 households to district heating. However, Greve Fjernvarme has not yet announced publicly which 2,000 households will be offered district heating in the first stage. Despite that, in an interview for this study, Energy Manager Line Carlsen from Greve

Fjernvarme revealed that the first stage will be split into three areas of around 700 households within the colored areas in figure 6, making a total of around 2,000 households (Appendix 1).

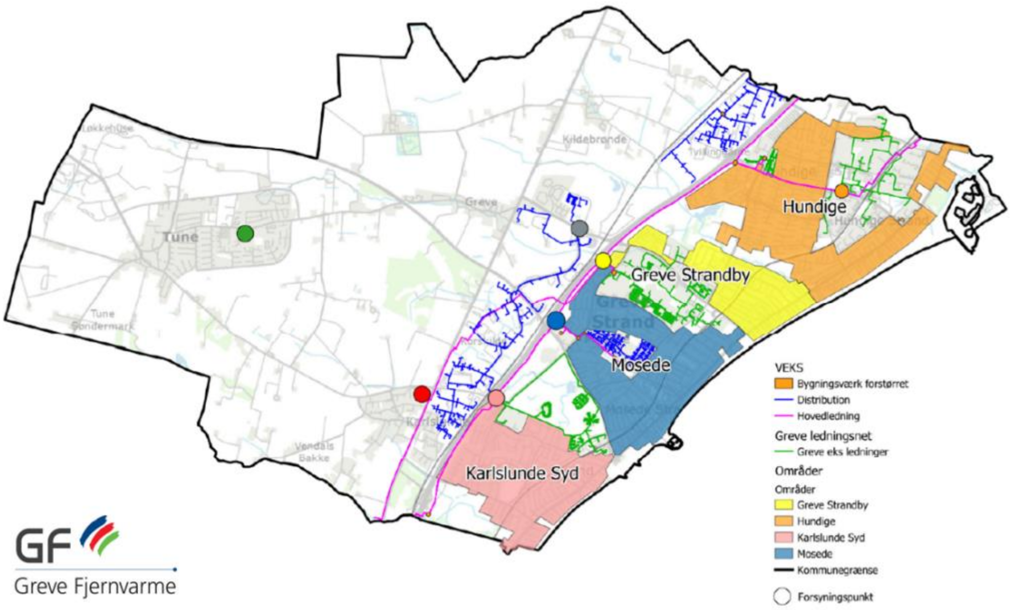

Figure 6. Greve Fjernvarme's distribution area in Greve - green lines and future district heating areas - colored areas (Greve Fjernvarme, n.d.)

The conversion plans towards more district heating in Greve are validated by the potential highlighted *in "Heat Plan Denmark 2021"* (Mathiesen et. al., 2021). Figure 7 illustrates the potential for district heating expansion in the Municipality of Greve.

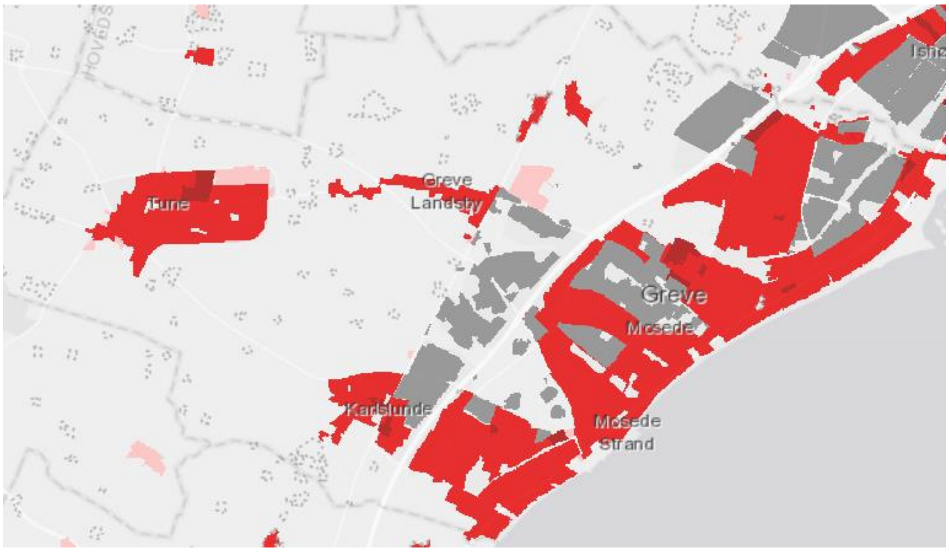

Figure 7. District heat potential in the Municipality of Greve from *"Heat Plan Denmark 2021"* (Mathiesen et.al., 2021).

Most of the potential is in Greve Fjernvarme's distribution area east of the motorway towards Copenhagen. This area holds a great potential for district expansion due to the high heat density as well as the existing district heating transmission and distribution grid (Appendix 1). The future district heating area seen in figure 6 and 7 is the same area that the municipality referred to as most suitable for individual solutions in their latest strategic energy plan. However, this stance from the municipality has changed since then, and the municipality is now aware of the district heat potential in the areas which will be visible in the new heat plan to come (Appendix 2).

1.2. Scope of study

The problem analysis of this study has primarily been focusing on natural gas consumption in Denmark and what policymakers are doing to change the dependency on natural gas in the heating sector from the supply side of the energy system. The reason for this is that the government as well as the local authorities in the Municipality of Greve, are primarily focusing on the supply side of the energy system when seeking independence from natural gas. The supply-side naturally plays an essential role in transitioning towards a fossil fuel free heating sector. However, a narrow focus on the supply-side violates fundamental principles set by the European Commission. EU Directive (2018/2002 § 2) prescribes how investments in energy efficiency improvements on the consumer side of the energy system should be prioritized over investments on the supply side if they are more cost-effective. This means that energy efficiency improvements should be implemented up until the point where they exceed the price for heating on the supply side.

The widespread potential for energy efficiency improvements in Danish building stock is measured in "*Heat Plan Denmark 2021".* The study concluded that the total heat demand for Danish building stock from a socio-economic perspective can be brought down by 36 percent without surpassing the fuel costs for heating (Mathiesen et.al., 2021). This correlation is also present for the Municipality of Greve and is highlighted by Mathiesen et.al. in publicly available energy maps (AAU, 2021). Furthermore, the correlation is present due to the previously highlighted fact that the primary heat source in the Municipality of Greve is natural gas and that natural gas prices are currently high. These circumstances make it beneficial to focus on energy efficiency improvements by lowering the heat demand. The purpose of this study is to clarify the private economic potential for energy efficiency improvements in Greve. The results can be included in the ongoing heat planning in the Municipality of Greve. Since the focus from the municipality and the utility primarily is the supply side of the energy system, this thesis will be focused on the consumer side of the system to compensate for their lacking focus and constitute knowledge for future heat planning.

1.3. Research question

Based on the above, the purpose of this study is to contribute to the existing knowledge gap by investigating benefits of implementing energy efficiency improvements on the consumer side of the energy system in the building stock in the Municipality of Greve. In this respect, factors that must be considered in relation to the implementation will also be investigated. Thus, this study aims to address the purpose through the following research question and sub-question:

How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit homeowners' private economy, and how does the private economic benefits correlate with socio-economic benefits?

- *Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*

THEORETICAL FRAMEWORK

2

2.Theoretical framework

This section of the thesis presents the theoretical framework that will be utilized to answer the research question and sub-question. The theoretical framework will be divided into, feasibility studies and behavioral economics, which will constitute the foundation for this study. Firstly, feasibility studies and how it is used to assess the feasibility of a particular initiative or technology is presented. Additionally, it will be presented how the feasibility can be affected by changes in the market and public regulation. Secondly, an introduction to the basics of behavioral economics will be presented. In this regard, the importance of behavioral economics in the context of energy efficiency improvements will also be elaborated on.

2.1. Feasibility studies

A feasibility study is a theoretical framework that can be used to assess the feasibility of specific technologies or initiatives. Furthermore, it can highlight needed changes in public regulation or market economics that are needed to make specific technologies or initiatives economically feasible, see figure 8 (Hvelplund & Lund, 1998).

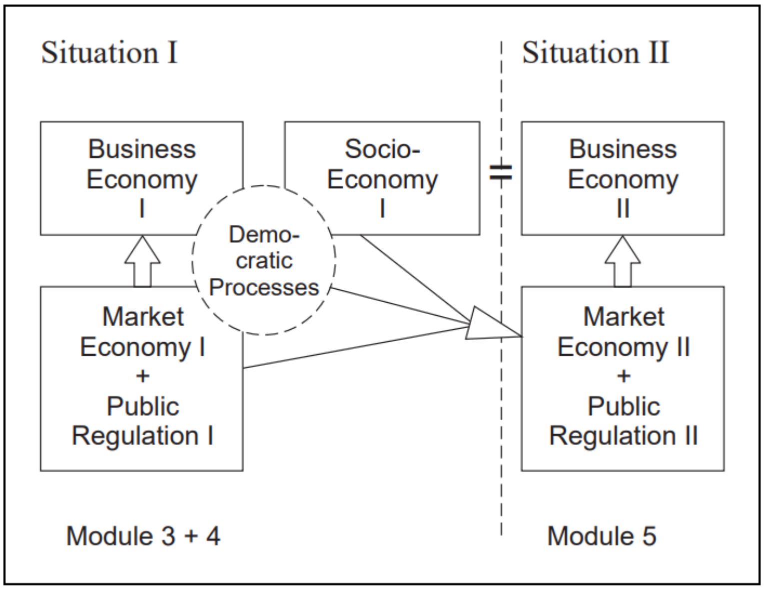

Figure 8. Illustration of the relationship between different economies and how democratic processes can change the settings to form a new situation (Hvelplund & Lund, 1998).

An example of this is the regulation taxation on electric cars. From a socio-economic perspective, electric cars perform better than fossil fuel-driven cars because of the externalities related to the use of fossil fuel-driven cars. The externalities related to fossil fuel cars that differ from electric cars are noise, air pollution, and effects on the worth of properties in proximity to heavily trafficked roads. These are all factors accounted for in socio-economic calculations, but these factors are not part of either business economic or private economic calculations. Despite these factors, electric cars still compete with fossil fuel-driven cars from a private economic perspective, but not to the same extent as the case for the socio-economic calculations. Therefore, even though investing in electric cars is a rational decision both from society's perspective and from the individual's perspective, there is still a discrepancy between the feasibility in business economy 1 and socio-economy 1 seen in figure 8 (Juul & Kristensen, 2014). In order to increase the sales of electric cars and even out the discrepancy between situations 1 and 2 as shown in figure 8, electric cars were exempted from registration tax until the end of 2015 (2016/1 LSF 210). Among other fiscal and technological changes, the removal of the registration tax for electric cars was one of the reasons why the market for electric cars boomed drastically. As the market conditions for electric cars have improved during the 2010s and electric cars have become cost-competitive with fossil fuel-driven cars, policymakers have decided to change fiscal legislation concerning electric cars (Elbilviden, n.d.).

When framing a feasibility study, the often makes sense to answer the following questions. ***What*** is studied, for ***whom*** is this studied, and ***why*** is the selected matter studied. Furthermore, the three questions should be considered in a certain time perspective depending on the context in that the questions are asked (Hvelplund & Lund, 1998). Returning to the example of electric cars versus fossil fuel-driven cars. Some people decide not to buy electric cars because the average electric cars investment costs are higher than fossil fuel-driven cars. However, when considered at lifetime, are average electric cars cheaper. This is mainly due to the lower fuel costs for electric cars compared to fossil fuel-driven cars (Lemche, 2018). The example illustrates why it is crucial to consider the time perspective when analyzing the feasibility of specific technologies.

2.1. Behavioral economics

Behavioral economics involves researching how psychological aspects of thinking about microeconomy affect individual decision-making. In the context of implementing energy efficiency improvements, behavioral economics terms will be used to determine the irrational behavior of not fully utilizing microeconomic potentials (Camerer & Loewenstein, 2004). The social norms of groups often influence the individuals they associate with, which can sometimes lead to irrational decision-making in various contexts. Research displays cognitive dissonance between individuals' attitude towards self-proclaimed environmental stance and their actions in reality. This means that individuals could be aware of the environmental benefits of implementing energy efficiency improvements, but it is not reflected in their actions (Wilson & Dowlatabadi, 2007). For this study, behavioral economics theory is truly relevant for of understanding how different initiatives can encourage the prevalence of energy efficiency improvements. Moreover, behavioral economics theory can help explain how different actors play a crucial role in this transition. In following sections of this study are some of the theoretical concepts that contribute to the prevalence of energy efficiency improvements presented.

2.1.1. Rational choice

Individual behavior towards energy efficiency improvements can deviate from at least one of the basic principles of neoclassical economics: individuals will seek to utilize their financial standing. Their behavior also deviates from that in social studies often referred to as rational choice model. Rational choice model encompasses how individuals seek to optimize their financial standing by making rational choices (Camerer & Loewenstein, 2004). The rational choice in the context of this study would be a private economy utilization of energy efficiency improvements up to the break-even point of the energy investments. Sub-analysis 3 in this study will assess some of the behavioral economic motives that hinder rational choices in the context of energy efficiency improvements and how these irrational motives can be dealt with.

2.1.2. Social norms

Throughout psychological research, it has been found that individuals tend to conform to social norms and the behavior of peer citizens. This conformity applies to rational as well as irrational behavior, which constitute some of the motives for not taking advantage of the benefits of implementing energy efficiency improvements (Zaki et. al., 2011). Consumers might know the effects of energy efficiency improvements in general but may not be fully aware of the potential benefits for their households. Consequently, this lack of knowledge can be a determining factor for them not to implement any improvements. Hence, a key aspect is the importance of communicating the proper information and knowledge to the consumer (Wilson & Dowlatabadi, 2007).

As outlined in the problem analysis and further described in the scope of this study, the lack of focus on energy efficiency improvements from the Municipality of Greve and Greve Fjernvarme negatively contributes to the behavior of citizens in Greve. Therefore, with inspiration from i.a. initiatives made by the Municipality of Helsingør, sub-analysis 3 will, through the utilization of theory on social norms, seek to analyse how the Municipality of Greve can increase the awareness and prevalence of energy efficiency improvements within the municipality.

2.1.3. Discarding the future

When trying to explain the irrational behavior associated with not investing in efficiency improvements, another theoretical term within behavioral economics is to discard the future. Discarding the future means that individuals tend to discard future benefits compared to the present or short-term rewards. When working with energy efficiency improvements, the concept of discarding the future becomes relevant. For instance, homeowners might not implement the improvements, as it often takes many years before the energy efficiency investments break-even through decreased heat costs (Cabinet Office, 2011).

2.1.4. Impart of defaults

The theory on the impact of defaults revolves around individuals' tendency to opt for predetermined defaults. An example of this is a study performed by McCally (2006) that investigates the impact of removing the default temperature settings on washing machines. The study involved two groups of individuals, of whom one group was allowed to use default temperature settings while the other group should manually set the temperature themselves. At the end of the experiment, McCally compared the energy used by the two observed groups. The results showed that the group forced to set the temperature themselves used 24 percent less energy (McCally, 2006).

McCally's study illustrates how individuals tend to use default options and how this can affect energy use. As energy efficiency improvements is not a default initiative, it requires homeowners to make an active decision. In sub-analysis 3, theory on impact of defaults will be utilized to assess how engagement with homeowners can affect defaults and raise the awareness of benefits from implementing energy efficiency improvements.

2.1.5. Hassle factor

One last factor that is evident when assessing the lack of implementing efficiency improvements is the hassle factor. The hassle factor represents the hassle associated with implementing efficiency improvements and the necessities associated with doing them (Cabinet Office, 2011). A British study from 2008 performed by Caird et. al. (2008) surveyed individuals' reasons for implementing or not being willing to implement different energy efficiency improvement initiatives. One of the surveyed initiatives was the consumers' motives for not implementing loft insulation that would otherwise help them to improve the energy efficiency of their homes. The answers showed that the main reasons for not adopting the initiative could be explained by the hassle factor. In this regard, 33 percent of the respondents answered that the hassle of cleaning the loft stopped them from doing it, and 37 % percent answered that it would minimize their storage space in the loft (Caird et. al., 2008).

In sub-analysis 3, it will be examined how initiatives can help counteract the consequences of the above-mentioned theoretical terms and how they must be dealt with in order to increase the prevalence of energy efficiency improvements. The analysis will draw on examples that have raised awareness of energy efficiency improvements elsewhere and assess actors that could play an active role in the prevalence of energy efficiency improvements.

METHODOLOGY

3

3. Methodology

This chapter of the study will present the methodology that has been utilized to answer the research and sub-question of this thesis. The chapter will be divided into three parts. Firstly, the research philosophy that this study is built upon will be presented. Secondly, the data collection and treatment of data will be elaborated on. Lastly, the methodological approach will be summarized in a research design that helps clarifying the coherence between the three sub-analyses.

3.1. Research philosophy

As the research philosophy sets the agenda for the entire research process, both in terms of formulating the research question, preparing the research design, collecting, and treating the data as well as conducting the analysis, it is important to define and elaborate on the applied philosophy.

This thesis is essentially based on the research philosophy of positivism, meaning that the study uses quantitative data analysis to verify or falsify the hypothesis stated in the research question of this study. However, it is recognized that the collection of qualitative data, including interviews and observations, is not considered in accordance with the methodology of positivism. As the quantitative data serves as the primary source of data for answering the research question and sub-question, the qualitative data serves as background knowledge that has been essential for the scope of this study.

The positivist attitude to science was explicitly formulated for the first time in the 1820s by August Comte, who is today considered the founder of positivism (Brier, 2005). Positivism is closely related to natural science, and the ultimate goal for the investigator is to achieve as specific knowledge as possible. Independently of disagreements between different movements within the positivist paradigm, the methodology of positivism involves setting up hypotheses that can either be verified or falsified by collecting data under controlled conditions (Nygaard, 2013).

Ontology	Epistemology	Methodology
The positivistic ontology is considered realistic, and reality is constructed from a combination of objects and individuals.	Knowledge is viewed as objective if we as researchers base our inquiries on empirical proven findings and observations.	The methodological approach is quantitative and seeks to prove the causal relations existing in our society.

Figure 9. Positivistic assumptions on ontology, epistemology, and methodology (Nygaard, 2013).

The positivistic scientific approach is characterized by four basic theoretical positions; (1) Science is based on observations from what is observable, which meanings that science cannot involve religious, metaphysical or subjective beliefs, (2) The unity of scientific perception, which meanings that all science should utilize follows likewise the same methodology no matter the type variant of science, (3) All phenomena have a natural explanation – also known as naturalism, (4) Verification or falsification of Prove or disprove a hypothesis with data by either experiment or performing quantitative analysis (Nygaard, 2013).

As a result of the chosen research philosophy, the hypothesis addressed in this study is that energy efficiency improvements can provide private economic benefits, as it is proven in similar cases under similar circumstances. Accordingly, it will be possible to reach similar findings in this study to what has already been proven by chosen energy efficiency improvement studies (Nygaard, 2013).

3.1.1. Cases study

A case study is a methodological approach that can be utilized to examine a phenomenon. Case studies can be used to verify and falsify a hypothesis by conducting quantitative data analysis, which is the case in this study (Flyvbjerg, 2010).

There are several reasons for selecting Greve, including the Municipality of Greve and Greve Fjernvarme, as the case in this study. As previously presented in the problem analysis, the Municipality of Greve is heavily reliant on natural gas for heating. This offers a great potential for energy efficiency improvements as well as heat supply transition, making the study of Greve relevant. Furthermore, Energy Manager at Greve Fjernvarme, Line Carlsen, suggested selecting Greve as the case when collaborating with her in relation to other projects. This means that this study will build on a thorough understanding of the transition that the Municipality of Greve is currently going through.

Concerning the chosen case, it is recognized that the quantitative results concerning the building stock in the Municipality of Greve will not be generalizable and applicable to all municipalities in Denmark. However, the study can serve as an example. The methods can be utilized elsewhere to assess the building stock in a given municipality by measuring the potential for energy efficiency improvements and the costs associated with those improvements.

3.2. Data collection and treatment of data

This chapter will present the methods utilized for collecting the qualitative and quantitative data for this thesis. Furthermore, it presents the methodological approach that is utilized in the treatment and clean-up of the quantitative data. Finally, the chapter also presents the methodological approach that is applied to measuring the private economic benefits of energy efficiency improvements in the Municipality of Greve.

3.3. Qualitative data

3.3.1. Interviews

For this study, two semi-structured interviews were conducted early in the process. Firstly, an interview with Greve Fjernvarme, who was represented by Energy Manager Line Carlsen and Project Manager Ole Magnussen, was conducted (Appendix 1). Secondly, an interview with Sanne Holst who is Energy Planner at the Municipality of Greve, was carried out (Appendix 2). Initially, the purpose of the interviews was to gain solid background knowledge about the planning process of phasing out natural gas for heating in the Municipality of Greve and the desire to confirm prejudiced assumptions about the transition in the municipality

The interview with Sanne Holst was kept relatively short, as the interview was primarily conducted in order to confirm the municipality's lacking focus on energy efficiency improvements. Moreover, the purpose of the interview was into get insights on which building data she was familiar with.

In both cases, I had a phone call with the interviewees ahead of the interview, in order to qualify the questions for the actual interview and align the point of departure for the interview. These calls also established a sense of community with the interviewees and made the interviews more comfortable for the interviewer. Both interviews were conducted as semi-structured interviews where the order of the questions could change to follow up on the interviewee's answers. As the interviewees were called ahead of the interviews, both parties established a common pre-understanding of the problem area of the study (Brinkmann & Tanggaard, 2015).

After conducting the interviews, it became clear that neither the Greve Fjernvarme nor the Municipality of Greve had initiatives for energy efficiency improvements in Greve's building stock. As a results of this, the lack of energy efficiency improvement initiatives from both parties contributed to defining the scope of this study.

Both interviews have been transcribed and are to be found in appendix 1 and 2.

3.3.2. Observations

As part of the data collection for this study, I participated in a public meeting about the district heating expansion in Greve on the 24th of March. The public meeting was facilitated by the homeowners' association Greve Strand and offered homeowners information and the opportunity to ask questions about the ongoing district heating projects in Greve Strand. Both Greve Fjernvarme and the Municipality of Greve were represented by Line Carlsen, Ole Magnussen, and Sanne Holst, who have all been interviewed for this study. The public meeting has not constituted any explicit outputs for this study but offered background knowledge and an opportunity to meet involved stakeholders. Furthermore, it emphasized the importance of researching energy efficiency improvements since the initiative was not mentioned at the public meeting.

In addition to the public meeting in Greve, I participated in a public meeting in Hornbæk facilitated by the Municipality of Helsingør. The public meeting in Helsingør focused on energy efficiency improvements and featured presentations from both SparEnergi and Bolius. The participating citizens received information about the benefits of implementing energy efficiency improvements, the costs of the investments, and the subsidies for which they can apply. Furthermore, local retailers offering solutions for the building and construction sector were represented at the meeting in order to offer guidance and tenders for interested homeowners.

The public meetings have not been documented but have provided essential knowledge of how different municipalities work with initiatives within the field of this study.

3.4. Quantitative data

3.4.1. Data set

In order to examine the potential benefits of implementing energy efficiency improvements in the Municipality of Greve, a data set containing building data on all buildings in the Municipality of Greve was obtained from The Danish Heat Atlas. The data from 2019 was obtained from Steffen Nielsen who is a Lector at the Institute of Planning at Aalborg University.

3.4.2. Data cleanup

The data set was available in different formats, but in this case, it was cleaned up as a shapefile in QGIS. The data cleanup method was inspired by "*The Danish Heat Atlas 2016 – Documentation",* also provided by Steffen Nielsen (AAU, 2016). Firstly, irrelevant information in the data was deselected. This involved house number, building coordinates, street code, municipality number, etc. Secondly, all buildings with an energy heat consumption of 0 were removed following, all buildings not supplied by either district heating or natural gas. Thirdly, all building types, except for 120 (one-family houses), 130 (terraced or double houses), 140 (apartment buildings), 320 (wholesalers), and 330 (retailers) were removed from the data set, of which building type 320 and 330 were joined to form one building type named 300. These building types were selected as they comprise the main part of the building stock in the Municipality of Greve and because it allowed for comparison with results from BUILD (Aggerholm et. al., 2017). Lastly, the natural gas supply was renamed to 1, and district heating supply was renamed to 2. Table 3 visualizes selected data types for buildings in the Municipality of Greve obtained from the Danish Heat Atlas.

All tables that have the reference (Own production) are based calculations conducted on data from The Danish Heat Atlas sent by Steffen Nielsen and accessed at BUILD (SBI, 2017- excel file).

Data type (name in excel file)	**Unit**
Building types (BuildType)	120, 130, 140 and 300
Construction year (Built)	Year
Building area (M2)	m^2
Yearly energy consumption (MWh)	MWh/year
Energy consumption pr m^2	KWh/m^2
Heat supply (Supply)	1 (Natural gas) or 2 (District heating)

Table 3. Selected data types from The Danish Heat Atlas (Own production).

The data set encompassed 16.543 buildings prior to the cleanup. After the cleanup, the data set encompassed 11.523 buildings in the Municipality of Greve which are presented in table 4.

Building types	1	2	**SUM**
120	8299	198	8497
130	1217	1316	2533
140	43	347	390
300	62	41	103
SUM	**9621**	**1902**	**11523**

Table 4. Number of buildings supllied with natural gas and district heating in the Municipality of Greve after data cleanup (Own production).

3.4.3. Method for calculating energy efficiency improvements

In order to determine potential energy efficiency improvement in the selected building and supply types, the method utilized in the study "*Varmebesparelse i eksisterende bygninger*" conducted by BUILD (formerly known as SBI) is utilized in this study (Aggerholm et. al., 2017). The study consists of a report and an appertaining excel file with results from the data analysis. The purpose of BUILD's study is to break down potential energy efficiency improvements in Danish building stock and measure the costs of implementing the energy efficiency improvements. The extent of the energy efficiency improvement is outlined in seven scenarios that gradually build on top of each other. The scenarios are listed below (Aggerholm et. al., 2017):

0. *Point of reference*
1. *Basic renovation of building components to comply with constructional building standards*
2. *Scenario 1 + Insulation of empty cavity walls*
3. *Scenario 2 + Windows with energy label A*
4. *Scenario 3 + Some insulation of loft and roof*
5. *Usual good practice of insulation when doing renovation*
6. *Energy focused insulation of renovated building components*
7. *Scenario 6 + extra insulation of loft and roof*

A scenario builds on top of a prior mentioned scenario, meaning that it is not possible to implement scenario 3 without having implemented scenario 1 and 2 first. Additionally, a scenario must be implemented in combination with the basic renovation of the buildings to be cost-efficient. Furthermore, it should be noticed that scenario 1 is the most cost-effective, followed by scenario 2 and so on (Aggerholm et. al., 2017).

The first step of the energy efficiency improvement calculations is to compute the heat consumption saving potentials for the selected building types shown in table 5 below. The potential heat savings are from Aggerholm et. al. (2017), who have calculated the average heat-saving potential for different building types in Denmark. An important assumption in this study is that the building stock in the Municipality of Greve is comparable to the average building stock in Denmark. This assumption is made because the calculation of heat-saving potential for the different improvement scenarios specific to the Municipality of Greve would require very detailed data about the construction of the buildings selected for this study.

Building types	1	2	3	4	5	6	7
120	0.169	0.198	0.254	0.299	0.335	0.362	0.369
130	0.17	0.182	0.247	0.275	0.313	0.341	0.349
140	0.182	0.21	0.269	0.291	0.311	0.322	0.324
300	0.185	0.198	0.259	0.29	0.319	0.34	0.346

Table 5. Potential heat saving in decimal numbers for selected building types and different energy efficiency improvement scenarios (Aggerholm et. al., 2017).

3.4.4. Method for calculating private economic costs of energy efficiency improvements

The potential heat savings shown in table 5 are used to calculate the reduction in heat costs for buildings supplied with natural gas and district heating over a 30-year statement period. For buildings that are currently supplied with natural gas, two calculations are made. One calculates the potential reduction in the heat costs with continued natural gas supply over the 30-year statement period, while the other calculates with district heating over the 30-year statement period. Buildings that are already supplied with district heating have one calculation since those buildings most likely do not change their heat supply over the 30-year statement period. Building type 300 (businesses) is assessed over a 20-year statement period (Aggerholm et. al., 2017).

Heat supply	Price kr./kWh ex VAT	Annual price increase %
District heating	1.23	1.6
Natural gas	0.46	1.1

Table 6. Heat prices for natural gas and district heating in Greve (Forsyningstilsynet, 2021; Gasguiden, 2022).

Table 6 shows the fuel prices that are used in this study. The district heating price in the Municipality of Greve is found on Forsyningstilsynet’s website, where all Danish utility companies’ heat prices are published twice a year (Forsyningstilsynet, 2021). The district heating prices used in this study represent the prices of Greve Fjernvarme from august 2021.

The natural gas prices are found at ‘Gasguiden’, where the prices are specific to the natural gas suppliers in the Municipality of Greve and the average natural gas use of buildings in Greve. The natural gas prices used in this study are from the 5th of May 2022. Natural gas supply companies are obligated to make their prices publicly available in order to inform customers of the relevant information when choosing a supplier. (LBK nr 126 af 06/02/2020 § 42a).

The annual price increases for natural gas and district heating are from Aggerholm et. al. 2017 who use it to calculate the increased heating prices of the 30-year and 20-year statement period.

As mentioned previously, the reduction potential of the seven scenarios used to determine the reduced heat cost over the statement period of the investments and this is done for three possible types of supply. *Natural gas,* which is buildings currently supplied with natural gas, *District heating NG* which is buildings currently supplied with natural gas but in this case, their heat supply changed to district heating. The last one is *District heating* which is buildings currently supplied with district heating. All calculations are conducted with average values for the three possible types of supply and buildings, meaning that the results create a generalized overview of the building stock in Greve municipality.

EEI investment costs kr/m2 sum							
	1	2	3	4	5	6	7
120	0	8	27	54	123	197	233
130	0	3	21	36	104	170	206
140	0	7	24	34	62	88	100
300	0	2	17	26	62	104	122

Table 7. Summarized costs for energy efficiency investments in DKK per m^2 for scenarios and building types (Aggerholm et. al., 2017 – excel file)

At each scenario, the marginal difference of the heat cost is compared with previously calculated scenario. The marginal heat cost difference is divided by the marginal cost of the energy efficiency improvement investment to find the payback time of the investments. The marginal costs of the energy efficicency improvement investments are based of the excel results file published together with Aggerholm et. al.’s study (2017). The marginal costs for the energy efficiency investments are shown in table 8, and the summarized cost of the investments are shown in table 7.

EEI investment costs kr/m2 marginal							
	1	2	3	4	5	6	7
120	0	8	19	27	69	74	36
130	0	3	18	15	68	66	36
140	0	7	17	10	28	26	12
300	0	2	15	9	36	42	18

Table 8. Marginal costs for energy efficiency investments for senarios and building types (Aggerholm et. al., 2017 – Excel file)

The costs of the energy efficiency improvement investments distinguish from the basic renovation investments. At each scenario is the energy efficiency improvements investments, the renovation that goes beyond the basic renovation and has the purpose of lowering the buildings heat demand. Therefore, it is a prerequisite for the prices of the energy efficiency improvements that they are done together with basic renovations seen in table 9. A basic renovation is a renovation the that ensures compliance with the constructional building standards and renovation that ensures a healthy indoor environment.

Basis investment kr/m2 sum							
	1	2	3	4	5	6	7
120	1099	1099	1120	1670	1968	1968	2069
130	1138	1138	1165	1627	1929	1929	2028
140	918	918	933	1087	1220	1220	1280
300	956	956	976	1271	1408	1408	1464

Table 9. Summarized costs for basic investment for renovation of basic contructional building components (Aggerholm et. al., 2017- Excel file).

3.5. Socio-economic energy efficiency improvements

The socio-economic energy efficiency improvement breakeven point is found in AAU's online available energy maps (AAU, 2021). Firstly, the layer "*Fjernvarmepotentiale"* is added to the map. After that, it is possible to click an area that will show what is seen in figure 10.

Figure 10. Illustration of heat demand for a certain area in the Municipality of Greve before and after socio-economic energy efficiency improvements are implemented (AAU, 2021).

The total socio-economic energy efficiency improvements breakeven point for the Municipality of Greve is calculated by summarizing the different heat areas in Greve. The difference in the heat demand before and after the potential energy efficiency improvements is then determined to be the socio-economic potential in the Municipality of Greve.

3.6. Research design

The research design can be viewed as the overall plan for how to go about answering the research question and sub-question of this thesis:

How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit homeowners' private economy and how do the private economic benefits correlate with socio-economic benefits?

- *Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*

In sub-analysis 1 the following question will be examined "*How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit homeowners' private economy?".* This research question is examined based on a quantitative excel analysis examining data for buildings supplied with natural gas and district heating in the Municipality of Greve. In the analysis it will be investigated how private economic savings, as a result of reducing the buildings' heat demand through energy efficiency improvements, depend on the building and supply type. Furthermore, these identified savings will be compared with the investment costs of implementing energy efficiency improvements to find the optimal degree of improvements as well as the economic return of the different energy efficiency scenarios.

The results of sub-analysis 1 will then create the basis for investigating correlate to the socio-economic benefits of energy efficiency improvements. Hereby, the results lead to sub-analysis 2 in which the second part of the research question will be examined: "(...) *how does the private economic benefits correlate with socio-economic benefits?".* The question be answer by analyzing the results in the context of theoretical framework of feasibility studies. The theoretical framework will be utilized to examine potential regulatory as well as institutional changes through democratic processes. Moreover, it will be analyzed how these potential changes can contribute to evening out the discrepancies between the private and socio-economy by implementing energy efficiency improvements.

Sub-analysis 2 will highlight the potential of implementing energy efficiency improvements from the perspective of the private household and the society. Thus, these results lead to sub-analysis 3, in which the last sub-question will be examined: "*Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?".* Sub-analysis 3 will include theory on behavioral economics in order to understand why people do not always act rationally in the context of implementing energy efficiency improvements. The analysis will be based on theoretical concepts such as discarding the future and power of social norms in order to assess the lacking prevalence of energy efficiency improvements. Furthermore, sub-analysis 3 will analyze possible ways of influencing the citizens in the Municipality of Greve towards a more rational behavior in regard to actively choosing to implement energy efficiency improvements.

ANALYSIS

4

4. Analysis

This chapter aims to answer the research question and sub-question of this thesis. Based on the collected data, the empirical findings of this study, presented and analyzed with respect to the previously outlined theoretical framework.

This chapter will be divided into three sub-analyses in order to adequately answer the research question and sub-question.

4.1. Sub-analysis 1 – Private economic benefits

The purpose of sub-analysis 1 is to answer the question: "*How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit citizens' private economy?".* This will be done by first presenting the data results for selected building stock in the Municipality of Greve. The data results involve calculations of heat reduction costs associated with implementation of the energy efficiency scenarios presented in figure 5. The heat reduction costs will then be compared to the investment cost of implementing the different energy efficiency improvement scenarios for the selected building types to find the payback of the investments.

4.1.1. Results - Building data Greve

This section presents the cleared-up data for selected buildings in the Municipality of Greve. The building data in this section creates the basis for the private economic calculations featured in the next section of this analysis.

Building types	**1 (Natural gas)**	**2 (District heating)**	**Total**
120	8,299	198	8,497
130	1,217	1,316	2,533
140	43	347	390
300	62	41	103
SUM	**9,621**	**1,902**	**11,523**

Table 10. Number of buildings per building type and heat supply (Own production)

Table 10 shows the distribution of buildings per building type and heat supply in the Municipality of Greve. Where 72 % of the selected buildings are single-family houses (120) supplied with natural gas, and of the total number of buildings are, 83 % supplied with natural gas.

Building types	1 (Natural gas)	2 (District heating)	Total
120	1,186,980	31,260	1,218,240
130	141,205	235,630	376,835
140	35,698	424,659	460,357
300	76,207	130,820	207,027
SUM	**1,440,090**	**822,369**	**2,262,459**

Table 11. Total floor space in m^2 per building type and heat supply (Own production)

Table 11 shows how single-family houses, constituting 54 %, make up the primary floor space of buildings in the Municipality of Greve. The total floor space for buildings supplied with natural gas and district heating deviates relatively less than the number of buildings for each supply type. This is because buildings supplied with district heating are relatively larger than buildings supplied with natural gas, as seen in table 12.

Building types	1 (Natural gas)	2 (District heating)
120	143.03	157.88
130	116.03	179.05
140	830.19	1223.80
300	1229.15	3190.73

Table 12. Size of buildings in m^2 for building types and heat supply

(Own production).

Building types	1 (Natural gas)	2 (District heating)
120	16.93	18.77
130	10.98	17.02
140	75.14	119.48
300	124.73	324.76

Table 13. Annual heat demand per building in MWh for building types and heat

supply (Own production).

Table 13 illustrates the annual heat demand per building type and heat supply. The annual heat demand for buildings supplied with district heating is higher than for buildings supplied with natural gas. The annual heat demand is higher because the buildings supplied with district heating are relatively larger than those supplied with natural gas.

Building types	1 (Natural gas)	2 (District heating)
120	119.93	118.71
130	94.02	91.42
140	96.40	89.49
300	116.68	110.19

Table 14. Heat demand in kWh/m^2 for building types and heat supply (Own production).

Table 14 illustrates the buildings current energy efficiency. Here it can be seen how buildings that are currently supplied with district heating are more energy-efficient than buildings currently supplied with natural gas.

4.1.2. Results – Private economy

In this section of the analysis,l the return on the energy efficiency improvements will be determined. This is analyzed in order to find the optimal degree of energy efficiency improvements where the marginal investments break-even with the marginal reduction in heating costs.

4.1.2.1. Heating costs

This section presents the results of the reduction in heating costs associated with the implementation of energy efficiency improvements. The marginal differences in heating costs from scenario to scenario will be used to determine the optimal degree of efficiency improvements together with the energy efficiency investments. Note that tables throughout this section of the analysis use Danish decimal figures.

District heating 300 NG Senario 1			Year	Fuel cost DH	Heat cost BF	Heat cost AF	Difference
Area	1229,15		1	0,46	65974,19	53768,97	12205,23
Heat demand Before	116,68		2	0,47	66699,91	54360,42	12339,48
Interest	1,011		3	0,47	67433,61	54958,39	12475,22
Fuel price NG Now	0,46		4	0,48	68175,38	55562,93	12612,44
Heat demand After	95,10		5	0,48	68925,30	56174,12	12751,18
			6	0,49	69683,48	56792,04	12891,44
			7	0,49	70450,00	57416,75	13033,25
			8	0,50	71224,95	58048,33	13176,62
			9	0,50	72008,43	58686,87	13321,56
			10	0,51	72800,52	59332,42	13468,10
			11	0,51	73601,32	59985,08	13616,24
			12	0,52	74410,94	60644,91	13766,02
			13	0,52	75229,46	61312,01	13917,45
			14	0,53	76056,98	61986,44	14070,54
			15	0,54	76893,61	62668,29	14225,32
			16	0,54	77739,44	63357,64	14381,80
			17	0,55	78594,57	64054,58	14540,00
			18	0,55	79459,11	64759,18	14699,94
			19	0,56	80333,16	65471,53	14861,64
			20	0,57	81216,83	66191,72	15025,11
Sum					1466911,19	1195532,62	271378,57

Table 15. Heating cost calculation for building type 300, supply type *District heating NG* (Own production)

Table 15 presents the heating cost calculated for building type 300 with the supply type *District heating NG* for scenario 1. As stated in the methodology, the statement period for building type 300 is 20 years. The blue column presents the annual running heating costs before the energy efficiency improvements are implemented, which in this case uses scenario 0 as point of reference. The grey column shows the annual running heating costs after the energy efficiency improvements associated with scenario 1 are implemented. The red column shows the running cost difference between scenario 0 and 1.

Natural gas 300 Senario 1			Year	Fuel cost NG	Heat cost BF	Heat cost AF	Difference
Area	1229,15		1	1,23	176409,25	143773,54	32635,71
Heat demand Before	116,68		2	1,25	179231,80	146073,91	33157,88
Interest	1,016		3	1,27	182099,50	148411,10	33688,41
Fuel price NG Now	1,23		4	1,29	185013,10	150785,67	34227,42
Heat demand After	95,10		5	1,31	187973,31	153198,24	34775,06
			6	1,33	190980,88	155649,42	35331,46
			7	1,35	194036,57	158139,81	35896,77
			8	1,37	197141,16	160670,04	36471,11
			9	1,40	200295,42	163240,77	37054,65
			10	1,42	203500,14	165852,62	37647,53
			11	1,44	206756,15	168506,26	38249,89
			12	1,46	210064,24	171202,36	38861,89
			13	1,49	213425,27	173941,60	39483,68
			14	1,51	216840,08	176724,66	40115,41
			15	1,54	220309,52	179552,26	40757,26
			16	1,56	223834,47	182425,09	41409,38
			17	1,59	227415,82	185343,89	42071,93
			18	1,61	231054,48	188309,40	42745,08
			19	1,64	234751,35	191322,35	43429,00
			20	1,66	238507,37	194383,51	44123,86
Sum					4119639,87	3357506,49	762133,38

Table 16. Heating cost calculation for building type 300, supply type *Natural gas* (Own production)

Table 16 illustrates the heating costs for build type 300 for buildings currently supplied with natural gas.

District heating 300 Senario 1			Year	Fuel cost DH	Heat cost BF	Heat cost AF	Difference
Area	3190,73		1	0,46	161734,43	131813,56	29920,87
Heat demand Before	110,19		2	0,47	163513,50	133263,51	30250,00
Interest	1,011		3	0,47	165312,15	134729,41	30582,75
Fuel price DH Now	0,46		4	0,48	167130,59	136211,43	30919,16
Heat demand After	89,81		5	0,48	168969,02	137709,75	31259,27
			6	0,49	170827,68	139224,56	31603,12
			7	0,49	172706,79	140756,03	31950,76
			8	0,50	174606,56	142304,35	32302,21
			9	0,50	176527,23	143869,70	32657,54
			10	0,51	178469,03	145452,26	33016,77
			11	0,51	180432,19	147052,24	33379,96
			12	0,52	182416,95	148669,81	33747,14
			13	0,52	184423,53	150305,18	34118,35
			14	0,53	186452,19	151958,54	34493,66
			15	0,54	188503,17	153630,08	34873,09
			16	0,54	190576,70	155320,01	35256,69
			17	0,55	192673,05	157028,53	35644,51
			18	0,55	194792,45	158755,85	36036,60
			19	0,56	196935,17	160502,16	36433,01
			20	0,57	199101,45	162267,68	36833,77
Sum					3596103,84	2930824,63	665279,21

Table 17. Heating cost calculation for building type 300, supply type *District heating* (Own production)

Table 17 illustrates the heating costs for building type 300 for buildings currently supplied with district heating.

4.1.2.2. Energy efficiency investments

This section features the energy efficiency investment costs for the selected building types. The correlation between the energy efficiency investment costs and the heat reduction costs is used to find the return on investments and the optimal degree of energy efficiency improvements from a private economy perspective.

		Scenarios	1	2	3	4	5	6	7
120 Natural gas sum		Scenarios	1	2	3	4	5	6	7
Area	143,027	EEI	0	1144	5006	12729	30322	58498	91823
120 Natural gas marginal		Scenarios	1	2	3	4	5	6	7
Area	143,027	EEI	0	1144	2718	3862	9869	10584	5149
120 District heating sum		Scenarios	1	2	3	4	5	6	7
Area	157,879	EEI	0	1263	5526	14051	33470	64572	101358
120 District heating marginal		Scenarios	1	2	3	4	5	6	7
Area	157,879	EEI	0	1263	3000	4263	10894	11683	5684

Table 18. Energy efficiency investment costs for building type 120. The first two rows are buildings currently supplied with natural gas and the last two rows are buildings currently supplied with district heating (Own production).

Table 18 displays investment costs associated with energy efficiency improvements for building type 120. Scenario 1 does not have any investment costs because all the improvements done in scenario 1 are basic renovation investments.

130 Natural gas sum		Scenarios	1	2	3	4	5	6	7
Area	116,027	EEI	0	348	2785	6962	19028	38753	62655
130 Natural gas marginal		Scenarios	1	2	3	4	5	6	7
Area	116,027	EEI	0	348	2088	1740	7890	7658	4177
130 District heating sum		Scenarios	1	2	3	4	5	6	7
Area	179,05	EEI	0	537	4297	10743	29364	59803	96687
130 District heating marginal		Scenarios	1	2	3	4	5	6	7
Area	179,05	EEI	0	537	3223	2686	12175	11817	6446

Table 19. Energy efficiency investment costs for building type 130. The first rows two are buildings currently supplied with natural gas and the last two rows are buildings currently supplied with district heating (Own production).

The energy efficiency investment costs for building type 130 are shown in table 19. Investments related to the implementation of scenario 2 are relatively lower than for building type 120 because building type 130 has fewer cavity walls to be insulated due to the construction of that building type.

140 Natural gas sum		Scenarios	1	2	3	4	5	6	7
Area	830,186	EEI	0	5811	25736	53962	105434	178490	261509
140 Natural gas marginal		Scenarios	1	2	3	4	5	6	7
Area	830,186	EEI	0	5811	14113	8302	23245	21585	9962
140 District heating sum		Scenarios	1	2	3	4	5	6	7
Area	1223,8	EEI	0	8567	37938	79547	155423	263117	385497
140 District heating marginal		Scenarios	1	2	3	4	5	6	7
Area	1223,8	EEI	0	8567	20805	12238	34266	31819	14686

Table 20. Energy efficiency investment costs for building type 140. The first two rows are buildings currently supplied with natural gas and the last two rows are buildings currently supplied with district heating (Own production).

300 Natural gas sum		Scenarios	1	2	3	4	5	6	7
Area	1229,15	EEI	0	2458	23354	55312	131519	259350	409305
300 Natural gas marginal		Scenarios	1	2	3	4	5	6	7
Area	1229,15	EEI	0	2458	18437	11062	44249	51624	22125
300 District heating sum		Scenarios	1	2	3	4	5	6	7
Area	3190,73	EEI	0	6381	60624	143583	341408	673244	1062514
300 District heating marginal		Scenarios	1	2	3	4	5	6	7
Area	3190,73	EEI	0	6381	47861	28717	114866	134011	57433

Table 21. Energy efficiency investment costs for building type 140. The first two rows are buildings currently supplied with natural gas and the last two rows are buildings currently supplied with district heating (Own production).

The investment costs for building type 300 are relatively lower costs in scenario 2 than for building type 140 and 120, due to the constructional composition of the building type. Energy efficiency investment costs for building type 300 and 140 are shown in table 20 and 21.

4.1.3. Return on energy efficiency investments

This section of the analysis will determine the return on the energy efficiency investments found. The return on energy efficiency investments clarifies how the investments payback throughout the statement period. In this regard, the value of 1 represents that the investment breaks-even in the statement period. Energy efficiency improvements should optimally be conducted up to a return greater than 1, as the reduction of heating costs will become lower than the energy efficiency investment costs after that point.

The optimal degree of energy efficiency improvements from the private economy perspective will in sub-analysis 2 be compared to the optimal degree from a socio-economical perspective in the Municipality of Greve.

Scenarios	1	2	3	4	5	6	7
120	0	20,38	16,57	9,37	2,93	2,05	1,09
130	0	17,63	15,92	8,23	2,46	1,87	0,98
140	0	18,05	15,69	9,94	3,23	1,91	0,75
300	0	21,79	13,63	11,54	2,70	1,68	1,12

Table 22. Return on energy efficiency investment scenarios for building types and supply type *Natural gas* (Own production).

Table 22 displays the return on energy efficiency investments for buildings currently supplied with natural gas. The results show a substantial potential for implementing cost-effective energy efficiency improvements for the examined building types currently supplied with natural gas. Building type 120 and 300 can implement all 7 scenarios and depreciate the energy investments in the statement period. To reach its full potential, building types 130 and 140 should implement up to and including scenario 6 to be able to depreciate the investments in the statement period.

The energy efficiency improvement potential for buildings supplied with natural gas in the Municipality of Greve is greater than the potential determined by Aggerholm et. al. (2017). Their results for the same building types supplied with natural gas indicated that the optimal degree of energy efficiency improvement was including scenario 5, except for building type 130 which could also include scenario 6 (Aggerholm et. al., 2017). The main reason for the discrepancy between their results and the potential found in this study is the price on natural gas. Natural gas prices in the Municipality of Greve (1,23 DKK/kWh) are currently more than twice the price as the prices used in Aggerholm et. al.'s study (2017) (0,52 DKK/kWh). This stresses the correlation between high energy prices and the use of energy efficiency improvements as an instrument to negate the rising energy prices.

Scenarios	1	2	3	4	5	6	7
120	0	7,06	5,74	3,25	1,02	0,71	0,38
130	0	6,11	5,52	2,85	0,85	0,65	0,34
140	0	6,26	5,44	3,45	1,12	0,66	0,26
300	0	7,76	4,85	4,11	0,96	0,60	0,40

Table 23. Return on energy efficiency investment scenarios for building types and supply type *District heating NG* (Own production).

Table 23 displays the return on energy efficiency investments for the same buildings that are shown in table 22 but with district heating supply instead of natural gas. The results still highlight a potential for implementing energy efficiency improvements, but the potential is less significant due to favorable district heating prices. Building type 120 and 140 should implement up to and including scenario 5 to return the investment throughout the statement period and building type 130 and 300 should only do up to and including scenario 4. These results are closer to the results presented by Aggerholm et. al. (2017) for buildings supplied with district heating, as their optimal degree of energy efficiency improvements does not go beyond scenario 5 either. This is due to the fact that the district heating prices have not changed significantly since then, when the price was 0,4 DKK/kWh (Aggerholm et. al., 2017), and the district heating price used in this study is 0,43 DKK/kWh.

The return on the energy efficiency investments shown in table 23 is presumably more accurate for buildings currently supplied with natural gas than the return rates shown in table 22. That is because of the political agenda to phase out natural gas for heating before 2028 (Regeringen, 2022). This heat transition would mean that the depreciation provision of the energy efficiency investments would change because of the difference between district heating and natural gas prices. Therefore, it is important that the heating supply transition is considered when deciding the degree of energy efficiency improvements. Otherwise, homeowners can end up losing money, due to the unfavorable depreciation provision of the investments.

Scenarios	1	2	3	4	5	6	7
120	0	6,99	5,68	3,21	1,01	0,70	0,37
130	0	5,94	5,36	2,77	0,83	0,63	0,33
140	0	5,82	5,05	3,20	1,04	0,62	0,24
300	0	7,33	4,58	3,88	0,91	0,56	0,38

Table 24. Return on energy efficiency investment scenarios for building types and supply type *District heating* (Own production).

Return on energy efficiency investments for buildings already supplied with district heating is displayed in table 24. The results are almost identical to the results presented in table 23. Building type 120 and 300 should optimally implement energy efficiency improvements up to and including scenario 5 and building type 130 and 300 should implement the improvements up to and including scenario 4. These energy efficiency improvements are still significant, and an implementation of scenario 5 and the preceding scenario for building type 120 would result in a 33,5% reduction in the building's heat demand.

4.1.4. Basic renovation investments

Table 25 shows the basic renovation investments for the different building and supply types. The basis investments are a prerequisite for the energy efficiency investments' profitability and must be considered when determining the degree of energy efficiency investments. The majority of the basic renovation investments are in scenario 1, which is solely basic renovation with no influence on the energy efficiency of the building.

Natural gas	Basic investment costs in DKK
120	295,923
130	223,816
140	1,012,827
300	1,799,469
District heating NG	Basic investment costs in DKK
120	281,477
130	188,776
140	1,012,827
300	1,562,244
District heating	Basic investment costs in DKK
120	310,705
130	291,315
140	1,493,037
300	4,055,420

Table 25. Total basic renovation investment costs for building types and supply types (Own production).

4.1.5. Sub-conclusion

The purpose of sub-analysis 1 was to examine how energy efficiency improvements in selected building stock in the Municipality of Greve could benefit homeowners' private economy. Here, the optimal degree of energy efficiency improvements from a private economy perspective was found (see table 26). This means that homeowners will benefit economically until the reduction the buildings heat demand do not exceed the values listed in table 26. The results of the analysis also indicate that the cost-efficiency of the scenarios decreased when further energy efficiency improvements were implemented. These results will be utilized in sub-analysis 2 to determine the correlation between the private economic heat savings potential and the socio-economic potential.

Natural gas	Optimal reduction potential %
120	36.9
130	34.1
140	32.2
300	34.6
District heating NG	Optimal reduction potential %
120	33.5
130	27.5
140	31.1
300	29
District heating	Optimal reduction potential %
120	33.5
130	27.5
140	31.1
300	29

Table 26. Optimal degree of energy efficiency improvements from a private economic perspective for selected building and supply types (Own production).

4.2. Sub analysis 2 – Feasibility of energy efficiency improvements

The purpose of sub-analysis 2 is to answer the question of: *"(...) how do the private economic benefits correlate with socio-economic benefits?"* Firstly, the results from sub-analysis 1 on private economic savings will be compared to the socio-economic potential for energy efficiency improvements in the Municipality of Greve. Additionally, the correlation between the private and socio-economic perspective is analyzed in the light of theory on feasibility. Finally, the theoretical framework on feasibility will be utilized to assess the differences between the two perspectives and how the differences can change in order to make energy efficiency improvements more feasible.

4.2.1. WWW-assessment

As outlined in the theoretical framework, three fundamental questions must be considered when determining the feasibility of energy efficiency improvements.

Firstly, *what is assessed*? This sub-analysis assesses the correlation between private economic and socio-economic benefits of energy efficiency improvements.

Secondly, *for whom is this being assessed*? The economic benefits are assessed from the perspective of homeowners in the Municipality of Greve living in building type 120 (one-family houses), 130 (terraced houses), 140 (apartment buildings) and 300 (business) who are either supplied with natural gas or district heating.

Lastly, *why is this being assessed*? The correlation between the private and socio-economic benefits of implementing energy efficiency improvements is being assessed, because a discrepancy between the two perspectives could hinder the implementation of improvements. This study seeks to assess and recommend possible initiatives that could be instrumental in offsetting possible discrepancies between the private and socio-economic benefits of implementing energy efficiency improvements.

4.2.2. Private economy vs socio-economy

There is a substantial unutilized potential for doing energy efficiency improvements in Denmark from the perspective of society. As previously referred to in the scope of this study was the total national potential for the society presented in "*Heat plan Denmark 2021*" and determined to be

36% (Mathiesen et. al., 2021). The socio-economic potential for energy efficiency improvement in the Municipality of Greve's building stock is 34,9 % (AAU, 2021).

Natural gas	Optimal reduction potential %
120	36,9
130	34,1
140	32,2
300	34,6
District heating NG	Optimal reduction potential %
120	33,5
130	27,5
140	31,1
300	29
District heating	Optimal reduction potential %
120	33,5
130	27,5
140	31,1
300	29

Table 27. Optimal degree of energy efficiency improvements from a private economic perspective for selected building and supply types (Own production).

Table 27 emphasizes the discrepancy between the socio-economic and the private economic potential of implementing energy efficiency improvements in the Municipality of Greve. The socio-economic potential is only surpassed by building type 120 which is currently supplied with natural gas. As described previously, the private economic potential for building type 120 is not accurate, as the supply will change to district heating during the statement period of the energy efficiency investment. This leads to the question:

Why is there a discrepancy between the cost-effective degree of energy efficiency improvements from a private and socio-economic perspective?

The answer to the question can be argued to be a combination of several factors. Firstly, it is a matter of the perspective of the investments. Implementing energy efficiency improvements from a private economic perspective is, as previously described, a balancing of heating costs and energy efficiency investments to the point where the investment breaks-even.

Whereas from the socio-economic perspective, more factors must be taken into the equation. One factor is that the energy efficiency improvements are assessed from an energy system perspective, meaning that the improvements do not only affect the end-use heat demand on a building level. This is so, as lowering the heat demand in the existing building stock decreases the need to establish new heat production capacity in the energy system. Furthermore, the improved energy-efficient building creates possibilities for lower flow temperatures in the district heating grid, resulting in lower heat losses in the district heating grid (Ea Energianalyse, 2019).

4.2.3. Energy efficiency initiatives

The previous section of this sub-analysis clarified the cost-efficiency of implementing energy efficiency improvements in buildings from the perspective of the society as well as private households. The analysis displayed a discrepancy between the private and socio-economic optimal improvement potential.

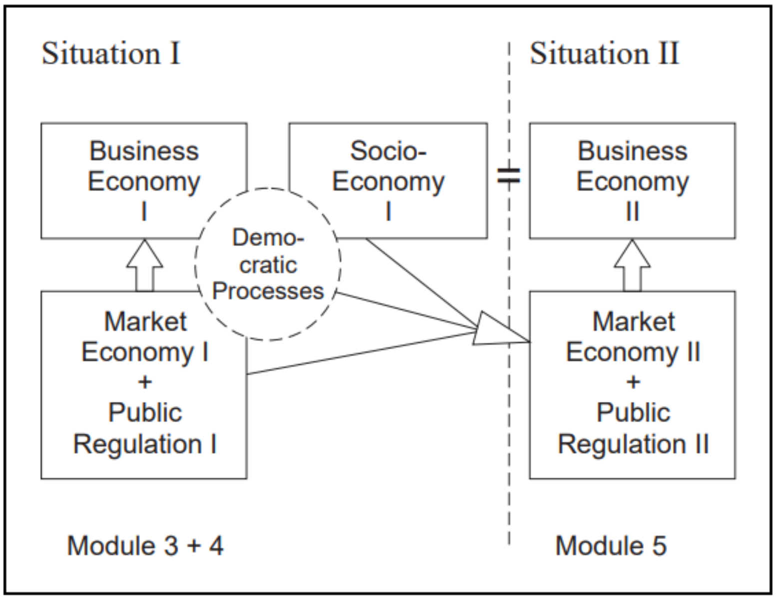

Figure 11. Theoretical framework used to assess the discrepancy between private and socio-economic benefits of implementing energy efficiency improvements (Hvelplund & Lund, 1998).

As outlined in the theoretical framework, discrepancies between the private and socio-economic feasibility of technologies or initiatives can sometimes occur. If the discrepancy favors the initiatives from the perspective of the society, as what is the cause in this study regarding energy efficiency improvements in the buildings. Policymakers could, in this case, adopt resolutions that empower the private economy investments in energy efficiency improvements to create a new situation (see figure 11). However, as explained in the previous section, it can be inefficient for the energy system and society to ignore the unutilized potential of energy efficiency improvements. As policymakers cannot force homeowners to conduct energy efficiency improvements, it can be argued that they must conduct public regulations that incentivize homeowners to implement them. Public regulations can involve different initiatives of which some will be assessed in the following sections of this analysis.

4.2.3.1. Building funds

Since 2020, it has been possible to apply for subsidies to conduct energy efficiency improvements. The fund is called Bygningspuljen and offers homeowners the opportunity to cover some of their investment cost from implementing energy efficiency improvements in permanent residences. In February 2022, the Danish State had disbursed DKK 867m in subsidies since the fund opened in 2020. Out of the total DKK 867m, around 40% of the subsidies were used for energy efficiency improvements in buildings. The rest of the funds were used to replace old oil and gas boilers with alternative heat supplies such as heat pumps (SparEnergi, 2022a).

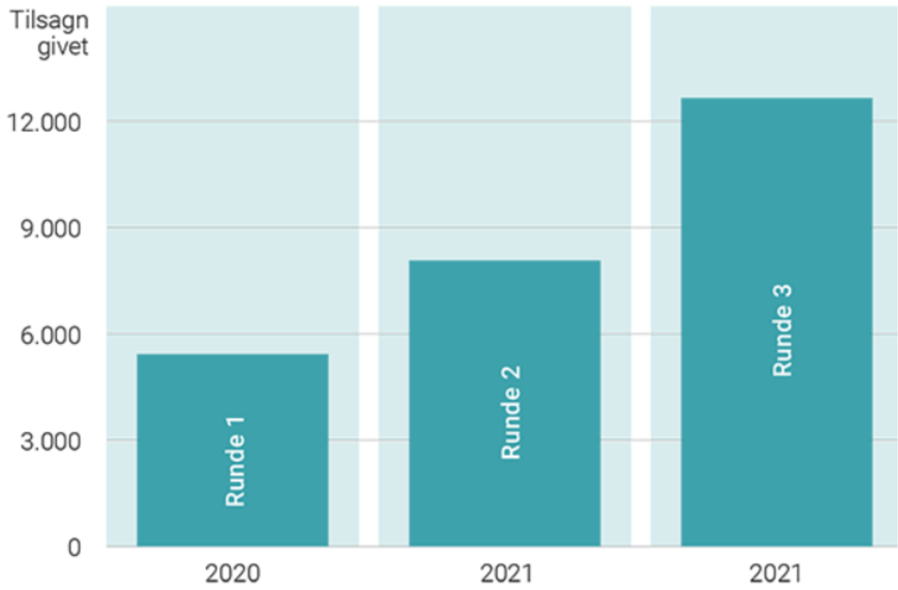

Figure 12. Number of fund applications for "*Bygningspuljen"* per round of application from 2020-2021 (Sparenergi, 2022)

Figure 12 illustrates the increase in popularity of Bygningspuljen since the introduction of the fund in 2020. The fund encompasses a particular value of money per application round which is then distributed by the principal; "first come, first served" (SparEnergi, 2022a). In 2021, The Danish Parliament decided to adjust the fund so that it is primarily allocated for buildings with the energy label E, F and G. The homeowners are handed the subsidies after the energy efficiency improvements are implemented and the subsidies cover a percentage of the investment depending on the improvement implemented. For instance, this means that a homeowner can be subsidized 15 percent of the investment costs when changing from windows with energy label 2 to windows with energy label 1 (Energistyrelsen, 2021b). The most recent round of applications was in March 2022. Here, the Danish Energy Agency received more than 16,000 applications and the fund was closed after two weeks since all subsidies (DKK 300m) were already allocated to applicants

(Energistyrelsen, 2022b). In this respect, it can be argued that policymakers with advantage could adjust the ratio of which the fund Bygningspuljen is distributed, in order to allocate more subsidies for implementing energy efficiency improvements. This could further offset the discrepancies between the private economy and socio-economy when implementing energy efficiency improvements.

4.2.3.2. Håndværkerfradraget

Håndværkerfradraget is a tax deduction scheme that has been available from 2011 until April 2022. The scheme allowed taxpayers to deduct up to DKK 25,000 per year for craftsmen's labor performed on their homes. The deduction scheme was implemented to increase the labor force in craftsman jobs and reduce the amount for moonlighting in the sector. Previously, the deduction scheme could be used for implementing energy efficiency improvements in buildings, but with this year's Finance Act this opportunity was removed. The argument for removing the deduction scheme was that from a socio-economic perspective it was an expensive way of creating jobs in the craftsman sector, since the sector is already experiencing prosperity (Bolius, 2022). Since the deduction scheme has been phased out, it does not have any effect on the discrepancy between the private and socio-economic benefits of implementing energy efficiency improvements in the future. However, it can still serve as an example of public regulation that affected the private economic latitude.

4.2.3.3. Clash with neoclassical economy

In this sub-analysis, it has been specified that there is a discrepancy between the private and socio-economic benefits of implementing energy efficiency improvements selected building stock in the Municipality of Greve. Even though the discrepancy between the two perspectives, there is still an extensive unutilized potential for implementing energy efficiency improvements from a private perspective.

The behavior of the homeowners living in the assessed building types in Greve, contradicts with one of the basic principles of neoclassical economics. As touched upon in the theoretical framework, a precondition for neoclassical economics is that actors in a well-informed and free market, which Denmark can be considered being, will act rationally and seek to optimize their financial potential (Camerer & Loewenstein, 2004). In the case assessed in this study, the homeowners in general have the possibility to optimize their economic conditions over the course of the statement period of the energy efficiency investments. However, most homeowners are not benefitting from this economic potential.

In sub-analysis 3 some of the reasons for why homeowners do not choose to benefit from their economic potential of implementing energy efficiency improvements will be examined.

4.2.4. Sub-conclusion

In this sub-analysis it has been found that there is a discrepancy between the private and socio-economic optimal potential of implementing energy efficiency improvements for the examined building and supply types in the Municipality of Greve. This discrepancy can, to some extent, be offset by public regulation enabling subsidies for energy efficiency improvements in private households. Even though the sub-analysis found a discrepancy between the private and socio-economic optimal potential of implementing energy efficiency improvements, there is still a substantial unutilized private economic potential. The following sub-analysis 3 will examine some of the reasons for this unutilized private economic potential.

4.3. Sub analysis 3 – Why are homeowners not investing in energy efficiency improvements?

In this sub-analysis, the following question will be examined: "*Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*" Even though a proven discrepancy between the private and socio-economic optimal potential of implementing energy efficiency improvements was found in sub-analysis 2, there is still a substantial unutilized private economic potential. In sub-analysis 3, this irrational behavior and how this can possibly be influenced will be analyzed through the use of perspectives from theory on behavioral economics. Some of the theoretical concepts that will be brought into perspective are the power of social norms as well as the use of default.

4.3.1. Implications for improvement of energy efficiency improvement

As highlighted in the previous section of this sub-analysis, there are several factors contributing to the lack in implementation of energy efficiency improvements. This section will analyze some of the possible adjustments needed in order to increase the number of homeowners choosing to implement energy efficiency improvements. These adjustments do not solely imply economic aspects but also educational initiatives that can affect the prevalence of energy efficiency improvements.

4.3.1.1. Moving and selling properties

Research indicates that people are more susceptible to change their behavior at given events during their lives. One of those events is when a homeowner sells a property or moves into a new home (Bamberg, 2006). Thus, by implementing energy efficiency improvements when moving into a new home, the hassle factor of i.a. cleaning-up lofts would be removed. Furthermore, basic renovations of buildings are more likely to happen when moving into a new home (Cabinet Office, 2011). The requisite for implementation of the energy efficiency improvements scenarios, as analyzed in sub analysis 1, was that the implementation is performed in connection with basic renovation of the building. Taking these factors into account, it can arguably be crucial to make homeowners aware of the potential benefits of implementing energy efficiency improvements when moving into a new home.

Another factor in this context is the value of an energy-efficient building from the seller's perspective. Energy efficient buildings are relatively more expensive than inefficient buildings.

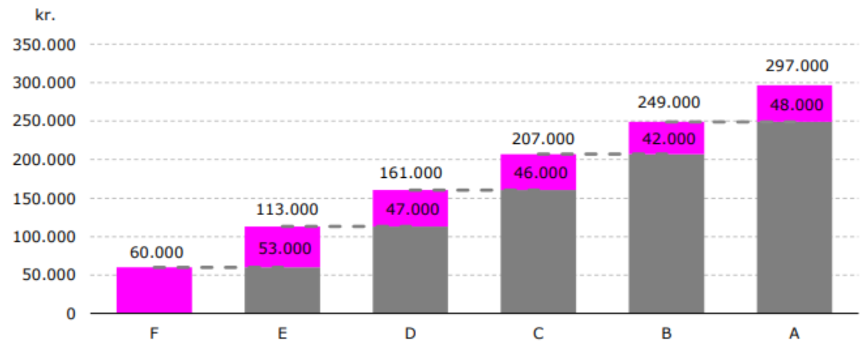

Figure 13. Correlation between buildings energy labels and house prices. Purple is the marginal difference between energy labels and grey is the summarized difference (Energistyrelsen, 2015).

Figure 13 highlights the correlation between buildings' energy labels and the house price. The prices represent a 100 m^2 house and the lowest energy label G is used as a reference (Energistyrelsen, 2021). It is argued that this positive correlation between energy labels and house prices is important knowledge that homeowners should be aware of. This is so, as an ignorance of this fact could potentially discourage the homeowners from implementing energy efficiency improvements, if they plan to sell their home before the energy efficiency investment breaks-even. Furthermore, this knowledge is also essential from the buyer's perspective, as the buyer must be aware of the benefits of having a better energy label to be willing to pay for it.

In sub-analysis 1 it was found that the return rate of the investments decreased as more energy efficiency improvements were implemented. Therefore, it would be optimal both from a private and socio-economic perspective to implement energy efficiency improvements up until the break-even point of the investments. Though, as the statement period of the investment is 20 and 30 years, homeowners might choose to implement less energy efficiency improvements due to indefinite long-term rewards and their tendency to discard the future rewards (Bolius, 2018).

The information institution Bolius published a homeowner analysis in 2018. The analysis encompasses several questions regarding homeowners' stance towards energy efficiency improvements. One of the questions sought to find the main barrier to not implementing energy efficiency improvements. The main barrier (48%) was found to be the amount of money needed for the investment, while the second most significant barrier (23%) was the extended return of the investments, which emphasizes Danish homeowners' tendency to discard the future (Bolius, 2018).

In 2017, only 29% of single-family houses and 51% of apartment buildings had an energy label, as it is only required to get the energy label when the property is put on the housing market. This means that homeowners living in these building types are not necessarily certain about the energy state of the building they live in. Heating bills are often just paid by default, and some homeowners are not aware of if the proportions of their heating costs are high, low, or average (Concito, 2017).

Real estate agent can play an essential role in this context since they communicate closely with both the seller and the buyers of buildings. Furthermore, they can make sure that the benefits of the energy label are explained in the sales literature of the building. It has been mandatory to inform about the energy labels of buildings in the sales literature since 2010, but that does not necessarily mean that buyers or sellers are aware for the significance of a specific energy label (Nedadovic & Bisp, 2021). Information about energy labels is especially important for buildings supplied with natural gas since the fuel prices for natural gas are high compared to other alternatives, making the the energy efficiency of buildings more significant. As presented in the results of sub-analysis 1 are, 72 % of the building examined in this study currently supplied with natural gas, which makes the information knowledge about energy efficiency very important when selling or buying building in the Municipality of Greve.

4.3.1.2. Ownership of buildings

In the context of this study, it is important to be aware of the fact that the ability to act on the potential energy efficiency improvements differ for the different building types assessed in this study. Building types 120 (one-family houses) and 130 (terraced buildings) usually only house one family which will also often be the owner of the building. The ownership improves the potential for implementing energy efficiency improvements, as the acceptance of the homeowner does not rely on others' willingness to invest in the improvements (Concito, 2017). However, there are situations where building types 120 and 130 are rented housing and in these cases the choice of implementing energy efficiency improvement will rely on the owner of the building. Even though you own the apartment you live in, it does not necessarily mean that you can implement energy efficiency improvements, as improvements involving the entire building will have to be agreed on in the owners' association. Since ownership influences the opportunity for implementing energy efficiency improvements, it makes sense to differentiate initiatives between different building and ownership types (Regeringen, 2014).

An example of this could be ESCO (Energy Service Company) which is a specific deal for businesses, apartment buildings and public buildings that want to improve the energy efficiency of their building. The building owner is guaranteed heat savings by the ESCO which in some cases takes care of the investment costs, so that the building owner avoids paying upfront. The investment costs will then be amortized to the ESCO through the promised heat savings. The ESCO model differs from the ordinary enterprise, as it involves an Energy performance contract called ESC. The ESC encompasses guaranteed energy efficiency improvements which continuously will be followed up after the improvements are implemented. This way of implementing energy efficiency improvements differs from an ordinary enterprise since the ESCO will handle all parts of the projects and not only the implementation. Since the ESCO partially gets paid through the saved heating costs as a consequence of the energy efficiency improvements they implement, ESCO naturally has an interest in optimizing the implementation. Likewise, ESCO is interested in maintaining the improvements on the buildings on which the energy efficiency improvements are performed. These mentioned factors contribute to making an ESC a low-risk investment for the building owner. Consequently, a mutual responsibility often improves the quality of the energy efficiency improvements conducted (SparEnergi, n.d.).

4.3.1.3. Local engagement

Municipalities generally play an essential role in the implementation of energy efficiency improvements. There are several reasons for why municipalities are considered a key player in, when working with these initiatives. Firstly, municipalities have an economic interest in decreasing the heat demand of municipal buildings in order to decrease the overall costs and greenhouse gas emissions associated with heating. Secondly and more importantly, the municipality is facilitating initiatives that result in CO2 emission reductions in households in the Municipality of Greve. The total CO2 emissions from households in the Municipality of Greve are almost 10 times higher than the public emissions, resulting in greater reduction potentials for households than the public. Since the CO2 emissions from households is primarily the consequence of fuels burnt for heating (Cf. figure 14), the municipality has an incentive to mitigate this tendency to reach their climate goals and take on climate responsibility. CO2 emissions from natural gas counted for 82% of the municipality's total emissions from heating. These facts form the basis for promoting reduction of natural gas consumption through energy efficiency improvements (SparEnergi, 2019).

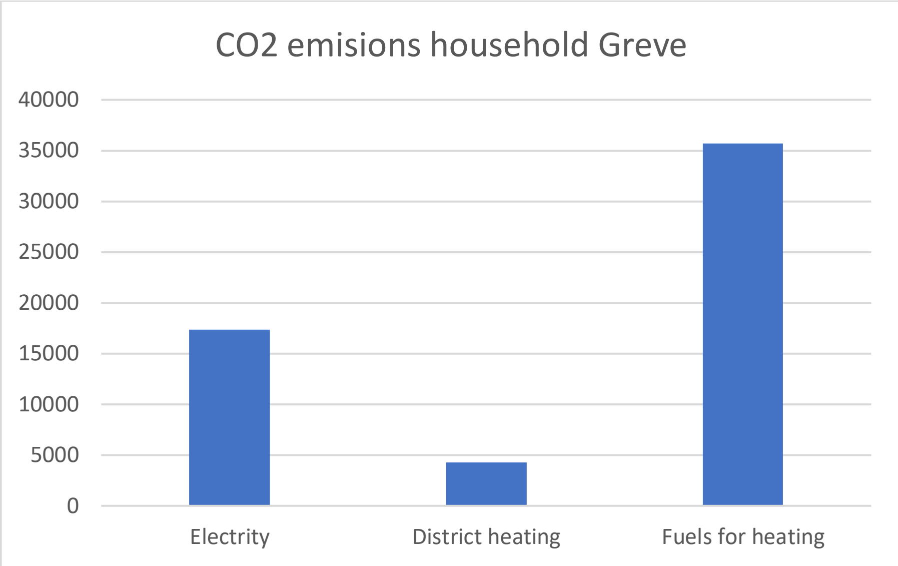

Figure 14. Ton CO2e emissions for households in Greve municipality from 2019 (SparEnergi, 2019)

In order to reduce CO_2 emissions caused by fossil fuels used for heating, the Municipality of Greve has different opportunities to help their citizens. One opportunity is the initiative, BedreBolig, which was launched in 2014 with the government's strategy for energy efficiency improvements in buildings (Regeringen, 2014). BedreBolig is an initiative that helps homeowners clarify the potential energy efficiency improvements relevant for their homes. The output of the initiative is an offer for homeowners to receive a report produced by a local energy advisor. The report will list recommended energy efficiency initiatives specific to the citizen's home with potential heating cost and CO_2 reductions (Energistyrelsen, 2014). The Municipality of Greve refers to the initiative of BedreBolig on their website. However, it can be argued that they could profitably use a more proactive approach to encourage the implementation of energy efficiency improvement (Greve Kommune, 2021).

An example of a proactive municipal approach to energy efficiency improvements is found in The Municipality of Helsingør. Since 2020, The Municipality of Helsingør has provided direct information through e-Boks to owners of homes with the worst-performing energy labels (E, F, and G) and additionally to owners of buildings that are built before 1969. The municipality has been using the platform Boliganalysen which is managed by KL, Real Dania, The Danish Energy Agency, and a couple of municipalities. The platform allows the municipality to send direct information to homeowners and offers them an energy assessment of their home which clarifies the potential benefits of implementing energy efficiency improvements. The reorganization of communication in the Municipality of Helsingør has created a high demand for energy efficiency assessment and there is currently a waiting list in the Municipality of Helsingør for receiving the energy efficiency assessment. Even though the homeowners do not necessarily implement the recommended energy efficiency improvements, at least it increases their knowledge level about the importance of energy efficiency improvements in buildings. This initiative can also help change norms and make energy efficiency improvements a more common investment (Kommunernes Landsforening, n.d.). A recent political agreement on energy efficiency improvements and the phase out of natural gas for heating has allocated DKK 5m for Boliganalysen. Municipalities can use Boliganalysen for free until the end of 2022 (Ministry of Climate, Energy and Utility, 2022b). Up until this political agreement, municipalities paid DKK 15,000 in yearly subscription fees to be able to use Boliganalysen (SparEnergi, 2022). With this political agreement, the municipality does not have any justification for not making use of the advantages that come with Boliganalysen and its ability to increase the prevalence of energy efficiency improvements.

Another opportunity for the municipality to raise awareness of the benefits of energy efficiency improvements is public meetings. It is possible for all municipalities in Denmark to hire an energy consultant for a public meeting through SparEnergi's website (SparEnergi, 2022). The presentation at the public meeting is outsourced to the consultant's company, Viegand Maagøe, that has published the outcome of their information a public meeting municipal meeting in 2017. The analysis involved interviews with 73 interviewees from the meeting and the results showed that the consultant's presentation at 39 public meetings in 2017 resulted in the implementation of energy efficiency initiatives in 50% of the interviewees' homes, corresponding to a reduction of 6,4m kWh/year in energy consumption (Viegand Maagøe, 2017). One of the municipalities that has made use of SparEnergi's offer is the Municipality of Helsingør that has been arranging public meetings through their campaign Grøn Bolig to promote the benefits of energy efficiency improvements (Kommunernes Landsforening, n.d.).

4.3.2. Sub-conclusion

The purpose of this sub-analysis was to answer the sub-question: "*Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*"

In the light of theory on behavioral economics, the irrational behavior that homeowners in the Municipality of Greve exhibit by not taking advantage of potential heating cost savings obtained from implementing energy efficiency improvements, was analyzed. The analysis included terms such as discarding the future which means that individuals are not willing to invest in energy efficiency improvements because the return on the investment is not obtained in the near future. Furthermore, the hassle factor was identified as playing a crucial role in building owners' willingness to insulate their loft. In this regard, it was found that the implementation of energy efficiency improvements is most likely to happen when moving into a new home. The analysis found moreover a correlation between the price of a building and its energy label, stressing the importance for building owners to obtain that knowledge as the energy efficiency investments also retain value besides the reduced heating costs. At last, the sub-analysis used Helsingør municipality's initiative Grøn bolig to illustrate how a proactive communication strategy can affect the homeowners' willingness to implement energy efficiency improvements.

DISCUSSION

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5. Discussion

This section features a discussion of how the current lack of building materials and labor in the building sector can possibly affect the implementation of energy efficiency improvements. Furthermore, the discussion will assess some of the rewards of implementing energy efficiency improvements that are not within the scope of the analysis but are valid reasons for implementing them. Lastly, it is discussed what the national political lack in energy efficiency improvements on the consumption side of the energy system means for the prevalence of energy efficiency improvements.

5.1. Lack of materials and labor

The current political willingness to phase out natural gas and expand renewable energy productions results in a high demand for labor and materials in order to speed up the transition. For instance, Denmark is experiencing labor shortage in all process of the district heating expansion that is currently going on. The labor shortage is present both in businesses planning the transition and in contracting companies implementing the actual projects (Mathiesen & Hagedorn-Rasmussen, 2022). Last year, 48% of green[1] businesses failed to recruit staff of advertised job positions. This is problematic since it can affect the speed and the current demand that the energy and building sector is experiencing (Klintefelt, 2021). On top of the labor shortage there is also a lack of building materials needed for projects, such as district heating and energy efficiency improvements (Kaldahl, 2021). This is not only a problem in Denmark but a general problem in most EU-countries were 30% of businesses that operate within the building and construction sector experience shortage of labor and materials, making them unable to meet the demand in the sector (Overvad et. al., 2022).

[1] A green business is working within following areas: Energy efficiency improvement, recycling, renewable energy etc. etc. (Klintefelt, 2021).

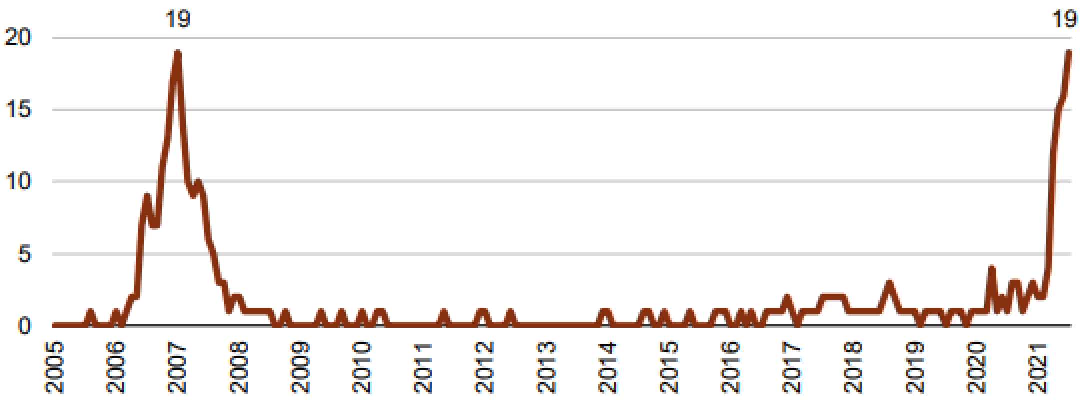

Figure 15. Percentage of businesses within the building and construction sector that experience shortage of materials (Kaldahl, 2021).

Figure 15 quantifies the percentage of businesses within the building and construction sector that can fulfill their demand for building materials. As the graph shows, it is a tendency that has been evolving to the worse and in 2021 19% of the businesses could not fulfill their demand. The situation has not been worse since the last financial crises around 2007 to 2008. This is not only problematic for the implementation of initiatives such as district heating and energy efficiency improvements, but it also reflects the prices of the building materials that have increased as well (Klintefelt, 2021). In relation to this study, shortage of labor in and around the Municipality of Greve could potentially affect the implementation of energy efficiency improvements. Furthermore, the currently high material prices could affect the investment costs and, in that way, the optimal degree of energy efficiency improvements. In reality homeowners would assess individual building potential before investing in the improvements. The results in this study represents a general overview of the potential for the selected building and supply types in the Municipality of Greve and how energy efficiency can be used the decrease the independence of imported natural gas as well as how the improvements can benefit private economy.

There are several ways that these abovementioned issues can be negated. For instance, when it comes to the shortage of labor, a tripartite negotiation between employers, labor unions and the state could be initiated in order to discuss how workers can undergo further training to meet some of the demand for labor in the energy and building sector. Furthermore, it would be beneficial if municipal as well as state driven projects prioritize the most essential construction projects and if necessary, postpone lower priority projects. These proposals are supported by SYNERGI which is a Danish interest group that advocates for increased energy efficiency improvements in all sectors (SYNERGI, 2022).

5.2. Political priority of energy efficiency improvements

As argued throughout this study, energy efficiency improvements constitute an important initiative both from an economic and environmental perspective. Binding political agreements supported by instruments that enable the implementation and compliance of political agreements is an essential part of sustainable progress. In the scope of this study, it was pointed out that instruments on the consumer side of the energy system was not prioritized as high as initiatives on the supply side when it comes to minimization and phasing out natural gas from the heating system. Energy efficiency improvements play a minor role in the Government's energy strategy *'Danmark kan mere II'* (Regeringen, 2022a) from this year. Energy efficiency improvements are only mentioned in relation the electrification of industries that currently use natural gas as well as in relation to the potential export of Danish energy efficiency improvement technologies (Regeringen, 2022a). However, the newly proposed greenhouse gas tax reform would incentivize industry to convert their fuel supply or at least implement energy efficiency improvements to minimize their consumption. The tax reform will add CO2 quota prices that are equal to EU quota prices with an additional charge depending on the type of industry. Furthermore, the tax will also encompass businesses that previously have been exempted from EU's quota system (Regeringen, 2022b). The possible changes that a greenhouse gas reform can bring is a step in the right direction, but the political ambitions still lack in initiatives and binding agreements that encompass energy efficiency improvements in private households.

Back in 2019 Denmark was criticized by the EU commission for not complying with the with EU directives regarding energy efficiency. The EU commission implied that the political regulations and target would need a "*Substantial increased level of ambition"* (Albrechtsen, 2019*, p. 1)* to comply with EU directives.

Current EU directives on energy efficiency improvements state that the member states must comply with the following:

> *"Member States are required to achieve cumulative end-use energy savings for the entire obligation period 2021 to 2030, equivalent to new annual savings of at least 0,8 % of final energy consumption. That requirement could be met by new policy measures that are adopted during the new obligation period from 1 January 2021 to 31 December 2030 or by new individual actions as a result of policy measures adopted during or before the previous period, provided that the individual actions that trigger energy savings are introduced during the new period. To that end, Member States should be able to make use of an energy efficiency obligation scheme, alternative policy measures, or both."* EU Directive (2018/2002 § 12)

Denmark’s stance towards the EU directive regarding energy efficiency seem to have changed to the better. The Danish representatives in the EU parliament are currently advocating for more ambitious obligations in the new EU directives that currently is in preparation, compared to the obligations in the abovementioned excerpt of the current valid directive (Pedersen, 2022). Taking the recent political agreement on energy efficiency improvement of phasing out natural gas for heating (Ministry of Climate, Energy and Utility, 2022b) into account, there is still a need for more initiatives and binding agreements that can increase the level of knowledge and the prevalence of energy efficiency improvements in buildings.

5.3. Multiple benefits of energy efficiency improvements

The scope of this study has been delimited to assess the private economic benefits of energy efficiency improvements, but energy efficiency improvements can also result in benefits that is not necessarily reflected in monetary value. These benefits also play a significant role in the implementation of energy efficiency improvements and will naturally be valued more subjective as not all of them have a monetary value. Among other things, energy efficiency improvements can contribute to a healthier indoor environment and a sense of contribution to the green transition among building owners who are implementing them (Concito, 2017). Other studies highlight a correlation between the energy efficiency of buildings and the health of its residents. People living in energy efficient buildings are less likely to attract respiratory diseases because of the improved indoor environment. The health-related issues associated with unhealthy indoor environments are more likely to impact the low-income segment of the population as their economic situation makes it harder for them to implement the necessary improvements. 3% of Denmark’s population experience energy poverty which mean that they cannot afford to sufficiently heat their homes in order to avoid health-related issues. Health-related issues can be measured in a socio-economic assessment of energy efficiency improvements but are not accounted for in private economic assessments. Studies indicate that energy efficiency improvements’ effect on health-related issues can be valued to DKK 15 pr GJ saved. In businesses there is a demonstrated correlation between the energy efficiency of the business’ building and the productivity of the employees (Ea Energianalyse, 2019).

Bolius’ Boligejeranalyse from 2018 shows that improvements of indoor environment were the second most significant reason for homeowners to implement energy efficiency improvements, while environmental aspects were the fourth most significant reason. Economic reasons for implementing energy efficiency improvements comes is considered the most significant factor.

However, the economic reasons and the improved indoor environment does only differ with 4% (Bolius, 2018).

CONCLUSION

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6. Conclusion

How can energy efficiency improvements in selected building stock in the Municipality of Greve benefit homeowners' private economy, and how do the private economic benefits correlate with socio-economic benefits?

- *Why are homeowners not investing in energy efficiency improvements when the potential is evident as well as economically feasible and how can this possibly be changed?*

The quantitative data analysis in sub-analysis 1 found that the private economic potential of energy efficiency improvements in selected buildings in the Municipality of Greve to be significant. The results showed a greater potential for buildings currently supplied with natural gas compared to buildings supplied with district heating due to the high natural gas prices. The potential for implementing energy efficiency improvements was found to be most extensive in single-family houses currently supplied with natural gas, but the other selected building types all showed great private economic potential. Homeowners of buildings currently supplied with natural gas must consider the district heating expansion plan in their area before they invest in energy efficiency improvements. This is due to the finding of changing heat supply will affect the return of energy efficiency improvements investments.

In sub-analysis 2 it was concluded that the socio-economic potential of energy efficiency improvements in the Municipality of Greve is greater than the private economic potential when considering future district heating expansion. The discrepancy between the private and socio-economic potential of energy efficiency improvements in the Municipality of Greve is caused by the prerequisites for the calculations. Here, factors such as the possibly to operate with lower flow temperature in the district heating grid were found to contribute to the discrepancy between the potentials. It was furthermore concluded that the discrepancy can be offset by subsidizes for energy efficiency improvements.

Lastly, in sub-analysis 3, it was analyzed how different behavioral economic concepts such as discarding the future and the hassle factor influence homeowners' willingness to invest in energy efficiency improvements. Here it was concluded that the implementation of energy efficiency improvements is most feasible and likely to happen when citizens move into a new home, hereby avoiding the hassle factor. In this regard, it was found that real estate agents or the municipality with advantage can offer new homeowners the needed information prior to moving into a new home. In the analysis, the Municipality of Helsingør's initiatives, Grøn Bolig, and their use of Boliganalysen was utilized in order to demonstrate how proactive communication can affect the level of knowledge and willingness to implement energy efficiency improvements among homeowners. Furthermore, the correlation between a building’s energy label and price of the house was used to validate the implementation of energy efficiency investments, as they were found to also increase the price of the house.

RECOMMENDATIONS

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7. Recommendations

Based on the discussion and the conclusion of this study, recommendations on a national and municipal level have been put forward. Those can be worth considering when working with energy efficiency improvements on national level as well as in the Municipality of Greve.

7.1. National level

- Set national binding targets for energy efficiency improvements in buildings
- Make it a requirement that all Danish municipalities make use of Boliganalysen
- Initiate initiatives that can counteract the labor and material shortages in the building and construction sector
- Increase funds for Bygningspujlen to offset discrepancy between private and socio-economy of implementing energy efficiency improvements
- Change Bygningspujlen’s distribution ratio so that energy efficiency improvements are subsidized equally to heat pumps

7.2. The Municipality of Greve

- Utilize proactive communication to the citizens in Greve, so they do not have to seek the information themselves. The communication effort should be focused on the time prior to new homeowners moving into their new homes
- Make use of Boliganalysen in order to implement energy efficiency improvements where the potential is greatest
- Organize public meetings about energy efficiency improvements and use the opportunity to involve SparEnergi and Bolius
- Formulate municipal energy efficiency targets
- The Municipality of Greve must implement energy efficiency improvements in their own building stock if the potential is evident in order to promote the prevalence of energy efficiency improvements
- Involve local resources such as energy efficiency improvement retailers, consultants and real estate agents to ease the Municipality of Greve’s limited resources

FURTHER RESEARCH

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8. Further research

This study outlines a broad overview of the potential energy efficiency improvements for the selected supply and building types in the Municipality of Greve. Further research could involve the implementation of the Municipality of Greve's heat plan that is currently being conducted. The plan should be published before the end of 2022 and hopefully it will include concrete initiatives that can increase the prevalence of energy efficiency improvements in the Municipality of Greve. As mentioned in the analysis, a recent political agreement has made it free for municipalities to make use of Boliganalysen until the end of 2022. Furthermore, compared to earlier there will be allocated more resources for municipalities' information campaigns in relation to public meetings. This is why further research could assist the Municipality of Greve in potential public meetings concerning energy efficiency improvements and in their use of Boliganalysen.

Greve Fjernvarme is currently working on a district heating project proposal which will offer 2,000 houseowners district heating. Future research in the Municipality of Greve could beneficially involve the implementation of new district heating and how Greve Fjernvarme is handling its cooperation with the Municipality of Greve. Greve Fjernvarme has a comprehensive amount of work in front of them in the years to come which will demand transparent communication to potential customers and a clear division of responsibility with the municipality.

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