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Master Thesis

Thermonet - A weapon of mass reduction?

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Abstract:

This master thesis investigates the research question:
"What parameters are needed to develop a standardised assessment for thermonet, and how can GIS analysis be used to identify a suitable area to calculate the consumer economics in Stevns Municipality?".
To answer this, parameters from thermonet project proposals and screenings were analysed and structured into a standardised assessment. A GIS analysis utilising parameters from COHEAT and additional identified parameters was used to locate a suitable case area in Stevns Municipality. The chosen case area included 16 houses in Store Heddinge. The standardised assessment was then applied to calculate consumer economics for the case area. Results show that while thermonet has technical and environmental potential, high investment costs currently limit its competitiveness and possibility of moving from a niche to established technology. A standardised approach can, however, support structure and transparency in order to enable comparison with other thermonet projects and air-to-water heat pumps.

Forord

This master thesis in Sustainable Energy Planning and Management was carried out during the period from February 1st to May 28th.

This project focus on a heating technology that uses uninsulated pipes to circulate low temperature brine to individual heat pumps, providing both heating and cooling from local energy sources. The technology goes by several names, such as 5th Generation District Heating and cooling (5GDHC), Ectogrid, ultra low temperature district heating, and thermonet. In this project, thermonet is used, as it is the most common term in Danish context.

The term thermonet is used to highlight that this technology is not the progression in the district heating development, but rather a potential solution designed for areas where traditional district heating is not possible. It is highlighted in a statement from Lund et al. [2021] that *"[...]5GDHC should not be seen as a sequential or serial development of 4GDH; [...] rather a parallel development"* according to Lund et al. [2021,p. 5] The term thermonet will be used from this point.

The project group, would like to sincerely thank supervisors Diana Moreno and Peter Sorknæs for guidance throughout the project period. The project group furthe wish to thank Søren Erbs Poulsen, Søren Skjold Andersen, Grethe hjortbak and The Danish Energy Agency for their collaboration, time for interview, and providing data throughout this project.

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Introduction 1

As consequence of CO_2 emissions, the global temperature have been impacted. In 2024 the global average temperature reached 1.6 °C over the preindustrial level [Møllgaard et al., 2025,p. 52]. This increase in temperature creates irreversible consequences such as, the melting of the Greenland ice sheet, loss of coral reefs, and the collapse of the North Atlantic Ocean current [Møllgaard et al., 2025,p. 54]. To mitigate these climate change, the world have to reduce the emissions of CO_2. Europe is the continent where the temperature is increasing the fastest [Møllgaard et al., 2025,p. 56], creating incentive to mitigate CO_2 emissions. EU has as a result committed to a goal of 55% reduction in emissions in 2030 compared to 1990, and climate neutrality in 2050 [Union, 2025]. Denmark, as part of EU is required to help reach EU's climate goals.

The consequences of global warming in Denmark can already be felt. In Danish weather history, 2023 and 2024 became the wettest years [Møllgaard et al., 2025,p. 55]. To mitigate this and to fulfill EU' climate goals, Denmark have committed to their own climate goals.

The Danish climate goals determines a reduction of emissions of 50-54% in 2025, 70% in 2030 compared to the 1990 levels and climate neutrality in 2050 [Ministry of Climate, Energy and Utilities, 2021]. The green transition in Denmark has come under additional pressure due to the conflict between Russia and Ukraine, which led to rising fuel prices, including a significant increase in natural gas prices [The Danish Government, 2022a]. Together, this results in a need for increasing the production of green heat, to fulfill the climate goal and become independent from Russian natural gas [The Danish Government, 2022a]. This transition is described in the climate agreement from 2022; "Danmark kan mere II-[The Danish Government, 2022b,p. 2].

The agreement of "Danmark kan mere II", dictates the role of the district heating sector in Denmark [The Danish Government, 2022b]. The district heating network needs to be expanded to accommodate a part of the approximately 500.000 households reliant on natural gas and oil boilers [Westergaard and Lock, 2024]. The ambition for these households is, that in 2035 they should no longer be heated by gas boilers [The Danish Government, 2022b,p. 13].

Though the district heating sector can partially cover the heat supply for households on natural gas and oil, not all geographical locations fulfill the requirements for implementation. These requirements usually revolves around financial aspects [Westergaard and Lock, 2024]. Results of not meeting requirements is implementation of individual heat supplies, such as heat pumps. This can be problematic in the outer communities due to investments being considered high, compared to house prices. For this reason collective solutions such as thermonet is being developed [Metro Therm, 2025b]. This is underlined by the making of the organisation "Termonet Danmark"in 2020 [Termonet Danmark, 2025d]. They highlight thermonet is "a weapon of mass reduction"in relation to quickly outfacing fossil fuels in the heating sector [Westergaard and Lock, 2024], helping reach the climate goals and the goal of becoming independent from Russian oil and gas.

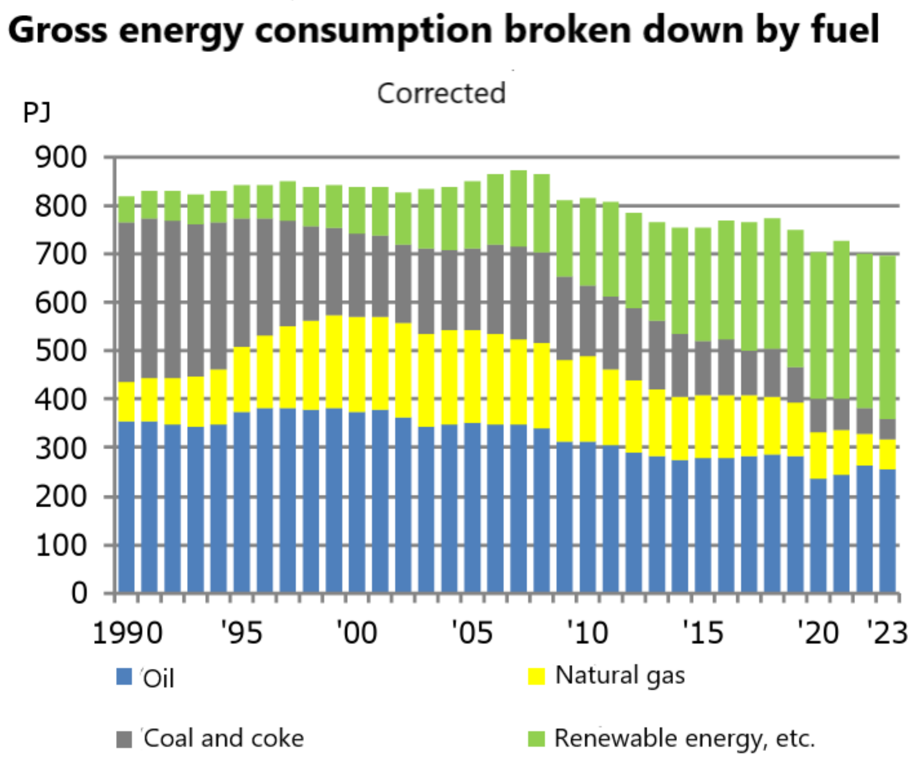
Problem analysis 2

This chapter investigates how Denmark's climate goals can be achieved through changes in the heat supply. It introduces the Danish energy system, the role of district heating and how the remaining households can be supplied in the future. The chapter presents thermonet as a potential technology to support the climate goals and the green transition. The Danish climate goal is to reduce the emission of greenhouse gasses with 70% in 2030 compared to 1990 and climate neutral in 2050 [Ministry of Climate, Energy and Utilities, 2021]. In relation to thermonet, the lack of knowledge utilising wast local heat sources is explored. Political aspects, including the Heat Supply Act are introduced in order to highlight how it affects the implementation of innovative heat producing technologies i Denmark. Lastly, the chapter includes a geographical analysis with the purpose of selecting a case area where thermonet can be implemented. This case area will be used throughout the project.

2.1 Danish energy system with focus on district heating

This section introduces an overview of Denmark's energy system, the development of the district heating sector, and its importance in reaching the Danish climate goals. The section also presents the need for alternative solutions in areas where district heating is not feasible, and explores the potential role of thermonet in Denmark's heating transition.

Denmark gross energy consumption was in 2023 696 PJ [The Danish Energy Agency, 2025b]. The share of fuels for the period is illustrated on Figure 2.1.



Figur 2.1. Visualisation of the Danish fuel consumption from 1990 to 2023 [The Danish Energy Agency, 2023,p. 21].

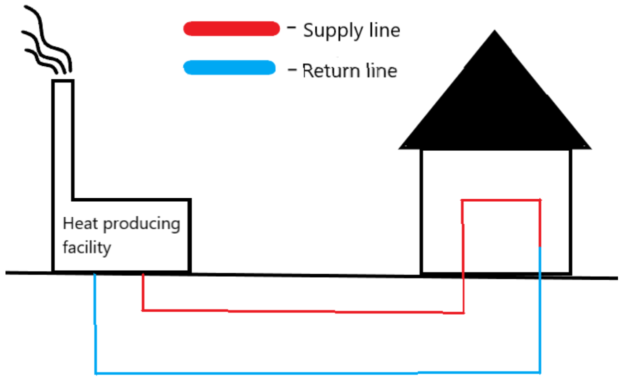
The Figure shows that the total energy consumption has decreased with 15% from 1990, to 2023 [The Danish Energy Agency, 2023,p. 21]. It shows that the share of renewable energy, from sources such as water, sun, wind, biogas and biomass, in the system has increased significantly, while natural gas, oil and coal and coke has decreased [The Danish Energy Agency, 2023,p. 6 & 21]. The trends seen in Figure 2.1 illustrates the transition in the energy sector is currently undergoing, to accomplish the Danish climate goals.

An central element of this transition includes developing the Danish heating sector, particularly the district heating sector, from fossil fuels to renewable sources. Developing the district heating sector to become CO_2 neutral in 2030, the goal of Fjernvarme Danmark, will result in a reduction in emissions. Reaching CO_2 neutrality in the district heating sector, is expected to result in a reduction of 9.4 million tonsCO_2, covering approximately 33% of the 2030 climate goal [Lysgaard, 2020].

The district heating sector is responsible for supplying around 70% of the total heat demand in homes in Denmark [Dansk Fjernvarme, 2025a].

District heating is defined by a transmissions system able to be connected to all types of heat production [Dansk Fjernvarme, 2025a].

It operates through a heat producing facility able to use various fuels or/and excess heat, to heat water, as illustrated on Figure 2.2. This heated water is then distributed through insulated pipes to consumers, where it is used for space heating and/or domestic hot water [Danfoss, 2025].



Figur 2.2. Visualisation of a simple district heating system. Made by the project group

At the consumers, the water from the district heating system can be utilised directly in the heating system, or the heat can be transferred by a heat exchanger. About 60% of district heat is delivered directly while 40% is indirect using a heat exchanger. The temperature of the water in the distribution pipes is around 50-70 °C, and the return temperature is around 30-35 °C [Bisp and Boding, 2025; Metro Therm, 2025b].

There are several benefits to implementing and utilising district heating:

- District heating is a low-cost heat solution [Aabenraa Fjernvarme, 2025].
- The security of supply is higher [Frederiksen and Werner, 2013,p. 25].
- For individual households, maintenance is not necessary since the district heating plants supplies this service [Aabenraa Fjernvarme, 2025].
- Implementing district heating is more environmental friendly since it reduces the burden on the climate [Frederiksen and Werner, 2013,p. 25].

More than 500 000 households in Denmark are supplied by heat from individual fossil fuel sources. Changing the heat supply in these households can ensure an additional reduction of emissions of 1.9 million ton CO_2. This correlates to a additional 7% on top of the 33% and together accounts for 40% of the overall 70% reduction goal of the 2030 goal [Lysgaard, 2020]. This emphasises the importance of transition from individual fossil based heat sources, in order to reach the 2030 goal. It has been evaluated that approximately 200 000 of these households can be covered by traditional district heating. For the remaining 300 000 households, other heating solutions are necessary to implement [Westergaard and Lock, 2024]. These are the households that this project focus on.

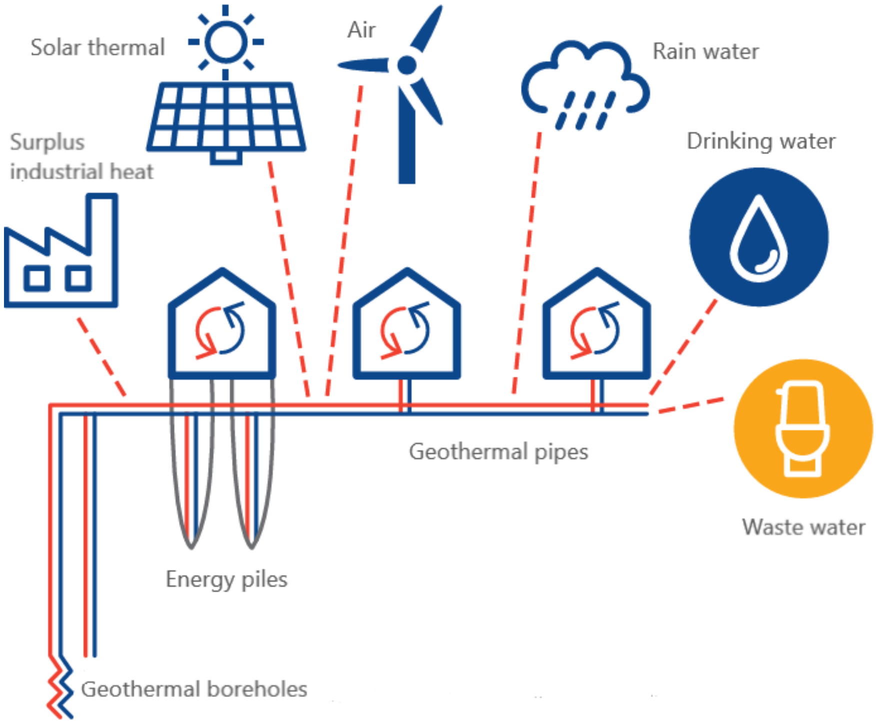
2.2 Thermonet

Thermonet is a way to provide heat to homes, in areas where district heating systems are not a possibility, due to the locations far from a district heating plants [Metro Therm, 2025b]. Thermonet offers a solution for the 300 000 homes in Denmark that need to transition from fossil fuel based heating sources, such as oil and gas, to more sustainable individual alternatives [Westergaard and Lock, 2024]. Termonet Danmark expects that 2000 villages in Denmark could benefit from thermonet [Westergaard and Lock, 2024]. The transition is essential to achieving Denmark's goal of reducing CO_2 emissions in 2030 by 70%, compared to 1990 [Ministry of Climate, Energy and Utilities, 2021]. Thermonet offers a collective heat solution in areas where district heating is not feasible, but is at this point not a mainstream heating method in Denmark [Westergaard and Lock, 2024]. There are currently 13 established thermonets in Denmark [Termonet Danmark, 2025f]. The sizes of thermonet are ranging from 2-91 houses [Termonet Danmark, 2025e].

Figure 2.3 illustrates a simple thermonet setup. Here the distribution net and service pipes consists of uninsulated pipes, similar to drinking water pipes [FUTURE, 2023,p.5-6]. This differs from the traditional district heating system described above. The temperature transported in the pipes in a thermonet are commonly below 10°C [Termonet Danmark, 2025d], as they collect geothermal energy from the ground [Termonet Danmark, 2024,p. 3-4] The low temperature results in that the system though circulation pumps, can provide both cooling in the summer and heating in the winter [Termonet Danmark, 2025d]. The focus of this project will be on the heating aspect as an interview with Søren Erbs Poulsen, a founding board member of the organisation Termonet Danmark, mentions that this is the most widespread use in Denmark [Poulsen, 2025a].

Instead of water thermonet uses brine as a frost-proof energy carrier in the system. The brine consist of water with anti frost solution added [Termonet Danmark, 2025b]. The Figure shows that thermonet uses two pipes, different from district heat, that uses one insulated pipe for supply and return [Østergaard et al., 2021,p. 13]. This means that when establishing thermonet two trenches must be dug, as the pipes must be laid approximately 1 meter apart to function optimally [Østergaard et al., 2021,p. 13]. This is based on the fact that they will transfer heat to each other, due to their uninsulated nature, if too close [Østergaard et al., 2021,p. 36].

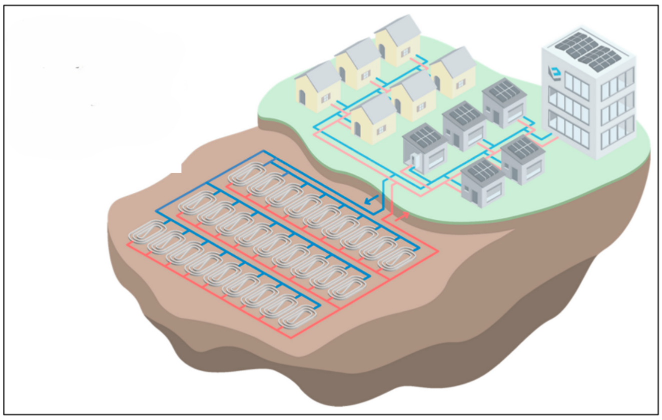
The pipes in a thermonet transport thermal energy from local heat sources such as geothermal pipes and boreholes, industries, solar thermal collectors, rain and waste water to individual ground source heat pumps in the houses [FUTURE, 2023,p.5-6]. An overview of potential heat sources can be seen in Figure 2.3.



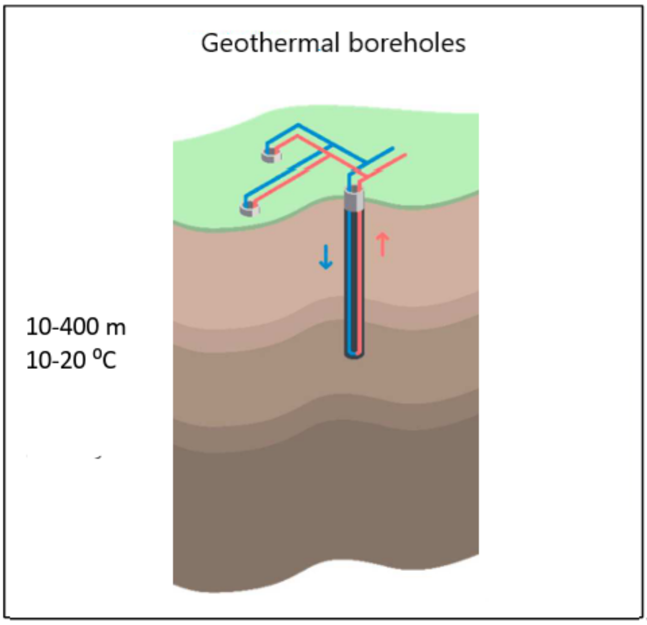
Figur 2.3. Overview of energy sources that can be utilised in the thermonet technology [FUTURE, 2023,p.6].

In Denmark the use of geothermal pipes and boreholes is the most utilised heat source from thermonet and will be presented on Figure 2.7. The geothermal pipes are placed horizontally in about a meters depth, this is illustrated on Figure 2.4. A rule of thumb is that for every m^2 of heated area, there is a need for 2 m^2 of ground area [Dansk Fjernvame and PlanEnergi, 2023,p. 15]. One advantage about thermonet is that the entire network is included in the needed m^2 , this also includes the service and distribution pipes [Dansk Fjernvame and PlanEnergi, 2023,p. 15].

Vertical geothermal boreholes are approximately 8–10 times more expensive to establish compared to horisontal geothermal pipes [Dansk Fjernvame and PlanEnergi, 2023,p. 15]. Vertical geothermal boreholes are illustrated on Figure 2.5. They are therefore only recommended in areas that are too developed or fortified for horisontal geothermal pipes to be cost effective. This is further due to the fact that vertical geothermal boreholes offer only a marginally better efficiency [Dansk Fjernvame and PlanEnergi, 2023,p. 15]. Vertical geothermal boreholes are typically between 40 and 200 meters deep and must be installed with a spacing of more than 5 meters to prevent interference between them [Østergaard et al., 2021,p. 13].

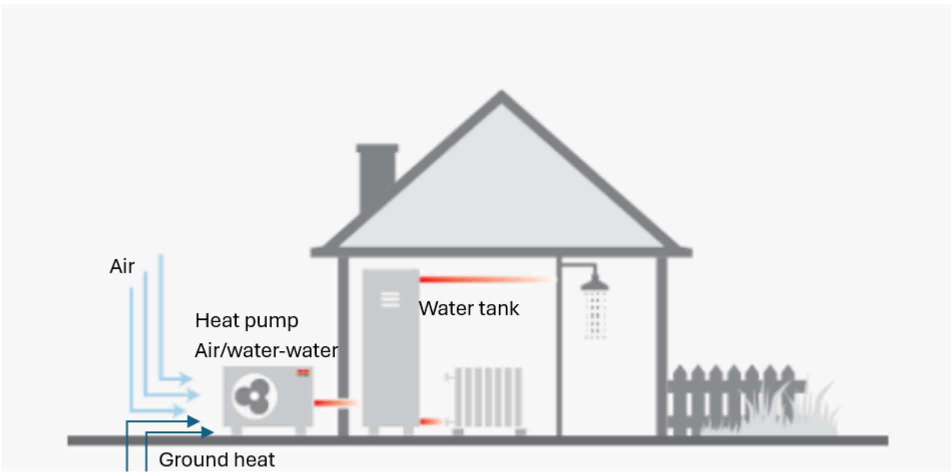


Figur 2.4. Illustration of a thermonet based on horizontal geothermal pipes [Termonet Danmark, 2025a]



Figur 2.5. Illustration of vertical geothermal boreholes [Termonet Danmark, 2025a]

The heat pumps used in thermonets are ground source heat pumps, meaning that they use the energy from the brine in the thermonet to produce heated water to heat the home and domestic hot water, as illustrated on Figure 2.6 [Metro Therm, 2025a; Termonet Danmark, 2025f]. The heat pumps varies in size based on demand and whether they are centralised or decentralised. In Denmark it is usually seen that decentralised heat pumps are used [Poulsen, 2025a], meaning they are placed in each house connected to the thermonet.



Figur 2.6. Illustration of heat pump, where air or water can be utilised as heat source[Metro Therm, 2025a].

There are several benefits of using ground source heat pumps rather than a air-to-water heat pumps, that is the most common heat pump in Denmark [OK, 2025c]. The first reason is that air-to-water heat pumps can be noisy, and cause visual disruptions on the exterior of the house, leading to inconveniences for both residents and neighbors [Termonet Danmark, 2022,p. 4-5]. The second reason, and arguably the most important when taking the Danish climate goal for 2030 into consideration, is that thermonet boosts the efficiency of the ground source heat pump [Dansk Fjernvame and PlanEnergi, 2023,p. 15]. The efficiency of the heat pump is important. When utilising a heat pump with higher efficiency will result in a lower electricity demand, affecting the needed electricity production [VVS eksperten, 2025].

The efficiency boost in ground source heat pumps, compared to air-to-water heat pumps stems from the fact that when the heat pump is connected to the thermonet. For thermonet, the temperature of the brine in the winter period is usually higher than the temperature of outside air. The temperature of the brine is around 7-8 °C degrees, whereas the air in winter months December to February reaches average temperatures of around 2.3°C [The Danish Meteorological Institute, 2024]. This means that when the air is cold and the need for heating is highest, the ground source heat pump connected to the thermonet does not have to use as much energy to increase the temperature as an air-to-water heat pump [Dansk Fjernvame and PlanEnergi, 2023,p. 15].

The energy efficiency of thermonet compared to individual air-to-water heat pumps is one of the arguments for thermonet as a solution for the 300 000 households, that need to transition from individual fossil-based heating solutions to renewable sources [Termonet Danmark, 2025d]. Another argument that is frequently used, is cost[FUTURE, 2023,p.4]. Termonet Danmark writes: *"Overall, it is cheaper to establish a thermonet with plastic pipes than a comparable district heating network with insulated steel pipes."* [Termonet Danmark, 2025d].

This contrasts with the fact that thermonet is a solution for individual heating systems, and not for district heating [COHEAT, 2023a,p. 15]. In this light, the argument that thermonet is a cheaper solution compared to other individual options falls short. According to calculations from the Danish Energy Agency regarding consumer economics, both the installation costs and the annual heating costs are higher than for both individual air-to-water and ground source heat pumps. This difference in cost is shown in Table 2.1. Based on the Danish Energy Agency's calculations, including installation cost per house and annual heating cost, the further focus of this project will be on consumer economics of thermonet projects.

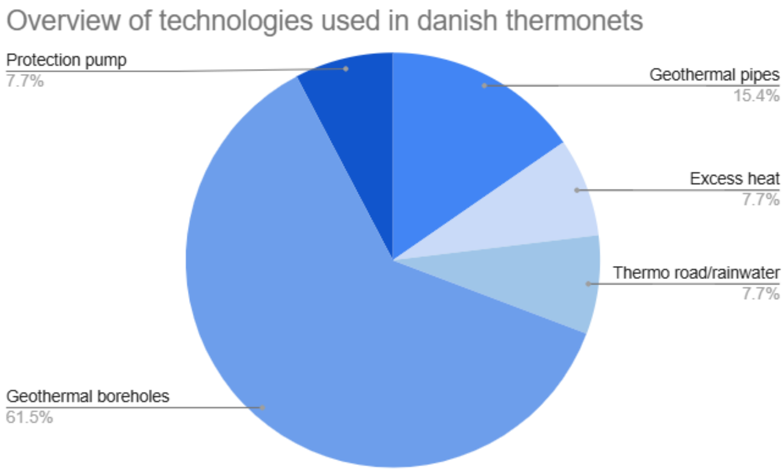
Summary of Costs		
	Installation cost per household	**Annual heating cost**
Individual air-to-water heat pump	DKK 129 000	approx. DKK 17 000–18 000
Individual ground source heat pump	DKK 183 000	approx. DKK 17 000–18 000
Thermonet (avg. of 19 budgets)	DKK 323 000	approx. DKK 26 000
Thermonet (realised project)	DKK 454 500	approx. DKK 33 000

Tabel 2.1. The Danish Energy Agency's calculations regarding thermonet, individual air-to-water and ground sorce heat pumps [The Danish Energy Agency, 2025e]

As shown in the table, the cost of thermonet is higher than both alternatives, which contrasts with the claim that price is an argument in favor of thermonet. Termonet Danmark has stated that they do not agree with the calculations made by the Danish Energy Agency. However, the Energy Agency argues that the cost of thermonet is relatively high, particularly because it requires a two-pipe system [The Danish Energy Agency, 2025e]. In addition, if the network has to be installed in fortified areas areas such as where there are roads, sidewalks, communication cables and water and sewage pipes, the installation cost is significantly higher than in non-developed areas [The Danish Energy Agency, 2025e]. However, most of the areas where thermonet is to be installed fall into this category, as the 300 000 houses are already build, where it can be assumed that parts of the installation will be in built-up areas. On top of this, there is also the cost of geothermal boreholes, which is often used when thermonet is installed in fortified areas. In such cases, the cost is approximately 8-10 times higher than if geothermal pipes are used as mentioned above. This and the lack of proper knowledge about the actual price for thermonet, is an obstacle for it to be a mainstream technology in the green transition of the heating in Denmark, to fulfill the 2030 climate goal.

2.2.1 Lack of knowledge about energy sources

This section will explore the lack of knowledge about thermonet. It will introduce the variation in heat sources from projects in Denmark and alternatives utilised in neighboring countries. In Denmark, the established thermonet projects utilised heat sources such as protection pumps, geothermal pipes, thermo roads/rainwater, excess heat and geothermal boreholes [Termonet Danmark, 2025e]. The share of these heat sources is introduced in Figure 2.7.



Figur 2.7. Share of established technologies for thermonet heat supply in Denmark [Termonet Danmark, 2025e].

It is often seen, that the technologies of geothermal boreholes and geothermal pipes are used as heat source for the thermonet projects [Poulsen, 2025a]. This is done even though several source highlight the benefits in utilising different energy sources to increase the efficiency of the heating pumps [Poulsen, 2025a; FUTURE, 2023,p. 5-7].

Based on the continued usage of geothermal boreholes and geothermal pipe technologies, the project group experienced limited information of when and how thermonet projects benefit from using different heat sources. As a result of not knowing which technologies can be used in thermonet projects, it can be assumed that it makes it harder to plan future projects. In the interview with Poulsen, he states that Termonet Danmark, have tried but not succeeded in informing different parties about the possibility [Poulsen, 2025a]. In several other countries like Germany and Sweden, technologies such as heat from river water, solar thermal facilities, sewage water and excess heat from residential and commercial buildings are utilised [Eon, 2025; nPRO, 2025]. This shows that thermonets utilising other energy sources are technological possible. This leads to the question of why more technologies are not used in Danish thermonets.

The overall knowledge in the Danish debate about thermonets have been low, but it is definitely the "in ground"part of the project where the knowledge is lacking [Poulsen, 2025a]. Based on the experience of the investigated heat sources for established thermonet projects in Denmark, this project will include the geothermal boreholes as heat source in later analysis.

Based on this project continuing it's focus on geothermal boreholes the geothermal pipes as a heating source will not be included. With the knowledge of the distribution and service pipes absorbing heat from the ground, these will now be mentioned as geothermal pipes in the project.

The lack of knowledge is not the only aspect affecting the implementation of thermonet. Political aspects are in regards to this relevant to explore.

2.3 Political aspects

This section introduces the political aspects regarding the technology of thermonet and how this affect the implementation. This is important due to the Danish policies creating the framework that thermonet has to evolve within.

The Danish organisation Termonet Danmark has raised concerns about the exclusion of the thermonet technology from the Heat Supply Act (Varmeforsyningsloven). The purpose of the Heat Supply Act is to promote socio economic and environmental friendly use of energy to supply buildings with heat and hot water while becoming independent of fossil fuels [The Ministry of Climate, Energy, and Utilities, 2024a]. The Danish Ministry of Climate, Energy, and Utilities argues that the reason for not including thermonet in the Heat Supply Act, is that the technology is not leading gasses or heated water through the pipes [The Danish Energy Agency, 2022]. The transport of brine fluids to the individual heat pumps does not change this fact. Additionally, the Danish Ministry of Climate, Energy, and Utilities point out that it is not a production facility or block heating plant [The Danish Energy Agency, 2022]. This exclusion from the Heat Supply Act have created a discussion where actors with interest in advancement of thermonet argues that inclusion can *"[...]support the rapid and efficient green transition of the heating sector in both cities and rural areas."* [Termonet Danmark, 2024,p. 9].

This is because of that a exclusion from the Heat supply act a cording to Termonet Danmark will have a *"significant, cost increasing, and potentially prohibitive consequences for otherwise economically and environmentally sound thermonet projects, particularly in rural villages"* [Termonet Danmark, 2024,p. 6]. This is due to Section §2d of the Heat Supply Act, which prohibits municipalities from guaranteeing loans for a *"company that operates heat pumps for the combined production of heating and cooling"* [The Ministry of Climate, Energy, and Utilities, 2024a]. Therefore, the inclusion of thermonet in future versions of the Heat Supply Act could significantly impact the expansion of thermonet systems in Denmark.

The discussion, surrounding if thermonet should be included in the Heat Supply Act, is by assumption heavily affected by different bias. The discussion primarily between the Danish Ministry of Climate, Energy, and Utilities and Termonet Danmark.

This projects understanding of the bias from Termonet Danmark, is that they are advocate for a wide spread implementation of thermonet. An example of where this is apparent is in an answer from the Minister of the Danish Ministry of Climate, Energy, and Utilities, to an inquiry from Termonet Danmark. In this inquiry the minister answer to a point of criticism, that the economic analysis that is basis for the costs in Table 2.1 is calculated using construction prices picked from the submitted material [The Minister of Climate, Energy, and Utilities, 2024].

Termonet Danmark have sent 19 cases, where they have pointed out five project of which they determine as the most accurate for the construction budgets. The Danish Ministry of Climate, Energy, and Utilities conducted the analysis on all 19 cases in Denmark. This argument for using all 19 cases, is to avoid a possible bias from Termonet Danmark, as the nature of the organisation is to advance thermonet [The Minister of Climate, Energy, and Utilities, 2024,p. 3]. This supports this projects understanding of the Danish Ministry of Climate, Energy, and Utilities bias, as they have conducted their own analysis' and investigations on the topic of thermonet.

Scientists in the field of energy have mentioned, that at this time there is not enough knowledge to evaluate whether or not thermonet is a financially viable solution and what impact it will have on the current and future Danish energy system [The Ministry of Climate, Energy, and Utilities, 2024b].

This stems from the overall investigations conducted of thermonets which do not include a standardised assessment to evaluate the projects [The Ministry of Climate, Energy, and Utilities, 2024b]. The inconsistent evaluation, means that projects cannot be directly compared when they are based on different parameters. It further results in difficulties in comparing to other heat solutions such as individual heat pumps [The Ministry of Climate, Energy, and Utilities, 2024b]. It is further described from The Danish Environmental Protection Agency that *"Standardisation [...] helps set the direction for new and existing technologies[...]. Standards are therefore an important driver not only for technological research aimed at market breakthroughs, but also for the further development of existing products-[The Danish Environmental Protection Agency, 2018,p. 10].*

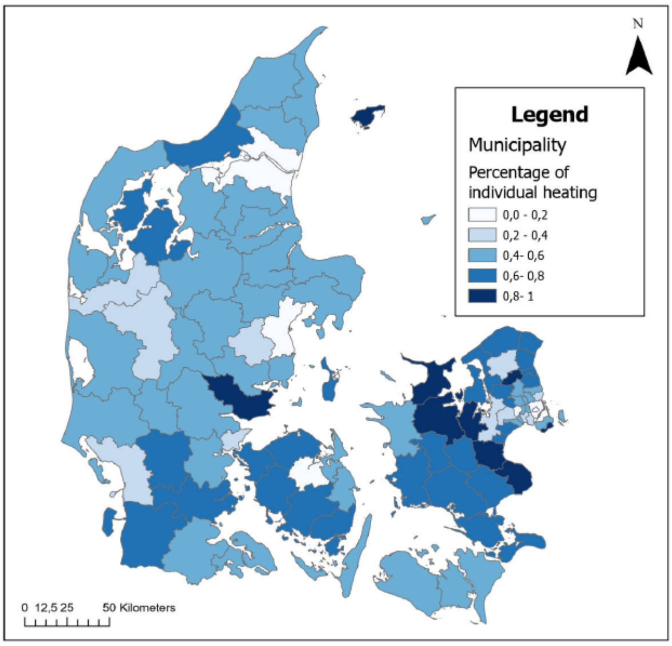
The assumption from the project group concludes that the lack of comparable investigations is based on the uncertainty in the industry, highlighting the need for further investigation in this area.

Based on the above, several challenges to the implementation of thermonet have been identified. Another important aspect to the technology of thermonet, concerns the geographical areas where thermonet could potentially be implemented, if the mentioned challenges are overcome. Therefore the following sections will explore the selecting of a case area for this project.

2.4 Area of interest

This section introduces an analysis of what geographical areas of Denmark could make use of the thermonet technology based on the share of individual heat solutions seen in the municipalities and the share of fossil fueled individual heat solutions. The result of the analysis is a case area this project will focus on in later analysis.

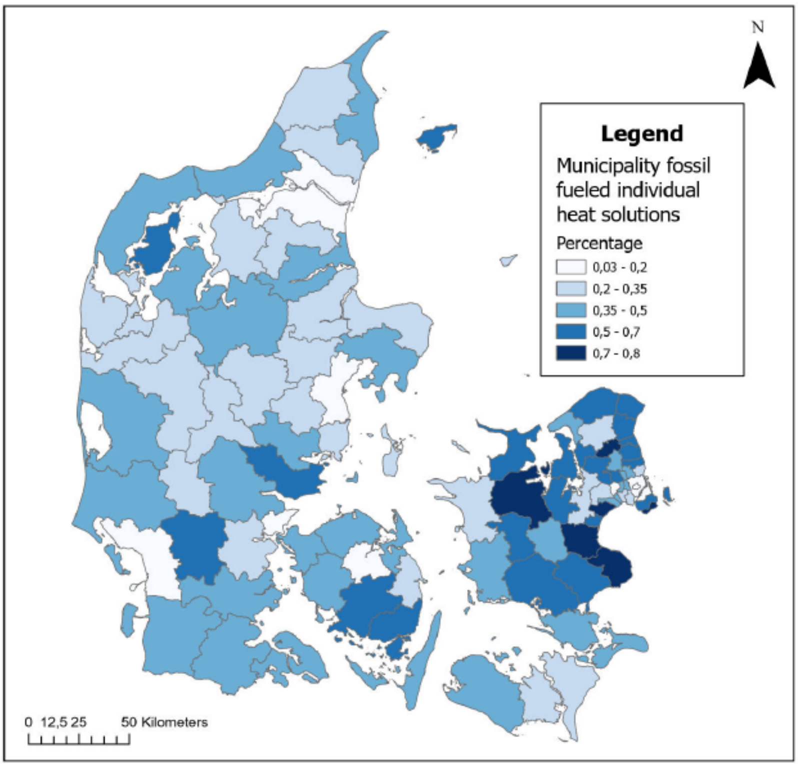
The analysis seen in Figure 2.8, shows a map of Denmark with a gradient illustrating the percentage of individual heating solutions in each municipality.



Figur 2.8. Map of the percentages of individual heating in municipalities, made using data from Aalborg University [2022]. Map created by the project group with data from [Aalborg University, 2022].

This Figure shows which areas would be most relevant to investigate later in the project, based on the sheer number of individual heating solutions. Municipalities with larger cities such as; Aalborg, Copenhagen and Aarhus, shows that individual solutions are less implemented due to these cities being supplied by district heating.

The aspect of having municipalities with a high share of individual heat solutions is not the only important parameter to argue where investigations of thermonet are most relevant. Thermonet is seen as an alternative to fossil fueled individual heating sources. Therefore it is necessary to additionally investigate where the share of fossil fueled heat individual solutions is high. An investigation of the share of fossil fuel in each municipality is seen in Figure 2.9.



Figur 2.9. Map of the percentages of individual heating without heat pumps in municipalities, made using data from Aalborg University [2022]. Map created by the project group using data from [Aalborg University, 2022].

Comparing Figure 2.8 and Figure 2.9, shows differences in areas of interest. The differences in the figures show that some area with a large share of individual heating, is not considered fossil fuel based. This result in an assumption that a large part of the individual heat solutions in some areas consists of individual heat pumps. This distinction is important as households that already have installed individual heat pumps or biomass boilers, are less likely to consider changing their heat solution to thermonet.

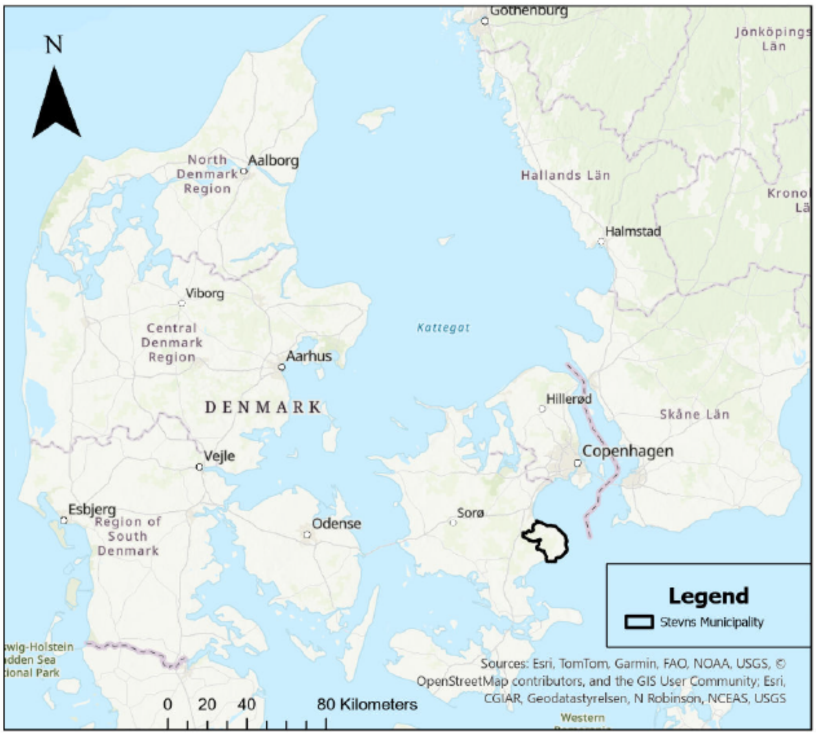
Figure 2.9, is made to illustrate the share of fossil fueled individual heat solutions in the respective municipalities. To create the illustration, the BBR data have been used. The BBR is based on data from individual house owners, and have therefore some degree of uncertainty due to the fact not all house owner are updating their heat solutions[Energistyrelsen, 2023,p. 13].

For this project the most relevant area of investigation would therefore be the areas with the highest percentage of individual heating solutions combined with the highest share of fossil fueled individual heat solutions. These areas are on Figure 2.8 and Figure 2.9 seen as municipalities with a 80% -100% share of individual heat solutions and a share of 70%-80%fossil fueled individual heat solutions.

The municipalities fulfilling the given parameters are primarily located in the middle part of Zealand. The chosen municipality, which will be the focus of the project, is based on this is Stevns Municipality.

2.4.1 Stevns Municipality

The location of the municipality of Stevns is seen in Figure 2.10.



Figur 2.10. Map showing the location of the municipality of Stevns. Map created by the project group [The Danish Agency for Data Supply and Infrastructure, 2025a].

Stevns is a municipality located on Zealand. It currently have 23 612 inhabitants, and have an area of 24 723 ha [Stevns Municipality, 2025b]. It contains more than 11 000 buildings with a total heat consumption of 218 878 MWh/year [Aalborg University, 2022]. The building types, number of buildings and heat consumption is seen in Table 2.2:

Type	Number	Heat consumption [MWh/year]
Farmhouses	953	20 002
Plot houses	6 342	107 320
Townhouses	1 137	14 428
Apartments	179	8 113
Other housing	197	6 311
Trade, services and business	544	30 677
Other	1 819	32 027
Total	**11 171**	**218 878**

Tabel 2.2. Heat consumption distributed by building use in Stevns Municipality [Aalborg University, 2022]

The table above shows that plot houses followed by farmhouses are the most dominant type of buildings in Stevns Municipality. Table 2.3, shows the heat solutions in the buildings in Stevns municipality, and their respective heat consumptions.

Type	Number	Heat consumption [MWh/år]
District heating	120	1 173
Natural gas	3 366	76 464
Oil	2 095	52 658
Biomass	1 022	23 358
Heat pumps	2 181	35 280
Other	2 387	29 945
Total	**11 171**	**218 878**

Tabel 2.3. Heating consumption divided into heating solutions and the numbers thereof [Aalborg University, 2022].

Table 2.3 shows, that with the purpose of changing the heat solutions utilising oil and natural gas as fuel, that 5461 houses could have interest in changing their heat solutions to alternatives such as individual heat pumps or thermonet. The 5461 houses have a heat consumption of 129 122 MWh/year that have to be covered. It is also visible from Table 2.3 that the share of natural gas and oil is responsible for 73% of the heat supply in Stevns Municipality.

According to Table 2.3, 120 houses on Stevns have district heating, this is considered a mistake in the BBR. Based on a conversation with the utility company KLAR FORSYNING, there is currently no district heating on Stevns. In regards to this, the mentioned 120 housed registered with district heating in BBR, is assumed to be a mistake based on individual house owners own responsibility of registering their heat supply [The Danish Assessment Agency, 2025]. Additionally, this mistake can stem from the heating atlas have counted the planned district heating plans. This could be a mistake as there have been several plans to make district heating in Stevns Municipality. These have, however, been canceled since being deemed a non-economic feasible investment [Stevns Municipality, 2025a].

This highlights the need for a change in individual heat sources in Stevns Municipality to help reach the Danish climate goals of a reduction in CO_2 with 70% in 2030 compared to 1990 [Ministry of Climate, Energy and Utilities, 2021].

2.5 Summary

Denmark's climate goals aim for a 70% reduction in CO_2 emissions by 2030 compared to 1990 levels. A challenge in achieving this target is transitioning the heating sector away from fossil fuels. While district heating covers 70% of Danish homes, many areas still rely on individual heating solutions, primarily natural gas and oil. This has created a need for alternative heating solutions, particularly in regions where traditional district heating is not a economic feasible option.

An alternative solution is thermonet, a heating system that uses uninsulated pipes to transport low temperature brine to individual ground source heat pumps. Despite its potential, the technology of thermonet faces several challenges that affects the implementation in the danish heating sector. One of these challenges is lack of a standardised assessment for determining the suitability of thermonet. It is stated that standardised assessment is important for thermonet to have a breakthrough on the market. Other challenges is from a policy perspective. The Danish Ministry of Climate, Energy, and Utilities has excluded thermonet from the Heat Supply Act, arguing that if it is not a traditional district heating system then it is not fit to be in the Heat supply act. This results in uncertainty regarding the future of thermonet.

Another challenge for the implementation of thermonet, is the variation in cost compared to alternative heat solutions. These variations are based on the Danish Energy Agency's consumer economic calculations and the fact that Termonet Danmark wanting to promote the technology. Based on this, it becomes relevant to investigate the consumer economics for thermonet. This will further become the focus of this project.

This chapter further introduced geographical areas in Denmark for implementing thermonet. A case area, containing a high share of individual heat solutions relying on fossil fuels, have through GIS analysis been chosen. This project identified Stevns Municipality as a case study area.

Given these challenges, the research question guiding this project is:

What parameters are needed to develop a standardised assessment for thermonet, and how can GIS analysis be used to identify a suitable area to calculate the consumer economics in Stevns Municipality?

Sub-questions:

1. *How can the parameters concerning consumer economics used in thermonet project proposals and screenings, contribute to creating standardised assessment?*

2. *How can GIS analysis, based on predefined parameters from COHEAT and newly identified parameters, be applied to identify suitable areas for implementing a thermonet systems in Stevns Municipality?*

3. *How can the previous sub-questions and the resulting analysis be combined into consumer calculations for the selected case area in Stevns Municipality?*

Analytical framework 3

This chapter seeks to introduce the structure of the project through the research design and analytical framework. It outlines the project's scientific approach and abductive reasoning, in relation to the overall research design. The theoretical framework of the project introduces Strategic Niche Management (SNM) and the technology model to define the structure used in the analysis.

3.1 Research design

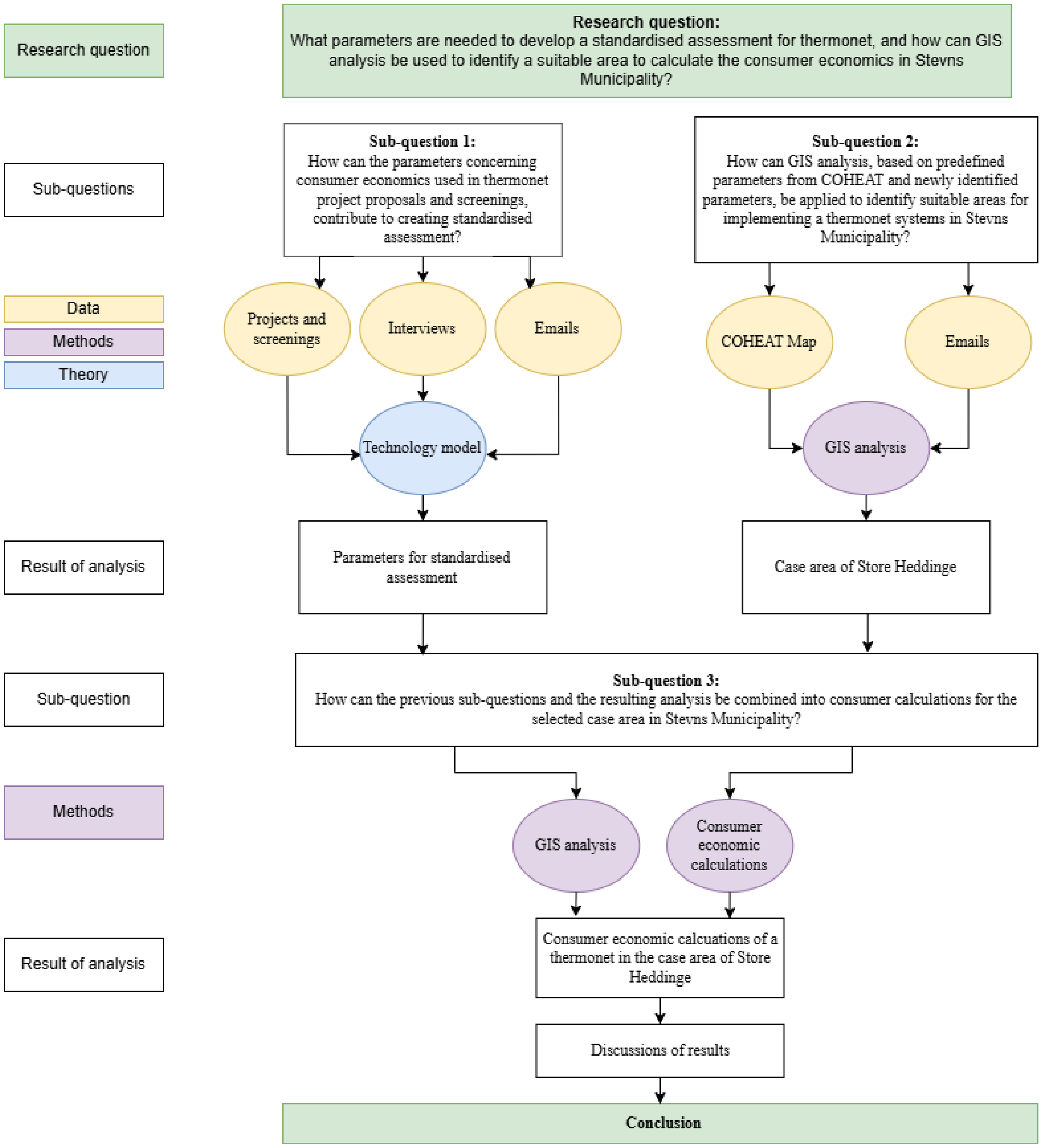
In this section, the project's approach, theory of science, and research design is introduced. The project's approach is shaped by its theory of science, which is rooted in critical realism. In critical realism, reality is understood as being more than what can be directly observed [Jespersen, 2021,p. 173–174]. Critical realism is based on the assumption that reality exists independently of our knowledge of it (ontology). This reality is objective and can consists of economic and technological structures and mechanisms. In contrast, our understanding of this world (epistemology), depends on our interpretation and perception of it [Næss, 2015,p. 1230].

By using critical realism as the project's approach to and understanding of the subject of thermonet, the project allows for the recognition that reality has two sides. On one side (ontology), data, economic conditions, and technical aspects are acknowledged as objective facts that exist independently. On the other side(epistemology), critical realism provides room to understand that the interpretation of these objective facts may diverge among different actors. This is evident, for example, in the differing perceptions of the feasibility of thermonet between the Danish Energy Agency and Termonet Denmark mentioned in Section 2.2.

The abductive approach is often used within critical realism, this is also the case in this project. The purpose of working abductively is to identify the most plausible explanation to a chosen subject or phenomenon [Mitchell, 2018,p. 105]. This is achieved by moving back and forth between theory and empirical data, testing arguments in order to explore actual practice [Mathiesen and Volckmar-Eeg, 2022]. In this project, this is achieved by switching between what is being said about thermonet and the data, such as budgets and technical requirements. This is then compared in order to better understand the complexity of thermonet.

This has led to the development of the project's research design. The research design serves as a visual representation of the structure of the project, outlining how sub-questions are addressed, which and when methods and theory is applied, and how the three analyses are connected. The data used for each sub-question, methods and theory is shown in the yellow, purple and blue circles. The project's research design is based on a combination of parallel and sequential analyses. This means that Analysis 1 and Analysis 2 are conducted independently of one another. The findings from these analyses are then used in Analysis 3, which therefore follows a sequential structure.

The research design is seen on Figure 3.1.



Figur 3.1. The research design for this project, made by the project group.

The three analyses seeks to answer the research question. To do this the analyses is divided in three parts, one for each sub-question. Analysis 1, includes an analysis of received data from actors in the heating sector, Termonet Danmark, The Danish Energy Agency and PlanEnergi. The parameters utilised is mapped and compared, to identify differences and similarities. These are used in determining what parameters to include in a standardised assessment.

In analysis 2, Stevns municipality is analysed through ArcGIS PRO, to find a case area for the consumer economic calculation of thermonet. This is done with a foundation in the parameters from the COHEAT map, introduced in Section 6.1, and other parameters deemed important by the project group.

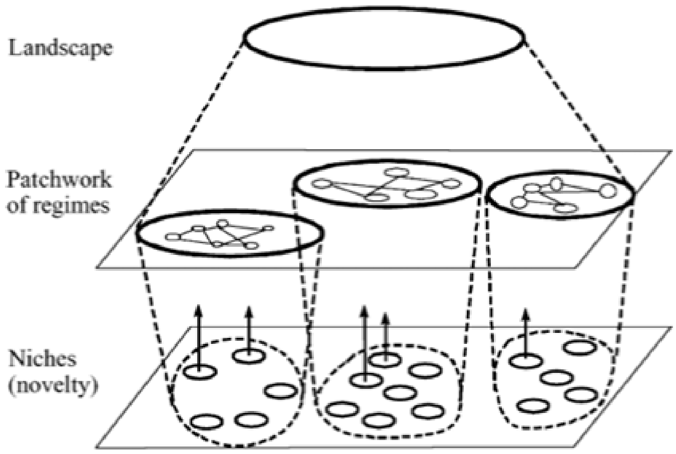
Analysis 3 includes the parameters from analysis 1 and the case area identified in analysis 2, to calculate the consumer economics for a thermonet. This is done to show how consumer economic calculations for an area using the standardised assessment can be conducted. The purpose is not to determine if thermonet is more consumer economic feasible compared to alternatives, but showcases an example for implementation of thermonet.

3.2 Theory

In this section the theory of Strategic Niche Management and the technology model is introduced. Strategic Niche Management is introduced as it is used as a theoretical framework to understand how thermonet can go from niche to established technology in regards to the external conditions. The inner workings of thermonet is addressed though the technology model and used in structuring the parameters in analysis 1.

3.2.1 Multilevel Perspective

To understand the theory of Strategic Niche Management (SNM), it is important to introduce the aspect of Multilevel Perspective (MLP) for a holistic understanding of technological changes. The idea of MLP is to establish a framework for the analysis of socio-technical transitions [Geels, 2011,p. 24]. MLP distinguishes between three levels: niche, regime and landscape [Geels, 2005,p. 449] and can be seen in Figure 3.2.



Figur 3.2. An illustration of the three levels of MLP in their hierarchy[Geels, 2002,p. 1261].

The framework shows that the technological change arise when niches are developed, regimes are destabilised and the landscape is shifting and creating an external pressure for change [Schot and Geels, 2008,p. 545]. Geels [2011] highlights that at both regime and niche level is influenced by the cultural narrative at landscape level [Geels, 2011,p. 30]. The cultural narrative of this project will be described in the following paragraph.

For the holistic understanding of this project, the three levels are understood as the following:
The landscape of this project is the external pressure of reaching the climate goals, among them the goal of 70% CO_2 reduction in 2030 mentioned in Section 2.2. This establishes the need for developing the transition in the Danish heating sector from fossil fuels to renewable sources. The landscape also include the intention of developing alternative heat solutions for the areas not covered by district heating. This is further relevant, when the resources in the outer areas of Denmark do not have access to the same resources as the larger cities in central Denmark.

The regime of this project is the established heat sources such as the district heating system, which supplies heat for 70% of Danish homes [Dansk Fjernvarme, 2025a]. In areas where district heating is not present, heat solutions like individual fossil fuel boilers and individual heat pumps are installed. Besides the heating regime, the integration of thermonet also have the potential to affect other regimes like the electricity production in regards to the demand and utilisation of fossil fuels. Furthermore it can affect the transport regime regarding the demand for transported fossil fuels.

The niche of this project is the development of innovative technologies to ensure alternative sustainable heat solutions to the areas not supplied by district heating. For this project the focus is on the niche technology of thermonet.

For the process of technological change, in this project the change from fossil based individual heating to renewable based solutions, niches play a vital role, as they serve as the foundation [Geels, 2011,p. 27]. In this, the theory of Strategic Niche Management (SNM) emerged as a way to manage niches and to change regimes [René Kemp and Hoogma, 1998,p. 185].

3.2.2 Strategic Niche Management

Strategic Niche Management is the theory about how to introduce new technologies to society, when they are affected by the competition with already established technologies. René Kemp and Hoogma [1998] proposed the following definition: *"strategic niche management is the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology"* [René Kemp and Hoogma, 1998,p. 186].

The wide implementation of the niche technologies can occur in several ways. The landscape can generate a pressure on the regime, resulting in a window of opportunity for the niche technology to replace the regime. Furthermore, it can be done through a high internal momentum. This momentum can be created through investments, high consumer demand, political support replacing the regime, without the pressure of the landscape [Geels, 2011,p. 32].

For new technologies, which are oftentimes inefficient and badly adapted, this means that they are not able to directly compete when presented to the market. In contrast it can be assumed that older technologies that are reintroduced or repurposed, might have an advantage of being more aligned to the demand on the market and directly compete. To account for this, a core assumption of the SNM, is to establish protected spaces and environments that allows for experimentation with these new technologies [Schot and Geels, 2008,p. 538]. The technologies that SNM is designed to manage are those aimed at achieving long term goals and that do not align with existing practices. For this reason SNM scholars point to real world experiments as an important way to develop niches. Where experiments on the implementation of the technology can be used to better and align the technology, consumer experience and sustainability [Schot and Geels, 2008,p.539]. The objectives of SNM is to:

- Identify needed change in both technology and regulations in order to create economical success [René Kemp and Hoogma, 1998,p. 186].
- Learn about the technical, economic benefits different technology options gives and the social acceptance of them [René Kemp and Hoogma, 1998,p. 186]. Thermonet can be evaluated through the Technological readiness level (TRL) which ranges from 1-9, or in other words where in the process from "basic principles observed and reported"to "actual system proven through successful operation". Thermonet has been proven to work through demonstration and several projects, therefore it is considered to be a TRL 9 [Mankins, 1995,p. 1-5]. This means for thermonet it not necessarily the technology itself that needs to be developed to enter the market. This means that other factors such as the political aspects, the need for a standardised assessment and competitive costs as mentioned in the problem analysis, can be relevant to explore.

- Encourage development of the technologies, create cost savings though mass production, support creation of related technologies, and promote changes in social structure to help spread the new technology [René Kemp and Hoogma, 1998,p. 186].
- Create a support group which includes, companies, researchers and public authorities. These are essential efforts for change regarding technologies and practices [René Kemp and Hoogma, 1998,p. 186].

3.2.2.1 Strategic Niche Management of thermonet

The relevance of this theory is based on the experience of thermonet being a solution in development. This is the case even though thermonet have been established for more than 20 years, but have only resulted in 13 conducted projects [Termonet Danmark, 2025e]. Since 2020 the organisation Termonet Danmark, have tried to introduce the technology to the regime, it is still not perceived as a competitive solution.

This theory gives an opportunity to understand how thermonet can utilise the pressure of Denmark's climate goals, on the sustainable heating solutions, to go from a niche technology to a successful integrated technology through a standardised assessment. This can destabilise the traditional heat solutions enough for thermonet to gain a foothold in the market and become a competitive heating alternative due to being able to directly compare to alternatives.

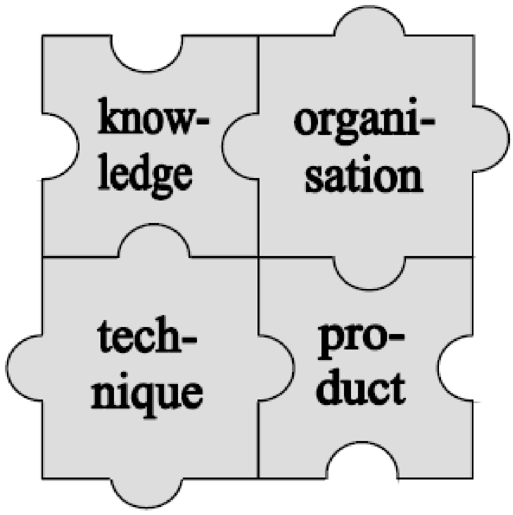
This project uses SNM as a way to understand the complexity in introducing a new technology in the Danish energy sector. SNM will be used as a framework to create a foundation for thermonet to create a high internal momentum through investments and consumer demand. The high internal momentum is utilised, due to the assumption that it is currently not visible where thermonet fits in the market, as it have not been deemed economic feasible compared to air-to-water heat pumps by The Danish Energy Agency. Therefore the aspect of thermonet inclusion in the market is based on high consumer demand and investments creating the internal momentum, which can become more apparent with the development of a standardised assessment. SNM provides an opportunity to test when the technology of thermonet becomes strong enough to destabilise the current heating regime. This is done through a case study, where an thermonet in a chosen area will be used as an direct example of applying the parameters from analysis 1, to calculate the consumer economics in analysis 3.

The analysis are covering the two last objectives, and is trying to develop a standardised assessments to strengthen the knowledge gap, that have been highlighted during the research process in the project [The Ministry of Climate, Energy, and Utilities, 2024b]. The standardised assessment creates a basis to fulfill the last objective, creating a support group. This is done through the opportunity to compare thermonet to other heat solutions, such as individual heat pumps and determine the economic feasibility of the projects. Creating the standardised assessment, have the potential to make it possible to receive the support from The Danish Energy Act and include thermonet in the Heat supply act, thus creating a support group. The economic calculations and the need for a support group is necessary for thermonet for it to be able to compete with other heating solutions. If it does not have economic feasibility, it is hard to create a demand. Additionally, the need for the standardised assessments is necessary to get researchers to support the technology. As of now, none of this is proven and therefore it is hard for both authorities and researchers to support the technology but also hard to get investments due to uncertainties in cost of investments.

As mentioned earlier Termonet Danmark is a support group that wishes to strengthen the use of Thermonet in Denmark. For thermonet to succeed, it is necessary for researchers, companies, homeowners and public authorities to support the implementation, create a demand and make thermonet go from niche to established.

3.2.3 Technology model

Strategic Niche Management offers a way to understand how a technology can evolve from niche to established, through external conditions. This complements the technology model by enabling an analysis of the inner workings of the technology, focusing on technique, knowledge, organisational structures, and product development. The combined use of these theories enables both an inward and outward analysis of thermonet. For this project, the technology model seen in Figure 3.3 is utilised in structuring the consumer economical aspects seen in Analysis 1. This is defined as the internal conditions of the technology.



Figur 3.3. Illustration of the technology model, defining the internal conditions of thermonet [Müller, 2013,p. 5].

The technology model consists of 4 aspects; technique, knowledge, organisation and product, and is described below in relation to this project:

Technique
The technique aspect of the technology model refers to the work process and the technologies used to conduct the work [Christensen et al., 1984,p. 17]. For this project and the purpose of using the model in structuring the techno-economical aspects of thermonet, it will include various payments to operation and maintenance, consumed electricity and investments for the technology itself.

Knowledge
The knowledge aspect of the technology model refers to the experience of the ones conducting the work. It is further a learning process and a combination of skills [Christensen et al., 1984,p. 18]. For this project it will revolve around the companies hired to conduct the project proposals and screenings. Based on this, it is assumed that the knowledge needed to conduct the projects, affects the cost for getting the analysis done. This aspect will affect the total cost of planning the project. It includes the expenses such as ground investigations and economic calculations. As these are assumed to be included in corporate economics, it lies outside the scope of the project, and will not be considered. Overall the aspects can be assumed to affect the consumer economics. This is based on the company can state their costs to the consumers, based on the final cost of the project being established. These cost are not directly stated, and will therefore not be considered.

Organisation
The organisation aspect of the technology model refers to the point of organising the work and operation. This can be roles such as management, who leads and divides the work assignments [Christensen et al., 1984,p. 19-20]. For this project is will revolve around the economy of the human factors such as administration, meter maintenance, subscriptions, fees and other organisational assignments.

Product
The product aspect of the technology model refers to the result of the technique, knowledge and organisation [Christensen et al., 1984,p. 21-22]. For this project the product will refer to the heat solution the individual house owners receive and pay for. The economical aspects for this part of the technology model will include the yearly heat price per house.

In summary, the technology model will in analysis 1 regarding economic parameters be used in structuring the data received from various actors which will be described in 4.3.3. Analysis 1 will include the three aspects of the technology model, technique, organisation and product, due to knowledge not being considered for the consumer economics. The utilisation of the technology model in analysis 1 will as mentioned be used in investigating the internal aspects of thermonet, in order to determine a standardised assessment. This standardised assessment will be able to create the possibility of going from niche technology to an established technology, which is introduced in the strategic niche management. This is based on the standardised assessment creating the direct opportunity to compare thermonet to other alternative heat solutions such as individual heat pumps. By doing this the a support group can possibly ensure more support through authorities, researchers and homeowners.

The use of the technology model in analysis 1 will further divide the parameters into categories, based on the uncertainty in values. These will be described below.

3.2.3.1 Categorisation

To structure this project the aspects of the technology model, technique, organisation and product is used. To further structure the many parameters from the thermonet projects a classification system have been put into place. The classes in the system are: high Uncertainty, moderate Uncertainty and relative Stability. Each class reflects how consistent, well defined, and impactful a parameter is in relation to total consumer costs.

In **high uncertainty**, the parameters vary significantly across projects in both definition and value. They are typically central to consumer economics, often involving large variations in costs. Additionally, there may be misalignment in assumptions across projects. These parameters have a strong influence on the total cost for a consumer and therefore require in depth discussions, analysis, and transparency in data. An example of the large variations in costs, is seen with the connection fees, which ranges from 25 000-63 375 DKK per house and will significantly affect upfront investment costs. Lastly, some data, is presented in different units, making them difficult to compare.

Moderate uncertainty applies to parameters where some variation exists, either in the values reported or in the methods used to calculate them. These include a smaller variation in cost than those in high uncertainty and have consistent units. These cost varies due to local conditions or implementation practices.

Relative stability includes parameters that are consistently defined and valued across projects, with low variation. Although these parameters are more consistent from an uncertainty perspective, they remain important for accurate modeling and should be included. As an example, a parameter with a relative stability, is the lifespan of the heat pumps. For the small heat pumps, the lifespan is similar across all project with 20 years.

By categorising parameters in this way, the analysis can be structured to create a thorough analysis of the parameters from all projects. The purpose of this is to improve the ability to compare projects more consistently.

3.2.3.2 Summary of theoretical framework

The theoretical framework presented in this chapter introduced three important perspectives for understanding and analysing thermonet as a technology in the green transition. The multilevel perspective (MLP) is used to introduce the pressure from the landscape to reach the transition and create opportunity for niche innovations. In addition to this, the strategic niche management (SNM) framework created insight for how thermonet can be supported and developed through support groups and learning processes. Lastly, the technology model is introduced, to explore the internal structures of thermonet relevant to the consumer economics.

Together, these theories form the foundation of the analytical framework for the project. MLP and SNM are used to understand the role of thermonet in the transition of the heating sector, while the technology model is used in analysis 1 for structuring the parameters gathered from the project proposals and screenings. This enables the development of a standardised assessment, creating the possibility of comparing thermonet to alternative heating solutions.

After the theoretical framework is presented, the following chapter similarly introduces the methods.

Methodology 4

This chapter seeks to introduce the methods utilised in the project and how these are relevant for the investigations conducted. The methods introduced are; Case study, the gathering of information though interviews, emails and received documents, use of ArcGIS PRO, consumer economic calculations in Microsoft Excel and use of ChatGPT. The section further introduces considerations of reliability and validity.

4.1 Case study

The method of case study is utilised in this project due to the construction of the research question seeking to utilise the consumer economic calculations on the chosen case area for Stevns Municipality. This will illustrate how the parameters relate to the consumer economics and what cost (total installation cost) or (annual cost per consumer) are affected.

The definition of a case study is by Schramm [1971] defined as *"The essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result"* [Schramm, 1971,p. 6].

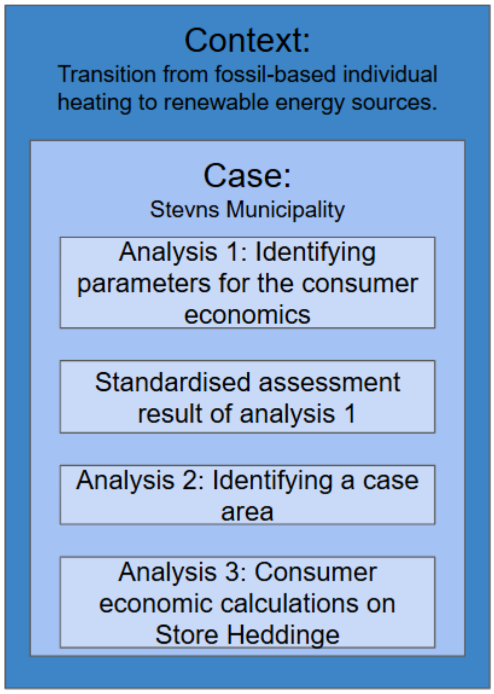
In this project, the use of a case study allows for an in depth exploration of thermonet as a heating solution within a case area in Stevns Municipality. It enables a holistic understanding of how technical and economic parameters, and local conditions interact. The approach demonstrates how consumer economic calculations can be carried out, adding a practical perspective to the parameters defined in the standardised assessment. This provides insight into how this project proposes that consumer economic analyses for thermonet projects could be conducted in the future.

4.1.1 Choosing the type of case study

This section introduces the single embedded case study type utilised in this project. The usage of a single embedded case study is relevant when investigating a case where specific analysis is to be investigated. Compared to a holistic case, it becomes more specific and detailed. As the holistic case, it is important to be aware of possible pitfalls. A pitfall mentioned by Yin [2014], is the idea of focusing on the subunits and therefore not returning to the overall larger analysis [Yin, 2014,p. 55].

The single embedded case study is chosen, due to the need of several analyses. This includes analyses for the parameters in the standardised assessment, the GIS analysis to find the case area in Stevns Municipality, and the consumer economic calculations in that case area. This is illustrated on Figure 4.1.

A reason for choosing a single case embedded study, is based on the time restraint of the project. This meant that, in case of more time or a further analysis in the future, a second case could have been chosen.



Figur 4.1. Illustration of the case study in this project. Made by the project group, with inspiration from Yin [2014,p. 50].

The case of Stevns Municipality and the case area within, is a strategic case [Flyvbjerg, 2010,p. 473]. A strategical case is by Flyvbjerg described to be a way to maximize the value and data a case give the project. The selection is based on the expectation of the information from the case [Flyvbjerg, 2010,p. 475].

The case study placement in Stevns municipality in this project is chosen due to the absence of current or planned district heating infrastructure, making it a highly relevant setting for evaluating the feasibility of thermonet systems in rural or decentralised areas [Stevns Municipality, 2025a]. The case area of Store Heddinge which is chosen in analysis 2, is addtionally a strategic case. This is due to the area being selected on the basis of the area having a relative high heat density representative for most groupings of houses, while also having few houses, no large consumers and being one of the areas chosen for district heat [Stevns Municipality, 2025a]. More about the selection of the case area of Store Heddinge will be presented in analysis 2.

These findings have the potential to help the technology of thermonet being included in the Heat Supply Act, through the standardised assessment. This is an important aspect due the support group having potential of creating equal conditions and political framework for thermonet in the regime.

While the chosen case study design supports exploring and evaluating thermonet in a case specific context, case studies are oftentimes a subject of misunderstandings and criticism. To clarify why the method of case study is validity in this project, five misunderstandings will be addressed below.

4.1.2 Five misunderstandings revolving around a case study.

When implementing a case study in a research project it is important to address of the five misunderstandings described by Flyvbjerg [2010], to argue why the method is relevant. The five misunderstandings is mentioned below:

1. General, theoretical knowledge is more valuable than concrete, practical knowledge [Flyvbjerg, 2010,p. 465].
2. One cannot generalise from individual coincidences, resulting in the case study not contributing to a scientific development [Flyvbjerg, 2010,p. 465].
3. The case study is used in the beginning of a project, due to it being best in creating hypothesis [Flyvbjerg, 2010,p. 465].
4. The case study contains a tendency to verify the researchers predetermined opinions [Flyvbjerg, 2010,p. 465].
5. It is seen as difficult to construct a concrete case study and develop general hypothesis and theories based on this [Flyvbjerg, 2010,p. 465].

The following text addresses the five misunderstandings in relation to this project, and prove why they are misunderstandings. It further describes why the aspects of the misunderstandings are relevant for the case study included in this project.

The first misunderstanding is based on the statement that theoretical knowledge is more important than practical knowledge, when working with a case study. Flyvbjerg describes that the researchers connection to real situation are important for several reasons. The first reason being the importance of developing a nuanced understanding of reality and the fact that the human behavior is not solely understood as a rule based action [Flyvbjerg, 2010,p. 467].

For this project, the practical knowledge gathered for choosing the case study area of Store Heddinge, is given a high value. The knowledge of the area is gathered through practical knowledge. This includes GIS analysis of the area, though data from the Danish heating atlas, and online sources with a connection. The Danish thermonet does not include a large variety of research an thereby theory to implement or test in a thesis project. A lot of the knowledge included in this project will therefore be collected by the study group through contact with the actors working in the sector. Since the actors contacted are either from the organisation Termonet Danmark, consulting engineering companies and the Danish Energy Agency, the knowledge collected is based on practical knowledge.

The second misunderstanding is based on the statement of it being impossible to generalise based on a singular case study. The criticism is based on the understanding that it is only possible to generalise by having large quantities of tests [Flyvbjerg, 2010,p. 469]. Flyvbjerg states that it is possible to create generalised knowledge from singular case, if it is chosen on a strategic foundation [Flyvbjerg, 2010,p. 470-471]. For this project, the implementation in Stevns Municipality represents a strategical case. The stretegic case, is used used to maximise the amount of data the project gets from the case area. The case serves a strategic function, as it highlights a context where thermonet could be the only collective heating solutions. The case area is used as a test for the parameters from the standardised assessment, and not as a basis for generalisation on where thermonet could be implemented. The single embedded case type supports the research question by having one case study area, used to perform the calculations.

The third misunderstanding is based on the statement of the case study being most suitable in creating hypotheses, therefore being usable in the first step of the research process [Flyvbjerg, 2010,p. 473]. This misunderstanding is a continuation from the previous misunderstanding. Based on this, Flyvbjerg states that it can be used in the creation of hypotheses but are not limited and can therefore still be used in other parts of the research process. It is further described that the case study do have value in all parts of the research process [Flyvbjerg, 2010,p. 473]. In this project, the case study is considered valuable throughout the whole process. This is based on the case study being utilised in both the process of choosing an area based on the identified parameters and the continued usage in analysis 3 where the consumer economics is calculated.

The fourth misunderstanding is based on the statement that the case study has a bias for verification, a tendency that the method confirms the researchers predefined opinions. This would create a doubtful scientific value [Flyvbjerg, 2010,p. 478]. The case study is described to, in the same way as other qualitative methods, lack verification and therefore create room for for the researchers subjective opinion [Flyvbjerg, 2010,p. 479]. Flyvbjerg states that it is the phenomenon falsification that characterises the case study and not the verification. Furthermore Flyvbjerg describes that the verification aspect will affect all methods and not only the case study [Flyvbjerg, 2010,p. 480]. To create transparency and to avoid the suspicion of the project group trying to verify their own opinions, the bias of the project group will be described here. The project group did not know of thermonet when choosing a thesis subject. The idea of investigating the topic is, as a third party, to look into the debate and the reasons as to why thermonet is not included in the Heat Supply Act, when organisations such as Termonet Danmark has deemed the technology feasible. To do this it would be investigated through a case chosen by the project group, and through exploring all project screenings and proposals.

To further avoid this misunderstanding the purpose of the project and the research question is carefully conducted to not pre-determine a specific outcome.

The fifth misunderstanding is based on the statement of it being difficult to develop hypotheses and theory from the cases. It is stated that due to the story element in a case study, it can be difficult to establish scientific thesis or theories based on this [Flyvbjerg, 2010,p. 481]. Flyvbjerg states that for a person used to working with case studies the story is not considered a problem, but a sign that the study is covering an actual problem [Flyvbjerg, 2010,p. 482]. Though it may be difficult to summarize case studies, Flyvbjerg states that the method can easily be used in the cumulative knowledge of the subject [Flyvbjerg, 2010,p. 485]. The point of this project is not to create theory, but to add to the pool of knowledge about the topic of thermonet in Denmark, The knowledge is as stated in Section 2.2.1 considered low.

4.2 Reliability and validity of the project

The quality of a case study can be evaluated using four criteria; construct validity, internal validity, external validity, and reliability. In this project, all except internal validity will be addressed. This is based on internal validity primarily being used in explanatory case studies [Yin, 2014,p. 46]. This project is an exploratory case study, as it does not seek to explain why something happens, but rather aims to identify which parameters are necessary to assess thermonet compared to traditional district heating and individual heating solutions such as individual air-to-water heat pumps [Yin, 2014,p. 238].

Constructed validity is about identifying and finding the right way to study, the chosen concept, in this project this is thermonet [Yin, 2014,p. 46]. To gain constructed validity, three study tactics are recommended: use multiple sources of evidence, establish chain of evidence and have the case study report draft reviewed by key informants [Yin, 2014,p. 45]. In this project multiple sources and ways of gathering information (triangulation) is used. These are, but not limited to: interviews, policy documents, budgets for thermonet projects and websites.

The information gathered are cross checked with additional sources to account for bias and attempting to reduce the risk of incorrect information. An example of this, is with the description of the interviewee, where the description of Poulsens bias is based on information from the university page of his place of employment, his personal LinkedIn profile and the observations from the interview. In several instances several sources are not added to the same paragraph to directly show the triangulation, but is checked before stating the information.

Chain of evidence is ensured by creating a transparent project, where the findings in the conclusion is derived from well supported and described decisions [Yin, 2009,p. 127-128]. Clear documentation of sources, data collection and transparency in the analyses gives the reader a way to follow the project from research question to conclusion, ensuring the constructed validity of the project. Lastly the third tactic for constructed validity is to have external actors review the case study draft [Yin, 2014,p. 47]. This is done by having the supervisors in this project, Peter Sorknæs and Diana Moreno, give feedback on both the written parts of the project, but also the analysis in ArcGIS PRO. External actors can include actors in the sector of thermonet. This is not done for this project, due to time restraints.

The external validity is about the generalisability of the findings in this project in other contexts and locations of situations [Yin, 2014,p. 46 & 48]. Two study tactics are used when addressing the external validity; use theory in single case study and use replication logic in multiple case study [Yin, 2014,p. 45]. In this project single case is used, meaning theory is used to create a external validity. In this case study the Strategic Niche Management theory is used as a framework, to understand how new technologies goes from niche to established. In this project this strengthens the external validity by explaining the landscape and regime thermonet is in, there by defining the domaine of generalisability.

Lastly to evaluate the quality of the case study is the question of reliability. To ensure this, two study tactics can be used; case study protocol and database [Yin, 2014,p. 45]. This is done to minimise errors and bias in this project [Yin, 2014,p. 49]. This reports methodology chapter is to act as a case study protocol, that outlines the methods, participants e.g. that is used to as a base of the analysis. Where the appendix and sources act as a database, where the reader can get insight into collected data and knowledge [Yin, 2014,p. 49].

4.3 Gathering information

This section introduces how information is gathered for the project. It includes the method of interviews, written correspondence with actors and the received project proposals and screenings.

4.3.1 Interviews

The method of interview have in this project been utilised for collecting knowledge not freely available from other sources. This is furthermore necessary when investigating the technology of thermonet, since the direction of this project it is currently affected by knowledge gaps.

The purpose of the interviews is to collect data, viewpoints and professional opinions from the interviewee [Kvale, 2003,p. 15]. The interview have been a conversation between the interviewer and the interviewee about the topic of thermonet. The interview conducted for this project is evaluated to be an expert interview, due to the fact that the interviewee is a professional working in the field of thermonet.

The expert interview are used to collect knowledge about thermonet, where the interviewee can be seen as a expert in this field of knowledge [Kvale and Brinkmann, 2014, s. 201].

For the interview, the format of a semi structured interview is utilised. This format is important for conducting the expert interview, since it allows for having a concrete purpose and structure for the interview to ensure the topics from the interviewer is covered. At the same time it gives the interviewer the opportunity to ask follow up questions. The semi structured interview further ensures that the interviewee can incorporate other topics in the conversation which can be of interest to the interviewer. It is an important aspect to be flexible in the structure and follow the statements of the interviewee, since the topics from the interviewer can still be covered [Brinkmann and Tanggaard, 2010,p. 38] [Kvale and Brinkmann, 2014, s. 47].

The questions in the semi structured interview is guided by a interview guide. This makes sure that the wanted questions is asked. The interview guide is created with the interviewees knowledge and area of expertise in mind, to make sure that they are able to answer the questions. The questions are designed to gather knowledge that are not available form other sources. It is also designed with the flexibility, so interviewer is able to ask follow-up and in depth questions, to gather more knowledge [Kvale and Brinkmann, 2014, s. 185].

4.3.1.1 Interview guide

An interview guide can beside, helping the interviewer with questions, and make sure that the wanted questions get asked, strengthen the projects validity. This is due to the interview guide encouraging reflections on whether the interview actually investigates what it is intended to examine [Kvale, 2003,p. 233]. The interview guide also enhances the reliability of the project. This is due to it providing transparency, allowing the reader to assess the credibility and soundness of the interview, as the outcome of an interview generally cannot be replicated [Brinkmann and Tanggaard, 2010,p. 491]. This section on interviews is also part of strengthening the methodological quality, as methodological reflection, according to Olsen, is an essential aspect of ensuring quality in the use of qualitative interviews [Brinkmann and Tanggaard, 2010,p. 491].

4.3.1.2 Validity and reliability

Validity and reliability is not just important to consider during preparation and execution but also in the transcription of the interview [Kvale and Brinkmann, 2014,p. 243]. The validity of a transcription is difficult to determine. It involves selecting the transcription type that best aligns with the purpose of the interviews is [Kvale and Brinkmann, 2014,p. 246]. In this project, the interviews is fully transcribed in a lightly edited version, meaning that filler words and minor errors have been removed to make the text easier to read. This approach ensures transparency for the reader and allows them to understand the context from which a quote is taken.

When converting spoken language into text, certain elements can be lost. This includes aspects such as sentence boundaries, emotional expressions like a tense voice or nervous laughter [Kvale and Brinkmann, 2014,p. 244]. This affects reliability, can another person transcribing the interview reproduce the same transcription? To address this issue, transcription tools from Microsoft Teams and Word is used to transcribe the interviews. These tools help enhance the reliability of the transcription and, consequently, the overall accuracy of the interviews. This approach aims to minimise interpretation in the transcription process, as described by Kvale and Brinkmann [2014].

The transcription are then manually reviewed for errors. An example of a corrected sentence is shown below:
Original: "For example, something like at the same time, that is to say. The installations you need in the ground to deliver the energy out. For the consumer, it becomes smaller when you bind people. Just the fact that you connect people in a pipe network, because of these simultaneous conditions. And the possibility of delivering cooling immediately is also really exciting [...]"

Corrected: "For example, something like simultaneity, that is to say, the installations needed in the ground to deliver energy to the consumer become smaller when you bind people together. Just the fact that you connect people in a pipe network due to these simultaneous conditions. And the possibility of delivering cooling immediately through the same pipe network is also really exciting [...]"

After transcription and proofreading, the interviews conducted in Danish will be translated using ChatGPT. The translations will then be reviewed to ensure that the meaning has not been altered.

The interviewee is introduced below.

4.3.1.3 Søren Erbs Poulsen

Søren Erbs Poulsen, is a research manager at VIA college for the program regarding energy and climate. Poulsen has a degree in Geology from 2006 and Ph.D. from Aarhus University in 2009 [Poulsen, 2025a]. Poulsen is additionally a founding board member at the organisation Termonet Danmark [Poulsen, 2025b].

The purpose of the interview with Poulsen, is to obtain general knowledge about thermonet. Additionally, the interview seeks to answer questions which occured during the study groups investigation of the topic. These questions incorporates both "wonder"about different aspects but also problems encountered.

Based on Poulsens work with thermonets and his role in the organisation Termonet Danmark, he is evaluated to have extensive knowledge of the topic and able to answer the study groups initial questions about thermonet. Therefore Poulsen is deemed important to contact.

For the interview with Poulsen it is important to establish and take into consideration any potential bias. Since Poulsen is a founding board member of Termonet Danmark and actively works on how to design and dimension thermonets, this is expected to affect his view of the technology. This means that for the interview conducted Poulsen can be expected to have a positive view on thermonet and want others to as well. It can be a result of him working with expanding the reach of thermonets in Denmark. For the general questions about the workings of the thermonet, more specifically how it directly works, the study group does not assume a bias is affecting the statements. For other questions where Poulsen mentions the benefits of the technology or when to use it, the bias might affect the answers. To take this into account, the study group seeks to triangulate the statements and knowledge from other actors or literature in the field of thermonet. This includes collecting knowledge from actors with different focus on the technology.

Statements from the interview with Søren Erbs Poulsen will be cited as: [Poulsen, 2025a]. The interview with Søren Erbs Poulsen is conducted on the 20th of February, the transcription of the interview is seen in Appendix 1.

4.3.2 Emails

As a part of the knowledge gathering in during this project, emails is used. The reason for this, is the lack of available sources and data places where knowledge in a project like this shall normally be gathered from. This is due to a knowledge gap regarding thermonets in Denmark. The project groups perception, is that there is only a few people with extensive knowledge on the subject of thermonet, and that this knowledge is not widely available. This is where emails serves as a way to obtain data and knowledge that is not available from other sources. For example, emails such as the one from Hjortbak have contributed by providing information that cannot be found elsewhere [Hjortbak, 2025].

The challenges arising using emails as a data collection tool includes misunderstandings, long wait times, and misaligned data. The first challenge is related to the latter, as misunderstandings leads to incorrect or incomplete data being sent. This is due to the data and responses to questions that the project group is looking for are complex, as thermonet is a complex topic. The project group is trying to mitigate this through proofreading emails, discussing the desired outcome of the emails, and considering how the recipient will interpret the content and wording of the email.

When data is to be collected via email, it naturally requires someone to find the data and/or respond to the questions contained in the email, which is time consuming. This is one of the reasons why longer response times, is experienced in some cases. Due to the complexity of the topic and the withholding and confidentiality, especially regarding the budgets the project group is trying to gain insight into, there have been long wait times. This has significantly impacted the overall process. To address this, efforts is made to send emails well in advance, to ensure there time for long response times, especially if issues related to the content, need to be clarified over several emails. This shows the importance of a structured approach when collecting data and knowledge though emails. Despite this, emails functions as a fundamental method for knowledge and data collection, which provides a basis for the analyses and the standardised assessment.

4.3.3 Actors providing data for the project

This section introduces the actors working with thermonet and the information gathered. The information gathered are primarily project proposal and screenings for thermonet.

The purpose of gathering knowledge through project proposals and screenings is to investigate the differences used in the process of evaluating the consumer economic aspects of thermonet. This is done through an analysis of the content [Brinkmann and Tanggaard, 2010,p. 144]. Through Brinkmann and Tanggaard [2010,p. 138], documents also includes written text such as news articles, transcribed interviews, academic books and policies.

4.3.3.1 Cooperative actors in the project

The Danish Energy Agency, PlanEnergi and Termonet Danmark is considered cooperative actors in this project, due to their role of providing documents and knowledge. It is important to considerate the actors sending the project group data and documents. All the received data is seen in Appendix 4. These considerations include the project groups assumptions about bias of the actors and how this may affect the documents received. It is further described how the project group accounts for, and handle the potential bias.

4.3.3.1.1 Termonet Danmark

Termonet Danmark is expected by the project group to seek to expand the technology, as it is an organisation focused on furthering the use of climate friendly solutions through the use of thermonet [Termonet Danmark, 2025d]. This is seen though their tireless work with participating in hearings and continuing to follow up be in contact with The Danish Energy Agency [Termonet

Danmark, 2024]. For the project this means that they potentiallt want to influence this project by first sending a large amount of documents, but also sending documents showing thermonet in a "positive light". To account for this, the project group ensures collecting data from several sources, in an effort to mitigate the influence of the bias in the project. The project group have been in contact with Termonet Denmark in the period 11th of until the 27th February. During this period, the project group received large quantities of information. Termonet Danmark have sent 36 documents and several emails with information. This information includes project proposals, screenings, hearing documents and slideshows.

Of these documents, several consist of Excel sheets with corporate economics for some of the project proposals. Of this type of document 4 is received. Furthermore, several documents with other actors wanting to know the cost of thermonet is received. A questionnaire is also received. This contained questions for different actors, asking if they expect thermonet to be implemented in their municipality and how many projects.

For the slideshows, these containes topics such as the expected heat demand for buildings, costs of thermonet conducted by The Danish Energy Agency and insight to the NEKST work group. The last slideshow includes a technical walkthrough created by technological Institute. The project group contacted the technological institute, but they did not want to send the presentation. This presentation is then received by Termonet Danmark instead.

The documents then contained the project proposals and screenings, 11 in total. These are the foundation of the analysis part 1.

The last documents is letters questioning the decisions of thermonet being part of The Heat Supply Act, consultant engineers comments on calculations, comments on the work of The Danish Energy Agency, answers for the expert meeting in the ministry and 8 hearing answers. Some of these, the project group skimmed in order to understand the "conflict"between the actors. A list of the received documents is seen in Appendix 4.

For several of the documents sent to the project group by Termonet Danmark, consulting engineering companies such as Sustain, Norsyn, WSP and PlanEnergi have been conducting the analysis'. Through investigation into the partners of Termonet Danmark, Sustain, Norsyn, WSP and PlanEnergi is explored as being members [Termonet Danmark, 2025c]. For this project, Norsyn, PlanEnergi and Sustain being members can be assumed to mean either of two thing: that they are convinced that thermonet is a feasible technology to implement and can therefore be affected by the bias of Termonet Danmark, or that they together with consulting engineering companies such as COWI and NIRAS are in agreement and have proven thermonet is a viable technology to implement.

4.3.3.1.2 PlanEnergi

PlanEnergi plays two roles in relation to this project. They acts as a cooperative actor by providing data in the form of the "Budget sent", and responding to written questions, which is seen in Appendix 2. PlanEnergi is a consulting engineer company specialising in a large variety of implementation and development projects. These projects includes the themes of district heating, biogas, power to X and strategy and planning. Within these themes, PlanEnergi provides services such as master plans, heating solutions, authority processing and everything regarding the planning of projects [PlanEnergi, 2025].

As they are a part of Termonet Danmark and work with thermonet, they are seen as a biased cooperative actor. This is due to them being assumed to believe in thermonet as a feasible source of heat. However, their involvement also brings valuable expert insight and access to project specific data, making their contribution both relevant and necessary.

4.3.3.1.3 The Danish Energy Agency

The Danish Energy Agency is a department under Climate, Energy and Ministry of Supply. The Danish Energy Agency supplies consulting services and guidance to central and local authorities and is responsible for securing a sustainable energy supply and its investments. Furthermore, they are responsible for ensuring that the energy system benefits most The Danish Energy Agency [2025a]. The purpose of The Danish Energy Agency is to take responsibility for ensuring a green and secure energy supply [The Danish Energy Agency, 2025a]. The Danish Energy Agency received 19 screenings and project proposals that they utilised for calculating the installation cost per consumer from Table 2.1. Furthermore, a second set of calculations is done based on the exact prices from a completed project. The results of the calculations done by The Danish Energy Agency, concludes that the projects are not economic feasible, as individual heat pumps is a less costly solution based on the consumer economics.

Based on their role, the Danish Energy Agency, is by the assumptions of the project group supposed to be unbiased. This is based on them working for implementing the most optimal solutions to implement in the danish energy supply. Observations in this project and insights from the hearing answers, suggest a certain level of bias. This could be connected to the Danish Energy Agency's obligation to follow the current government's political agenda, particularly when it comes to promoting specific heating solutions. resulting in an affect on what niche technologies, like thermonet, are supported. Additionally, Termonet Danmark suggest there may be some bias in the methods used for the installation cost per consumer. From a critical realist view, this means the Danish Energy Agency's calculations might not reflect the full reality, by missing data from some projects or not including the real budgets needed to carry them out.

To ensure to mitigate any bias, the project group is requesting, all 19 budgets regarding the thermonet projects the Danish Energy agency have used in their calculations. In a conversation with the Danish Energy Agency, it is possible to receive the public budgets and request access to the documents to obtain all budgets. This means that in a correspondence in the period 25th of February until the 14th of April, the project group requested and received access to documents. The received 13 documents includes, project proposals and screenings, their considerations for consumer economy calculations, and an email with information that can be seen in Appendix 3. This long process is due to the need to hear all parties involved in each project budget, to ensure that nothing potentially affecting the businesses is included in the project. Despite the lengthy process, the project group still decides to request all budgets. The project group receives 13 of the 19 budgets, even though the Danish Energy Agency states that they have fulfilled the "access to documents"request.

4.3.3.2 Actors and documents included in this project

The actors responsible for conducting the economic feasibility studies and their projects is introduced below. The introduction includes projects from PlanEnergi, Sustain, Norsyn and WSP. All documents are received from Termonet Danmark, PlanEnergi and The Danish Energy Agency.

4.3.3.2.1 PlanEnergi

PlanEnergi as a company is explained above. The following section introduces the projects, Silkeborg, "Budget sent", Fjeldsted-Harnerup and Gate 21, from PlanEnergi.

For the project of Silkeborg, PlanEnergi have the role of consulting Engineer, creating the project proposal and the economic aspects for evaluating the feasibility of the project. The project itself includes 15 new build houses, in an area where the traditional district heating is not possible to implement [PlanEnergi, 2019,p.3]. The utility company still wants to offer a collective heat solution for the new households, due to the fact that there is financial benefits of utilising collective solutions [PlanEnergi, 2019,p. 18].

The project proposal of "Budget sent", is created for a city including all 318 houses. The name "Budget sent"is used as the name of the document, as the location is to be kept anonymous. The project proposal investigates the economic aspect of implementing either district heating, individual heat pumps or thermonet. PlanEnergi have been responsible for the calculations.

For the project proposal for Fjeldsted-Harndrup, Planenergi have the role of consulting engineer and is calculating the feasibility of the possible heat solutions. The project proposal concerns 131 houses primarily heated by natural gas. The purpose of the project proposal is to enlighten the newly established Fjelsted Harndrup Nærvarme A.M.B.A of the feasibility of district heating and possible alternatives alternatives.

For the Gate21 Future report, PlanEnergi conducted the report and FUTURE published it in coorporation with Gate21. Gate21, is a partnership for municipalities, companies and institutions, who together strengthen competencies and innovation, for ensuring climate change [Gate21, 2025]. The report focuses on four different cases from the cities of Køge (1100 houses), Kalundborg (235 houses), Fredensborg (100 houses) and Lidsø Resort (42 houses). The four cases are evaluated for 6 different solutions each, 4 solutions containing different implementations of thermonet, and two solutions containing different district heating solutions [Østergaard et al., 2021,p.11-12].

4.3.3.2.2 Sustain

Sustain is a consulting engineering company specialising in energy renovation for municipalities, housing associations, private individuals, and institutional investors. They have a holistic approach to projects, as they provide consulting, project planning, execution, and financing. They describe themselves as experts in the collective energy network of the future, thermonet [Sustain, 2025a,b].

Based on this, Sustain have conducted screenings in eight areas, as well as developed two project proposals for the establishment and expansion of thermonet. The screenings are carried out for Lejre Municipality in the towns of Vestre Såby, Øm, Kirke Sonnerup, Kirke Såby, Gevninge, Ejby, Dalby and Lyngerup. Here the size of the thermonets is ranging from 89-592 houses [Sustain, 2023h,i,f,g,e,d,b,a].

The first project proposal include the expansion of the existing Thermonet for Aabenraa Fjernvarme a.m.b.a in Årøsund in 2022 [Sustain, 2022]. The amount of connected consumers is expected to be 142 [Sustain, 2022,p. 8].

The second proposal is for the establishment of a Thermonet in Skanderborg Municipality in Sjelle By in 2023 [Sustain, 2023c]. Here the number of connected houses is assumed to be 114 [Sustain, 2023c,p. 9].

4.3.3.2.3 Norsyn

Norsyn is the new name for the consulting engineering company Damgaard. They will in the project be mentioned as Norsyn. They are a consulting engineering company specialising in planning energy and construction. In the field of energy, they consult about a large variety of themes such as district heat, thermonet, strategic planning and general consulting. Norsyn is further a member of the organisation Termonet Danmark [Termonet Danmark, 2025c].

Norsyn is additionally also a part of the two project proposals, Sjelle By and Årøsund, in cooperation with Sustain, these will not be included in this section, but is included in the section above about Sustain. For both project proposals in this section, Norsyn have the role of being the consulting engineer, creating the feasibility study together with socio economics, consumer economics and corporate economics [Damgaard, 2023b,p. 3].

The first project proposal is created for Svendborg Municipality, for the city of Thurø By. The purpose of the project proposal is to evaluate the implementation of thermonet and the alternative of heat pumps. Thurø By consists of 1450 houses primarily heated by natural gas. The number of houses connected in the starting phase is evaluated at being 537, with additional 557 to be connected within the first 5 years [Damgaard, 2023b,p. 3-4].

The second project proposal revolves around Jystrup, covered by the utility company Ringsted Forsyning A/S. Jystrup is a city in Ringsted Municipality with 300 houses. The purpose of this project proposal is to shed light on the feasibility of implementing thermonet, compared to other solutions such as individual heat pumps and traditional district heating [Damgaard, 2023a,p. 3-4]. The expected number of houses connected within 10 years is 218.

4.3.3.2.4 WSP

WSP is an international consulting engineering company that work within 100 sectors, such as sustainability, biodiversity, mobility, city planning and district heat and cooling [WSP, 2025b,a].

The project proposal is about the future heat source in Hjortsvang in Hedensted Municipality. The focus is to evaluate if thermonet is a better solution than individual heat pumps, as the area is deemed none feasible in regards to district heating. The area contains 55 small consumers and two large consumers [WSP, 2023,p. 4].

An overview of the documents of the projects described above can be seen in Table 4.1 below.

Consulting Engineer:	Sustain	PlanEnergi	Norsyn	WSP
Project:	Screening Vester Såby	Silkeborg	Projekt proposal Sjelle by	Project proposal Hjortsvang
	Screening Øm	"Budget sent"	Projekt proposal Årøsund	
	Screening Kirke Sonnerup	Fjeldsted-Harndrup	Thurø By	
	Screening Kirke Såby	Gate21 Future report	Project proposal Jystrup	
	Screening Gevinge			
	Screening Ejby			
	Screening Lyngerup			
	Screening Dalby			
	Projekt proposal Sjelle by			
	Projekt proposal Årøsund			

Tabel 4.1. A overview of the projects and their respective consulting engineer [PlanEnergi, 2019, 2024, 2023; Østergaard et al., 2021; Sustain, 2023h,i,f,g,e,d,b,a,c, 2022; Damgaard, 2023b,a; WSP, 2023].

For the sake of the transparency in method of gathering the parameters and values for each of the project proposals and screenings, this process is shortly described. To find these and create the tables from Appendix A, each project is investigated to find parameters present for the consumer economics and their values. The parameters are then listed for each project. Afterwards, the parameters are compared in order to identify which are present across multiple projects and which are present in individual projects. In addition to this, all the different types of parameters are listed. This means that if a parameter is included in several projects, it is represented in one parameter. By doing this, a complete list of current consumer economics is created.

In summary, the material received from various actors clearly shows that they hold different views on the feasibility of thermonet. The Danish Energy Agency evaluates the technology as not feasible compared to individual air-to-water heat pumps, while Termonet Danmark is actively promoting the technology.

While the section above clarifies the context of the actors working with thermonet, it does not provide insight into local conditions which influence the implementation. To ensure these considerations are taken intro account, a GIS analysis is conducted. The purpose is to assess and identify areas with high share of individual heat solutions, high share of fossil fuels as a case for further analysis. The GIS methodology is introduced below.

4.4 GIS analysis

GIS analysis with the program ArcGIS pro, is conducted in the project for the problem analysis, in terms of selecting a municipality with high share of individual heat solutions and fossil fuels. In analysis 2, a GIS analysis utilises the parameters for establishing thermonet result in a specific case area, Store Heddinge. Analysis 3, utilises GIS for determining location specific aspects, such as pipe length for the consumer economic calculations.

This section seeks to introduce the ArcGIS tool and the usage in the project for each of the analysis conducted. It also introduces the utilised data and describe the different analysis tools in the program.

ArcGIS Pro is a program allowing for geospatial analysis. Using ArcGIS Pro, it is possible to explore and analyse data creating graphics, through different parameters [esri, 2025a]. Using GIS programs such as ArcGIS Pro, it is possible to draw insights from location information [esri, 2025a]. The program is further an important tool in the development of renewable energy [esri, 2025c]. The program ArcGIS Pro is chosen instead of other GIS programs due to its license for Aalborg University and the possibility of receiving supervision in the GIS analysis.

The utilised analysis tools throughout the project is described below:

- **Select by location**, is a tool that allows to select features based on their location in relation to features in another layer [esri, 2025f].
- **Export layer**, is a tool that have been utilised in exporting layers containing chosen features.
- **Buffer** is a tool to create a buffer of a specific distance from a input feature, this can e.g. be points. In the program ArcGIS Pro, the default version is utilised, this means that the buffer is created by the Planar method. The Planar method calculated the distance between the houses in a straight line, not accounting for the curvature of the earth. [esri, 2025b].
- **Multipart to singlepart** is a tool that separates multipart features into singleparts, giving them new feature ID's. This means the individual e.g. polygons can now be investigated individually [esri, 2025e].
- **Summarize within** is a tool used to summarize data from one layer when overlaying a layer with a polygons. This can include a summary of data such as points, areas, and total heat demands [esri, 2025h].
- **Identify points by number** is a tool that for this project have been utilised for counting the number of houses in each polygon. This was done in the first part of the analysis to remove all polygons containing more than 15 houses. In the refined part of the GIS analysis, the tool was primarily used in stating the number of houses in each polygon.

- **Select layer by attributes** is a tool used to select features in a map based on their attribution. Using this feature opens a SQL query to enter an expression, choosing the attributes wanted [esri, 2025g].
- **Join features** is a tool that integrates attributes from one layer to another, combining them [esri, 2025d].

4.4.1 Data source: The Danish Heat Atlas

In regards to the GIS analysis, it is important to shortly introduce the Danish Heat Atlas created by Aalborg University as the data from this analysis is utilised in the creation of the maps in this project. The Danish Heat atlas have since 2006 been developed. The purpose is to estimate the yearly heat demands for heat and water on a building level. At this point, no etablished database is created for this type of data [Sorknæs et al., 2024,p. 13]. The Danish Heat Atlas utilises data from BBR together with a heat demand model from AAU, to create the map. The Danish Heat atlas included in this project have data collected from 2022 [Sorknæs et al., 2024,p. 13]. Utilising the Danish Heat atlas in this project gives the opportunity to create analysis, for both the whole of Denmark identifying Stevns Municipality and for the case area of Store Heddinge. This shows the details of the data within the Heat Atlas. The data used from the Danish Heat Atlas is the heat source in homes, heat demand, Energy demand per square meter, house area and house type.

The GIS analysis utilising The Danish Heat Atlas is described below.

4.4.2 Utilising GIS in the problem analysis

The purpose of utilising GIS in the problem analysis, is to identify the the municipalities in Denmark with the highest share of individual heating accounting for those with heat pumps, would not change their heat solution. To do this the data from the Danish Heat Atlas is applied to the municipality map [Sorknæs et al., 2024; The Danish Agency for Data Supply and Infrastructure, 2025a].

To create the maps, the following analysis tools and data is used:

- Add three fields in attribute table. One to calculate the total heat demand for each municipality and one to calculate the percentage of the total heat demand that is covered by individual sources. The last field added is one to calculate the percentage of fossil fueled individual heat solutions with heat pumps excluded.
- Symbology is used to create a gradient of the results.

For the map of illustrating the location of Stevns Municipality the following analysis tools are utilised:

- Select layer by attribute is used to locate Stevns Municipality on the Municipality map.
- Export layer is used to isolate Stevns Municipality and give it a individual layer.

The data utilised is the Danish Heat atlas, Danish background provided by ArcGIS Pro and the municipality map from Dataforsyningen [Sorknæs et al., 2024; The Danish Agency for Data Supply and Infrastructure, 2025a].

4.4.3 Utilising GIS in analysis 2

For analysis 2, GIS is utilised in investigating the possible locations, where thermonet can have potential for implementation. This is done through the parameters identified to be integrated in the analysis. These are presented in analysis 2.

The GIS analysis includes the aspect of choosing a case area based on a representative heat density for the polygons identified. For this reason, the use of heat density is described.

4.4.3.1 Utilising heat density for choosing a case area

In this project, the heat density is used as a method for determining the heat demand in a limited area, these are the polygons containing the houses in the GIS analysis. The purpose, based on the parameters from COHEAT, is to evaluate if an area have potential for collective or individual heat solutions. The utilisation of COHEATs parameters for determining what heating solutions have potential of implementation, are presented in Section 6.2. These describes that a higher heat density, which in this case is considered 9 kWh/year or above, provides an argument for implementation of traditional district heating. Lower heat densities, in this case 7 kWh/year and below, is considered relevant when considering thermonet and individual heat solution.

For the case of Stevns Municipality, where district heating is not an option, the heat density does not limit the areas for thermonet. Instead it is utilised for choosing a case representing the most common heat density among the polygons.

An example of a calculation for the heat density in a polygon:

$$\frac{\text{Total heat demand}}{\text{Polygon area}} = \text{Heat density}$$

4.4.3.2 Selecting the case study area

The data utilised for this analysis was the Danish background map provided by ArcGIS Pro, the Danish Heat Atlas, together with the municipality map from Dataforsyningen [The Danish Agency for Data Supply and Infrastructure, 2025a; Sorknæs et al., 2024]. For this map the following analysis tools is utilised:

- Select by location is used exclude the data outside of Stevns Municipality. Moving forward will only revolve around Stevns.
- Select by attributes is used to used to remove all building with no heat demand such as farm building.
- Buffer is used to create buffers of 20 meter for the houses found using the Danish Heat Atlas data [Sorknæs et al., 2024].
- Multipart to single part is used to create polygons from the buffers that are connected.
- Summarize within is used to find the total area of the polygons.
- Identify points is used to determine how many building each polygon contains.
- Select by attributes is used to find and remove polygons with only one building. This is due to the lower limit of two houses in a thermonet.
- Summarize within is used to find the total heat demand of the polygons.
- Calculate field is used to calculate the heat density for each polygon.
- Symbology is used to group the heat demand in three ranges for categorising and presenting.

4.4.4 Utilising GIS in analysis 3

The purpose of Analysis 3 is to calculate the consumer economics for a thermonet in the case area identified in Analysis 2. GIS is utilised to estimate the length of the geothermal distribution and service pipes, which is the basis for calculating their cost and the amount of boreholes. Additionally, GIS is used to show the location of the geothermal boreholes. To do this the following tools and functions used, are:

- Distance and angles measurement to draw and find the length of the distribution and service pipes.
- Edit is used to create point for the boreholes.
- Buffer is used to show the boreholes is placed 7 meters or more apart.

By utilising these tools, two maps are created to show the distribution and service pipes and the geothermal boreholes.

In summary, the use of ArcGIS Pro in this project creates a spatial approach to the problem analysis, Analysis 2, and Analysis 3. Through the data and integrated tools, it is possible to select both Stevns Municipality and Store Heddinge.

4.5 Calculating the consumer economics

This section introduces the process of calculating the consumer economics, which is done in analysis 3. The section touches upon calculations for determining the number of boreholes needed for the case area which is necessary for further calculating the installation cost per house and the annual cost per house. For the calculations, the program Excel is utilised.

4.5.1 Calculating the number of boreholes

In calculating the number of boreholes, 5 steps is conducted. The variables and their units is shown in Table 4.2.

Variable	Meaning	Unit
E_{hp}	Electricity demand for heat pump	kWh/year
Q_{heat}	Total heat demand	kWh/year
SCOP	Seasonal Coefficient of Performance	–
Q_{net}	Heat delivered by the thermonet	kWh/year
L_{pipes}	Length of distribution and service pipes	m
a_{pipes}	Heat absorption rate of pipes	W/m
t_{op}	Operation hours of the thermonet	hours/year
Q_{pipes}	Heat absorbed from the pipes	kWh/year
$Q_{\text{borehole, needed}}$	Heat needed from geothermal boreholes	kWh/year
D_{borehole}	Borehole depth	m
a_{borehole}	Heat absorption rate of boreholes	W/m
Q_{borehole}	Heat produced per borehole	kWh/year
$N_{\text{boreholes}}$	Number of required geothermal boreholes	–

Tabel 4.2. Variables, meanings, and units used in calculating the number of boreholes needed in Store Heddinge

Step 1 includes finding the electricity demand for the heat pumps when the heat demand and SCOP is known.

$$E_{\text{hp}} = \frac{Q_{\text{heat}}}{\text{SCOP}}$$

After knowing the electricity demand, it is possible to determining the amount of heat needed from the thermonet.

$$Q_{\text{net}} = Q_{\text{heat}} - E_{\text{hp}}$$

Step 2, investigates what part of the heat needed, is received through the horisontal plastic pipes.

$$Q_{\text{pipes}} = L_{\text{pipes}} \cdot a_{\text{pipes}} \cdot t_{\text{op}}$$

Step 3, calculates the amount of heat needed through the geothermal boreholes, when the total heat demand and heat received through the plastic pipes is known.

$$Q_{\text{borehole, needed}} = Q_{\text{net}} - Q_{\text{pipes}}$$

Step 4, calculates the heat possible to extract from one borehole when the dimensions, number of operation hours and heat absorption per meter is known.

$$Q_{\text{borehole}} = \frac{D_{\text{borehole}}}{a_{\text{borehole}}} \cdot t_{\text{op}}$$

Step 5, the number of boreholes is then calculated based on the heat received through the boreholes and the amount needed to supply the houses in the case area.

$$N_{\text{boreholes}} = \frac{Q_{\text{borehole, needed}}}{Q_{\text{borehole}}}$$

The result of the calculations is seen in analysis 3.

4.5.1.1 Calculating the total installation cost per house

The calculation of cost for the total installation cost per house, is a summation of all cost for a project related to the individual house. This gives a total cost per house. For further consideration, an interest rate is added for the purpose of showing the cost, when accounting for the homeowners possible need to take out a loan in the bank. The parameters included in this calculation are presented in analysis 3.

4.5.2 Calculating the annual cost per house

To calculate the annual cost per house a summation of the cost related to each individual house heat demand is calculated. The cost includes aspects related to the technology and payments determined by the company owning the project. The parameters included in this calculation are presented in analysis 3.

4.6 Utilising ChatGPT in the project

In this project, the AI chatGPT have been utilised. It's usage is introduced in this section, and follows the guidelines of Aalborg University.

ChatGPT is during the project period used in several instances. The main use is during the idea-generation phase, wording in sentences, locating specific sources and translating the transcriptions. In the idea-generation ChatGPT is utilised in defining knowledge gaps within the topic of thermonet and aiding the project group in finding ideas for the direction of the project.

ChatGPT is not used for producing any text for the project, but is used in the way, that sentences is inserted for the purpose of finding alternatives for specific words/synonyms, to ensure the correct understanding of the sentence or an academic formulation. Literature on the topic of thermonet is limited, therefore to help in the search of information, data etc. ChatGPT is utilised. This means that ChatGPT in itself is not used in providing direct data for the project group but used in guiding towards links and literature.

AI is further used as a tool in the development of the standardised assessment. In this case, ChatGPT is utelised to compile and identify similar parameters and their ranges from the tables in Appendix A. Lastly, as mentioned in 4.3, the AI is used in processing the transcriptions from the performed interview. For the project, the above mentioned means, that the pitfalls of using AI such as false information and statements is avoided, and only includes fact checked information cited with sources.

Analysis 1 5

This chapter seek to investigate and answer the first sub-question of *"How can the parameters concerning consumer economics used in thermonet project proposals and screenings, contribute to creating standardised assessment?"*. This chapter explores the thermonet projects presented in Section 4.3.3, and the parameters used to evaluate the consumer economics. For the project, it means that the economic parameters included in this analysis and standardised assessment affects the cost, each household pays for thermonet. The cost affecting the corporate economics and socio-economics are therefore not directly included. Aspects of corporate economics economics, which affects the consumer economics are however, included.

The aim of this analysis is to create a standardised assessment for the purpose of being able to compare the technology of thermonet to other heating solutions such as individual heat pumps. This is done to be able to further investigate if thermonet have the opportunity of evolving from a niche technology to an established heating alternative. Barriers toward this transition includes the point of consumer economic calculations across thermonet projects, are based on different assumptions, parameters, values and units [The Ministry of Climate, Energy, and Utilities, 2024b]. The parameters and values for the consumer economics of each project is attached in Appendix A.

The parameters presented in Appendix A is based on the technology model. As explained in Section 3.2.3, the parameters are grouped according to the three aspects of the model: technique, organisation, and product. These aspects are further structured using the categories; high uncertainty, moderate uncertainty, and relative stability, as described in Section 3.2.3.1. The parameters in each aspect is not representative for all projects, but a collection of the parameters. This approach is chosen due to the fact that the parameters included in each project varies. This makes it difficult to define a common set of parameters. Instead the parameters is clustered and categorised in order to structure these based on their values and relevance.

Below is the parameters concerning the consumer economics. These parameters is investigated and discussed with the purpose of evaluating the values and if any of these are representative in the final standardised assessment.

5.1 Technique

This section introduces and explores the parameters for the technique aspect of the technology model these can be seen in Table 5.1. The parameters covers the project proposals and project screenings introduced in Section 4.3.3. The technique parameters covers payments directly connected to the technology such as investment cost, performance of heat pumps, plastic pipe lifespan, electricity prices, operation and maintenance (OM), technology lifespan, loan payback times and cost of metering systems.

Technique	
Parameters:	**Value:**
Electricity Price	1.3-1.6 DKK/kWh 532.14-1 004 DKK/MWh
COP/SCOP	COP:3.35-3.7 SCOP:3.05-3.55
Heat Pump Investment	Small: 45 000–116 000 DKK Medium: 370 000–530 000 DKK Large: 1 490 000 DKK
Heat Pump Installation	5 000 DKK
Heat Pump Lifespan	Small/Medium: 20 years Large: 25 years
Heat Pump OM	Small: 1 200–2 300 DKK/year Medium: 5 700–7 500 DKK/year Large: 17 500 DKK/year
Geothermal Pipe Cost	60-1500 DKK/m 255 000–370 000 DKK per house Total: 11-18.8 million DKK
Geothermal Boreholes	60 000–80 000 DKK
Plastic pipes Lifespan	50–100 years
Geothermal pipelines and Boreholes Lifespan	60-70 years
Heat Pump Payback Time	20 years
Geothermal Pipes Payback Time	30 years
Energy Meters	3 000 DKK

Tabel 5.1. A table showing the technique parameters from the project proposals and screenings for thermonet. The parameters are summarised, meaning the various values are shown in ranges[Sustain, 2023h,i,f,g,e,d,b,a,c, 2022; The Danish Energy Agency, 2025g; Østergaard et al., 2021; PlanEnergi, 2019, 2024, 2023; Damgaard, 2023a,b; WSP, 2023].

The table showcases that for evaluating thermonet, several different investments and values are utilised in the consumer economic calculations. It further clarifies that in some values are large variations and other where the actors agree or to some extent agree on the value.

5.1.1 Technique - High uncertainty

From Table 5.1, it is seen that the largest variations in values are seen in investments, the performance of the technology and their lifespans. These parameters are dependent on the size of the project, based on the number of houses and the individual demand from the buildings.

5.1.1.1 Investment cost heat pumps

Figure 5.1 showcases the the investment cost of heat pumps for thermonets. Across projects it is seen that the investment cost of heat pumps are affected by the possibility of buying large quantities of the heat pumps, to get a discount for the consumer [Damgaard, 2023b,p. 12], [Damgaard, 2023a,p. 6]. The quantity of heat pumps to invest in, in order to receive the discount is assumed to vary based on the company supplying the heat pumps. The aspect of the cost variation is important since these are a large part of the investment.

As an example of this, the case of Thurø illustrates that the individual consumer have a investment cost of approximately 160 000 [Damgaard, 2023b,p. 18]. The heat pump investments are set at 68 400 DKK. This showcases that the heat pumps for the project of Thurø, accounts for approximately 43%. It illustrates the insecurity for investments and that it is not possible to directly transfer the cost from project to project.

From the documents received, the projects range from including 15 to 1100 houses as mentioned in Section 4.3.3 and contains several different types of consumers. These consumers are in some projects divided by small, medium and large consumers [Damgaard, 2023b,p. 3]. For the consumers, the heat pumps will vary in size based on their heat demand. Observed in the documents is a variation in investment cost for heat pumps for a small consumer from 45 000 - 116 000 DKK [Østergaard et al., 2021; Sustain, 2023c, 2022; The Danish Energy Agency, 2025g; PlanEnergi, 2024; Damgaard, 2023a,b]. The cost for the small heat pump of 45 000 DKK, compared to the cost of 116 000 DKK shows a difference of 61%.

Four out of the seven projects show a similar cost of around 68 000 DKK per small heat pump, which suggests this may be a common or average price. This is based on larger projects like Thurø (537 houses), the "Budget sent"project (318 houses), and Jystrup (218 houses), which all maintain similar cost levels [Damgaard, 2023b; PlanEnergi, 2024; Damgaard, 2023a]. In contrast, smaller projects such as Sjelle (114 houses) report significantly higher costs, up to 116 000 DKK per heat pump [Sustain, 2023c]. This suggests that a more houses likely correlates to lower heat pump prices in larger thermonet projects. However, local conditions and project specific factors may also influence cost differences. For medium consumers, the cost vary from 370 000-530 000 DKK, which is a difference of 30% [Sustain, 2022, 2023c; Damgaard, 2023a]. For the large consumers, a cost example is at 1 490 000 DKK [Damgaard, 2023b].

The projects further introduces different types of payment for the heat pumps. These include direct payment for the heat pump and a leasing plan. Not all projects state what kind of payment plan that is used, though some introduces a subscription cost. For those project not stating this, it is possible that the consumers just directly pay the total cost of the heat pump themselves and then additionally have to pay a yearly OM cost. This is not directly known but based on assumptions from the project group. The leasing plan includes a monthly cost. This cost includes the heat pump and operation an maintenance [OK, 2025b]. Then the cost of electricity for the heat pump is payed separately [OK, 2025a]. The project proposals including this payment plan is seen with the project of Årøsund [Sustain, 2022,p. 18] and Jystrup [Damgaard, 2023a,p. 7].

Based on the considerations of different payment plans for the heat pumps, this project will include the plan of the company behind thermonet owning the heat pumps. It is further not known if the plan of leasing a heat pump would be possible for at ground source heat pump connected to thermonet. For the investigated options of leasing a heat pump, this includes the traditional air-to-water heat pump [OK, 2025a]. The project proposal of Årøsund, the Aabenrå district heat owns the ground source heat pumps and leases them out to the consumers [Sustain, 2022,p. 18]. The project of Jystrup mentiones OK as supplier for leasing [Damgaard, 2023a,p. 7].

For the costs of heat pumps, some includes the cost of installation, while others only cover the cost of the heat pump. This affects what cost can be expected for the heat pump it self and what level the cost of installation is valued at. For this project the heat pump investment and installation cost is combined due to this being the consensus across the investigated projects, as Gate 21 future is the only one stating the cost individually [Sustain, 2022, 2023c; The Danish Energy Agency, 2025g; Østergaard et al., 2021; PlanEnergi, 2024; Damgaard, 2023a,b]. The varying costs of heat pumps gives the incentive to consult different companies of what cost they can provide the heat pumps for. As stated, companies have the opportunity at providing large orders with discounts [Damgaard, 2023a,p. 6].

5.1.1.2 Performance of heat pumps

The efficiency of the heat pump (COP/SCOP) varies. The COP stands for coefficient of performance and indicates the correlation between the amount of heat produced and the amount of electricity used to deliver that heat. In other words, the higher the COP, the more efficient the heat pump is [Teknologisk Insitut, 2025]. SCOP stands for seasonal coefficient of performance. Unlike COP, which provides a snapshot at a given moment, SCOP represents an annual average calculation. This annual average shows how efficiently the heat pump delivers heat over the course of an entire year [Teknologisk Insitut, 2025]. This means that both of them can be used to tell the efficiency of the heat pump. However SCOP is, according to Teknologisk Institut, the best indicator of efficiency, as this number is based on more data [Teknologisk Insitut, 2025]. Both of these are also used the project proposals and screenings, where most use SCOP [Sustain, 2022, 2023c; The Danish Energy Agency, 2025g; PlanEnergi, 2019, 2024; Damgaard, 2023a,b; WSP, 2023]. This value is based on the direct specification of the heat pumps chosen for the individual project, combined with the heat input from the brine in the geothermal pipes and the temperature needed in the buildings [Amalo, NA]. The heat supplied through the geothermal pipes varies based on the quality of the establishment and the climate. The recommendation is that the standardised assessment uses SCOP if available.

5.1.1.3 Investment cost geothermal pipes and boreholes

For the geothermal pipes and geothermal boreholes the cost is expected to vary dependent on the project area. This is especially important to note since the cost is heavily dependent on the surface of installations, such as grass fields, or fortified areas. The considerations of the surface of installations for this project includes the assumptions of the area being fortified. Specific project criteria can also have an impact on the cost level. The investment cost of geothermal pipes further varies based on the size of the pipe and the meters required. This is expected to be specific to the individual projects, due to e.g. distance between houses.

These aspects, are not necessarily something that can be addressed through a standardised assessment, due to the individuality to chose the location of the area. However, it does open up for addressing the necessity of including uniform location specific considerations in the projects to make evaluations without making it "random". It would at the same time make it necessary to gather data the same way for each project and further present it with the same transparency. The transparency in the documents vary from project to project and from expense to expense. An example of this is seen when comparing Østergaard et al. [2021]'s Future analysis of thermonet and Sustain [2023c]'s project proposal, where the former, included a enterprise cost index, describing the costs for the ground work, which in the project proposal is not included. For the standardised assessment it is recommended, the costs of geothermal pipes are shown in two examples. One showcasing the price per house and one showcasing the total cost of the geothermal pipes in the project. This is due to directly being able to state the price for each house, while being able to compare the prices from project to project.

The different types of ownership for the thermonet, distribution and service pipes and the heat source, such as horisontal geothermal pipes and boreholes, is stated below:

- **Financing through a company model:** A company owns the thermonet, including the service and distribution pipes as well as the heat source (e.g., geothermal pipes or boreholes). The company takes out a loan to cover the investment, and consumers pay for it through an annual fee.
- **Upfront consumer payment:** Similar to the first model, but here each consumer pays their share of the cost as a one time payment, which can be assumed to be financed through a personal bank loan, due to the large cost.
- **Consumer owned network:** In this model, there is no company involved. The consumers own the network collectively and are responsible for financing the entire thermonet. Due to the high upfront cost, this is also usually financed through bank loans.

The ownership model of the thermonet significantly affects whether, and how much, consumers need to borrow money to participate in the project. For this project the consumer economics in analysis 3, includes an up-front consumer payment. This means that for analysis 3, the calculation of total installation cost is to be the up front payment.

5.1.1.4 Plastic pipes lifespan

The last aspect of the high uncertainty considerations includes the stated lifespans of the plastic pipes used for transporting the brine. The lifespan of the plastic pipes in the thermonet, is across all projects evaluated at 50-100 years. There are several types of plastic pipes, and if a specific pipe type have not been determined for thermonet projects, this aspect of the projects are evaluated to be varying based on pipe type and not just from company to company. The lifespan of the pipes are dependent on factors such as materials and performance [IFAN, 2022].

Plastic pipes for transporting water and brine, can be pipes such as PE and PE-X pipes [IFAN, 2022]. The reason for choosing pipes can be different, since they have varying qualities. Some pipes have more environmental benefits, high temperature resistance, corrosion resistance, and toxic materials [IFAN, 2022]. The cost of the pipes are assumed to have a high impact on the total cost paid per household, since they vary dependent on qualities. Pipes are therefore considered a post where the project can save some investment cost by choosing the cheapest option or include more environmental and performance considerations and increase the cost accordingly. The projects in Denmark utilises pipes such as PE [Sustain, 2023c; Damgaard, 2023b,a; PlanEnergi, 2023], while other projects excluded a statement of the type of pipe [WSP, 2023; PlanEnergi, 2019].

According to the manufacturer, the minimum lifespan of PE pipes is 50 years, provided they are installed according to the recommended standard, which includes placement on a layer of sand [Wavin, 2022]. The pipes does have potential to work for more than a 100 years and is supported through investigations [Wavin, 2025]. This means that while several projects utilises the PE pipes, the lifespan stated can be the minimum of 50 years or vary op to 100 years. If this is the case and a "random"number is chosen based on the minimum and maximum, it can still be difficult to compare. A way to account for these statements would be to put the pipe type and their lifespan range into the projects. It would make an incentive to rely on the 50 years, and then in the years after, making controls to determine the state of the pipes.

5.1.2 Technique - Moderate uncertainty

For the technique aspect, one parameter have moderate uncertainty. This is the electricity price.

5.1.2.1 Electricity price

The electricity price in the projects vary. This is expected due to the projects being established in different years. It can further be dependent on the location of the project, whether it is in DK1 or DK2 [nettopower, 2025]. Lastly the price variation can be due to the inclusion of the lack hereof, of grid tariffs and taxes. In some projects like Årøsund, it is disclosed that tariffs and taxes are included, in others like Sjelle by, this is not directly stated [Sustain, 2023c, 2022]. Despite the different years for the electricity being used, there is a general consensus that it is directly stated what year and mostly what quarter of the year, that represents the electricity price.

It is further observed, that the costs are given with different units throughout the projects. For the electricity prices, these vary between kWh and MWh and a direct price in DKK for the yearly cost of electricity [Sustain, 2022, 2023d; PlanEnergi, 2019]. This results in difficulties comparing the projects since they first have to ensure a similar use of units. For the standardised assessment kWh will be used, as this is the unit electricity prices are stated in for consumers. It is also recommended that the cost is stated with tariffs and taxes, to ensure transparency and comparability to both other thermonet project and air-to-water individual heat pumps.

5.1.3 Technique - Relative stability

For the projects, several parameters have a more similar value. This is seen in the parameters regarding operation and maintenance costs, technology lifespans, payback times and cost of meters. The technologies included in the projects are similar. This includes technologies such as heat pumps and geothermal boreholes.

5.1.3.1 Operation and maintenance heat pumps

The operation and maintenance costs are throughout the projects mostly well specified. For the heat pumps of various sizes the operation and maintenance cost are in a range from 1 200 - 2 300 DKK/year for small heat pumps, 5 700 - 7 500 DKK/year for medium sized heat pumps and around 17 500 DKK/year for large heat pumps. OM for the heat pump is described to vary based on the COS/SCOP of the heat pump, the size, usage and the service [Vöge, 2025].

Overall for the operation and maintenance cost, the costs have a slight variation and can therefore ensure some security in the economic factors since these do not drastically change. As mentioned is the cost for OM of a heat pump depended on the specification for the heat pump, for this reason a specific number or range will not be defined.

5.1.3.2 Technology lifespans

In addition to the operation and maintenance, the lifespans of the technologies is further included in the technique aspect of the technology model. The lifespans are included in "relative stability"due to these being roughly the same throughout the projects. For the small and medium heat pumps, which are represented a majority of the time through the projects, the lifespan is 20 years [Sustain, 2022; Damgaard, 2023a]. Large heat pumps have lifespans up to 25 years [Damgaard, 2023b].

Geothermal pipes and geothermal boreholes have a lifespan ranging from 60-70 years [Damgaard, 2023a,b]. For this project, the lifespan of 60 year will be recommended based on it being the minimum. The pipes can possibly last longer but is to be investigated specifically for each project.

5.1.3.3 Payback times for loans

For the loans to the investments in thermonet, heat pumps and geothermal pipes, the payback time are essentially the same throughout the projects. For heat pumps the payback time is evaluated at 20 years, while the geothermal pipes have a payback time of 30 years [The Danish Energi Agency, NA]. The payback time for the heat pumps matches the lifespan, resulting in the technology being able to repay itself before the end of it's technical lifetime and the investment in a new.

For the geothermal pipes, the technology have a operation period long after the loan has been paid, as they have a lifetime upwards of 60-70 years. This means that the pipes provide a operation for 30-40 years after the loan has been repaid, without the need for reinvestment.

5.1.3.4 Cost of energy meters for heat pumps

The energy meters related to the heat pump comes with a cost around 3 000 DKK. This cost is only specific to the project from Gate21, due to them directly stating this cost [Østergaard et al., 2021]. For the remaining projects, the cost of meters are not observed, but might be included in other costs. The lack of observation of the meters, refers back to the transparency of the project and the possibility of comparing to other projects. Only knowing the specific cost for the meter system from one project, creates a barrier for other and for the ones paying for the project, of knowing if the cost is market value and if it correlates to similar investments.

Lastly, heat pumps have several types of meters connected. Among these are flow meters, electrical meters and heat meters [Bygningsreglementet.dk, 2023]. The cost of 3 000 DKK do not state if this covers all types of meters. For full transparency of this investment cost would be to state all types of meters and their individual cost. Not being able to directly compare this investment cost to the other projects, puts it in the relative stability section, due to only one known cost. Due to only one project stating this cost by it self, it is assumed that it is included in the price of the heat pump or subscription and is therefore not a recommended cost for the standardised assessment.

In summary, the analysis of the parameters included in the technique aspects from the projects identifies how the they fit in the three levels of uncertainty. The investment costs and the specifics and performance of the heat pumps shows high uncertainty due to varying project sizes, consumer types and area conditions. The moderate uncertainty is found in the use of electricity prices. These parameters are dependent on the time of the project and the location. In contrast to the above mentioned two levels of uncertainty, the operation costs, lifespans, payback times and meter cost considered relative stable. Based on this, the technique aspect shows a need for clarifying the data included in the projects, adding transparency and possibility of comparison.

5.2 Organisation

This section outlines the parameters associated with the organisational aspects of the technology model, as listed in Table 5.2. The parameters included are the project proposals and screenings from Section 4.3.3. Focus is placed on costs related to coordination, such as subscription fees, connection charges, and service related contributions, all of which reflect the human and structural effort needed to support system functionality. These are then addressed according to the categorisation explained above; high uncertainty, moderate uncertainty, relative stability.

Organisation	
Parameters:	**Value:**
Subscription fee	500 DKK/year
Meter subscription	200 - 750 DKK/year
Fixed contribution	1 625 DKK/year 17.39 - 63.94 DKK/m^2 house/year
Construction contribution	1 688 DKK/year
Consumer contribution	324.55- 352.72 DKK/MWh 8 428 DKK/year
Heat pump subscription cost	3500-4375 DKK/year
Pipe wall penetration service	13 000 DKK per house
Real interest rate	-4.2% - 5%
Annual percentage rate (APR) 5% individual, 15 years	5 085 DKK/year
Connection fee	20 000-63 375 DKK per house
Late connection fee	30 000 - 38 200 DKK per house
Yearly Electricity Cost	14 900–16 000 DKK/year
Annual subscription	9 400–12 500 DKK

Tabel 5.2. A table showing the organisational parameters from the project proposals and screenings for thermonet. The parameters are summarised, meaning the various values are shown in ranges[Sustain, 2023h,i,f,g,e,d,b,a,c, 2022; The Danish Energy Agency, 2025g; Østergaard et al., 2021; PlanEnergi, 2019, 2024, 2023; Damgaard, 2023a,b; WSP, 2023]

5.2.1 Organisation - High uncertainty

The high uncertainty of the organisational dimension is addressed in this section. The high uncertainty is observed across projects in relation to connection fees, interest rates, inconsistent units in fixed and consumer contribution. These inconsistencies highlight the need for a standardised assessment, providing a basis for comparing Thermonet projects internally, as well as a consistent foundation for evaluating them against individual heat pump solutions.

5.2.1.1 Connection Fees

The high uncertainty is visible when looking at connection fees range in Table 5.2. Here the ranges, for the cost per house, is relatively large. Connection fees have a range from 20 000-63 375 DKK per house, a difference of 43 375 DKK per house or 68.5%.

This raises the question: Why is the difference so significant across projects? This difference argues for a standardised assessment, as this could mitigate some of the differences. A reason behind the difference in cost related to connection fees, is the fact that these are calculated by different companies. These have different costs and parameters that is included in the connection fee cost.

The range in connection fees is partly due to the projects using different contractors for excavation work, the proportion of fortified ground varies across sites, and the required sizes of distribution and service pipes differs depending on the scale of the project. All these are possible explanations on why the range is to wide in relation to connection fees.

None of the investigated projects and screenings including a connection fee have documented what the cost covers [Sustain, 2023h,i,f,g,e,d,b,a,c; PlanEnergi, 2019]. However, as visible in appendix A, none of the screenings or projects that contain connection fee, presents the parameter electrical connection fee. This is another high uncertainty of establishing a thermonet, and a possibility is that this expenditure is contained within the connection fee. The electrical connection fee is a high uncertainty because of the large range in cost. The range of 8 200-15 000 DKK per house illustrates a difference of 6 800 DKK per house or 45% [Østergaard et al., 2021; PlanEnergi, 2024].

The project group have tried uncovering what aspects the electrical connection fee entails. It have not been possible to uncover these aspects. This is why electrical connection fee is not a parameter in the standardised assessment. This is based on the assumption that this is included in the connection fee in other projects, and will not be in the standardised assessment. This highlights the issue of transparency in the calculations and parameters. The lack of transparency do not only affect this project, but also create a problem when comparing the costs of projects. This could create dissatisfaction among consumers, as they may not understand why their connection fee for thermonet is higher than that of others.

The costs of each of the projects that includes connection fees and electrical connection fees are visible in Table 5.3.

Connection fee	
Project:	**Value:**
Screenings	25 000 DKK per house
Project proposal Sjelle by	Small: 20 000 Medium: 50 000 DKK per house
Silkeborg	63 375 DKK per house

Tabel 5.3. The cost of connection fees in the different projects [Sustain, 2023h,i,f,g,e,d,b,a,c; PlanEnergi, 2019].

Based on the cost from Table 5.3, most of the projects is in the ranges 20 000-50 000 DKK per house. Here Silkeborg with a cost of 63 375 DKK per house, is considered a outlier as it respectively is 27% and 217% higher than 50 000 and 20 000 DKK per house. This argues for that a connection fee should be in the range of 20 000-50 000 DKK per house, depending on what the cost covers.

The project proposals of Sjelle by and Årøsund also have a late connection fee, this connection fee is for the consumers that is joining the thermonet after the initial establishment [Sustain, 2023c, 2022]. The range is 30 000-38 200 DKK per house, with a difference of 8 200 or 27.3% [Sustain, 2022,p. 18][Sustain, 2023c,p. 13]. This significant range for both regular and late connection fee reflects project specific factors, such as local infrastructure, contractor pricing, and implementation strategies. As such, a fixed or recommended cost for all projects cannot be determined, and the fee must be assessed individually for each project context.

5.2.1.2 Interest rates

The cost of thermonet across the different screenings and projects is not only unpredictable due to the aforementioned factors. It is also affected by the use of varying financing models and interest rates in consumer economic calculations. As shown in Table 5.2 and Appendix A, only the project in Silkeborg apply the Annual Percentage Rate(APR), Hjortsvang and Årøsund uses an interest rate, while several others use the real interest rate [PlanEnergi, 2019; Svane et al., 2023; The Danish Energy Agency, 2025g; Damgaard, 2023a,b; WSP, 2023].

APR is the total yearly costs for a loan in percent, but do not account for inflation. It includes the nominal interest rate for the loan as well as additional fees such as administrative charges and loan establishment costs [Fernando, 2024]. The real interest rate is where the interest rate have been adjusted to remove the effects of inflation. This means that if an interest rate is 6% and the inflation is 4% then the real interest rate is:

$$6\% - 4\% = 2\%$$

This gives the borrower an insight into the actual cost of borrowing [Cussen, 2025]. The interest rate applied in the Hjortsvang project is 5%. However, to ensure comparability with other projects that use a real interest rate, it is necessary to convert this into a real rate. This requires adjusting for inflation, which in May 2023, when the project proposal is from, was 2.9 compared to May 2022% [Danmarks Statistik, 2023]. Subtracting this from the nominal rate gives a real interest rate for Hjortsvang of:

$$5\% - 2.9\% = 2.1\%$$

This is also the case with Årsøsund, that have a interest rate of 4.5% and with the inflation in December of 2022 was 8.9% compared to December 2021 [Danmarks Statistik, 2022]. This gives a real interest rate for Årøsund of:

$$4.5\% - 8.7\% = -4.2\%$$

While the Årøsund project applies a nominal interest rate of 4.5%, the real interest rate in December 2022 was negative due to high inflation (8.7%). However, over a 30 year loan period, inflation is expected to fluctuate, meaning the real interest rate will not remain negative throughout the entire repayment period [Cussen, 2025]. Though inflation over the years fluctuate, it is the goal of The European Central Bank(ECB) to have a steady inflation rate of 2% [The European Central Bank, 2025]. The real interest rate for the Årøsund project, with an inflation rate of 2%, based on the ECB inflation rate, would be:

$$4.5\% - 2\% = 2.5\%$$

This demonstrates that the real interest rate will not always be negative.

A point of criticism regarding APR is that it can underestimate the cost of borrowing and therefore does not always reflect the actual cost of a loan. Lenders have significant influence over which fees and charges they choose to include, making APR non transparent and difficult to compare across loans [Fernando, 2024]. Additionally, APR does not account for inflation and is thus not ideal for long term loans [Fernando, 2024]. A long term loan typically spans a period of 3-25 years [Segal, 2024]. This unsuitability is a major drawback in the context of Thermonet and heat pump loans, as these are often taken over extended periods.

As previously described, real interest rates removes the effects of inflation [Cussen, 2025]. However, using real interest rates alongside or instead of APR presents several challenges. First, real rates depend on accurate inflation estimates, which can vary across projects and over time, making comparisons inconsistent. Second, real interest rates are not typically disclosed in consumer loan documents, limiting transparency and making it difficult for end users to interpret costs [The Investopedia Team, 2024]. Despite the shortcomings of the real interest rate, it is the most suitable option when it comes to consumer economics for a thermonet system. This it providing the most accurate reflection of long term costs, which is essential in the context of thermonet. Furthermore, it reduces the risk of underestimating the cost burden for consumers. This is supported by the fact that most consultants use the real interest rate in their calculations [Svane et al., 2023; The Danish Energy Agency, 2025g; Damgaard, 2023a,b; WSP, 2023].

This is why this project recommends future project to use real interest rate in their consumer economic calculations. As visible in Table 5.4 is the range of real interest for the consumers rate between 2-3.5% [Svane et al., 2023; The Danish Energy Agency, 2025g; Damgaard, 2023a,b; WSP, 2023].

Real interest rate	
Project:	**Value:**
Project proposal Årøsund	May 2022: -4.2% ECB: 2.5%
Energistyrelsen	3.5%
Jystrup	2%
Thurø By	2%
Hjortsvang	2.1%

Tabel 5.4. The real interest rates in the different projects. Note that Årøsund both contain one based on inflation in May 2022 and ECB recommendations [Svane et al., 2023; The Danish Energy Agency, 2025g; Damgaard, 2023a,b; WSP, 2023]

The range of real interest rates is between 2-3.5%, if the real interest rate for Årøsund is calculated based on the inflation rate in March 2025. This is used as the negative real interest rate is based on a short term high inflation in 2022 [Danmarks Statistik, 2025b], and can distort the result of the cost of the loan. While there is not standard rate of real interest in thermonet projects in Table 5.4, a rate of 2% is applied in three proposals, Jystrup, Thurø By and Hjortsvang [Damgaard, 2023a,b; WSP, 2023].For purposes of comparability as well as realistic depiction of consumer economic calculations, a 2% real interest rate is recommended using only the project from Table 5.4.

The only project that states what the interest rate is based on, is Hjortsvang. The project proposal for Hjortsvang states that interest rate is based on the mortgage loan (realkreditlån) rate in May 2023 [WSP, 2023,p. 10]. A mortgage loan is a long term loan secured against a property [Realkredit Danmark, 2025a]. The use of a mortgage loan in Hjortsvang, combined with the fact that this type of loan is commonly used in Denmark to finance home purchases, renovations, and energy related upgrades such as heat pumps or thermonet connections, is the reason why this project uses it as the basis for the recommended real interest rate.

Data shows that the current mortgage interest rates for mortgage loans with a fixed interest rate for 20-30 years is between 3.5%-4.1% depending on the loan type [Nykredit, 2025]. These mortgage loan rates are a interest rate, meaning they do not subtract inflation. To estimate a real interest rate, the current or expected inflation must be subtracted. With the inflation rate in March 2025 at 1.5% [Danmarks Statistik, 2025a], this results in an estimated real interest rate ranging between 2%-2.6%. This supports the use of a 2% real interest rate in consumer economic analyses, as it reflects both current market conditions and the rate already adopted by several thermonet projects. The recommendation of this project based on the analysis above is a real interest rate of 2%.

5.2.1.3 Missing unit standardisation

Finally, the last high uncertainty is the inconsistency in the use of units across thermonet projects. This is evident in Table 5.2, for the parameters fixed and consumer contribution. This inconsistency makes it difficult to compare consumer economics across projects and undermines transparency for consumers. Without a clear, uniform basis for calculating and presenting contributions, consumers can find it hard to understand what they are paying for and why they are charged differently than others.

Fixed contribution

A fixed contribution is relevant in the case of thermonets due to it being a yearly fee to cover fixed cost, for the thermonet. The fixed cost are cost that do not vary in relation to the sold heat. These can be, but are not limited to in a case of district heating, power contribution, subscription contribution, administration and meter rent [BDO, 2019,p. 69]. This is assumed to be similar in the case of thermonet, as none of the projects that includes fixed contribution in their consumer economic calculations, disclose what is included in the cost [Sustain, 2022, 2023c; Damgaard, 2023a,b; WSP, 2023].

The fixed contribution is reported either in DKK/year or in DKK/m^2/year. Among the reviewed projects, the proposal for Årøsund is the only one that reports the fixed contribution in DKK/year. An interesting fact concerning the inconsistency of units, is that the two project proposals Årøsund and Sjelle By respectively uses DKK/year and DKK/m^2/year, though they both are made by Sustain [Sustain, 2022, 2023c]. This again highlights the need for a consisted use of units in the consumer economics. The use of DKK/year in Årøsund is based on an average consumer with a heat demand of 17.2 MWh/year, resulting in the fixed contribution to be set at 1 625 DKK/year [Sustain, 2022,p. 21]. To enable comparison, the fixed contribution for Årøsund is changed, so that it is also expresses per square meters of heated area. This is done since Sustain states that the average consumer in the project occupies a house of 130m^2 [Sustain, 2022,p. 8]. This allows for conversion from m^2 to DKK/m^2/year, resulting in a fixed contribution in the Årøsund project of:

$$\frac{1625 \text{ DKK/year}}{130 \text{ m}^2} = 12.50 \text{ DKK/m}^2\text{/year}$$

The highest set fixed contribution is for the project proposal for Sjelle By and is 63.94 DKK/m^2/year [Sjelle ByVarme A.m.b.a, 2024]. This means that the fixed contribution ranges from 12.5-63.94 DKK/m^2/year, corresponding to a difference of 51.5 DKK/m^2/year or 80.5% [Sustain, 2022, 2023c; Damgaard, 2023a,b; WSP, 2023].

This significant range in fixed contributions highlights the same issue seen with connection fees, it is unclear what the costs actually include. Similarly, none of the projects that includes a fixed contribution provide a breakdown of what the charge covers [Sustain, 2022, 2023c; Damgaard, 2023a,b; WSP, 2023]. However it is important, as mentioned earlier, that the fixed contribution only covers expenses that are constant regardless the amount of heat sold [BDO, 2019,p. 69]. The fixed contributions costs for the 5 project that includes this cost in their consumer economics, is shown in Table 5.5.

Fixed contribution	
Project:	**Value:**
Project proposal Årøsund	1625 DKK/year 12.5 DKK/m^2/year
Project proposal Sjelle by	63.94 DKK/m^2/year
"Budget sent"	27.8 DKK/m^2/year
Jystrup	17.39 DKK/m^2/year
Thurø by	17.48 DKK/m^2/year

Tabel 5.5. The costs of the fixed contributions in the different projects [Sustain, 2022, 2023c; PlanEnergi, 2024; Damgaard, 2023b; WSP, 2023]

The values in Table 5.5 shows that the project proposal of Sjelle by is a outlier, with a cost of 63.94 DKK/m^2/year [Sjelle ByVarme A.m.b.a, 2024]. The others is in a range from 12.5-27.8 DKK/m^2/year [Sustain, 2022; Damgaard, 2023a,b; WSP, 2023]. The recommended unit is DKK/m^2/year for the standardised assessment.

Consumer contribution

As shown in Table 5.2, the consumer contribution is also using different units, DKK/MWh of heat and DKK/year. None of the observed projects describe what the cost of consumer contribution covers. However in the case of district heat it is the cost the consumer pays for the energy they actually consume. This is why this is a variable cost presented in DKK/MWh [BDO, 2019]. This is assumed to be the same in the case of thermonet.

The consumer contribution in the cases of "Budget Sent", Jystrup, Sjelle By and Silkeborg the contribution is expressed in DKK/MWh, ranging from 324.55-437.5 DKK/MWh [PlanEnergi, 2024; Damgaard, 2023a,p. 3] [Sjelle ByVarme A.m.b.a, 2024,p. 2] [PlanEnergi, 2019,p. 13]. Årøsund, on the other hand, reports the consumer contribution in DKK/year, similar to the connection fee [Sustain, 2022,p. 21]. However, since the cost is based on an average household with an annual heat consumption of 17.2 MWh/year, it is possible to convert this value to DKK/MWh [Sustain, 2022,p. 21]. This is done by dividing the annual cost (DKK/year) by the annual heat consumption (MWh/year), resulting in:

$$\frac{8428\ \text{DKK/year}}{17.2\ \text{MWh/year}} = 490.12\ \text{DKK/MWh}$$

Table 5.6 provides a cost overview of the consumer contribution used in five projects, including both the reported units and any calculated conversions in the Årøsund project proposal.

Consumer contribution	
Project:	**Value:**
Project proposal Årøsund	8428 DKK/year 490.12 DKK/MWh
"Budget sent"	329 DKK/MWh
Jystrup	352.72 DKK/MWh
Sjelle By	324.55 DKK/MWh
Silkeborg	437.5 DKK/MWh

Tabel 5.6. The consumer contributions for the four projects [Sustain, 2022; PlanEnergi, 2024; Damgaard, 2023a; Sjelle ByVarme A.m.b.a, 2024].

Based on the data from Table 5.6, the consumer contribution ranges from 324.55-490.12 DKK/MWh. The recommendation for consumer contribution is that the standardised assessment uses the unit DKK/MWh for consumer contribution.

5.2.2 Organisation - Moderate uncertainty

The moderate uncertainty for the organisation aspects of the technology model includes the, subscription cost for heat pumps, pipe wall penetration and meter subscription.

5.2.2.1 Subscription cost for heat pumps

The subscription cost is a part of the moderate uncertainty due to it varying but staying in a relative small range from 3 750-4 375 DKK/year. The subscription includes, based on Dansk Fjernvarmes "Fjernvarmeordbogen", tariffs, expenses for loan of meters and administration [Dansk Fjernvarme, 2025b]. The slight variation in cost can be considered positive due to showcasing a limitation and predictability in the cost level of subscriptions for heat pumps.

This predictability supports more accurate and reliable budgeting for thermonet projects when cost ranges remain narrow. In the projects the most common occurrence is set as 4 375 DKK/year [Sustain, 2022; Damgaard, 2023a]. In the following analysis 3, the case will revolve around the individual house owners, not buying the heat pumps. This is the case because it can negatively affect the connection percentage [Damgaard, 2023a,p. 7]. For the standardised assessment the unit of DKK/year will be used.

5.2.2.2 Pipe wall penetration

The parameter of pipe wall penetration is related to houses with previous installed heat source inside, where the thermonet is led to the house from the outside, requiring a connection through the wall. The placement in moderate uncertainty does not necessarily refer to the cost of this service, but more the uncertainty whether or not houses need to do this. The project referred to as "Budget sent"has the only occurring cost for pipe wall penetration, which is set at 13 000 DKK per house [PlanEnergi, 2024].

Several reasons can explain the exclusion of pipe wall penetration in the projects, are based on the assumptions from the project group. The reasons refers to the possibility of costs varying dependent on the material of the house and what time and tools it requires, it can otherwise be an aspect the house owner is responsible for, making it possible for having flexibility in the solution and cost level. The cost of 13 000 DKK per house might come across as an extra service the company responsible for the project, can offer at a specific cost. For this project it means that it gives an idea of what level this service is cost at. For other projects it might be included in other cost examples, but not stated directly. Based on this, the pipe wall penetration cost will not be included in further analysis for thermonet.

5.2.2.3 Meter subscription

Meter subscription covers the cost of renting a meter, combined with the cost of installation [Fjernvarme Fyn, 2025]. This definition is for district heat, but is assumed to be the same regarding thermonet. Although the meter subscription is consistently presented in the same unit, DKK/year, the range of 255–750 DKK/year, with a difference of 495 DKK/year or 66%, indicates a need for transparency in the coverage of the cost [Damgaard, 2023a,b; Sustain, 2022]. Although the meter subscription is assumed to cover the same as in district heat, this is not defined in the projects. This creates a lack of transparency, which causes moderate uncertainty within the organisational aspect. The unit for the meter subscription the standardised assessment is DKK/year.

5.2.3 Relative stability

For the relative stability of the organisation aspect of the technology model the parameter; subscription fees and annual subscription will be addressed in this section.

5.2.3.1 Annual subscription

Annual subscription have a range of 9 400-12 500 DKK, however it is placed in the relative stability category because of it only appears in the screenings [Sustain, 2023h,i,f,g,e,d,b,a]. A reason for this could be that this fee covers different service and fees other projects covers separately. The annual subscription covers the monthly payment on the heat pump, but other cost such as OM and administration could be included in this fee. This is however unknown and contributes to the difficulty of comparing different projects and supports the need for a standardised assessment. This is not a part of the standardised assessment due to the unknown content.

5.2.3.2 Subscription fee

The subscription fee of 500 DKK/year from Table 5.2, only appears in "Budget Sent"and is based on FFV Varmeforsyning's 2023 district heating costs [PlanEnergi, 2024]. This fee reflects a standard administrative or service cost modeled after existing district heating structures [Dansk Fjernvarme, 2025b] and do not represent a broader thermonet pricing practice, as it is not seen in other projects. It could in other project be under OM or fixed contribution [BDO, 2019,p. 69]. Based on this, the subscription fee of 500 DKK will not be used in both the standardised assessment or analysis 3. However, this parameter name is used to group together other subscription fees, such as the meter subscription, heat pump subscription and the annual subscription in the standardised assessment, using the unit DKK/year.

Overall, this section analyses the organisational parameters of thermonet projects using the technology model and uncertainty classification. It identifies and categorises costs such as connection fees, interest rates, fixed contributions, and administrative expenses, that are important for understanding the consumer economics. This section shows that inconsistent definitions, pricing methods, and units across thermonet projects make it difficult to compare costs. This highlights the need for a standardised assessment, both to support fair project comparison and to enable reliable evaluations against alternative heating technologies.

5.3 Product

This section introduces and explores the parameters for the product aspect of the technology model. The aspects included are yearly cost per house, installation cost per house and annual cost- large consumers. These are seen in Table 5.7.

Product	
Parameters:	**Value:**
Yearly cost per house	13 7936–35 999 DKK/year
Installation cost per house	178 000–451 000 DKK
Annual cost – large consumer	56 327 DKK/year

Tabel 5.7. A table showing the product parameters from the project proposals and screenings for thermonet. The parameters are summarised, meaning the various values are shown in ranges[Sustain, 2023h,i,f,g,e,d,b,a,c, 2022; The Danish Energy Agency, 2025g; Østergaard et al., 2021; PlanEnergi, 2019, 2024, 2023; Damgaard, 2023a,b; WSP, 2023].

5.3.1 Product - High uncertainty

The high uncertainty aspects of the technology models product, includes a large range for the yearly cost per house and the installation cost per house.

5.3.1.1 Yearly cost per house

The yearly cost per house ranges from around 14 000-36 000 DKK/year. This range is expected to occur, due to different methods for calculating the costs. The large variation in cost is 22 000 DKK/year or 61%. This is expected to have be able to have an affect on the implementation, since the consumers cannot be certain of what cost they will commit to. Compared to other alternatives, these might include more stable costs, and therefore becoming more attractive for the house owners. The large variations in yearly cost per house can be seen in Table 5.8.

Projects	**Annual cost per house**
Screenings	29 000–31 000 DKK/year
Årøsund	24 116 DKK/year
Sjelle by	-
Energistyrelsen	26 000–33 000 DKK/year
Gate 21 Future	35 999 DKK/year
Silkeborg	13 793 DKK/year
"Budget sent"	24 238 DKK/year
Fjeldsted-Harndrup	22 770 DKK/year
Jystrup	27 880 DKK/year
Thurø	28 200 DKK/year
Hjortsvang	18 776 DKK/year

Tabel 5.8. A table showing the annual costs per house with thermonet as the heat source. The project of Sjelle by does not occur to have stated a yearly cost per house.

5.3.1.2 Installation cost

The installation cost per house, ranges from 178 000-451 000 DKK according to The Danish Energy Agency [The Danish Energy Agency, 2025e]. The two calculations can be difficult to determine where the calculations vary, based on the lack of transparency in showing all the costs and including the same type of investments. Additionally is not possible to directly investigate the calculations conducted by the actors. Another aspect where the costs may vary is due to the inflation, mentioned above. Since the projects is not assumed to adhere to the same cost year, this affects the cost.

As to the total installation cost per house, The Danish Energy Agency did the calculations based on an average of the 19 conducted budgets and one established project. The average of the 19 budgets, resulted in a cost of 323 000 DKK. The average of the established projects resulted in a cost of 454 500 DKK, around 200 000 DKK more than not yet established thermonets [The Danish Energy Agency, 2025e]. This misalignment in expected investment and total investment is not observed in the projects. If the calculation and the statement from The Danish Energy Agency is correct, then it is difficult for other projects to compare, because then the costs and expenses mentioned not the actual costs. Having projects so misaligned with the expected cost per house, are a reason for caution for others wanting to do the investment.

The significant misalignment between projected and actual costs per household can create hesitation among potential investors. From a Strategic Niche Management perspective, this highlights a key challenge for thermonet as a niche technology, it lacks a basis for comparison among thermonet projects, which hinders its integration into the established market. Another issue regarding The Danish Energy Agency's calculations is the estimation of the cost of individual air-to-water heat pumps at 129 000 DKK and ground source heat pumps at 183 000 DKK. This adds to the cost difference in investing in thermonet and alternative heat solutions, rendering thermonet a less feasible heating solution when considering consumer economics, which affects the transition from niche to established.

5.3.2 Product - Moderate uncertainty

For the moderate stability, the considerations of the medium and large consumers are included. Costs for heat pumps for medium and large consumers, are included in some of the projects [Sustain, 2023c; Damgaard, 2023b; WSP, 2023]. Of these projects, only Hjortsvang presents an annual cost for a large consumer of 56 327 DKK/year. This means that other projects includes the costs on the different heat pump sizes but do not further calculate the annual cost. This leads to the question of why including the various costs on the heat pumps if they are not going to use it in further analysis?

The only reason as to include the different sizes of heat pumps, is if preliminary screenings establish that medium and large consumers are present in the project area. Having only heat pump cost and not the resulting calculations adds a perspective of confusion, and as mentioned in other aspects, a lack of transparency.

Building owners considered medium or large consumers do not have the same foundation to make a decision of being connected to the thermonet as other consumers in standard houses. They are not able to directly state if it makes economically sense for them to make the investment, because of the lacking annual cost. Excluding conducting an analysis for each type of consumer profile present for the project, refers to the lack of consistent and in depth analysis.

Overall this section addresses the product aspect of the technology model by analysing parameters such as yearly cost per house, installation cost per house, and annual costs for large consumers, as shown in Table 5.7. The analysis highlights high uncertainty in yearly and installation costs, due to inconsistent units, inflation assumptions, and transparency issues. The lack of detailed or consistent economic analysis for larger consumer profiles suggests a need for more comprehensive project evaluations. These variations undermine consumer confidence and make comparisons across projects difficult.

For the purpose of investigating the comparability of thermonet to the technology of individual heat pumps, the next section will investigate project proposals for the latter.

5.4 Consumer economics for heat pumps

This section investigates how the the consumer economics for individual heat pumps are conducted. The purpose of this is to compare the parameters to the ones identified and analysed in the sections above. It further seeks to investigate if additional parameters are relevant to include in the consumer economics for thermonet, to be able to compare the two technologies to each other.

The Danish Energy Agency do not have specific criteria for the calculations of the methods utilised in calculating consumer and corporate economics [The Danish Energy Agency, 2019,p. 3]. For this reason, this section directly looks into established projects or project proposals for the establishment of individual heat pumps, and thereby compare the parameters.

5.4.1 Parameters in established individual heat pump projects

For investigation of the parameters utilised in calculating the consumer economics for individual heat pumps, two projects conducted by PlanEnergi and Rambøll have been used [Rambøll, 2021; PlanEnergi, NA]. The two projects uses the parameters presented in Table 5.9.

Project	**PlanEnergi**	**2023 prices**	**Rambøll**	**2021 prices**	**2023 prices**
Parameters	COP	3.15	COP	2.9	2.9
	Electricity price	647 DKK/MWh	Electricity price Under 4 MWh	800 DKK/MWh	849 DKK/MWh
	tariffs	622.29 DKK/MWh	Electricity price Above 4 MWh	600 DKK/MWh	637 DKK/MWh
	Tax	8 DKK/MWh	Amortisering	7 688 DKK/year	8 159 DKK/year
	OM	2300 DKK/year	Fixed cost	2 400 DKK/year	2 547 DKK/year
	Yealy cost per house	24 666 DKK/year	Variable cost	546 DKK/year	579 DKK/year
	Heat pump investment	102 000 DKK	Yearly cost per house	13 188 DKK/year	13 995 DKK/year
	Loan rate	6%	Heat pump investment	92 000 DKK	97 631 DKK
			Disconnect gas grid	6 560 DKK	6 962 DKK

Tabel 5.9. Table showing the parameters from the two projects from PlanEnergi and Rambøll. Rambøll includes both the value for 2021 and an adjusted value for 2023 [Rambøll, 2021,p. 18], [PlanEnergi, NA,p. 31]. Table created by the project group.

The table shows a number of parameters which is utilised in determining the consumer economics for the implementation of individual heat pumps. These parameters covers aspects such as technical and economic considerations. For both projects the parameters includes values of COP, electricity prices, OM, investment cost of the heat pumps, fixed and variable cost and disconnection from the gas grid cost.

The table further showcases the project of Rambøll from 2021, with prices for 2023 for enabling comparison. The calculation of 2021 costs to 2023 costs is done by adding the inflation rate of 2%

over 3 years [Brooke, 2025]. This calculation look like:

$$\text{Adjusted Cost} = \text{Original Cost} \cdot (1 + \text{Inflation Rate})^{\text{Number of Years}}$$

Table 5.9 shows the difference between the heat pumps in the two projects. The heat pumps vary in COP value, which is assumed to also be reflected in the investment cost of the two projects. The project from PlanEnergi have a heat pump with a COP value of 3.15 with a cost of 102 000 DKK, while Rambøll introduces a heat pump with a COP of 2.9 with a cost of 97 631 DKK adjusted to 2023 prices.

From the project created by Rambøll, the OM is described at being a part of the fixed cost. This is considered very similar to the OM cost from PlanEnergi. It showcases a limited variation in this type of expense for the individual heat pumps.

The yearly cost per house varies from 15 460 DKK/year to 13 995 DKK per year. This is an important aspect for the consumers. The cost difference is likely to be a result of the difference costs in heat pumps, electricity cost based on cost per MWh and their demand, tariffs, which is not mentioned in the Rambøll project, and then the loans.

5.5 Summary on comparing thermonet projects to those of individual heat pumps

Based on the data collected from the thermonet projects and the data used in calculating the consumer economics for individual heat pumps, the parameters now align. It is still seen that while the technical aspects may differ due to the scale of the project and the infrastructure, the underlying economic and technical variables are overall comparable. This means that utilising the parameters gathered across all the thermonet projects in a consistent way as a standard, the two types of technologies may be compared in the decision between implementing individual heat pumps and thermonet.

This means that the inability to compare the thermonet project at this point in time without the standardised assessment does not correlate to the lack of data but rather the inconsistency of the parameters included and how these are depicted in the projects investigated. Many of the thermonet projects uses different methods of depicting the data for aspects like OM, connections fees, subscriptions and COP/SCOP values. Furthermore, is the varying of data regarding rates, lifetimes, payback times across projects. These aspects will in the results affect the consumer economics presented directly to the consumer but also other actors who could have an interest in investigating the total annual costs per house for technology of thermonet.

The recommendations for a standardised assessment for thermonet for the purpose of comparing them with other thermonet projects and to other technologies such as individual heat pumps, is included below.

5.6 Recommendations for a standardised assessment for thermonet

Throughout Analysis 1, a systematic effort has been made to identify and categorise the technical, organisational, and product related parameters that influence consumer economics in thermonet projects. To promote greater transparency and comparability across future thermonet projects, these parameters are used to establish a set of recommendations for a standardised assessment. The importance of formulating these recommendations lies in addressing the current uncertainties and lack of comparable data. A standardised assessment for evaluating thermonet projects not only strengthens the basis for decision making but also contributes to greater transparency in project economics, development of thermonet.

This is achieved by establishing the support structures that Strategic Niche Management (SNM) in Section 3.2.2, highlights as essential for the successful development of niche innovations. SNM argues that for a new technology to move beyond the niche phase and become established, it requires a stable network of actors, shared expectations, and learning processes [René Kemp and Hoogma, 1998,p. 186].

In the case of thermonet, developing and applying a standardised assessment contributes directly to this. It creates transparency and comparability across projects, thereby making a shared understanding of thermonets consumer economic implications. The standardised assessment strengthens the alignment of actors and supports the transition of thermonet from a niche to an established heating technology in the Danish energy system. Finally it creates a momentum toward including thermonet in the Danish Heat Supply Act, that can increase the implementation of thermoent according to Termonet Danmark.

The recommended parameters presented in the following Table 5.10, outlines a set of recommended parameters for a standardised assessment.

Recommended parameters for a standardised assessment for thermonet		
Technique:		
Parameters	**Unit**	**Note:**
Electricity Price	DKK/kWh	
SCOP	-	COP can be used if SCOP is not available

Table 5.10 continued from previous page

Recommended parameters for a standardised assessment for thermonet		
Heat Pump Investment	DKK	
Heat Pump Lifespan	Years	
Heat Pump OM	DKK/years	
Geothermal Pipe Cost	DKK per house and total	
Geothermal Boreholes	DKK	
Plastic pipes Lifespan	Years	50–100 years
Geothermal pipelines and Boreholes Lifespan	Years	60-70 years
Heat Pump Payback Time	Years	20 years
Geothermal Pipes Payback Time	Years	30 years
Organisation:		
Parameters	**Value and/or unit**	**Note:**
Subscription fee	DKK/year	All projects include subscription fees. For transparency, all subscription fees should be listed.
Fixed contribution	DKK/year	
Consumer contribution	DKK/MWh	
Real interest rate	%	2%
Connection fee	DKK/per house	
Late connection fee	DKK/per house	
Yearly Electric Cost	DKK/year	Based the electricity price, size of heat pump and COP/SCOP
Product:		
Parameters	**Value and/or unit**	**Note:**
Yearly cost per house	DKK/year	
Installation cost per home	DKK	
Annual cost – large consumer	DKK/year	

Tabel 5.10. Table showing recommended parameters, units and data for the standardised assessment for thermonet

The table presents the parameters and their recommended units. In addition to this, some parameters are value specific. These includes direct suggestions for the values of real interest rate, service and distribution pipes lifespan, geothermal pipelines and boreholes lifespan, heat Pump payback time and geothermal pipes payback time.

- The real interest rate of 2% is selected based on market conditions and the real interest rate already used by several thermonet projects [Realkredit Danmark, 2025b; Nykredit, 2025; Damgaard, 2023a,b; WSP, 2023].
- Plastic pipes lifespan, is based on the the minimum lifespan of the pipes stated by a company in the pipe industry [Wavin, 2022]. Though the pipes lasts over 100 years, these can after the time period of 50 undergo checks to ensure continued usage.
- Geothermal pipelines and boreholes lifespan is 60-70 years based on information from thermonet project proposals [Damgaard, 2023b,a].
- Heat Pump payback time is based on the lifespan of the heat pump. This means that the heat pump i able to be repaid before reinvestment.
- Geothermal pipes payback time of 30 years are based on The Danish Energi Agency [NA]; The Danish Energy Agency [2025g].

The specific values of the parameters included in the recommendations, are based on the data from the projects and knowledge external to the analysed projects. These values are therefore not only derived from, or justified by, the data collected from the existing thermonet projects. Rather, they are based on literature and sources from companies in the sector.

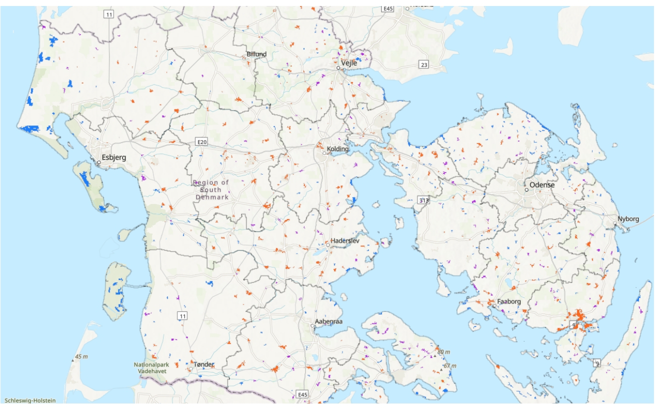
The parameters are evaluated to be necessary to calculate the installation cost and yearly cost per house. This is the cost that is needed for the consumer to make the decision of whether they want to implement thermonet or individual air-to-water heat pumps. These costs gives the consumers an indication of the loan amount required, and the expected annual payment.

Analysis 2 6

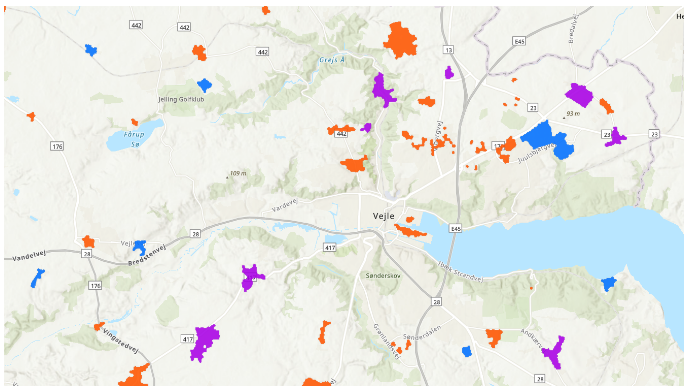
This chapter seeks to answer the research question by addressing the aspects of the second sub-question; *"How can GIS analysis, based on predefined parameters from COHEAT and newly identified parameters, be applied to identify suitable areas for implementing a thermonet systems in Stevns Municipality?"*. This is done by investigating a map for Southern Denmark, illustrating areas with potential for different heat solutions and identifying previous defined parameters utilised in a GIS analysis for locating areas which have potential for implementing thermonet. The section further seek to explore if additional parameters are relevant to include in the mapping of potentials. Lastly, the parameters are included in a GIS analysis, resulting in a map of Stevns Municipality thermonet potentials.

6.1 Map of southern Denmark

This section seeks to investigate if areas in Denmark are mapped for implementation of thermonet. For this investigation, COHEAT, a partnership consisting of several municipalities in Denmark, organisations, and consulting engineers, conducts an analysis of the potential for different heat solutions in Southern Denmark [COHEAT, 2025]. The following two Figures 6.1 and 6.2 illustrates the potentials mapped in the region of Southern Denmark.

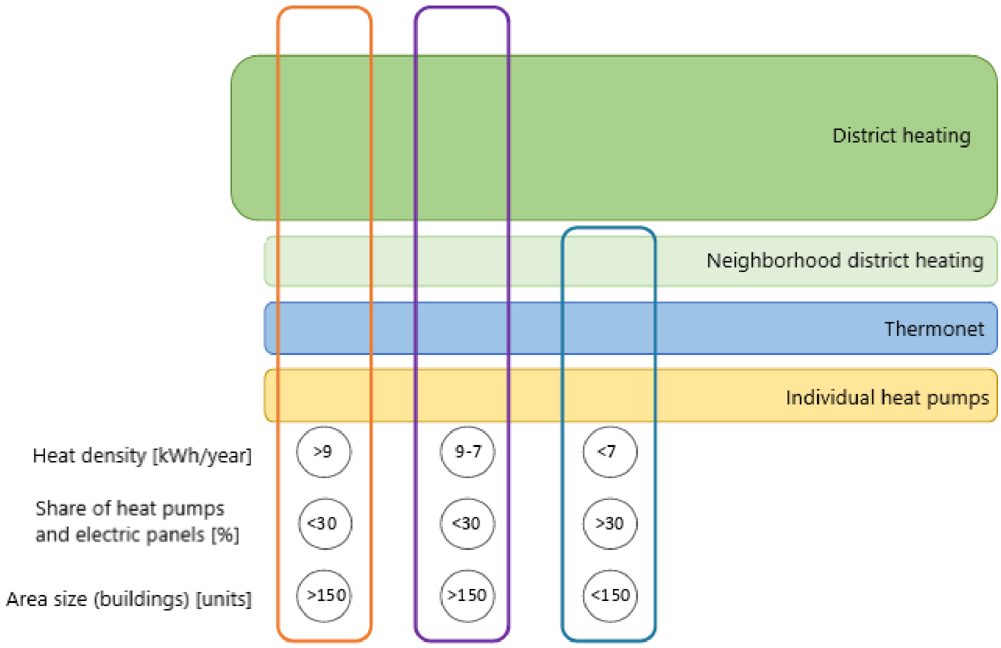


Figur 6.1. Geographical area of southern Denmark with heat densities illustrated. Orange illustrates a heat density of >9 kWh/m2, purple 7-9 kWh/m2, and blue <7 kWh/m2 [COHEAT, 2023b].



Figur 6.2. Geographical area: example of Vejle with heat densities illustrated. Orange illustrates a heat density of >9 kWh/m^2/year, purple 7-9 kWh/m^2/year, and blue <7 kWh/m2 [COHEAT, 2023b].

The heat densities shown on Figure 6.1 illustrates the potential of where traditional district heating is possible, where thermonet and neighborhood district heating is possible and where individual heat pumps are possible. This is further described in Figure 6.3.



Figur 6.3. Figure edited by the project group based on COHEAT [2023a,p.15]. The figure illustrates options of heating based on the heat density, share of heat pumps and electric heating together with the number of buildings. **The orange box** illustrates all heat solutions are possible. **The purple box** illustrates that district heating might be feasible, due to the varying heat density. **The blue box** illustrates that district heating i not an option, but refers to implement more local heating solutions instead. [COHEAT, 2023a,p.15].

This initial investigation is used to help determining where it could be advantageous to establish thermonets. The investigation is not to stand alone, and needs additional analysis for deeper evaluations of the potential for an area [Poulsen, 2025a].

In Figure 6.3 a heat density of less than 7 kWh/m^2/year is relevant for neighbor district heating (nabofjernvarme), thermonet projects or individual heat pumps. Neighbor district heating is not the focus of this project and will not be discussed further.

6.2 Parameters gathered from COHEAT

The map in this analysis takes inspiration from the COHEAT map from Section 6.1. The parameters that the COHEAT map is based upon, and how they are used to make a map for Stevns Municipality is described below. The COHEAT map is used as a basis for the map in this analysis, based of its simple visualisation on which areas are suitable for thermonet. It is important to note that the COHEAT map is created to estimate the district heat potential in Southern Denmark, and not thermonet, even though thermonet is mentioned [Dansk Fjernvarme and PlanEnergi, 2023,p. 11]. Due to this, it is necessary to evaluate the parameters in relation to thermonet.

The parameters below are divided into red and green color to give a quick overview if they are relevant for the implementation of thermonets and are included in the GIS analysis. Red is used when parameters will not be used to make the map. Green is used for the parameters that are included in the analysis of Stevns Municipality.

- *Heat density*, as described in Section 6.1 and Figure 6.3 is a key aspect when deciding whether district heat, individual heat pumps or thermonet is economic feasible in an area [COHEAT, 2023a,p. 6-7]. The COHEAT map defines the threshold for thermonet being a heat density lower than 7 kWh/m^2/year and that fulfills the other parameters.

  In Section 2.4.1 it is mentioned that district heating is deemed non-feasible in Stevns Municipality. This removes the need for a threshold for heat density. Therefore thermonet will not be affected by the heat density where COHEAT have determined is suitable for implementing district heating seen in Figure 6.3. This argues for that each municipality evaluates a thresholds for when thermonet or individual solutions is preferred and feasible compared to district heating.

- *Connection percentage*is commonly used in the evaluation of district heating potentials. Areas with district heating potentials are evaluated to require a connection percentage of 70%, depending on the heat density. In areas with individual heat solutions such as heat pumps and electric heating of 30% or more, district heating is not evaluated to be a feasible solution. The tendency seen, is that oil and gas fueled households with high prices are inclined to participate in a common solution [COHEAT, 2023a,p. 7]. For this reason is connection percentage not used as a parameter in this map.

- *Areas* are in the COHEAT map made by using 50 meter buffer zones. Each house from the Danish heating atlas, that have a heating requirement, have been given a 50 meter buffer. This was done to create areas where the space between houses do not exceed 100 meters [Dansk Fjernvarme and PlanEnergi, 2023,p. 7]. The houses within the buffer zones are then made into one area [Dansk Fjernvarme and PlanEnergi, 2023,p. 7]. This project will use a buffer of 20 meters, to make sure that the distance between the houses are less than 40 meters. This is based on a statement made from Hjortbak, that PlanEnergi's rule of thumb is that, if the area where the thermonet is to be established is fortified then a maximum for 40 meters between houses [Hjortbak, 2025].

- *Large consumers* are present in some areas of the COHEAT map. Large consumers pose a risk to the heat system if their demand changes. [COHEAT, 2023a,p. 9]. No correlation has been found between the number of large consumers and areas with district heating potential [COHEAT, 2023a,p. 9]. Their consumption is important to understand both regards to the historical and the future expected district heat consumption.

  Additionally, the placement of large consumers within the system is significant, as incorrect placement and fluctuations in consumption can affect the hydraulics in the system [COHEAT, 2023a,p. 9]. This is also considered important in the context of thermonet. This is because of pipes in thermonet and district heat have to be dimensioned correctly according to the estimated consumption. As the number of large consumers do not have a direct impact on the potential, these will not be considered during the mapping process, but are important to look closer into it an area have potential for thermonet.

- *Pipe length* per building in the distribution systems is rarely less than 20 meters, as stated in the COHEAT reports. In the example from COHEAT [2023a], a connection percentage will in the case result in a pipe length of 29 meters which will affect if a project is financially viable [COHEAT, 2023a,p. 7]. Based on COHEAT's numbers the threshold of the length of pipes per building, is 30 meters. Above this, the area is no longer considered a district heating potential [Dansk Fjernvarme and PlanEnergi, 2023,p. 14].

  The distribution pipes length from district heating of 30 meters is not considered in the map of Stevns Municipality. This is due to both the consideration of maximum 40 meters between the houses, but also that it is not considered in the COHEAT map, and the FUTURE analysis of thermonet [Østergaard et al., 2021,p. 14].

- *Number of buildings* in a thermonet can vary. It is stated that the lower limit to thermonet is two houses, due to the assumption that a similar system for one house is not considered a thermonet but a geothermal heat system. At the same time, the upper limit is not defined based on thermonets being made to accommodate large amounts of buildings. The thermonets in Denmark varies from 2- 91 buildings [Termonet Danmark, 2025e]. In other countries with systems similar to thermonet, the number of connected houses can reach several hundred [nPRO, 2022].

  PlanEnergi estimates that a thermonet is most feasible with 15 houses or less [Hjortbak, 2025]. This contrast with sustain statement in the screening concerning Vestre Såby that "*There is a relatively low number of potential connection points (101) in the city of Vester Såby,* *which is why it will require a higher connection percentage than in some of the other cities screened.*-[Sustain, 2023g,p. 4]. This is both concerning the screenings, where the lowest number of houses is 89, and in both the project proposals that have respectively 142 and 114 possible houses connected. This present a contradiction in the understanding of the size of feasible thermonet. From PlanEnergi's statement it should only be implemented on a small scale, but this is not the case. In PlanEnergi's own calculations, the sizes of the thermonets ranges from 42-1100 houses. For the GIS analysis this means, that areas including a minimum of two houses can be used, with no upper limit.

- *Distance to district heating plants, transmission pipes*, is not a necessary aspect to incorporate in the GIS analysis. This is because of the lack of implemented district heating in Stevns Municipality. Due to a focus on the Stevns municipality alone, district heating plants that could provide heating to houses within the Municipality have been left out.

In summary the parameters from COHEAT that will be included in the GIS analysis is areas within the 40 meter buffer zone and a minimum of 2 houses. Other parameters for the GIS analysis can be relevant to include, these will be introduced i the section below.

6.3 Additional parameters

This section introduces other parameters not included in the COHEAT map. Similar to the section above, it evaluates the parameters by the colors red and green.

- *Excluding holiday houses*, is a parameter utilised in the GIS analysis. Since the holiday houses are mainly used in summertime and therefore have a low heat demand centered around the summer period, district heating solutions are rarely established [Frederiksen, 2025]. This is in correlation to the fact that it the houses is further expected to be mostly vacant in the Winter period with the highest heating demand. Following this logic with the implementation of thermonet, areas with holiday houses are not a relevant case. For this reason holiday houses are not included in the GIS analysis.

- *Excluding heat pumps and electric heating* are set as a parameter in the GIS analysis, due to the assumption that households with already installed heat pump and electric heating might not want to invest further.

Based on the evaluation of the abovementioned parameters, the GIS analysis for Stevns Municipality will now be conducted, and will contain the exclusion of heat pumps and electric heating, areas with the 40 meter buffer zone and exclusion of holiday houses.

6.4 Thermonet potentials for Stevns Municipality

In this subsection, the map of Stevns municipality with areas identified for implementing thermonet, is conducted and described.

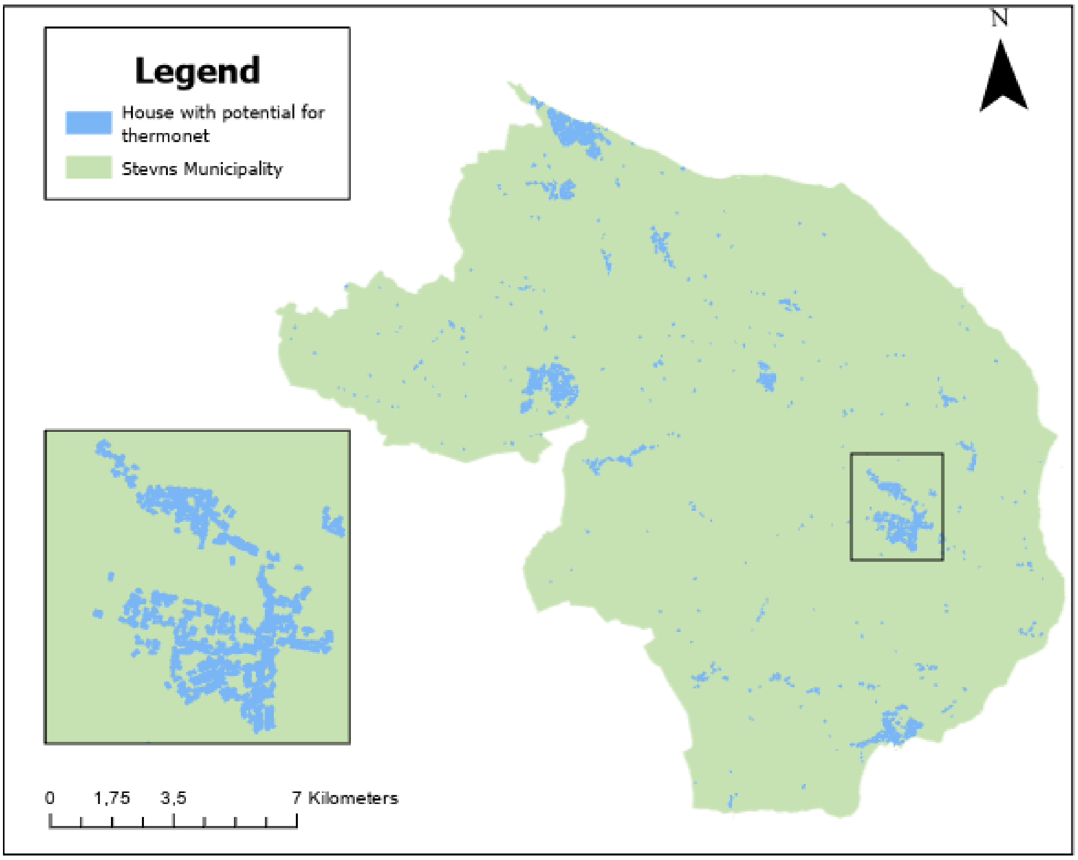
As mentioned above, the map will include the parameters of a minimum of 2 houses and no upper limit, a maximum distance of 40 meters between houses, exclusion of houses with heat pumps and electric heating and a no limit on the heat density.

The process of identifying the groupings of houses for implementation of thermonet, is done through two steps.

1. The first step includes sorting the buildings to exclude barns and other outhouses without a heat demand. This is also here the holiday houses are excluded. After the sorting, a buffer is set for the point of each house to 20 meters. This is done to exclude the houses with distances of 40 meters and more between them. This results in groups of minimum of 2 houses.

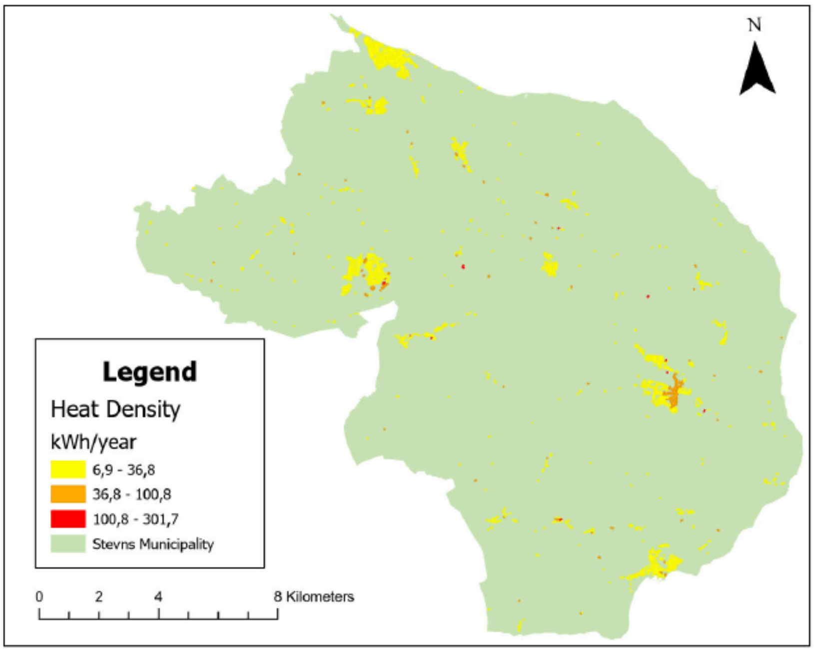
2. The second step was to find the heat density, and to do this several calculations were done. The danish heat atlas supplied the heat demand per m^2 for each of the buildings. At the same time, it supplied the area of the building. Based on the data, it was possible to calculate the sum of heat demand for each building. When the groupings of the houses were done, the heat demand for all building were summarised. This heat demand and the total area of the polygons for the groupings of houses, resulted in the opportunity to calculate the heat density. At this point the layer included polygons with a variety of heat densities.

A visualisation of the map with potential houses for implementation of thermonet created using the parameters in step one, is seen in Figure 6.4.



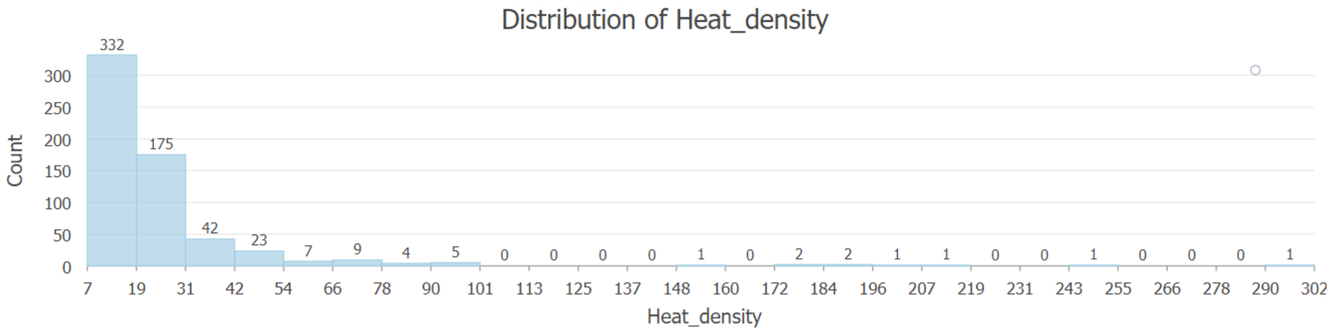
Figur 6.4. Map showing the identified houses in Stevns Municipality with potential for thermonet using the 20 meter buffer. The map zooms in on the case area Store Heddinge. Created by the project group using data from [Aalborg University, 2022] and [The Danish Agency for Data Supply and Infrastructure, 2025a].

The calculations of the heat density for the polygons described in step 2 is visualised in Figure 6.5.



Figur 6.5. Map showing the identified areas suitable for implementing thermonet, and the varying heat densities for each of the polygons. Created by the project group using data from [Aalborg University, 2022] and [The Danish Agency for Data Supply and Infrastructure, 2025a].

In Figure 6.5 it is visible that the lowest heat density is 6.9 kWh/m^2/year. As mentioned, the heat density threshold of 7 kWh/m^2/year is not relevant for Stevns municipality due to the decision of rescinding the district heating projects. Based on the calculated heat densities it is therefore relevant to show what heat densities are seen in Stevns Municipality. As an addition to Figure6.5, a histogram in Figure 6.6 is conducted. this shows the number of polygons within each heat density range.



Figur 6.6. Histogram showing the heat densities from Figure 6.5. Created by the project group using data from [Aalborg University, 2022] and [The Danish Agency for Data Supply and Infrastructure, 2025b].

In the histogram the heat densities ranges from 7-302 kWh/m^2/year. It is seen that the majority of the polygons is within the 7-30.6 kWh/m^2/year range. This showcases that the threshold of 7 kWh/year for Stevns Municipalities is outside of the calculated heat densities and is therefore not relevant.

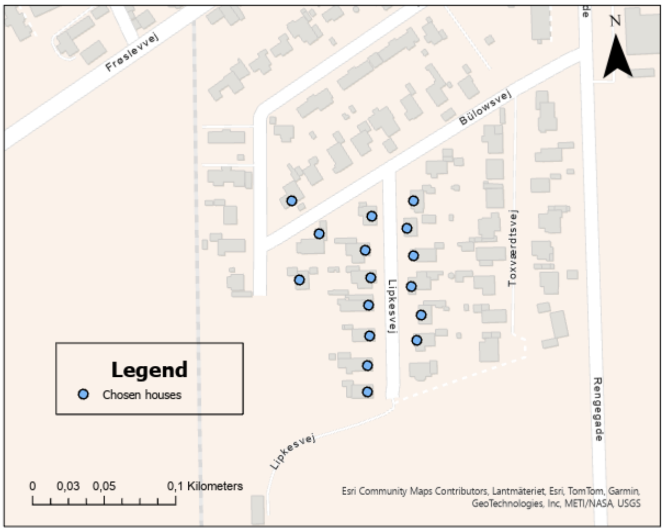
6.5 Choosing the case area

This section introduces the chosen case area for utilisation in analysis 3. The selection is based on the parameters identified above together with the aspect of choosing a representative case. This is necessary due to the project only including one case due to the limitations of the project. This means that the project is limited by time. The time constraints further limits the possibility of choosing a case with a large amount of houses, this means that the number of houses for this investigation will vary from 15-20 houses. This range has been selected based on the project group's objectives for the following analyses, as well as considerations regarding the number of houses that can be examined within the time frame allocated to the project.

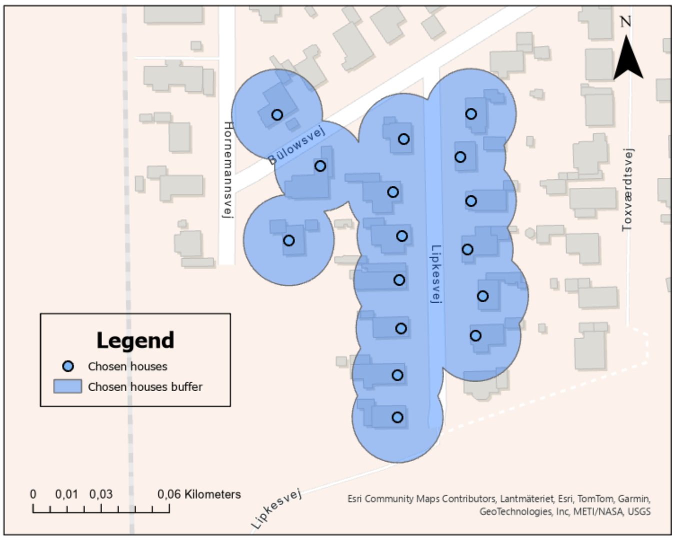
The range is also based on the statement from Hjortbak, that the smaller systems is the most energy and cost efficient. This is both regarding better heat absorption from the ground in smaller pipes, electricity and investment for the circulation pump [Hjortbak, 2025]. As an additional consideration, an area without a large consumer is chosen, since the time limits the possibility of investigating the consumers historical and future consumption. Another parameter for selecting the area is heat density. As shown in Figure 6.6, the majority of the selected polygons have a heat density between 7 and 19 kWh/m^2/year. Utilising a heat density within this range, makes it possible to represent the majority of the polygons for Stevns Municipality through the analysis.

Based on the above, a case area containing 16 houses is chosen. The buildings in this area is ordinary parcel houses on a small villa road in the city Store Heddinge. Store Heddinge is the Municipality's second biggest city, with a population of 3513 [Askgaard et al., 2021]. Store Heddinge was a part of the plans to make district heating in Stevns municipality, but in 2025 these plans are withdrawn due to not being economic feasible [KLAR Forsyning, 2024]. The city of Store Heddinge was by KLAR FORSYNING one of the areas chosen for developing district heating in Stevns Municipality. The estimated price to be connected to the district heating was set to 40 000 DKK for the installation cost and 20 000-25 000 DKK/year for the yearly heat price [KLAR FORSYNING, 2024]. From this, it is derived that the municipality is interested in a collective heating solution in this area, as a alternative to fossil based individual heating solutions if its economically feasible.

An overview of the area and the houses is seen in the following Figure 6.7. The houses in the selected area are located less than 40 meters from the nearest neighboring house, as illustrated in Figure 6.8.



Figur 6.7. Map of the chosen area of Stevns Municipality. The case area includes 16 houses. Created by the project group using data from [Aalborg University, 2022].



Figur 6.8. Map of the chosen area with buffer of 20 meters. Created by the project group using data from [Aalborg University, 2022].

The Table 6.1, shows the data from the chosen houses:

Road name	**House number**	**Area**	**Heat supply**	**House type**	**kWh/m^2/year**
Lipkesvej	14	110	Natural gas	Parcel house	13 530
Lipkesvej	12	169	Natural gas	Parcel house	20 787
Lipkesvej	11	111	Natural gas	Parcel house	13 653
Lipkesvej	10	110	Oil	Parcel house	13 530
Lipkesvej	9	95	Natural gas	Parcel house	11 685
Lipkesvej	8	153	Natural gas	Parcel house	18 819
Lipkesvej	7	124	Natural gas	Parcel house	15 252
Hornemannsvej	25	95	Oil	Parcel house	11 685
Lipkesvej	6	153	Natural gas	Parcel house	18 819
Lipkesvej	5	131	Natural gas	Parcel house	16 113
Lipkesvej	4	126	Natural gas	Parcel house	15 498
Bülowsvej	9	144	Oil	Parcel house	17 712
Lipkesvej	3	96	Natural gas	Parcel house	11 808
Lipkesvej	2	104	Oil	Parcel house	12 792
Bülowsvej	16	132	Natural gas	Parcel house	21 516
Lipkesvej	1	98	Natural gas	Parcel house	12 054

Tabel 6.1. Heating source, house type, location and heat demand for the 16 houses

In total, the polygon created by the buffer area in Figure 6.8, contains 16 houses, have an estimated heat demand of 245 253 kWh/year and a heat density of 17.9 kWh/m^2/year.

In summary the purpose of this section was to identify the areas suitable for implementing thermonet in Stevns Municipality. To be able to make the identification, the parameters from COHEATS map of Southern Denmark was explored in relation to the implementation of thermonet. Further parameters of excluding the houses with already installed heat pumps and electric heating and holiday houses are identified. These parameters are used to find an area suitable for implantation of thermonet. This leads to the selection of the case area in the city of Store Heddinge. This case area is utilised in the investigation in analysis 3.

7 Analysis 3

This chapter seeks to determine the consumer economic aspects of thermonet and answer the third sub-question *"How can the previous sub-questions and the resulting analysis be combined into consumer calculations for the selected case area in Stevns Municipality?"*. For this analysis, the parameters recommended in Section 5.6 is applied to the case area of Store Heddinge. The purpose of this analysis will be to showcase that the consumer economics is calculated with parameters similar to individual heat pumps, in order to directly compare the heat solutions.

The thermonet project is set up in the case area of Store Heddinge, identified in analysis 2. The heat source is both the distribution and service pipes, based on the uninsulated pipes works as geothermal pipes, and boreholes. Boreholes is chosen based on the area is fortified and due to it being the most used heat source in established thermonets i Denmark. The financial setup for this, is upfront consumer payment. This means that the consumers pay the total cost of installation one time. The heat pumps are owned by the company and the consumers pay an annual fee.

7.1 Geothermal pipes and boreholes

Before calculating the consumer economics, there is a need to calculate the cost for the geothermal pipes and boreholes. This is necessary due to not being able to find an average cost or ranges for the price of geothermal pipes and boreholes through the investigated projects. Therefore these costs are determined based on the case area of Store Heddinge. This is relevant as the cost of the geothermal pipes are dependent on the length of the pipe. This length have a impact on how many boreholes is needed, for the case area, as they have also work as a heat source. The amount of boreholes is important to know as this affects the cost of boreholes. Like the heat pumps, it is possible to obtain a lower cost if a certain amount is needed [Østergaard et al., 2021,p. 15].

The calculation for the length of geothermal pipes and number of boreholes is done through the following steps. This is done in this analysis, and not as a part of analysis 2, as these parameters as mentioned earlier are location specific.

The first step is to find the length of the geothermal pipes, which entails the distribution and service pipes transporting the brine, in the case of this project. This is done by creating a plan of how the thermonet is designed. The design can be seen in Figure 7.1. Following this, it was possible to measure the length of each pipe for the calculations. The pipes on Figure 7.1, represents the placement of the two needed pipes in thermonet. One for warmer brine to the heat pumps and one for the colder brine after the heat pumps.

Figur 7.1. Placement of the Geothermal distribution and service pipes in the case area. Created by the project group using house placement from [Aalborg University, 2022].

Based on this the total pipe length was estimated at 1292 meters, and the price per meter geothermal pipe is 1500 DKK/m [Østergaard et al., 2021,p. 15]. The price of the geothermal pipes per houses is:

$$\frac{1293 \text{ meters} \cdot 1500 \text{ DKK/meter}}{16 \text{ houses}} = 121\,218.75 \text{ DKK per house}$$

These values, combined with a heat absorption from the geothermal pipes of 20 W/m and boreholes of 35 W/m with a depth of 120 meters, 2850 hours of operation [Østergaard et al., 2021,p. 13], a total heat demand of 245 253 kWh/year and a heat pump with a SCOP of 3.28, it can be calculated that for Store Heddinge is a need for 8 geothermal boreholes. With this data it is possible to determining the total price of the boreholes to:

$$8 \text{ boreholes} \cdot 66\,000 \text{ DKK} = 528\,000 \text{ DKK}$$

Based on the above, a final sheet of data utilised in calculating the consumer economics for Store Heddinge is made.

7.2 Consumer economics

In the section the consumer economics is calculated. This entails the total installation cost per house and the annual cost per consumer. The data, sources and explanations behind the values that is utilised in conducting the calculations for both aspects of consumer economics are shown in Table 7.1. The results of the consumer calculations made using the data from the table below are presented in the two Tables 7.2 and 7.3.

Recommended parameters for a standardised assessment for thermonet			
Technique:			
Parameters	**Value:**	**Explanation:**	**Source:**
Electricity Price	2.9 DKK/kWh	2024 Q4	2024 Q4
SCOP / COP	3.28	Average of SCOP from analysis 1	Årøsund, Sjelle by, Danish Energy agency, Gate 21, Jystrup, Thurø and Hjortsvang
Heat Pump Investment	74 800 DKK	Small consumers average with installation price for Gate 21 Future added to the investment price	Årøsund, Sjelle by, Danish Energy Agency, Gate 21, "Budget sent", Jystrup and Thurø
Heat Pump Lifespan	20 year	Most agreed on lifespan for small heat pumps	Årøsund, Danish Energy Agency, Sjelle, Jystrup, Thurø and Hjortsvang
Heat Pump OM	1420 DKK/year	Average cost, excluded Gate 21 Future	Årøsund, Sjelle by, Danish Energy Agency, Jystrup and Thurø
Geothermal Pipe Cost	1500 DKK/meter 121 125 DKK per house 1 938 000Total	Based on cost per meter and pipe size and type	Cost per meter Gate 21 Future
Geothermal Boreholes	66 000 DKK/PCS 33 000 DKK per house 528 000 Total	Medium price because of the amount of boreholes (8 PCS)	Gate 21 Future

Table 7.1 continued from previous page

Recommended parameters for a standardised assessment for thermonet			
Plastic pipes Lifespan	50 years	Based on the lowest number,as this is the minimum expected lifetime	Danish Energy Agency
Geothermal pipelines and Boreholes Lifespan	60 years	Based on the lowest number, as this is the minimum expected lifetime	Jystrup
Heat Pump Payback Time	20 years	Based on the most agrred on payback time	Årøsund, Sjelle by, Danish Energy Agency, Jystrup, Thurø and Hjortsvang
Geothermal Pipes Payback Time	30 years	Based on The Danish Energy Agency payback time	Danish Energy agency,
Energy Meters	0 DKK	Based on that the consumers rent	
Organisation:			
Parameters	**Value:**	**Explanation:**	**Source:**
Subscription fee	Heat pump: 4166 DKK/year Meter: 553 DKK/year	Heat pump: Average cost Meter: Average cost	Heat pump: Thurø, Jystrup and Årøsund Meter: Thurø, Jystrup and Årøsund
Fixed contribution	18.8 DKK/m2/year	Average cost, excluding Sjelle	Årøsund, "Budget sent", Jystrup and Thurø
Yearly Electric Cost	16 000 DKK/year	Standard house uses 18.1 MWh heat, divide by SCOP. Then calculate the price of electricity.	
Consumer contribution	386.8 DKK/MWh	Average cost	Årøsund, "Budget sent", Jystrup, Sjelle and Silkeborg
Real interest rate	2%	Based on projects and mortgage loan rate	Mortgage loan rates(Nykredit), Jystrup, Thurø and Hjortsvang

Table 7.1 continued from previous page

Recommended parameters for a standardised assessment for thermonet			
Connection fee	36 125 DKK/house	Based on average	Screenings, Sjelle By and Silkeborg
Late connection fee	34 100 DKK/per house	Based on average	Årøsund and Sjelle by
Product:			
Parameters	**Value:**	**Explanation:**	**Source:**
Yearly cost per house	DKK		
Installation cost per home	DKK		
Annual cost – large consumer	DKK		

Tabel 7.1. The table shows the chosen values used in the consumer economic calculations. These are based on both averages from the project proposals and screenings together with data from external sources.

7.2.1 Total cost of installation per consumer

To calculate the total installation cost per consumer, data from Table 7.1 is used. The relevant data for this section includes the calculated costs of geothermal pipes and boreholes from the previous section, the connection fee, and the real interest rate. These data is presented below in Table 7.2.

Total cost of installation per consumer:	
Geothermal pipe cost	121 125 DKK
Geothermal boreholes	33 000 DKK
Connection fee	36 125 DKK
Total:	190 250 DKK
Real interest rate	2%
Total over 30 years (2% bank loan)	**304 400 DKK**

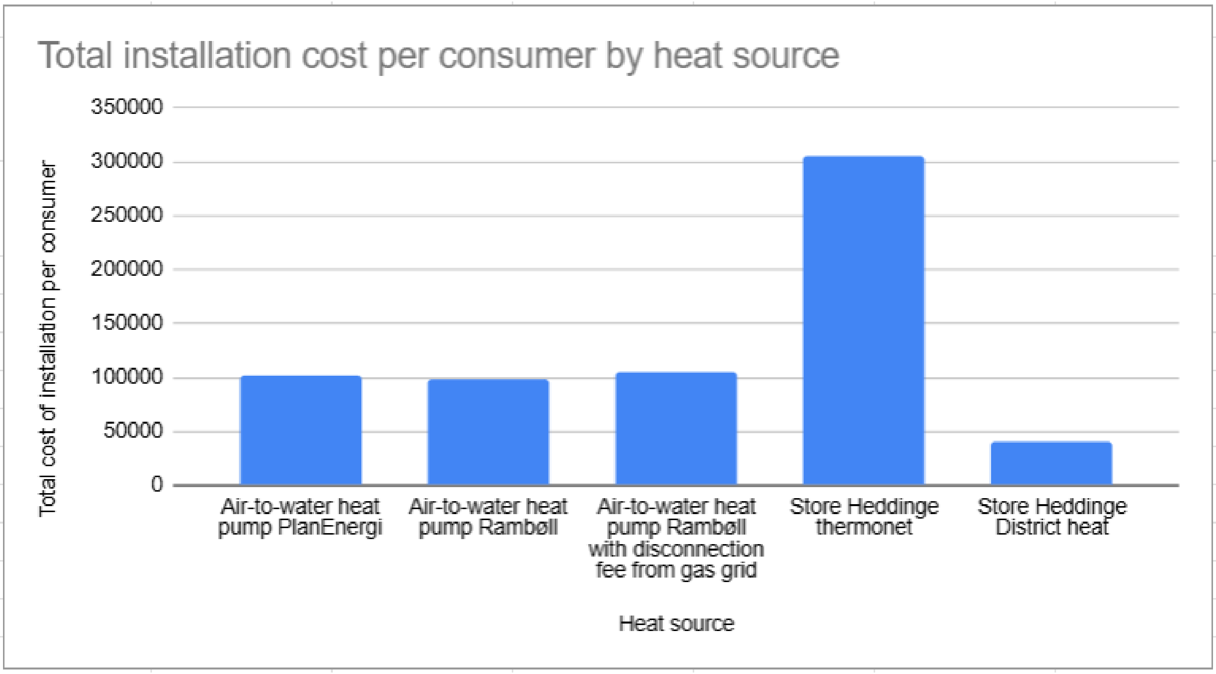
Tabel 7.2. The total cost of installation per consumer of the thermonet in the case area of Store Heddinge, shown on Figure 7.1. Data from Table 7.1.

The cost of installation per consumer if all 16 houses is connected to the thermonet is 304 400 DKK assumed they take a 30 year loan with a 2% real interest rate.

This project, however, focus on comparing thermonet with an individual air-to-water heat pump. The installation cost for an air-to-water heat pump primarily consists of the purchase of the unit itself. Based on the data from Table 5.9, the price of a heat pump is 102 000 DKK and 97 631

DKK [Rambøll, 2021,p. 18], [PlanEnergi, NA,p. 31]. For customers connected to the gas grid, there is an additional disconnection fee of 6 962 DKK [Rambøll, 2021,p. 18].

The total installation cost per consumer is compared for the thermonet project in Store Heddinge and the air-to-water heat pump projects by Rambøll and PlanEnergi in Figure 7.2. For the Rambøll project, costs are shown both with and without the gas grid disconnection fee. Additionally the installation cost of the planned district heat of 40 000 DKK is also added to Figure 7.2 [KLAR FORSYNING, 2024].



Figur 7.2. The total installation cost for thermonet in Store Heddinge, air-to-water heat pump in project from PlanEnergi and Rambøll, and the price of the planned district heating [Rambøll, 2021,p. 18] [PlanEnergi, NA; KLAR FORSYNING, 2024].

Figure 7.2 shows that whether or not the gas disconnection fee is included, the installation cost per house is lower with an air-to-water heat pump than with the thermonet in the case area of Store Heddinge. It is further illustrated that the installation cost of thermonet is significantly higher than that of the planned district heat. This is a difference of 87%.

7.2.2 Annual cost per consumer

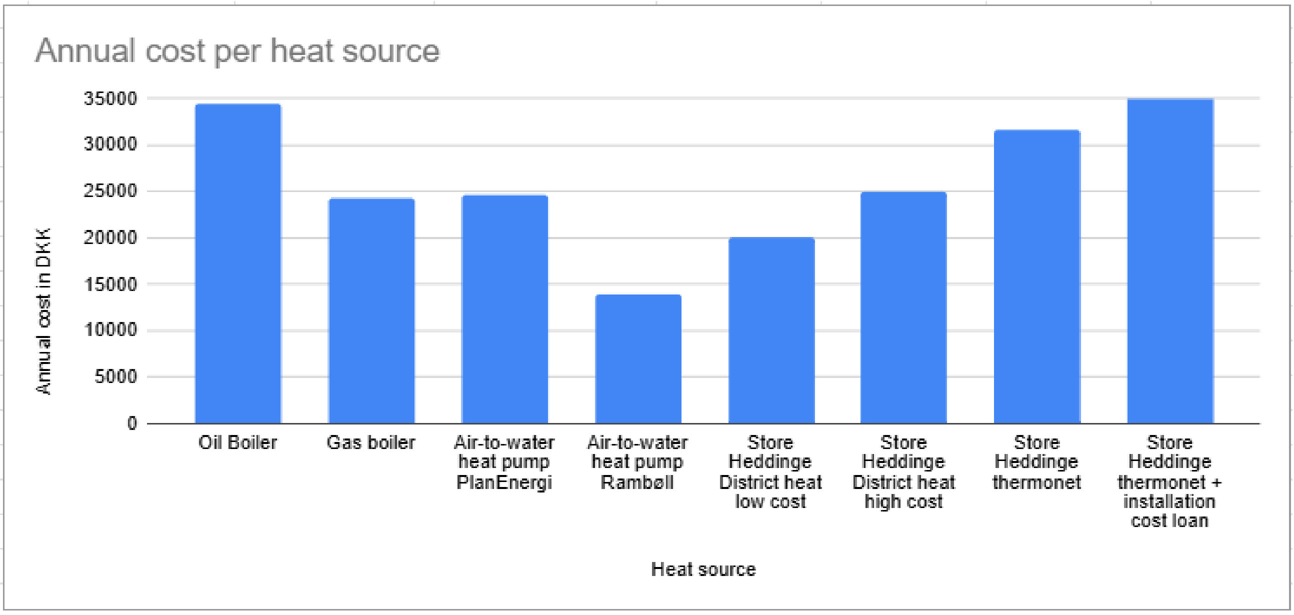
The calculations for the annual cost per consumer are conducted in this section. The calculations ate based on the parameters and values presented in Table 7.1. The annual cost per consumer is presented in Table 7.3.

Annual cost per consumer:	
Heat Pump OM	1 420 DKK/year
Subscription fee	4 719 DKK/year
Fixed contribution	2 444 DKK/year
Annual electric	16 000 DKK/year
Consumer contribution	7 001 DKK/year
Total:	**31 584 DKK/year**

Tabel 7.3. The annual cost per consumer of the thermonet in the case area of Store Heddinge.Data from Table 7.1.

The annual cost per consumer for Store Heddinge is calculated to 31 584 DKK/year. This cost consists of all costs dependent on heat demand, electricity demand, contribution and subscriptions to the utility company and OM. In the case of upfront consumer payment, the consumer taking out a loan of 2% over a 30 year period in the bank to pay the installation cost of thermonet, this can be added as a extra annual cost. This results in a annual consumer cost of 41 731 DKK/year.

These houses changes their heat solution from natural gas and oil. The annual cost of natural gas boilers is exemplified to 24 200 DKK/year, while oil boilers are exemplified to an annual cost of 34 500 DKK/year [Patursson and Boding, 2025]. For the planned district heat, the annual cost is estimated to be ranging between 20 000-25 000 DKK/year [KLAR FORSYNING, 2024].



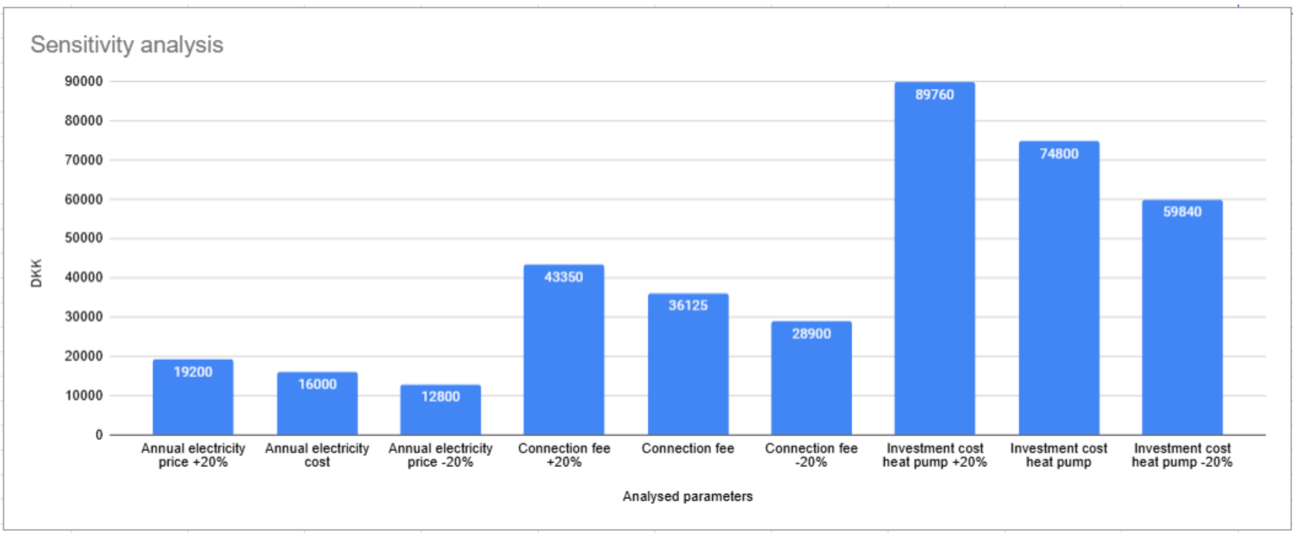
Figur 7.3. The annual heat cost for gas and oil boilers, heat pump cost from two projects, thermonet in Store Heddinge and high and low annual cost for district heating [Rambøll, 2021,p. 18] [PlanEnergi, NA,p. 31] [Patursson and Boding, 2025; PlanEnergi, NA; KLAR FORSYNING, 2024].

As visible from Figure 7.3, these cost results in users of natural gas receiving a higher annual cost, while users of oil is experiencing savings each year. It is also more expensive that the district heat that was planned. The heat pump projects presented in Table 5.9, have an annual costs of 24 666 DKK/year and 13 995 DKK/year [Rambøll, 2021,p. 18], [PlanEnergi, NA,p. 31]. The annual cost of thermonet for Store Heddinge, combined with the observed costs from the project proposals and screenings seen in Table 5.8, showcases an average cost of 25 527 DKK/year. Comparing the cost of thermonet to projects of individual heat sources presented above in Figure 7.3, the thermonet excluding the installation cost loan is higher in all instances other than the oil boiler. This may affect the heat solution chosen, when deciding between the two technologies, as cost can be an important for consumers when choosing a heating solution [Hansen, 2013].

7.3 Sensitivity analysis

In this section a sensitivity analysis of chosen parameters is presented. The sensitivity analysis is conducted due to the expectancy of varying prices for the consumer economics. This can entail varying prices of parameters such as electricity prices, connection fees, and heat pump investment cost. These parameters are chosen based on their categorisation of high uncertainty. The electricity price is chosen based on the cost of how the electricity cost impacts the annual cost for utilising a heat pump as heat solution. It is further chosen due to the electricity price spike in 2021 and 2022 as a result of the war in Ukraine [Energinet, 2023].

These costs are investigated with an addition of 20% and a substraction of 20%. The 20% is based on the observed variation in costs investigated [Damgaard, 2023b; Sustain, 2023c]. The sensitivity analysis can be seen in Figure 7.4.



Figur 7.4. Figure showing the results of the sensitivity analysis including parameters such as electricity prices, connection fees and heat pump investment cost. The cost will vary with 20%

The parameters included in a sensitivity analysis, can vary from project to project, based on what is deemed important. The sensitivity analysis shown in Figure 7.4, showcases that the investment cost in heat pump have the largest impact on the total cost. Followed by the connection fee and electricity cost. From the cost utilised in this project and the difference of 20%, the heat pump investment varies with 14960 DKK, the connection fee varies with a cost of 7 225 DKK, while the electricity price varies with 3 200 DKK.

Discussion 8

This chapter seeks to discuss the key findings and theoretical and methodological aspects of the project. The purpose is to critically reflect on the recommendations for the standardised assessment, the data used and the GIS map of Store Heddinge combined with the calculations of the consumer economics.

8.1 The standardised assessment

The first aspect of the discussion revolves around the recommendations for the standardised assessment presented in Section 5.10. The standardised assessment provides a structure and foundation for introducing a higher degree of transparency and consistency to ensure comparability of thermonet to individual air-to-water heat pumps. While this is much needed, it can be discussed if the assessment presented is mature enough as is or if it at this point could be used as a preliminary framework, which will require further exploration and development to become a finalised tool.

Despite it's potential to identify key economic parameters and structuring them for comparison, the varying local conditions, project designs and implementations can present an argument for refining the standardised assessment. Refinement of the standardised assessment could be done in several ways. one way, which includes the support group mentioned in the theory of strategic niche management, would be to construct several spaces to test the technology in different conditions, to be able to test the standardised assessment before it is adopted in public and possible being used in future projects.

Another way, could be to test the standardised assessment on pilot project or having partners such as municipalities test and verify the assessment. This would ensure the potential of uncovering challenges not identified in an academic setting.

In further reflections upon the standardised assessment, the aspect of directly including the importance and need for sensitivity tests in thermonet projects. On one hand, the sensitivity analysis is a integrated part of the documents investigated in this project, and revolves around variables such as electricity prices, heat demand and investment costs [Damgaard, 2023b,p.20]. Including a sensitivity analysis could strengthen the standardised assessment, as it would underline that changing certain parameters presents different results. This becomes relevant for thermonet projects due to many parameters regarding investment costs, rates, ground work and electricity prices.

On the other hand however, it can be questioned if a sensitivity analysis should be part of a standardised assessment, focusing on creating comparability across projects and heat solutions. Testing different parameters and ranges through a sensitivity analysis can result in lack of comparability. To mitigate the lack of comparability it could be necessary to state guidelines for the sensitivity analysis to ensure a consistency, as is the purpose of establishing the standardised assessment. Based on this, it is argued that the sensitivity analysis is an important aspect of individual projects, but might not be considered a core part of the standardised assessment itself.

Upon looking at the standardised assessment, it is further seen that it does not recommend specific values for each of the parameters, but focus on defining the units that the values should be presented in. This was due to the project proposals and screenings only having one project realised. This is the project of Silkeborg. Several projects states that specific data is based on experiences from previous projects [Østergaard et al., 2021,p. 15][PlanEnergi, 2023,p. 12][WSP, 2023,p. 6].

It could be argued that these projects could have potential for directly stating values for the parameters, however this is not the case of this project. In addition to this it could be argued that directly stating values for all future projects, based on the data from three is not necessarily something that can be relied on. For few specific parameters, such as interest rate and lifespans, a value based on a combination of the projects and external sources has been recommended. Approaching the standardised assessment this way, reflects on the decision of prioritising the comparability aspect, rather than try to specify values, as these are specific to the individual projects. Including the standardised units, the standardised assessment acknowledges the individuality of the projects, while ensuring comparability.

In regards to this, it could be argued that limiting the standardised assessment to presenting units, could potential limit its potential in decision making. This aspects does dependent on who the intended user of the standardised assessment is. In the situation of consultants are specified as users, the exclusion of specific values can potentially make it difficult to determine if the values gathered for a project is similar to that of other projects, or if the cost is an outlier. This would make it possible to keep the cost of thermonet more stable, than if all projects are made differently without the possibility of comparison. Despite this, it would be difficult at this point to create a standardised assessment which includes ranges of values. This is due to the current projects not being comparable. Making these projects comparable is a task that would require thorough insight to each project to obtain transparency in the costs and what they cover. Further it would require to conduct calculations in order to present the values in the specified units. At this point, it is not expected to be done, firstly due to the rather large task, but secondly, who should be responsible for the task?

8.2 Data considerations

This section will discuss the limited data insight affecting the standardised assessment and Analysis 3, as well as the use of COHEAT map parameters in Analysis 1.

8.2.1 Limited insight in data

The data used in constructing the standardised assessment and conducting the calculations in analysis 3, stems from the projects proposals and screenings introduced in Section 4.3.3. A key challenge in both analysis 1 and Analysis 3 is the limited availability of detailed data.

Large quantities of the data utilised in analysis 3, is based on estimations and averages from the project proposals and screenings, of which most are not realised. The only realised project the project group received is that of Silkeborg. Furthermore, data was received from The Danish Energy Agency. This data showcases results from their own calculations regarding the installation cost of thermonet compared to other solutions such as individual air-to-water heat pumps. These results, seen in Table 3.1, shows two costs for thermonet. One based on an average of 19 budgets, while another depicts the cost of a realised project.

The calculations and data from the Danish Energy Agency, shows a discrepancy of 131 500 DKK between average price of non-realised projects and the example of a realised project [The Danish Energy Agency, 2025g]. The Danish Energy Agency does not specify which project the realised thermonet is, making it impossible to identify the reason behind the high cost. Are there location specific factors that naturally lead to higher prices? It is impossible to say, as the underlying project budget is not disclosed This highlights that there could be an uncertainty in using data from non-realised projects.

Another aspect concerning the data from The Danish Energy Agency revolves around the access to documents that the group obtained. The data did not reveal how the installation cost calculations had been performed, only the underlying assumptions. This was the case even though the calculations were specifically requested and the Danish Energy Agency state that full disclosure had been given [The Danish Energy Agency, 2025c,d].

The access to documents did give the project group 13 thermonet project proposals and screenings, listed in Appendix 4. However these materials carry data uncertainty, based on the Danish Energy Agency had to consult the affected parties before releasing them. This was to ensure nothing harmful or otherwise damaging to the companies was shared [The Danish Energy Agency, 2025f]. Consequently, data or knowledge may have been withheld and are therefore unavailable for use in the standardised assessment or in Analysis 3. This may undermine the data foundation for the standardised assessment and the calculations in analysis 3. Nevertheless, the assessment draws on as many projects as possible, which limits the impact of any missing information. Furthermore, it remains debatable how much data and knowledge were removed from the screenings and project files, as these should not have contained anything harmful.

8.2.2 COHEAT parameters

The COHEAT map utilised in analysis 2 to create the parameters to identify what areas are suitable for thermonet, is created to determine areas for district heat [COHEAT, 2023a,p. 5]. It directly states that: *"The purpose of this guide is to help municipal heating planners pinpoint areas [...] that could be supplied by district heating [...]. The guide also presents alternative collective heat supply solutions [...] which circumstances each option is most appropriate."* [COHEAT, 2023a,p. 5].

The parameters were originally developed for district heating, although they also touch upon other collective heat supply solutions. The parameter analysis in Section 6.2 shows that these do not fit thermonet as is, and must be adapted before they can be used to find suitable thermonet areas.

In addition, it becomes clear in the analysis of Stevns Municipality that the parameters analysis 2 finds to be appropriate for thermonet, are not valid for all areas. This is based on the case area of Stevns Municipality, not having access to district heating, is seen as a local condition, resulting in some parameters becoming redundant[Stevns Municipality, 2025a]. It is therefore not possible to set any general parameters for which areas that are suitable for thermonet, other than the 40 meter between houses. While general parameters might streamline nationwide assessments, the work with Stevns Municipality in relation to the COHEAT map, demonstrates that local conditions have a big impact on parameters relevancy.

Ignoring local conditions can disqualify or misjudge an areas thermonet potential. This highlights how challenging it is to create general parameters for suitable thermonet areas.

8.3 Relevance of reinstating parameters from GIS analysis

In the GIS analysis, it was stated that several parameters from COHEAT, would not be relevant for Stevns Municipality. This was based on the fact that the district heating potentials was proven non-feasible and therefore withdrawn, The parameters evaluated not relevant for Stevns Municipality was those of the number of houses and the heat density. Based on this, it could be questioned if the process of identifying areas with potential for implementation of thermonet could be transferred to other municipalities in Denmark on a broader scale.

One one hand it has been proven that the parameters, excluding heat density and number of houses, can be used in determining areas for implementing thermonet. This means that in a broader perspective, the process could be used. This is due to the GIS analysis excluding houses not expected to be connected, such as houses with already establised heat pumps, buildings with no heat demand and holiday houses. Additionally, the analysis includes the parameter regarding distance between houses, to limit the cost of each consumer through the pipe costs. All these considerations are necessary to reflect upon and take into consideration when establishing thermonets, and would therefore be transferable.

On the other hand is the question that if the areas identified for thermonet, aligns with the requirement set of COHEAT for areas with district heating potential, wouldn't district heating be implemented? This is relevant due to most municipalities having district heating companies, as a contrast to Stevns Municipality. Upon further reflection, it could be considered if the limitations on the number of houses and the heat density should be reapplied, when looking on a broader scale. This adds another question of, if the limitations of houses and heat density should be added in municipalities with district heating, why do some projects have up to 1100 houses? These considerations leads to the option of being able to use the process of locating thermonet projects on a broader scale, and if those same areas further proves potential for district heating, a feasibility study could determine what heat solution to implement.

8.4 GIS and calculation considerations

In the GIS analysis it is seen that the last house on Lipkesvej is not included in the polygon and the further analysis of calculating the consumer economics. As a result, it was excluded from the consumer economic calculations in Analysis 3. This decision was based on the predefined parameters of a maximum distance, which the house did not fulfill due to its location more than 40 meters away from the nearest neighbor. However, this highlights a central dilemma in planning: Should strict parameter based selection be prioritised over real world practicalities? In a real implementation, the household may as well choose to participate, especially if the benefits (such as collective investment and cheaper operation) outweigh the additional costs. This brings into question whether parameter based exclusion risks overlooking economic feasible participants and thereby underestimates the potential scale of a project.

Figur 8.1. Map showing the identified two extra geothermal pipe for the 17th house and extra borehole. Created by the project group using data from [Aalborg University, 2022].

To reflect this, the calculations were revised to include the 17th house, see on Figure 8.1, updating the required pipe lengths and total heat demand. This resulted in a need for additional pipe length and an additional borehole, increasing the total number from 8 to 9. Adding the 17th house decreases installation costs per consumer by approximately 1800 DKK. This is not a significant decrease, and shows that adding the last house will positively impact the installation cost per consumer. This leads to a broader discussion on how flexible or rigid the area selection should be, particularly when moving from theoretical analysis to real world implementation. A strictly GIS-based model offers clear boundaries and objectivity, but may not reflect the social or behavioral dynamics that influence participation in community energy solutions. Therefore, future assessments may benefit from scenario based analysis, where both idealised and more inclusive layouts are tested to understand all of the economic and technical consequences.

Had it been the other way, resulting in a increase of the installation cost per consumer, it would then raise the question that, even if it might be "good practice" to offer the last house to be included, would the cost difference exclude the offer? Further, it could be discussed that if the 16 original houses have already accepted the project of thermonet at a lower cost, some houses may retract their support for the project. This is due to the mentioned cost being an important factor when deciding or planning on a new heating solution. The consumer economics calculated for Store Heddinge is already more expensive that the air-to-water heat pump project proposals from Table5.9. It questions much more expensive the thermonet be, before consumers chose air-to-water heat pump over thermonet?

8.5 Is thermonet worth it?

In Chapter 7.2 the consumer economics regarding total installation and annual consumer cost was calculated. These calculations showed that the total installation cost for thermonet was more expensive than those for air-to-water heat pumps. The annual consumer cost was also higher that all other alternative individual heat sources, except oil boiler. This shows that for the case area in Store Heddinge is thermonet not a economic feasible alternative to keeping the existing gas boilers or installing new air-to-water heat pumps. To understand how the parameters electricity prices, connection fees, subscriptions fees and fixed contribution could impact the annual consumer cost. This analysis showed that to make thermonet cheaper and make it more competitive to gas boilers and air-to-water heat pumps, a lower electricity price, lower fees and a smaller house makes thermonet cheaper for the consumer on a annual basis. All of this make sense, however as mentioned in the standardised assessment section a sensitivity analysis could be a part of it. This is because that the price This could beside what is in analysis 3 also contain, different geothermal pipe costs, heat pump cost as these have a large impact on the cost of the annual cost per consumer.

The case area of Store Heddinge is, as mentioned earlier, one of the areas that was originally planned to receive district heating before those plans were withdrawn [Stevns Municipality, 2025a]. This means that the thermonet does not have to compete with district heating as a heat source. In theory, this should give thermonet an advantage, as it is the only collective heating solution available for the area. However, this does not seem to have an impact, since it is still a more expensive solution compared to individual systems.

It could be argued that the case area of Store Heddinge actually is ideal for thermonet, as the heat density is high enough to be considered for district heating, but district heating was dropped due to high costs. Thermonets often present themselves as a cheaper alternative because they use uninsulated pipes, making them significantly less expensive than district heating, as mentioned in Section 2.2. This is mainly due to the higher efficiency of ground source heat pumps connected to a thermonet compared to air-to-water heat pumps.

Since the investment and annual costs are not lower than for air-to-water heat pumps, it could be argued that the higher efficiency could lead to lower annual electricity costs. However, it is debatable whether this yearly saving is large enough to justify the significantly higher investment costs. In fact, this argument quickly falls apart. The annual electricity cost for the thermonet in Store Heddinge is 16 000 DKK/year, while the air-to-water heat pumps from Table 5.9 are 11 457 DKK/year for

PlanEnergi and 5 448 DKK/year for Rambøll [Rambøll, 2021,p. 18][PlanEnergi, NA,p. 31]. So, the annual electricity cost for the thermonet is clearly much higher than for heat pumps.

However, it should be noted that the electricity prices for the air-to-water heat pumps seem relatively low compared to what is typically reported online. One source estimates that with an electricity price of 2.4 DKK/kWh, the annual electricity cost is 13 790 DKK/year for an air-to-water heat pump and 12 590 DKK/year for a ground source heat pump [Gravesen, 2025]. These values are closer to the calculated cost for the thermonet in Store Heddinge. Even when comparing with these more realistic online figures, it remains debatable whether an annual saving of 1 650 DKK is enough to justify the significantly higher investment cost of a thermonet.

8.6 Impact on the Danish energy system

Lastly, the impact of thermonet on the Danish energy system will be reflected upon. Thermonet is based on low temperatures, close to the ground temperature of 5-8 degrees and can based on this have a significant role in the future Danish energy system. This is especially in areas where the traditional district heating is not feasible. In these areas the strategy normally revolves around individual air-to-water heat pumps. Air-to-water heat pumps are reliant on aspects such as electricity and heavily affected by the fluctuating outside temperatures. These aspects are able to affect the efficiency of the heat pump, especially in winter.

In contrast to the air-to-water heat pumps, thermonet provides a more stable and in periods higher input temperature to the ground source heat pump. This affects the efficiency (COP) of the heat pumps and can thereby reduce the overall electricity consumption for each household [Indeklima, NA], compared to the installations of individual air-to-water heat pumps. As a result of this, thermonet can contribute to reducing the pressure on the electricity grid. This is important when the Danish electricity grid has to undergo expansions [Ministry of Climate and Utilities, 2024]. Further this becomes valuable considering the electricity produced in Denmark is not 100% renewable [The Danish Energy Agency, 2024]. By limiting the electricity demand needed from the heat pumps through thermonet, is can be possible to help avoid the challenges in peak load hours, where fossil fuels might be utilised in supplying the needed electricity. This can be the case of cold winter days.

This approach further aligns with the purpose of the Heat Supply Act (§1, Stk. 2), which states that "the planning of the heat supply should aim to promote the combined production of heat and electricity as much as possible-[The Ministry of Climate, Energy, and Utilities, 2024a]. By mitigating the electricity demand and integrating various energy sources, the technology of thermonet supports this statement.

Reducing the demand for electricity through the implementation of thermonet, could free up capacity in the grid and provide stability. This would contribute to the need of expanding the electricity grid. It would still be necessary to do, but might reduce some of the pressure. In addition to this, thermonet supports the integration of several types of energy sources, which might go unused, Different types of heat sources for thermonet was introduced in Section 2.2 and Figure 2.3. Based on the above, thermonet offers an important alternative to the individual air-to-water heat pumps through offering energy efficiencies locally, lessening the pressure on the Danish electricity grid and support the future transition towards a decarbonised energy supply in Denmark.

Conclusion 9

The aim of this project was to answer the research question of: *What parameters are needed to develop a standardised assessment for thermonet, and how can GIS analysis be used to identify a suitable area to calculate the consumer economics in Stevns Municipality?* In order to answer this, three sub-questions was made and answered.

In answering the first sub-question of *"How can the parameters concerning consumer economics used in thermonet project proposals and screenings, contribute to creating standardised assessment?"*, parameters used in thermonet screenings and project proposals were collected and analysed. These included technical, organisational, and economic parameters such as heat demand, investment costs, electricity prices, and the lifespan of components. A categorisation of these parameters into three levels of uncertainty showed that several cost related parameters such as connection fees and geothermal installation costs are related to high uncertainties. This is due to a discrepancy in values and units that highlights the necessity for developing a standardised assessment. The standardisation is done to ensure thermonet projects can be compared internally to other thermonet projects and to alternatives such as individual heat pumps. This standardised assessment is presented as a table containing recommended parameters for conducting a consumer economic calculation of thermonet systems. Only the parameters lifespan, payback time and real interest rate include recommended values or ranges. The remaining parameters are accompanied by recommendations regarding the units in which their values should be presented in. The standardised assessment can be seen in the end of the conclusion in Table 9.1.

In answering the second sub-question of *"How can GIS analysis, based on predefined parameters from COHEAT and newly identified parameters, be applied to identify suitable areas for implementing a thermonet systems in Stevns Municipality?"*, a GIS analysis was used to integrate predefined parameters from COHEAT with newly identified ones. The parameters from COHEAT included heat density, connection percentage, large consumers, pipe length, number of buildings, distance bewteen houses and distance to district heating plants. Where only distance between houses was used to find the case area of Store Heddinge. The additional parameters identified and utilised in finding the case area, was excluding holiday houses, due to to assumption of them having a low heating demand which is centered around the summer period. Lastly the houses already having heat pumps or electric heat was also excluded, due to them not wanting to invest further. Based on the exclusion of district heating in Stevns Municipality, several parameters were deemed unnecessary.

This mean that the identification of potential areas for thermonet, were not limited by number of houses and a specific heat density. However these could be reconsidered for another areas, where district heating is considered feasible. Based on a representative heat density for the areas in Stevns Municipality, an area of 16 houses in the city of Store Heddinge was chosen.

In answering the third sub-question of *"How can the previous sub-questions and the resulting analysis be combined into consumer calculations for the selected case area in Stevns Municipality?"*, the standardised parameters and selected case area were combined to perform consumer economic calculations. These calculations included estimates of installation and annual costs per household. The results revealed that while thermonet offers collective benefits and potential efficiency advantages over air-to-water heat pumps, it remains a more expensive heat solution. This is due to the high initial investment required for geothermal boreholes and a two pipe network.

In addition to the consumer economic analysis a sensitivity analysis showed that changes in electricity prices, connection fees, and borehole costs significantly affect the overall economic feasibility. The sensitivity analysis was conducted by including a difference of ±20% compared to the used values. Through the sensitivity analysis, it was observed, that connection fee has the largest impact of the total cost, followed by the cost of electricity.

In conclusion, a standardised assessment for thermonet was conducted. This is essential for enabling a structured and transparent comparison of parameters internally for thermonet project, but additionally for comparison of air-to-water heat pumps. GIS analysis is shown to be a useful tool for identifying suitable areas by combining parameters with local map data, as shown in Store Heddinge. The assessment helps guide planning, but current consumer costs show that thermonet is still relatively expensive. This suggests that in order for thermonet to go from a niche technology to an established technology in the market, there is a need for lowering costs, and more political support to make it a more realistic option compared to air-to-water heat pumps.

Recommended parameters for a standardised assessment for thermonet		
Technique:		
Parameters	**Unit**	**Note:**
Electricity Price	DKK/kWh	
SCOP	-	COP can be used if SCOP is not available
Heat Pump Investment	DKK	
Heat Pump Lifespan	Years	
Heat Pump OM	DKK/years	
Geothermal Pipe Cost	DKK per house and total	
Geothermal Boreholes	DKK	
Plastic pipes Lifespan	Years	50–100 years
Geothermal pipelines and Boreholes Lifespan	Years	60-70 years
Heat Pump Payback Time	Years	20 years
Geothermal Pipes Payback Time	Years	30 years
Organisation:		
Parameters	**Value and/or unit**	**Note:**
Subscription fee	DKK/year	All projects include subscription fees. For transparency, all subscription fees should be listed.
Fixed contribution	DKK/year	
Consumer contribution	DKK/MWh	
Real interest rate	%	2%
Connection fee	DKK/per house	
Late connection fee	DKK/per house	
Yearly Electric Cost	DKK/year	Based the electricity price, size of heat pump and COP/SCOP
Product:		
Parameters	**Value and/or unit**	**Note:**
Yearly cost per house	DKK/year	
Installation cost per home	DKK	
Annual cost – large consumer	DKK/year	

Tabel 9.1. Table showing recommended parameters, units and data for the standardised assessment for thermonet

Litteratur

Aabenraa Fjernvarme (2025). 5 fordele ved fjernvarme. https://www.aabenraa-fjernvarme.dk/priser/hvorfor-vaelge-fjernvarmec/fordele-ved-fjernvarme/. Accessed: 06-03-2025.

Aalborg University (2022). Varmeatlas 2022. https://energymaps.eu/?page_id=33. Accessed: 17-03-2025.

Amalo (NA). COP-Faktor: Forståelse og Betydning for Din Varmepumpes Effektivitet. https://www.amalo.dk/viden/cop. Accessed: 14-05-2025.

Askgaard, H., Olesen, R. S., and Andersen, R. (2021). Store heddinge. https://trap.lex.dk/Store_Heddinge. Accessed: 14-04-2025.

BDO (2019). Varmeforsyning- regler og vejledninger 2019. , Dansk Fjernvarme. Accessed: 05-05-2025.

Bisp, H. and Boding, J. T. (2025). Sådan fungerer fjernvarme til opvarmning af din bolig. https://www.bolius.dk/saadan-fungerer-fjernvarme-til-opvarmning-af-din-bolig-17059. Accessed: 06-03-2025.

Brinkmann, S. and Tanggaard, L. (2010). *Kvalitative metoder- En grundbog*. Hans Reitzel.

Brooke, A. (2025). Modelling inflation. https://www.fe.training/free-resources/project-finance/modelling-inflation/? Accessed: 22-05-2025.

Bygningsreglementet.dk (2023). Energiforsyningsanlæg i tilknytning til bygninger (§ 299 - § 328). https://www.bygningsreglementet.dk/historisk/br18_version6/tekniskebestemmelser/12/krav/325_327/#2e96502c-7dcf-4921-999d-496844fbb7f8. Accessed: 03-05-2025.

Christensen, P., Müller, J., and Remmen, A. (1984). *Samfundets teknologi - teknologiens samfund*. Number ISBN: 87-7351-226-5 in Paperback. Systime A/S.

COHEAT (2023a). *Delrapport 1- Vejledning til grøn omstilling af varmeforsyningen - delrapport 1*. https://coheat.eu/groen-omstilling-af-varmeforsyningen/. Downloadet: 20-02-2025.

COHEAT (2023b). Potentialeområder syddanmark. https://coheat.eu/resultater-og-dokumentation/kort/. Accessed: 20-02-2025.

COHEAT (2025). Om coheat. https://coheat.eu/om-coheat/. Accessed: 20-02-2025.

Cussen, M. P. (2025). Interest Rates Explained: Nominal, Real, and Effective. https://www.investopedia.com/articles/investing/082113/understanding-interest-rates-nominal-real-and-effective.asp. Accessed: 02-05-2025.

Damgaard (2023a). Varmeforsyning i Jystrup. Accessed: 22-04-2025.

Damgaard (2023b). Varmeforsyning i Thurø By. Accessed: 22-04-2025.

Danfoss (2025). Hvordan fungerer fjernvarme? https://www.danfoss.com/da-dk/about-danfoss/our-businesses/heating/knowledge-center/heating-school/how-does-district-heating-work/. Accessed: 06-03-2025.

Danmarks Statistik (2022). Fortsat aftagende inflationen. https://www.dst.dk/da/Statistik/nyheder-analyser-publ/nyt/NytHtml?cid=39966. Accessed: 05-05-2025.

Danmarks Statistik (2023). Aftagende inflation for syvende måned i træk. https://www.dst.dk/da/Statistik/nyheder-analyser-publ/nyt/NytHtml?cid=45052. Accessed: 05-05-2025.

Danmarks Statistik (2025a). Fald i inflationen. https://www.dst.dk/da/Statistik/nyheder-analyser-publ/nyt/NytHtml?cid=49618. Accessed: 05-05-2025.

Danmarks Statistik (2025b). Forbrugerprisindeks (2015=100) efter enhed, varegruppe og tid. https://www.statistikbanken.dk/pris111. Accessed: 05-05-2025.

Dansk Fjernvame and PlanEnergi (2023). Delrapport 2-Vejledning til Grøn omstilling af varmeforsyningen. , COHEAT. Accessed: 20-02-2025.

Dansk Fjernvarme (2025a). Fakta om fjernvarme. https://danskfjernvarme.dk/om-os/fakta-om-fjernvarme. Accessed: 06-03-2025.

Dansk Fjernvarme (2025b). Fjernvarmeordbogen. https://danskfjernvarme.dk/viden-vaerktoejer/fjernvarmeordbog. Accessed: 06-05-2025.

Dansk Fjernvarme and PlanEnergi (2023). Bilagsrapport Vejledning til Grøn omstilling af varmeforsyningen. , COHEAT. Accessed: 18-03-2025.

Energinet (2023). Året der gik 2022 i el- og gassystemerne. https://energinet.dk/media/amyd0exe/aaret-der-gik-2022-i-el-og-gas.pdf. Accessed: 22-05-2025.

Energistyrelsen (2023). Klimastatus og –fremskrivning 2023 (KF23): Husholdninger. , ENergistyrelsen. Accessed: 17-03-2025.

Eon (2025). Ectogrid increases energy efficincy resuing excess heat in combination with heat pumps. https://heatpumpingtechnologies.org/annex47/wp-content/uploads/sites/54/2019/02/annex-47ectogrid.pdf. Accessed: 27-02-2025.

esri (2025a). Arcgis pro. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview. Accessed: 11-04-2025.

esri (2025b). Buffer (analysis). https://pro.arcgis.com/en/pro-app/latest/tool-reference/analysis/buffer.htm. Accessed: 11-04-2025.

esri (2025c). Gis-software. https://www.geoinfo.dk/Vi-tilbyder/arcgis-software?gad_source=1&gclid=CjwKCAjwtdi_BhACEiwA97y8BMmE_rsMlJDPW5z_UTjBuPNVBs4ljmC9W5hXCZlQpPheRuTTEQ4uIxoC0l8QAvD_BwE. Accessed: 11-04-2025.

esri (2025d). Join features (geoanalytics). https://pro.arcgis.com/en/pro-app/latest/tool-reference/big-data-analytics/join-features.htm. Accessed: 11-04-2025.

esri (2025e). Multipart to singlepart (data management). https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/multipart-to-singlepart.htm. Accessed: 11-04-2025.

esri (2025f). Select features by location. https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/select-features-by-location.htm. Accessed: 11-04-2025.

esri (2025g). Select features using attributes. https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/select-features-using-attributes.htm. Accessed: 11-04-2025.

esri (2025h). Summarize within (analysis)). https://pro.arcgis.com/en/pro-app/latest/tool-reference/analysis/summarize-within.htm. Accessed: 11-04-2025.

Fernando, J. (2024). Annual Percentage Rate (APR): What It Means and How It Works. https://www.investopedia.com/terms/a/apr.asp. Accessed: 02-05-2025.

Fjernvarme Fyn (2025). Målerbidrag. https://www.fjernvarmefyn.dk/priser/overblik/forbrugspriser/saadan-er-din-regning-sammensat/maalerbidrag/. Accessed: 06-05-2025.

Flyvbjerg, B. (2010). Fem mistforståelser om casestudiet. , University of Oxford. Accessed: 15-04-2025.

Frederiksen, S. (2025). Opvarmning af sommerhuse. https://www.bolius.dk/opvarmning-af-sommerhuse-18558. Accessed: 29-04-2025.

Frederiksen, S. and Werner, S. (2013). *District heating and cooling*. Number ISBN: 978-91-44-08530-2 in Paperback. Studentlitterature.

FUTURE (2023). Håndbog om termonet. , Gate21. Accessed: 24-02-2025.

Gate21 (2025). Sådan arbejder vi. https://gate21.dk/saadan-arbejder-vi/. Accessed: 03-04-2025.

Geels, F. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31:1257–1274.

Geels, F. (2005). The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology Analysis & Strategic Management*, 17:445–476.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, 1(1):24–40.

Gravesen, N. (2025). Hvad koster en varmepumpe i drift? Alt om varmepumpens forbrug. https://www.greenmatch.dk/blog/2014/11/varmepumpens-effektive-stroemforbrug. Accessed: 16-05-2025.

Hansen, F. M. (2013). Danskerne stopper med at udskifte gasfyr med varmepumper: 'det går den forkerte vej. https://ing.dk/artikel/danskerne-stopper-med-udskifte-gasfyr-med-varmepumper-det-gaar-den-forkerte-vej. Accessed: 14-05-2025.

Hjortbak, G. (2025). Written questions to Grethe Hjortbak from PlanEnergi. Received: 27-02-2025, can be seen fully in appendix 2.

IFAN (2022). Typer af plastrør. https://dk.ifan-plast.com/info/types-of-plastic-pipes-76428907.html. Accessed: 04-05-2025.

Indeklima, D. (NA). Hvornår er en varmepumpe mest effektiv og hvornår stopper den med at fungere? https://dk-indeklima.dk/hvornaar-er-en-varmepumpe-mest-effektiv-og-hvornaar-stopper-den-med-at-fungere/. Accessed: 16-05-2025.

Jespersen, J. (2021). *Videnskabsteori i samfundsvidenskaberne*, chapter 5- Kritisk realisme- Teori og Praksis, pages 171–191. Samfundlitteratur. Editor = Lars Fuglsang, Poul Bitsch Olsen og Klaus Rasborg.

KLAR FORSYNING (2024). Fjernvarme i stevns: Sådan bliver prisen for tilslutning. https://klarforsyning.dk/nyheder/fjernvarme-stevns-saadan-bliver-prisen-tilslutning. Accessed: 14-04-2025.

KLAR Forsyning (2024). Klar forsyning anbefaler at stoppe udrulningen af fjernvarme i stevns. https://klarforsyning.dk/nyheder/klar-forsyning-anbefaler-stoppe-udrulningen-fjernvarme-stevns. Accessed: 14-04-2025.

Kvale, S. (2003). *Interview, En introduktion til det kvalitative forskningsinterview*. Hans Reitzels Forlag.

Kvale, S. and Brinkmann, S. (2014). *Interview : det kvalitative forskningsinterview som håndværk*. Hans Reitzel Forlag.

Lund, H., Østergaard, P. A., Nielsen, T. B., Werner, S., Thorsen, J. E., Gudmundsson, O., Arabkoohsar, A., and Mathiesen, B. V. (2021). Perspectives on fourth and fifth generation district heating. *Energy*, 227:120520.

Lysgaard, M. (2020). Fjernvarmeselskaberne kan levere 44 procent af den nødvendige CO2-reduktion. https://danskfjernvarme.dk/maerkesager/groen-varme/groen-varme-til-alle? Accessed: 06-03-2025.

Mankins, J. C. (1995). Technology readiness levels. , Office of Space Access and Technology NASA. Accessed: 17-05-2025.

Mathiesen, I. H. and Volckmar-Eeg, M. G. (2022). En abduktiv tilnærming til institusjonell etnografi – et bidrag til sosiologisk kunnskapsutvikling. https://www.scup.com/doi/10.18261/nost.6.1.2. Accessed: 17-05-2025.

Metro Therm (2025a). Brugsvandsvarmepumper. https://www.metrotherm.dk/produkter/varmepumper/brugsvandsvarmepumper. Accessed: 24-02-2025.

Metro Therm (2025b). Termonet skal hjælpe i yderområderne. https://www.metrotherm.dk/videnscenter/termonet-skal-hjaelpe-i-yderomraderne. Accessed: 24-02-2025.

Ministry of Climate, E. and Utilities (2024). Bred aftale sikrer hurtigere og mere effektiv udbygning af elnettet. https://www.kefm.dk/aktuelt/nyheder/2024/dec/

bred-aftale-sikrer-hurtigere-og-mere-effektiv-udbygning-af-elnettet. Accessed: 16-05-2025.

Ministry of Climate, Energy and Utilities (2021). Bekendtgørelse af lov om klima- LBK nr 2580 af 13/12/2021. https://www.retsinformation.dk/eli/lta/2021/2580. Accessed: 06-03-2025.

Mitchell, A. J. (2018). A review of mixed methods, pragmatism and abduction techniques. *The Electronic Journal of Business Research Methods*, Vol. 16, No. 3:s. 103–116.

Møllgaard, P., Halkier, B., Kristensen, N. B., Heiselberg, B. B. P., Knudsen, M. T., Münster, M., Richardson, K., and Thorsen, B. J. (2025). Statusrapport 2025. , Klimarådet. Accessed: 18-05-2025.

Müller, J. (2013). An other path: Local systems of innovation in the south. *Forum for Development Studies*, 40:235–260.

nettopower (2025). Hvad er nord pool. https://www.nettopower.dk/nyheder/hvad-er-nord-pool/. Accessed: 02-05-2025.

nPRO (2022). 5gdhc network in achern. https://www.npro.energy/main/en/5gdhc-networks/5gdhc-districts/achern-arealnetz-lott. Accessed: 27-02-2025.

nPRO (2025). Fifth generation district heating and cooling. https://www.npro.energy/main/en/5gdhc-networks. Accessed: 27-02-2025.

Nykredit (2025). Renteprognose. https://www.nykredit.dk/dit-liv/bolig/kurser/renteprognose/. Accessed: 05-05-2025.

Næss, P. (2015). Critical realism, urban planning and urban research. *European Planning Studies*, Vol. 23, No. 6:s. 1228–1244.

OK (2025a). Hvad koster en luft til vand-varmepumpe? https://www.ok.dk/privat/produkter/varmepumper/vi-tilbyder/luft-til-vand-varmepumper/priser. Accessed: 06-05-2025.

OK (2025b). Leasing af varmepumpe. https://www.ok.dk/privat/produkter/varmepumper/oekonomi/leasing. Accessed: 06-05-2025.

OK (2025c). Tips til valg af varmepumpe – hvilken varmepumpe skal du vælge? https://www.ok.dk/privat/produkter/varmepumper/viden/valg-af-varmepumpe. Accessed: 17-05-2025.

Patursson, T. and Boding, J. T. (2025). Det koster de forskellige opvarmningsformer. https://www.bolius.dk/det-koster-de-forskellige-opvarmningsformer-887. Accessed: 20-05-2025.

PlanEnergi (2019). Afsluttende rapport om kold fjernvarme. , PlaneEnergi. Accessed: 03-04-2025.

PlanEnergi (2023). Projektforslag for etablering af fjernvarmeforsyning (termo- net) i fjelsted-harndrup. Recived: 14-04-2025.

PlanEnergi (2024). Budget sent to the project group. Recived: 27-02-2025.

PlanEnergi (2025). Vores ydelser. https://planenergi.eu/da/arbejdsomraader/. Accessed: 03-04-2025.

PlanEnergi (NA). Projektforslag for etablering af transmissionsledning, samt konvertering af forsyningsområde i Thyregod. , PlanEnergi. Accessed: 07-05-2025.

Poulsen, S. E. (2025a). Interview with Søren Erbs Poulsen. Date: 20-02-2025, see appendix 1.

Poulsen, S. E. (2025b). Søren Erbs Poulsen. https://www.linkedin.com/in/s%C3%B8ren-erbs-poulsen-47b3971a/?originalSubdomain=dk. Accessed: 21-05-2025.

Rambøll (2021). Projektforslag fjernvarmeudbygning i gladsaxe. , Rambøll. Accessed: 07-05-2025.

Realkredit Danmark (2025a). Hvad er et realkreditlån? https://rd.dk/kundeservice/faq-and-guides/faq/hvad-er-et-realkreditlaan? Accessed: 05-05-2025.

Realkredit Danmark (2025b). Renteprognose. https://rd.dk/kurser-og-renter/renteprognose. Interest rate forecast as of April 30. Accessed: 05-05-2025.

René Kemp, J. S. and Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, 10(2):175–198.

Schot, J. and Geels, F. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, 20:537–554.

Schramm, W. (1971). Notes on case studies of instructional media projects. , Stanford University. Accessed: 12-03-2025.

Segal, T. (2024). Term Loan Definition, Types, and Common Attributes. https://www.investopedia.com/terms/t/termloan.asp. Accessed: 02-05-2025.

Sjelle ByVarme A.m.b.a (2024). Takstblad, spørgsmål og svar. https://byvarme.sjelle.dk/wp-content/uploads/2024/05/Takstblad-2024-05-23.pdf. Accessed: 04-05-2025.

Sorknæs, P., Nielsen, S., Skov, I. R., Lund, H., and Nielsen, F. D. (2024). Forundersøgelse af grundlag og muligheder for udnyttelse af overskudsvarme fra power-to-x i region hovedstaden - baggrundsrapport. , Aalborg Universitet. Accessed: 30-04-2025.

Stevns Municipality (2025a). Kommunalbestyrelsen følger anbefaling og stopper fjernvarmeprojekt. https://stevns.dk/nyheder/2025/januar/kommunalbestyrelsen-foelger-anbefaling-og-stopper-fjernvarmeprojekt. Accessed: 24-03-2025.

Stevns Municipality (2025b). Nøgletal: Fakta om Stevns Kommune. https://stevns.dk/om-kommunen/noegletal. Accessed: 17-03-2025.

Sustain (2022). Projektforslag vedrørende udbygning af Termonet i Årøsund. Accessed: 01-04-2025.

Sustain (2023a). Lokal varme screening for Frederikssund Kommune- Dalby. Accessed: 14-04-2025.

Sustain (2023b). Lokal varme screening for Frederikssund Kommune- Lyngerup. Accessed: 14-04-2025.

Sustain (2023c). Projektforslag vedrørende etablering af termonet i Sjelle By. Accessed: 01-04-2025.

Sustain (2023d). Termonet screening for Lejre Kommune- Ejby, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2023e). Termonet screening for Lejre Kommune- Gevninge, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2023f). Termonet screening for Lejre Kommune- Kirke Sonnerup, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2023g). Termonet screening for Lejre Kommune- Kirke Såby, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2023h). Termonet screening for Lejre Kommune- Vester Såby, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2023i). Termonet screening for Lejre Kommune- Øm, December 2022 – januar 2023. Accessed: 01-04-2025.

Sustain (2025a). Energigreonvering oversigt. https://sustain.dk/energirenovering-oversigt/. Accessed: 01-04-2025.

Sustain (2025b). Om os. https://sustain.dk/om-os/. Accessed: 01-04-2025.

Svane, S., Hansen, F. L., Søgaard, U., and Bock, U. (2023). Stor opbakning til termonet i Årøsund. https://jv.dk/debat/stor-opbakning-til-termonet-i-aaroesund. Accessed: 16-04-2025.

Teknologisk Insitut (2025). COP, SCOP, EER og SEER. https://www.teknologisk.dk/ydelser/cop-scop-eer-og-seer/39744. Accessed: 08-05-2025.

Termonet Danmark (2022). Grøn Forretningsplan for udbredelse af termonet i Region Sjælland 29. marts 2022- Implementering af termonet i DK2020 planer. https://termonet.dk/wp-content/uploads/2022/09/Notat-Implementering-af-termonet-i-DK2020-planer-Vers.-2.0.pdf. Accessed: 07-03-2025.

Termonet Danmark (2024). Termonet danmarks høringssvar vedrørende forslag til lov om ændring af lov om varmeforsyning og lov om planlægning (j. nr. 2024 - 7178). https://termonet.dk/wp-content/uploads/2024/08/20240819-Hoeringssvar-til-Lov-om-aendring-af-varmeforsyningsloven-fra-Termonet-Danmark.pdf. Accessed: 25-02-2025.

Termonet Danmark (2025a). 20240617 Fjernvarme baseret på termonet og overfladenær geotermi, infoark, v1.0. https://termonet.dk/wp-content/uploads/2024/06/2_20240617-Fjernvarme-termonet-overfladenaer-geotermi-infoark-v1.0.pdf. Accessed: 09-04-2025.

Termonet Danmark (2025b). Artikel om fjernvarme baseret på termonet i vridsløsemagle. https://termonet.dk/artikel-om-fjernvarme-baseret-paa-termonet-i-vridsloesemagle/. Accessed: 24-02-2025.

Termonet Danmark (2025c). Medlemmer af foreningen termonet danmark. https://termonet.dk/medlemmer/. Accessed: 16-04-2025.

Termonet Danmark (2025d). Ofte stillede spørgsmål. https://termonet.dk/foreningen/ofte-stillede-spoergsmaal/. Accessed: 07-02-2025.

Termonet Danmark (2025e). Projekter. https://termonet.dk/projekter/. Accessed: 27-02-2025.

Termonet Danmark (2025f). Termonet. https://termonet.dk/. Accessed: 24-02-2025.

The Danish Agency for Data Supply and Infrastructure (2025a). Administrativ inddeling til præsentationsformål. https://dataforsyningen.dk/data/4847. Accessed: 11-04-2025.

The Danish Agency for Data Supply and Infrastructure (2025b). INSPIRE - BBR bygninger og boliger. https://dataforsyningen.dk/data/3829. Accessed: 01-04-2025.

The Danish Assessment Agency (2025). BBR's forvaltningsområde. https://bbr.dk/bbr. Accessed: 17-05-2025.

The Danish Energi Agency (N/A). Termonet-priser. Recived: 01-04-2025.

The Danish Energy Agency (2019). Vejledning i brugerøkonomisk kontrolberegning. , Energistyrelsen. Accessed: 07-05-2025.

The Danish Energy Agency (2022). Energistyrelsens vejledende udtalelse om, hvorvidt kold fjernvarme/termonet er et kollektivt varmeforsyningsanlæg efter varmeforsyningsloven. Accessed: 25-02-2025.

The Danish Energy Agency (2023). Data, tabeller, statistikker og kort energistatistik 2023. , Energistyrelsen. Accessed: 06-03-2025.

The Danish Energy Agency (2024). Rekordhøj produktion af sol- og vindkraft sidste år. https://ens.dk/presse/rekordhoej-produktion-af-sol-og-vindkraft-sidste-aar. Accessed: 16-05-2025.

The Danish Energy Agency (2025a). Ansvar for energien. https://ens.dk/. Accessed: 16-04-2025.

The Danish Energy Agency (2025b). Danske nøgletal 2023. https://ens.dk/analyser-og-statistik/noegletal-om-energiforbrug-og-forsyning. Accessed: 06-03-2025.

The Danish Energy Agency (2025c). Delafgørelse 1 om aktindsigt. Recived: 10-04-2025.

The Danish Energy Agency (2025d). Delafgørelse 2 om aktindsigt. Recived: 14-04-2025.

The Danish Energy Agency (2025e). Mail with data. Received: 21-03-2025, can be seen fully in appendix 3.

The Danish Energy Agency (2025f). Telephone call with the Danish Energy Agency. Made: 02-04-2025.

The Danish Energy Agency (2025g). Termonet og sædvanlige, individuelle varmepumper – forudsætninger for brugerøkonomiberegninger. Recived: 14-04-2025.

The Danish Environmental Protection Agency (2018). Standardisering som redskab i den grønne omstilling. , The Danish Environmental Protection Agency. Accessed: 17-05-2025.

The Danish Government (2022a). 250 millioner kroner til mere grøn varme. https://regeringen.dk/nyheder/2022/250-millioner-kroner-til-mere-groen-varme/. Accessed: 19-05-2025.

The Danish Government (2022b). Klimaaftale om grøn strøm og varme 2022- et grønnere og sikrere danmark, danmark kan mere ii. , The government (Social Democrats), Venstre (The Liberal Party), Socialist People's Party, Social Liberal Party, Red-Green Alliance, Conservative People's Party, Danish People's Party, Liberal Alliance, The Alternative, and Christian Democrats. Accessed: 19-05-2025.

The Danish Meteorological Institute (2024). Sammendrag af vinter 2023-2024. https://www.dmi.dk/fileadmin/user_upload/Afrapportering/Seasonsammendrag/Sammendrag_2024_vinter.pdf. Accessed: 05-03-2025.

The European Central Bank (2025). Inflation and consumer prices. https://www.ecb.europa.eu/stats/macroeconomic_and_sectoral/hicp/html/index.en.html. Accessed: 19-05-2025.

The Investopedia Team (2024). Real Interest Rate: Definition, Formula, and Example. https://www.investopedia.com/terms/r/realinterestrate.asp. Accessed: 02-05-2025.

The Minister of Climate, Energy, and Utilities (2024). Svar til spørgsmål 16. https://www.ft.dk/samling/20241/lovforslag/L78/spm/16/svar/2098535/2954931/index.htm?utm. Accessed: 25-02-2025.

The Ministry of Climate, Energy, and Utilities (2024a). Bekendtgørelse af lov om varmeforsyning. https://www.retsinformation.dk/eli/lta/2024/124. Accessed: 25-02-2025.

The Ministry of Climate, Energy, and Utilities (2024b). Høring 24-10-2024. https://www.ft.dk/aktuelt/webtv/video/20241/kef/td.2077715.aspx?as=1. Accessed: 24-02-2025.

Union, T. E. (2025). European Climate Law. https://climate.ec.europa.eu/eu-action/european-climate-law_en. Accessed: 18-05-2025.

VVS eksperten (2025). Virkningsgrad på varmepumper. https://www.vvs-eksperten.dk/virkningsgrad-varmepumpe. Accessed: 05-03-2025.

Vöge, M. (2025). Varmepumpe priser: Installation, service og drift. https://1komma5.dk/varmepumpe/varmepumpe-priser. Accessed: 14-05-2025.

Wavin (2022). Pe 100 standard. https://wavin.com/dk/da/s/C01_F002_S007/PE-100-standard. Accessed: 05-05-2025.

Wavin (2025). 100 års levetid for pp og pe kloakrør underbygges af rapport. https://blog.wavin.com/da/100-aars-levetid-for-pp-og-pe-kloakroer. Accessed: 05-05-2025.

Westergaard, M. M. and Lock, R. (2024). Termonet kommer borgere uden fjernvarme til undsætning. https://www.energiforumdanmark.dk/viden-og-temaer/08-06-2023-termonet-kommer-borgere-uden-fjernvarme-til-undsaetning/. Accessed: 07-02-2025.

WSP (2023). Fremtidens varme i hjortsvang. Recived: 14-04-2025.

WSP (2025a). Hvad vi laver. https://www.wsp.com/da-dk/hvad-vi-laver. Accessed: 23-04-2025.

WSP (2025b). Ydelser. https://www.wsp.com/da-dk/ydelser. Accessed: 23-04-2025.

Yin, R. K. (2009). *Case study research and applications: : design and methods*. Sage Books.

Yin, R. K. (2014). *Case study research and applications: : design and methods*. Sage Books.

Østergaard, D. S., Worm, J., and Jensen, L. L. (2021). Future termonet. , Gate21. Accessed: 20-03-2025.

Appendix 1

Transcription of interview with Søren Erbs Poulsen This section presents the transcription of the interview with Søren Erbs Poulsen and the project group.

Søren Erbs Poulsen (SOEB)

Project group (AAU)

The transcription is translated with ChatGPT.

The transcription is seen below.

AAU Just to start, we want to introduce ourselves. We are a 10th semester study group from Aalborg University, and for our thesis, we would really like to explore more about thermonets and what they actually are. Right now, we're very interested in understanding when thermonets versus individual solutions, like individual heat pumps, make sense in different contexts. At the moment, we're very much in the initial phase where we're trying to gather as much information as possible. Before we move on to our questions, could you introduce yourself and talk a bit about what you work with? Just for clarity.

SOEB My name is Søren, and I'm the research leader here at VIA in our energy and climate program. I'm a geologist by training and earned my PhD from the University in 2009. I initially worked with deep geothermal energy, which is becoming a bit of a success story for traditional district heating—if I may say that. I came to VIA for a permanent position, which meant I had to leave deep geothermal and instead began working with shallow geothermal energy—initially in relation to traditional individual systems like ground source heating. But we carried out some projects exploring what happens if you connect people through a pipe network to utilize shallow geothermal energy the same way ground source heating works here in Denmark. Definitions vary, but if you look at the EU Commission, they define geothermal as energy in the ground from the surface and downwards. So, I refer to all of it as geothermal. In these projects, we discovered several benefits commonly associated with district heating that can also be achieved when people are connected through a network to use shallow geothermal. For instance, simultaneity—meaning the installations needed in the ground to deliver energy to consumers become smaller when people are connected, because of these simultaneous usage patterns. And the possibility of delivering cooling through the same network is also exciting and something we explored in our projects. So, when comparing the establishment of individual ground source systems versus thermonets, we can say with complete certainty that thermonets are more advantageous. They're cheaper for households. The question you'll probably be exploring is whether to go with air-to-water heat pumps or thermonets.

AAU Yes.

SOEB It has become a bit of a battleground between different interests, and these economic calculations can often be shaped depending on what assumptions are made—about efficiencies, electricity prices over the next 30 years, etc. So it becomes easy to cast doubt on how reliable socio-economic analyses really are because of all the uncertainties. My philosophy is that we should choose the most energy-efficient solutions. That should be our guiding star. And the EU has a principle that we must select the most efficient options. Thermonets are better than air-to-water because of their higher efficiency. We know this from research. Studies on the efficiencies of air-to-water heat pumps versus ground source heat pumps (used in thermonets) show that the latter are significantly more efficient, use much less electricity, and place less strain on the power grid. So, focus on thermodynamic efficiency—without the costs going completely out of control. That's a good way to choose the right solutions. Right now, I have five ongoing projects and just finished a project where we implemented a thermonet for new buildings that provides both heating and cooling. It's fully instrumented with energy and electricity meters. Determining real-world heat pump efficiency is tricky. If you ask manufacturers, you get numbers that are often based on lab tests with little to do with reality. We want to measure actual performance and bring empirical data into the conversation. That's been hard with thermonets—we really want to get these data out into the open so we can have a more informed discussion.

AAU That sounds great. I hear you call the system a "thermonet." Is that what it's called in Denmark? Because we've also seen it referred to as 5th generation district heating, and low or ultra-low.

SOEB Yes, there are many terms used. In Germany it's one thing, in the UK they call it "network heat pumps," and in the U.S. they also say "TEN" (thermal energy network). We call it "termonet," some use "thermonet"—there are so many terms. Some call it 5th generation district heating. Personally, I think that's a poor term because it's hard to define something entirely new based on four previous generations. I've never really understood that definition. Your supervisors Peter and Brian are also puzzled by the whole generational concept. I see it as unnecessary to mix the two. Thermonets are fundamentally different from district heating with insulated pipes. The most principal difference is that district heating uses insulated pipes, while thermonets use uninsulated ones. The reason for using uninsulated pipes is because the temperatures are so low that you can also absorb energy through the distribution network. It's a whole different paradigm and technology. So part of the challenge is giving it the right name—and getting people to understand what it actually is. Even those working with it seem a bit confused.

AAU So we're not the only ones, then.

SOEB Exactly. But basically, we shouldn't get too hung up on definitions. We should look at whether the technology solves problems—and thermonets undoubtedly do.

AAU You mentioned you recently completed a new thermonet. The ones listed on your website—are those the only ones in Denmark, or just the ones you've been involved with?

SOEB I'm currently finalizing a review paper summarizing Danish thermonets. We have info on 14, but I believe there are about 17—we just lack details for the last few, so it's hard to include them. We do have some knowledge, but when we dig into it, we realize we actually know very little—especially about how they perform. That's what I'm trying to address in my projects by instrumenting them with energy and electricity meters. Real data from actual systems—not estimates from manufacturers. We have a project in Silkeborg with measurements, plus our own system here, and maybe a few others. It's a mixed picture, which is typical of immature technologies. Some systems perform well, as expected. Others don't, due to various technical or practical missteps. I have an overview of them—it's in review right now. We're battling with one of the reviewers, but it will be published sometime this year for sure.

AAU We've been trying to find out what different thermonet projects exist and which technologies they use—just for our own understanding.

SOEB I can give you a quick rundown. Maybe I can send a list, but you can also compile one yourselves. A typical thermonet solution in Denmark delivers only heating—similar to district heating. That might be more tradition than necessity. I'd say roughly half of the systems use boreholes—what we'd call geothermal boreholes. Others use horizontal loops. One project, in Mageløse, uses a remediation borehole used to pump up water due to groundwater contamination. That water contains a lot of thermal energy, which is used in a thermonet to supply 30 homes. There's also a project using spiral boreholes about 5 meters deep, in Rungsted.

AAU What does the future hold?

SOEB The future is more balanced systems—we see that abroad, and they work very well. Early research shows that if you regenerate the ground (i.e., replenish it with excess heat in summer from solar panels or wastewater), you can maintain good performance and reduce the number of boreholes required, which are expensive. In Hornsyld, at our live lab, we're doing exactly that—recharging the ground. The research clearly shows this improves overall economy. In Austria, it's a legal requirement that ground energy use be net-zero. In Vienna, there's a large thermonet that's recharged using air-to-water heat pumps in the summer.

AAU Yes.

SOEB That system runs really well with efficiency ratios around 5 for heating. The idea is to treat the ground more like a battery than just an energy source. That's the future perspective.

AAU You mentioned that thermonets can also be used for cooling. How does that work in practice? From what we've researched, it seems like cold water can be circulated through floor systems, for example?

SOEB Yes. It depends on the type of building. Most new buildings have ventilation systems, so you can start by placing cooling coils in them. We conducted a cooling test using something called energy piles—ground exchangers embedded in foundations—at Rosborg High School. They had cooling coils in the ventilation system, and we ran a passive cooling test in the summer of 2018. That means we didn't use a heat pump—we just circulated the cold geothermal fluid and observed the cooling effect. We had a cooling output of around 40–50 watts per square meter. The maximum room temperature was 23.5°C, while reference rooms were 4–6°C warmer. In the auditorium, which had less solar gain, we cooled it down to 18°C, which was uncomfortably cold. When cooling through ventilation systems, you avoid condensation issues, because those systems always include drip trays connected to drains. That's not always the case when cooling via the floor, where condensation can become a problem if cooled too much. We're working on a model that combines both: ventilation provides immediate cooling, while the floor system continuously extracts heat from the building mass day and night during warm periods. This benefits both the thermonet operator—because more energy is extracted—and the user. Especially in new Danish buildings, which we know tend to overheat. And when I say passive cooling, I mean highly energy-efficient cooling. At Rosborg, we had an Energy Efficiency Ratio (EER) of around 25—compared to 2–4 for traditional air conditioning systems. So it's a very effective way to cool.

AAU Okay.

SOEB And keep in mind—this is seasonal thermal storage. The heat doesn't just disappear into the atmosphere—it's stored in the ground.

AAU Can you walk us through the journey from idea to completed thermonet? How does it typically start, and who manages the process?

SOEB Sure. There's been a political process about how to handle thermonets under the Danish Heat Supply Act. Now, they've been removed from that law—so they are fully commercial now.

AAU Yes.

SOEB So now there's room for commercial players to step in. Thermonets are incredibly easy to establish in new developments during the construction phase, and also very, very inexpensive. They can solve both heating supply and issues with overheating. So in a commercial market, it will typically be a private actor—if we start with that. There are various models for how it can be delivered. If you look abroad, the successful ones are companies like Kensa in the UK. Take a look at their website—they're doing something interesting. What's very important, as with many other green technologies, is that you have a business model where the company owns the infrastructure—and also takes the risk of establishing it—while simply selling energy to the customer. So the customer doesn't own the infrastructure, especially not what's underground. They might own the heat pump and be responsible for it, but that's not an especially good model. It's better if someone owns all the installations and just sells energy to the customer, like in district heating. It's the same model used in deep geothermal energy—the so-called "buying energy at the garden gate"model. The district heating company has no risk, owns no infrastructure, and just buys the energy. That model also works well for thermonets, because the capital investment is large—something most people can't just pay upfront. Spreading the cost over time makes it easier to justify. That's probably the model we'll see going forward: commercial players targeting new developments. Once the market matures, they might target the next customer segment, a bit like Tesla did. And maybe one day it will be so streamlined that they can reach oil-heated villages with existing buildings—without relying on the Danish Heat Supply Act.

Before this political process, there was a lot of uncertainty. First the Danish Energy Agency said one thing, then they said something else. It was a pretty terrible process—the technical level was very low. I accessed public records and could see who the advisors were. They were really fumbling in terms of understanding the technology. You don't need to quote me on that—but it wasn't good. There were some projects where the district heating companies did the installation. In Silkeborg we have a demo project, and then there's Vridsløsemagle in Høje Taastrup.

AAU Right.

SOEB In that model, they also own the heat pumps—everything, including the underground infrastructure. But that's not a model we'll likely see in the future. So it might be more interesting for you to focus on the commercial path for this type of solution.

AAU You mentioned that both district heating companies and private actors install thermonets. We've seen district heating systems with as few as 50 connected houses. Where is the cutoff? Why not use thermonets instead of district heating for just 50 houses? Do you know?

SOEB Yes, I've heard about the 50-house figure. For example, X (a utility) operates with a threshold of 500 houses before they even consider a district heating project. So what the real number is, I'm not sure. But at that size, you can explore the different alternatives and their economic consequences—and you typically choose the cheapest solution based on your assumptions, which can be reasonable or not. One thing to keep in mind with thermonets is the technical lifespan of the pipes. PE pipes have a lifespan over 100 years—something we know from water supply systems. That gives them longer depreciation periods, though you can't always account for that today. So you could end up with an asset that still has value in 70 years, even after 30 years of operation—and how to capitalize on that today is a challenge. But it might be appealing to investors or companies that like the idea of owning an asset that continues generating income far into the future.

AAU How many houses are usually connected to a thermonet? We've had some trouble finding that.

SOEB The smallest one in Denmark connects 3 houses. The largest connects 71. There are larger systems abroad.

AAU We've been searching online and haven't found any clear requirements for installing a thermonet. Does there have to be a minimum number of houses? Because we've seen examples with as few as 3. Is heat density important? Total heat demand? Distance from district heating? Or how far apart can the houses be?

SOEB Distance definitely matters. The cost of digging and laying the distribution network gets expensive quickly.

AAU Yes.

SOEB It's good to have an anchor customer—like a sports hall or a boarding school—something in the village that consumes a lot of heat and gives you some predictable income. We know that matters. But it will always be project-specific. Digging costs matter. Is it a paved area? Is it easy to access? How difficult is it to install heat pumps in the houses? What systems are already in place? It's very project-dependent. I don't know if you've seen the video—we made a design tool for this.

AAU Yes.

SOEB You can use that to get an idea of the infrastructure required. If you combine it with GIS, you can also assess where paved areas are and how costly the project might be. That's likely the way forward—similar to how we already assess district heating projects.

AAU You previously touched on the Danish Heat Supply Act. We saw a hearing on thermonets, where Brian Vad Mathiesen from Aalborg University also presented. They raised the question of when it makes sense to use individual solutions versus thermonets or district heating. It seems like no one really knows specifically when each solution is best. Can you help clarify that?

SOEB No, I don't think that analysis has been done yet.

AAU No.

SOEB And if I had done that analysis, some people would go completely bananas—because then you'd have assumed certain efficiencies for air-to-water heat pumps, and people who favor those would do their own calculations with different assumptions. It just ends up being mudslinging. My take is: choose the technology that is thermodynamically the most efficient.

AAU Yes.

SOEB And if it's not significantly more expensive than the alternatives—which nothing suggests thermonets are—then that's what we should do. Because we can never calculate whether it will be economically advantageous. Who knows what electricity prices will be in 30 years? No one. But we do know they can get really high, and we can be more robust against price hikes by choosing something that's energy efficient. Thermonets can be documented to be significantly more energy efficient than individual air-to-water heat pumps, which also come with other issues—noise, visual impact. No one finds those outdoor units particularly attractive. Personally, I'm a big fan of collective supply systems, including district heating. I think it's excellent. I don't see why we should use individual solutions when houses are located close to each other. It's much better to create collective systems—whether it's district heating or thermonets doesn't matter to me.

AAU You mentioned the noise issues with air-to-water. But in our comparison of thermonet projects, most used individual heat pumps—not central ones. Why is that? We initially thought central heat pumps would be the better solution since you'd only have one noise source.

SOEB Yes, but thermonet heat pumps don't have an outdoor unit. That's the noisy part.

AAU That's true.

SOEB So inside your house, there's a box that's basically silent—more like having a fridge. It's usually placed in a utility room. You can technically have a central heat pump in a thermonet system, but then you'd need other branches in the network—it's a bit tricky to explain.

AAU Yes.

SOEB But you can imagine a setup where a central heat pump draws thermal energy from the thermonet and delivers it through individual units in homes. But in most cases, we want the supply network to also deliver energy—so we stick with uninsulated pipes all the way to the consumer. When we do that, we need the heat pump to be located at the end user. The idea is to have a system driven by demand, rather than supply-driven like in district heating, where hot water just sits in the pipe waiting to be used. With a thermonet, energy is generated when there's demand. That's why it's essentially a loss-free system.

AAU We saw some projects that mix central and individual heat pumps. If you use a central heat pump, how far away can it be from homes? Would the pipes then have to be insulated?

SOEB Which projects are those with central heat pumps? I'm not familiar with all of them in Denmark.

AAU Rugmarken, Stage D, in Roskilde Municipality. They have a central heat pump.

SOEB Rugmarken? Over in Jyllinge? Or Tune?

AAU Yes.

SOEB They have distributed heat pumps. It's a slightly unusual solution over there. They only supply space heating and use the ventilation exhaust for domestic hot water production, as far as I know.

AAU Okay.

SOEB You should double-check what's what in that project.

AAU Yes.

SOEB (shows PowerPoint slides)

SOEB In our definition, the thermonet is just the distribution network. It doesn't include the heat pumps or what's connected to it. As shown here, the thermonet can go all the way to the consumer. But you can also have a section with a central heat pump supplying heat, similar to traditional district heating.

AAU Yes.

SOEB This figure tries to define what's what in a thermonet-based system. That's why we call it "district heating based on thermonets."

AAU Yes. So when you have a central heat pump producing heat for the houses, you need insulated pipes, right?

SOEB Yes, and that's illustrated here by the red and yellow colors. That's where you have higher temperatures and therefore need insulation to deliver the heat.

AAU Yes.

SOEB To the consumers who just have units, not individual heat pumps.

AAU But that setup doesn't seem very common, does it?

SOEB No, I think there are a few examples, but it's not what we generally see.

AAU No, because that kind of defeats the purpose of thermonets being cheap and simple to install. That was a bit surprising to us.

SOEB Yes, it complicates things and complications usually increase costs—no matter how good you are at managing them.

AAU Exactly.

SOEB And those homes without heat pumps—if they needed cooling, well, too bad. They should have chosen a different model with individual heat pumps.

AAU Yes.

SOEB But many existing buildings in Denmark don't have significant cooling needs. That's mostly relevant for new buildings.

AAU Yes. When you do these economic calculations on whether a thermonet is financially viable. . .

SOEB Yes, I don't do those myself. Advisors usually handle that.

AAU Is there anyone with a lot of experience that you'd recommend we talk to?

SOEB Yes, I would talk to Sustain.

AAU Yes.

SOEB Sustain Solutions—they've done a lot of screenings in Denmark. They're not full socio-economic evaluations, but they're still solid.

AAU Yes.

SOEB They've screened several villages in Denmark. There's also PlanEnergi—they've done quite a bit on thermonets. I believe WSP and other advisors have experience too.

AAU Great. We also read that if a thermonet system has a capacity over 0.25 MW, it falls under the Heat Supply Act. What does that mean? Does it mean you can get financial support?

SOEB No, I don't think so, because it's specifically written out—that it doesn't fall under it.

AAU Okay, yes. So does that mean commercial companies handle it instead?

SOEB Yes, and you can't really call it support. What you get under the Heat Supply Act is a loan guarantee and access to Kommunekredit (a low-interest public financing option). That used to be a big advantage due to the low interest rate. The main benefit is that if the project fails, the municipality guarantees it and writes off the debt. Without that, you might rely on consumers for guarantees—if their properties have enough value. That's how it worked in places like Rungsted, where people have enough money. But the issue is that without the Heat Supply Act, it's hard to reach rural villages with limited financial means. They get left behind in the green transition and are worse off than city residents with access to district heating.

AAU Yes.

SOEB They're clearly worse off. They have to buy their own system—usually an air-to-water heat pump—and deal with maintenance and replacement. It's not as convenient as district heating, where if something breaks, someone else fixes it.

AAU Yes. So ideally, we'd want to bring these systems to more disadvantaged areas in Denmark?

SOEB Yes, from an altruistic societal perspective, absolutely. We could create value for people in rural villages—places already struggling with depopulation, low property values, and other challenges.

Unfortunately, that's not something there's political support for right now—and that's just how it is.

AAU In our summary, we also saw that most established thermonets use geothermal boreholes.

SOEB Yes.

AAU And from what we can tell, that's the most expensive solution.

SOEB Yes.

AAU So why use it? Is it the most efficient, or is it just what people are used to—so they copy it without exploring new technologies?

SOEB Good question. Often it's just that—if you want to use horizontal loops, you need enough land to lay them out, like plowing them in. That's a much cheaper solution. There's a factor of about 10 in cost per meter between boreholes and horizontal loops.

AAU Yes.

SOEB Boreholes are better in that they have a more stable temperature, so the number of watts you can extract per meter is higher—but not 10 times higher. In terms of cooling, boreholes also offer better potential.

AAU Okay.

SOEB These are the kinds of considerations that can go into a spreadsheet and be used to calculate whether it's a good or bad idea.

AAU Yes.

SOEB In the cases where boreholes have been used, they've somehow made the economics work.

AAU I saw one place used a "thermo-road."?

SOEB That's ours—that's our thermonet.

AAU Yes. Do you think that will be the future? It seems smart killing two birds with one stone.

SOEB Maybe. It's a sector-coupled solution, which by nature is complex.

AAU Yes.

SOEB But our experience from the full-scale demo project, now with real consumers connected, was that both the development consultant and the contractor were totally comfortable building it. They didn't see it as rocket science—it wasn't a big problem to build. And I like the idea that when you're digging infrastructure, you do everything you can at once. The idea behind the thermo-road is also to handle stormwater in the road itself—able to retain two 100-year events in terms of rainfall and flooding. We keep hearing that flooding is a growing issue—just look at what happened in Vejle.

AAU Yes.

SOEB I'm not saying the thermo-road could've solved that, but it could help with stormwater retention. The challenge is that current legislation doesn't allow you to replace surface stormwater basins with underground solutions like this. So legally, we can't roll this out on a large scale yet. But the business case really depends on being allowed to remove those aboveground basins—because that frees up land. And the further into urban areas you go, the more valuable that land is. If you take the thermo-road as an example: normally, for local stormwater management, you'd have to dedicate an entire lot for a stormwater basin. But if you could avoid that, you could build a house instead.

AAU Yes.

SOEB The housing company GS Bolig, which owns that area, could then earn rental income, and the municipality would get tax revenue. Right now, you just have a dead area that generates no value and only costs money. In our calculations, it's clear: for the thermo-road concept to work, we have to be allowed to replace stormwater basins. Danish water regulations say you can't just discharge into a recipient—you have to treat the water with BAT (Best Available Technology), which currently means basins. But we had a PhD project with Aalborg University that showed the gravel filter in our road solution cleans water just as well—if not better—than traditional stormwater basins. As for the energy side of things, we're already digging the road anyway. We made the roadbed slightly deeper and added pipes. Installing those PE pipes costs next to nothing. So the resulting heat price is lower than all other alternatives—including traditional district heating.

SOEB We're already in the ground there. Laying down these PE pipes costs almost nothing—it's not a big expense. And we've used the heat sources carefully. We have boreholes, we reuse heat from wastewater, and we have pipes in the roadbed. The roadbed stabilizes the asphalt so it doesn't crack. So—is it the future? Maybe. Maybe not.

AAU Back to the geothermal boreholes—you said earlier it's sometimes hard to find information on different technologies used in thermonets. Do you think this lack of information is due to poor knowledge sharing between the parties who might be interested in setting up thermonets?

SOEB At the risk of offending someone—I'd say the level of knowledge in the whole thermonet debate has been shockingly low.

AAU Yes.

SOEB We've tried to be open and share information as best we can—but it hasn't really succeeded. So yes, I think it's largely a knowledge problem. Anytime something new emerges, it's hard—especially when it involves a shift in paradigm. This isn't a total paradigm shift, but it is a new technology that requires understanding of things that people didn't necessarily think about before. One major knowledge gap—even among experts—is what happens underground. So we need to continue educating and informing people. That's why we developed the PyThermonet tool—to simulate these things based on the physical laws that govern heat transfer in the ground. Those laws dictate how the ground behaves—not our opinions.

AAU Yes.

SOEB So the debate has been full of opinions and low on facts.

Another thing I forgot to mention about boreholes: Denmark has many groundwater protection zones. So in many areas, you're not even allowed to drill. Even though there are many projects with boreholes, it's often hard to get permission. And there's growing awareness about protecting drinking water. We constantly see reports in the news about contaminated wells—mostly due to agricultural runoff.

AAU That makes sense. We saw the webinar you shared with us about PyThermonet. It got us thinking—can we access the data or files used in the examples? So people can follow along? Are those available somewhere?

SOEB If you download the repository from GitHub, there are some examples—like from the Silkeborg thermonet.

AAU OK.

SOEB There, you can see how the files are set up and how the system is modeled. And the final report from Silkeborg explains the system in detail. Once you read that, you'll understand how to use the tool and even play around with scenarios. Like: what if we had offered cooling in Silkeborg? How would that affect dimensioning? Could we make the boreholes shorter? What cooling price would we need to break even? For example, district heating is already present on the street there, so it's the cheapest solution—but what if you had income from selling cooling too? That's the kind of thing the tool lets you explore.

AAU Yes.

SOEB And you're welcome to reach out to me or my colleague Karl—he's in the webinar too and explains how to use it.

AAU We also found something from Gate 21. They helped Kalundborg Municipality create an Excel sheet for utility companies to help with design. Do you have access to that?

SOEB Yes—well, no. It's spreadsheet-based. It's really hard to model thermonets in Excel. You can use some rules of thumb, but that's about it. Still, it's good that it exists. You can always compare your Excel output to what you get from more sophisticated tools like Termostat—or even more advanced ones.

For example, Modelica—we've worked with Lund University, who are really good at time-based simulation of these systems. So it's important to double-check Excel models. But it's great that there's a tool that gives you quick estimates.

PyThermonet is also fast—it only takes a few seconds to calculate. But setting up the input is painful if you have a large network—because you have to describe the topology in a text file.

AAU Yes.

SOEB You can imagine how tedious that is?

AAU Yes.

SOEB But I can also say—we're working on a hobby project to generate that input from GIS data. So you'll be able to just draw your network and get quick results.

AAU That doesn't sound bad at all. We also found something called Thermonet Calculator EU.

SOEB Yes.

AAU That one's very simple.

SOEB Yes—it's a physical model, but quite primitive. But with the developments in this field over the past 10 years, we now have very fast and advanced tools. The key is just generating the input efficiently. And that's something we're also working on.

Appendix 2

Translation of the Questions and answers from the project group to Grethe Hjortbak from PlanEnergi

Question: You have three classifications of heat density. Have you considered how to further divide the low-density category to determine when individual solutions versus thermonet make sense?

Answer: No, we have not. We have considered whether it would be possible to create a simple way to rank heating areas, so that in some of the low-density zones, one could identify sections with relatively higher heat density.

Question: What is the heat density threshold for thermonet? (At what point does it no longer make sense?)

Answer: It's hard to say. Our experience shows that the determining factor for whether a project is economically viable is the **length of piping in paved areas**. If pipes can be installed in a grass strip or a football field, for example, then greater distances between houses are acceptable. There is still limited experience with thermonet in Denmark, so we are lacking significant knowledge in this area.

Question: What requirements do you consider when designing a thermonet?

Number of houses? There is a thermonet with only two houses, so there is no minimum limit. Actually, PlanEnergi believes that smaller networks (under approx. 15 houses) are better than large networks, although this has not been thoroughly tested. This is partly because smaller networks can save on pumping power and potentially use a shared pump. Additionally, they require fewer large pipes, and smaller pipes are better at absorbing heat from the ground and are cheaper.

Heat demand? If the heat demand is high, many meters of ground loops will be required, meaning a large land area is needed.

Question: Is there a rule of thumb for how far apart houses can be in a thermonet?

Answer: From the approximately 300 screenings we have conducted, my rule of thumb is that the distance between houses should be under 40 meters if pipes are laid in paved areas (roads, etc.).

Question: For the thermonet projects you have worked on, have you conducted economic calculations? If yes, which parameters do you use?

Answer: We use the best available price estimates. - For example, the heat pump price is based on ground-source heat pumps, as they are fundamentally the same technology. - We add the cost of connection boxes, so the heat pumps can be centrally controlled, benefiting the electricity grid. - Ground loops are designed by hydraulic engineers, and we obtain market prices for installation.

Question: Do you follow an industry standard for these parameters?

Answer: I don't think there is a standard.

Question: How do you see thermonet's role in the future energy system?

Answer: Difficult, that is probably the best word to describe it.

The technology itself is not unknown, but the regulatory framework is problematic. District heating companies won't adopt thermonet because it does not fall under the Heat Supply Act. It has taken several years to clarify this, creating uncertainty around thermonet and making projects more difficult.

Since thermonet is not covered by the Heat Supply Act, municipalities cannot provide financial guarantees, meaning that thermonet projects must be financed under market conditions. This requires finding a bank or other lender, which raises questions about loan interest rates and the portion of the investment that can be financed.

Regarding the energy system, thermonet has clear advantages. Using centralized heat pumps with ground loops helps optimize energy use. Unlike air-to-water heat pumps, which rely on air, thermonet uses the ground as a heat source, reducing the strain on the electricity grid.

This would be especially beneficial on cold winter days, which are often windless and dark times when many individual heat pumps switch to their built-in electric cartridge to supplement heating. Thermonet avoids this issue, leading to better electricity grid utilization and reducing the need for additional power generation capacity, which would otherwise only be used during extreme cold periods.

Question: What is your personal opinion on thermonet?

Answer: I think it has clear societal benefits, particularly because it does not generate noise pollution. I also believe there should be a much greater focus on using ground heat instead of air heat.

Appendix 3

Translation of the mail received by the project group form the Danish Energy Agency

Dear Amalie and Inger,

Thank you for your inquiry. Your thesis sounds very interesting.

New rules concerning thermonets were adopted in December 2024 and came into force on 1 January 2025. Based on your inquiry, I am unsure whether you are referring to the Danish Energy Agency's legal assessment of whether thermonets were covered by the Heat Supply Act up until January 2025, or the political decision regarding the future regulation of thermonets, which constitutes the applicable law from 1 January 2025.

If you have not already done so, I would suggest reading the explanatory notes to the bill that came into effect on 1 January 2025. There you will find descriptions of the technology, previous regulation, and the newly adopted regulation. You can find the proposed bill here.

In particular, the following sections of the bill are relevant to you:

- 1. Introduction
- 2.6. Operations involving decentralised heat production using heat pumps, including on the same terms as affiliated activities for municipalities.
- Explanatory notes to the individual provisions of the bill:
  - Section 1: Nos. 2, 5, and 6
  - Section 3

Additionally, I would refer you to the fact that the topic of thermonets was also discussed during the parliamentary debate. You can find questions and answers from the committee stage [here].

Whether thermonets should be covered by the Heat Supply Act going forward was a political decision. That decision was based on background work, including legal, technical, and economic considerations. This work was initiated through the NEKST working group "favel til gas i de Danske hjem". You can read more about the working group's recommendations here.

As I understand your inquiry, you are interested in gaining insight into the economic considerations that formed part of the political basis for the current regulation of thermonets.

As part of the NEKST work, the Danish Energy Agency reviewed 19 budgets relating to proposed thermonet projects as well as figures from the only recent, large-scale implemented thermonet project (55 connections). All of the mentioned projects concern existing buildings. The 19 budgets relate to projects at 15 locations, as four of the locations had two versions of the budget – one with high and one with low connection rates.

The expected average installation cost per household is approx. DKK 323 000 based on the 15 thermonet project proposals. There is significant price variation: from DKK 178 000 to DKK 451 000. In the realised thermonet project, the budgeted cost was approx. DKK 260 000, while the actual cost came to approx. DKK 454 500 per household. In comparison, the average realised installation cost for an individual ground-source heat pump is approx. DKK 183 000, and for an individual air-to-water heat pump approx. DKK 129 000 per household, according to the latest data from the heat pump subsidy scheme, see Table 3.1.

The high installation cost is primarily due to the requirement for a double-pipe buried network connecting the connected heat pumps to ground loops placed within or outside the residential area. Installing such a network within existing infrastructure – roads, pavements, paths, driveways, street and path lighting, electrical and communication cables, water and sewer lines – is highly expensive, even though the pipes used are cheaper than district heating pipes. An individual air-to-water or ground-source heat pump does not require such a network.

If the above average of budgeted installation costs is used, the calculated annual heating cost of a thermonet is approx. DKK 26 000. If the actual cost from the realised project is used, the annual heating cost is approx. DKK 33 000. In comparison, the calculated heating cost of an individual air-to-water or ground-source heat pump is approx. DKK 17 000–18 000 per year, based on the same assumptions for electricity prices, interest rates, etc. The prices are summarised below in Table 3.1.

Summary of Costs		
	Installation cost per household	**Annual heating cost**
Individual air-to-water heat pump	DKK 129 000	approx. DKK 17 000–18 000
Individual ground source heat pump	DKK 183 000	approx. DKK 17 000–18 000
Thermonet (avg. of 19 budgets)	DKK 323 000	approx. DKK 26 000
Thermonet (realised project)	DKK 454 500	approx. DKK 33 000

Tabel 3.1. The Danish Energy Agency's calculations regarding thermonet, individual air-to-water and ground sorce heat pumps [The Danish Energy Agency, 2025e]

It should be noted that the installation and operating costs for thermonets could potentially be reduced if there is easy access to low-temperature heat, e.g., from wastewater. However, none of the reviewed thermonet projects made use of such a solution, and it remains unclear how often this will be feasible.

At present, 12 thermonets have been established or are under construction in Denmark. As previously mentioned, the Danish Energy Agency is also aware of the 15 proposed thermonet projects, which equate to between 3340 and 4020 potential customers, depending on the connection rate. The number of expected connections per proposal varies from 57 to 1092. The latter is the 10-year projection for the most extensive of the proposals.

Please note that the above calculations were not part of the Danish Energy Agency's legal assessment of whether thermonets were covered by the Heat Supply Act before 1 January 2025. The calculations did, however, form part of the decision-making material for the political agreement behind the bill.

I hope this answers your questions. Please feel free to get back in touch if you have any further queries.

Appendix 4

All the documents received during the project period

The Danish Energy Agency	
Consulting Engineer:	**Project:**
Norsyn	Projekt proposal Sjelle by
Norsyn	Projekt proposal Årøsund
Norsyn	Thurø By
Norsyn	Thurø By appendix
	Overview of the budgets
Sustain	Screening Lyngerup
Sustain	Screening Dalby
Sustain	Powerpoint Lejre Municipality Kirke Såby and Vestre Såby
Sustain	Powerpoint Lejre Municipality Gevinge and Øm
Sustain	Powerpoint Lejre Municipality Ejby and Kirke Sonnerup
Norsyn	Jystrup
WSP	Project proposal Hjortsvang
The Danish Energy Agency	Termonet and conventional individual heat pumps – prerequisites for user economy calculations
PlanEnergi	Project proposal Fjensted-Harnrup

PlanEnergi	
Consulting Engineer:	**Project:**
PlanEnergi	"Budget sent"

Termonet Danmark	
Consulting Engineer:	**Project:**
Sustain	Screening Vester Såby
Sustain	Screening Øm
Sustain	Screening Kirke Sonnerup
Sustain	Screening Kirke Såby
Sustain	Screening Gevinge
Sustain	Screening Ejby
Norsyn	Projekt proposal Sjelle by
Norsyn	Projekt proposal Årøsund
PlanEnergi	Kold Fjernvarme Silkeborg
The Danish Energy Agency	Thermonet prices powerpoint
Norsyn	Appendix 1, cooperate economic calculations Jystrup, table
Norsyn	Appendix 1 - cooperate economic calculations Jystrup
Norsyn	Appendix B, cooperate economic calculations Thurø, table
Norsyn	Appendix B, cooperate economic calculations Thurø, v2
Sustain	Thermonet overview
Termonet Danmark	Access to documents NEKST meeting on termnet 10 October
Teknologisk institut	Thermonet Technical Review 10/10-2023
Termonet Danmark	2023-11-15 Prices for thermonet
NEKST and Termonet Danmark	Background note. Thermonet with comments
Termonet Danmark	Follow-up inquiry regarding L 78 answers to questions 2 and 6
Termonet Danmark	Possible legal issues regarding L 78 in the Danish Constitution and the EU law
Termonet Danmark	Termonet Denmark's consultation response regarding the executive order on costs based on individual heat supply and calculated consumer prices for heat supply companies and methodological note (J. no. 2024-10297)

Table 4.1 continued from previous page

Termonet Danmark	
Termonet Danmark	Termonet Denmark's consultation response regarding supplementary consultation on proposal for an act amending the Heat Supply Act and the Planning Act (J. no. 2024-7178)
Termonet Danmark	Termonet Denmark's consultation response regarding the executive order on the recognition of operating depreciation, etc. (J. no. 2024-10297)
Termonet Danmark	Termonet Danmarks høringssvar vedrørende forslag til Lov om ændring af lov om varmeforsyning og lov om planlægning (J. nr. 2024 - 7178)
Termonet Danmark	Note l Danish Energy Agency - Consequences for the thermal grid within and outside the VFL April 24, 2023
Norsyn, SWECO, NIRAS, PlanEnergi and Sutain	Consultants' comments on thermal network calculations
Ministry of Climate, Energy and Utilities and Termonet Danmark	Pt. 2 - 8. Delivery note - Clarification on regulation of the thermal network with comments
Ministry of Climate, Energy and Utilities and Termonet Danmark	Pt. 2 - 7. Delivery note - Completed analysis work in connection with thermal network
Energy and environment law firm	Memorandum of 23 May 2023 on thermonet and the Heat Supply Act
Termonet Danmark	Review of Rambøll's consultancy on heating supply in Tønning
WSP	Assessment of future energy consumption by converting building heating
Termonet Danmark	Exploratory questionnaire survey
EGEC and REScoop.eu	Re.Open expert hearing on thermonet
Termonet Danmark	2023-11-15 Prices for thermonet with comments
Termonet Danmark	2023-11-15 Prices for thermonet with comments v2