AALBORG UNIVERSITY
STUDENT REPORT

Alternatives for the heat supply in the new urban area Aars West

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Alternatives for the heat supply in the new urban area Aars West

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Abstract:

As the growth in the larger cities within the municipalities are increasing, so is the heat load on the collective heat supply. The increased population in the cities influence the development in the city. The Energy Agreement, 2018, have changed the framework conditions for the municipalities to enforce mandatory connection to new urban areas established after 2019 and forward. This challenges the DH systems, whose current DH network might not be dimensioned to supply the new consumers. This is because they must invest in upgrading measures to ensure the security of supply in these areas which include high investment costs. They will however not have a guarantee that the consumers will connect to the DH system or remain part of the system throughout the depreciation period which are often 20 years or above. Aars city is expanding their city area to the west, where surplus heat factory Dania is located. Hereby it is interesting to investigate ***"How can Aars District Heating ensure the security of supply for the new urban area Aars West from a technical, - business- and socio-economic perspective?"*** to answer this both a hydraulic analysis of the DH network and techno-economic analysis in relation to the production side is investigated. This is done to indicate what alternative that can ensure the security of supply while providing the highest business- and socio-economic value.

Preface

This Master thesis is written by a 4th semester individual in the master's programme of Sustainable Energy Planning and Management at Aalborg University. The Master thesis focuses on applying aspects of theories, methodologies, tools and techniques developed during the studies at the University.

I would like to say a special thank you to my supervisor Steffen Nielsen for proper and structured guidance throughout the thesis. A special thanks to him for being very flexible, mindful and fast to respond to questions related to the thesis and overall problems. I would also like to thank Aars District Heating and especially Kasper Neve, for providing me with data and intel about their current energy system, distribution network, hydraulic knowledge and future expectations in relation to the development in Aars. I would also like to thank COWI A/S Århus hereby Poul Lyngdal-Christensen for providing me with the necessary licence tools to conduct the hydraulic analysis in TERMIS.

Reading guide

Figures and tables are numbered according to the chapter of their appearance. For example, the first figure in Chapter 1, will be numbered 1.1, same applies for tables. Every figure and table in the thesis are provided with a caption, next to the figure number, explaining its content. The equations will have an expanded description of the variables used in the equation underneath. The used abbreviations in the thesis are located on a separate nomenclature list on the next page. When an abbreviation is first introduced in the project, it will be written in full, followed by the abbreviation presented in parenthesis. All EnergyPRO figures will be in Danish and to account for this a Glosery for EnergyPRO figures in Danish is constructed to translate the given values underneath the Nomenclature list. The thesis will use English punctuation rules and character sets in relation to numbering of data.

The literature references are structured by the Harvard method, and therefore will all literature references appear in a parenthesis stating the author's surname, or the website/ organisaations name, if no author appears, and year of publication, an example of this is (Author, Year). The notes will refer to the complete bibliography list in the end of the thesis on page 81, where books are put with author, title, year, publisher and ISBN, and web pages are put with author, title, company name, URL and date. All organisations will be referred to in their native company name in the reference to make sure that their company name is not lost in translation.

Nomenclature

Abbreviations

CHP	-	Combined heat and power
COP	-	Coefficient of performance
DH	-	District heating
HP	-	Heat pump
WCB	-	Wood chip boiler
O&M	-	Operation and Maintenance
NPV	-	Net Present Value
EU	-	European Union
MWh	-	Mega Watt Hours
SCADA	-	Supervisory Control and Data Acquisition
Delta T	-	Temperature difference
CO_2	-	Carbon dioxide
PSup	-	Supply pressure
NPC	-	Net production costs
Alt.	-	Alternative
DKK	-	Danish Kroner

Glosery for EnergyPRO figures in Danish

Modtaget fra Aars Fjernvarme – Heat received from Aars DH

Varmeforbrug - Heat consumption

Affald VV ovn 1 – Waste incineration plant furnace 1

Affald VV ovn 2 – Waste incineration CHP plant furnace 2

Kedel – boiler

Træpille kedel – Wood pellet boiler

Elkedel – Electric boiler

Varmepumpe Dania – Heat pump Dania

Overskudsvarme – Excess heat production unit

Lager kapacitet – Storage capacity

Lagerbeholdning – Storage content

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Dansk resume

Urbaniseringen, folk som flytter fra landområder til byområder, har øget presset på de gamle fjernvarmeværker, som blev etableret ifm. oliekrisen og varmeforsyningsloven for at mindske efterspørgslen på olie i samfundet fra 1960-1980'erne. Byerne bliver udvidet med nye områder, som skal forsynes med varme. Tidligere har kommunen kunne pålægge nye områder at have tilslutningspligt og forblivelsespligt, hvis der ud fra et projektforslag kunne dokumenteres, at den kollektive forsyning var det mest samfundsøkonomisk rentable alternativ. Dette er ikke længere muligt med de nye rammevilkår fra Energiaftalen 2018, som liberaliseret varmesektoren. Dette har øget konkurrencen imellem fjernvarme og individuelle løsninger. Et eksempel på by i vækst er Aars, hvorved byen vokser mod vest. I den vestlige del er en del industri, herunder jernstøberiet Dania, som i dag bortkøler en stor del af deres overskudsvarme. Aars Fjernvarme overvejer om, de skal forsyne Aars Vest med fjernvarme til trods for, at der ingen sikkerhed er for, at alle forbrugerne vil tilslutte sig fjernvarmen. Aars fjernvarmeværk er etableret i år 1955, hvorved det er nødvendigt at undersøge, hvorvidt fjernvarmenettet overhovedet er dimensioneret til at forsyne den nye bydel Aars Vest eller om, de skal geninvestere i opgraderinger i fjernvarmenettet. Med baggrund i de mulige synergier og problematikker tager dette speciale udgangspunkt i følgende problemformuleringen:

"Hvordan kan Aars Fjernvarme sikre forsyningssikkerheden i det nye byområde Aars Vest ud fra et teknisk, virksomhedsøkonomisk- og samfundsøkonomisk perspektiv?"

Til at undersøge forsyningssikkerheden af det nye boligområde er det først nødvendigt at estimere det kommende varmebehov i Aars Vest og dermed belastningen af forsyningsledningen, som grænser op til området. Aars Vest spidslast varmeeffekt vil blive brugt til at ledningsdimensionere distributionsnettet i området medregnet samtidighedsfaktoren. De tekniske alternativer, som undersøges, er udarbejdet i samarbejde med Aars Fjernvarme og Vesthimmerlands Kommune. Dette er gjort for at sikre, at alternativerne kan implementeres, men også at de mest relevante alternativer bliver undersøgt. Der undersøges 7 scenarier med reference og seks alternativer; Reference – ny ledning, Alternativ 1 – overskudsvarme fra Dania ved 65°C og Danpo ledning, Alternativ 2 – Varmepumpe Dania med overskudsvarme på 24°C og akkumuleringstank, Alternativ 3 – Overskudsvarme Dania på 65°C med akkumuleringstank, Alternativ 4 – Danpo ledning med akkumuleringstank, Alternativ 5 – Træflis blokvarmecentral og Alternativ 6 – individuelle luft til vand varmepumper. Aars Fjernvarme har nogle tekniske bestemmelser både til forbrugerne og til fjernvarmenettet for at sikre forsyningssikkerheden i ledningsnettet. Til at sikre at disse bestemmelser overholdes, er der anvendt energisystemanalyser ved brug af Termis, som analyserer hydraulikken og termodynamikken i fjernvarmenettet og EnergyPRO, der kigger på produktionssiden fremfor ledningssiden. EnergyPRO anvender forudsætningerne fundet i Termis til at beregne, hvordan varmebehovet i Aars Vest sikres samt omkostningerne forbundet med varmeleverancen. Denne produktionsfordeling er anvendt for hvert alternativ til at analysere, hvilket alternativ som kan levere den højeste virksomhedsøkonomiske- og samfundsøkonomiske værdi. Her viser den virksomhedsøkonomiske analyse, at kun 2 ud af de 6 alternativer kan sænke varmeprisen og har en positiv nutidsværdi ift. reference systemet. Disse alternativer er Alternativ 1 og 3, hvor Alternativ 3

har den højeste nutidsværdi af de to på 5.078.000 DKK. I den samfundsøkonomiske konsekvensberegning er det også kun Alternativ 1 og Alternativ 3, som kan sænke den samfundsøkonomiske påvirkning ift. referencen. Her giver Alternativ 3 også den laveste påvirkning på samfundet på -72.975.000 DKK. Dette betyder, at Alternativ 3 både har den højeste virksomhedsøkonomiske- og samfundsøkonomiske værdi. Analysen har nogle usikkerheder tilknyttet ift. varmebehov, investeringsomkostninger, brændsel- og elpriser og diskonteringsrenter både virksomheds- og samfundsøkonomisk. For at belyse indflydelsen af usikkerhederne på resultatet, så er der udarbejdet en følsomhedsanalyse. Følsomhedsanalysen viser, at Alternativ 3 stadigvæk har den højeste virksomheds- og samfundsøkonomiske værdi i de testede følsomheder. Virksomhedsøkonomien er dog meget afhængig af, hvilket prisleje Aars Fjernvarme skal betale for overskudsvarmen ved Dania, fordi hæves prisen til 75 DKK/MWh, så forsvinder rentabiliteten ved både Alternativ 1 og 3 under forudsætning af overskudsvarmeafgiften er 90 DKK/MWh. Overskudsvarmeafgiften afhænger af om virksomheden er certificereret eller ej, og hvis de har opnået certificeringen, reduceres afgiften til 36 DKK/MWh.

Fjernvarmens rolle i fremtiden bør også diskuteres i et mere holistisk perspektiv, da den antages at have en vigtig rolle i stabiliseringen af elmarkedet ved den stigende mængde af vedvarende energi, som tilføres energisystemet frem mod 2050. Fjernvarmen tilføjer fleksibilitet til energilagring og en mere effektiv udnyttelse af de forskellige ressourcer, som der er tilgængelige i energisystemet. Disse energikilder herunder overskudsvarme, affald og biomasse er nødvendige for ikke at overbelaste el systemet til sammenligning med at flere konvertere til elvarme. Fjernvarmens rolle kræver dog, at den hele tiden udvikler og effektivisere sig. Dette er på baggrund af, at selvom større varmepumper er mere effektive, så skal den højere effektivitet kunne gøre op for varmetabet i nettet for at kunne konkurrere med hhv. individuelle varmepumper. Dermed hvis varmetabet herunder temperaturniveauet i fjernvarmenettet ikke reduceres i fremtiden, kan fjernvarmeværkerne have svært ved at konkurrere med de individuelle løsninger i nye områder, hvis bolig er dimensioneret til lavere temperaturer. Anvendelsen af hhv. varmepumper, solvarme, geotermi og overskudsvarme mv. kræver også at forbrugernes temperatur niveau sænkes, da disse opererer bedst ved mellem 55-65^{o}C i fremløb.

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1. Introduction

1.1 Danish national energy goals and the role of district heating

The Danish Government have established a long-term goal about being independent upon fossil fuels in 2050, meaning that Denmark must produce enough renewable energy to cover the total Danish energy consumption (Regeringen, 2019). To reach this goal The Danish Parliament agreed upon the "Energy Agreement" in 2018, where and the district heating (DH) sector must convert to be based on 90% other energy resources than natural gas, oil and coal in 2030. Thus, the DH systems who currently utilize coal, natural gas and oil must consider new CO_2 neutral solutions (Energi-, Forsynings-, og Klimaministeriet, 2018). The DH sector presents a high potential in relation to reaching the 2050 goals both technically and organisationally, since it enables the integration of renewable energies, improvement of the overall energy efficiency and sector coupling between heating, electricity and mobility (European Commission, 2016).

To integrate the heat and electricity sector some of the solutions can involve e.g. electric boilers, heat pumps (HP), biomass plants and waste incineration plants. To utilize the potential within the DH sector the old DH systems must be technically retrofitted or upgraded. This includes improving the heat generation (flexible energy system with different heat sources, heat storages etc.), heat distribution (optimized piping, reduction of leakages, temperature levels etc.) and heat use of the consumers (monitoring of substations, prediction of future insolation status) (Werner, 2017).

Today, around 64% of the Danish households are supplied by DH while the rest are supplied by natural gas or individual solutions such as, HP, oil boilers, biomass boilers and natural gas boilers. DH differentiates from individual solution by being a collective network which distribute the heat from the plant at the main central to the consumers. DH heating systems have been very successful in integrating renewable energy resources as 60% of the heat is already produced by CO_2 neutral sources (Dansk Fjernvarme, 2017a). The reason for the large utilization of DH in Denmark and its future role within an energy system independent of fossil fuels, is the flexibility it provides, since DH has the potential to integrate different energy sources (Werner, 2017). The main idea with DH is that it can utilise local fuel resources that would normally be wasted or unused, which makes it both feasible and efficient. A DH system often consists of many different production units utilising different fuels making it a complex energy system. A DH system can integrate every single heat producing unit and heat supply into the energy system, if the DH network is flexible enough in relation to temperature requirements at the consumers (Euroheat & Power, 2018). This enables many DH systems to find and explore different alternatives by implementing different CO_2 neutral energy resources due to the versatility of DH. Another benefit with DH is that it enables benefits regarding the economics of scale when investing in e.g. HP's or claiming a fixed fuel price from the fuel suppliers. These benefits must however make up for the biggest challenge with DH, which is the heat loss in the network together with heavy investments related to installing production units, piping network and O&M of the DH network (EA Energianalyse, 2017a).

Many of the DH systems in Denmark were established with the political transition away from oil towards coal and natural gas from 1970-1990. This was due to the oil crisis in the 1970's and the implementation of the heat supply act in 1979. The DH systems based upon oil are even older (Østergaard, 2015). With the implementation of collective heating systems utilising natural gas and coal, the DH systems began to expand throughout Denmark, which have led to the high utilisation of DH in Denmark together with the increased population in the cities (Østergaard, 2015).

1.2 The Danish Urbanizations influence on the district heating systems

The movement from rural- to urban areas is a global trend, which also takes place in Denmark. Over the last 35 years the population in Denmark have increased with 11%. This have occurred within and around the big cities, and this tendency will continue in the future both locally and regionally. The largest city in almost every municipality is increasing more than the total population within the municipality. This is mainly because the larger cities within the municipality attain many people from smaller cities within the municipality (Danmarks Statistik, 2018). In 1980 around 29% of the Danish population lived in a municipality further away from the larger cities, defined as a municipality with below 45,000 inhabitant and more than 30 minutes of transport time to the larger city. The latest prognosis from Danish Statistics concludes that this number will decrease to only 24% in 2040. This tendency with more people moving away from the rural areas and closer to the main cities can create a problem for the small district heating systems in the rural areas, because they will lose consumers leading to increased operational costs and a less effective DH system (Grøn Energi, 2016). This development challenges the DH systems, because with the development of CHP plants in 1980-1990, the decentralised CHP plants primary revenue came from the electricity sale, but due to political initiatives, tariff and tax changes, the heat production became the primary product instead of being the secondary (Østergaard, 2015). However, a challenge for some is sometimes an advantage for others. The Danish populations concentration around the larger municipality cities have increased since 1980, but also the municipalities that are located close to a larger city is increasing and expected to increase further, which is illustrated on Figure 1.1. The increased urbanization does however not only create challenges for the DH systems. It also creates new opportunities to integrate new CO_2 neutral resources e.g. excess heat from the industries that are being developed within the large cities (Christensen, 2016).

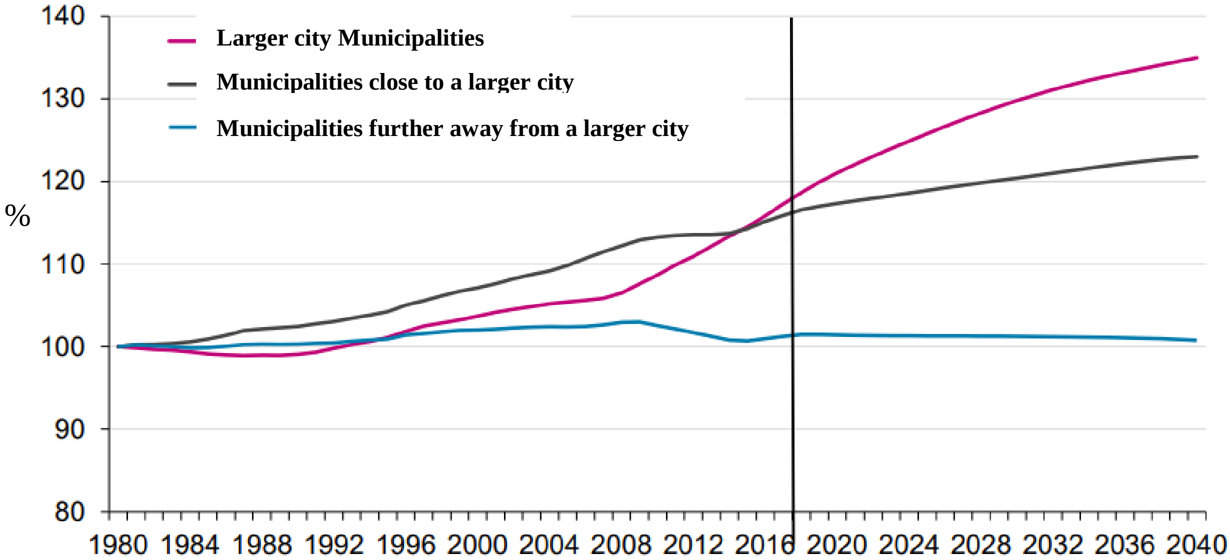


Figure 1.1 - Projected Development of population in the Danish municipalities towards year 2040, (Dansk Industri,2016) The classification is built upon DØRS/EVM.

Figure 1.1 illustrates that the larger cities, defined as above 45,000 inhabitants, have experienced the highest growth, and the municipalities located close the larger cities, defined as inhabitants below 45,000 with less than 30 minutes of transport, have also increased and is expected to increase. The municipalities further away from a large city, defined earlier in the Section, have decreased, but is expected to stagnate. The growth in the big cities and municipalities close by is mainly due to the centralisation of industry and companies making it attractive to live close by. The municipalities close to the big cities are also growing due to the development of the house prices in the big cities and the improvements in infrastructure that makes it possible to travel from A-B faster than before (Danmarks Statistik, 2018). This development emphasizes mergers between DH systems to reduce the overall administrative costs and future reinvestments, but also to increase the consumer base so the benefits of scale can maintain. An analysis from The Danish District Heating Association in 2016 illustrated that since 2010 over 40 DH systems have already merged. However, the merges and increased population in the main cities of the municipalities increases the pressure on the old district heating systems production, distribution- and transmission capacity in the network. This means that they must invest in upgrading measures such as reinvestments in pipes, new production units or pumps or heat exchangers etc. The DH systems who merge receive all the consumers from the former DH companies. Some of these consumers might be located in the outskirts of the city, making it very costly to provide them with DH compared to the individual solutions, which are being promoted by the government with the Energy Agreement from 2018.

The Danish Government have made some active initiatives to change the framework conditions to emphasize a green transition by *reducing the electricity to heat tax* for HP's. The electricity to heat tax is a taxation on units that use electricity to produce heat. The taxation will be reduced from around 30.7 øre/kWh to 15.5 øre/kWh in 2020 (Energi-, Forsynings- og Klimaministeriet, 2018). Another taxation, which is being discussed is the taxation on excess heat that is distributed, currently at 18.58 øre/kWh, but it can maximum be 33% of the remuneration from the heat delivery. Kim Mortensen, CEO of the Danish District Heating Association criticize this taxation as being the large barrier for not utilising the excess heat from the industries today. This is because the companies must also pay the electricity for heat tax on the HP that often must boost the excess heat temperature to have the right temperature for the DH system (Mortensen, 2018). The Danish Government made an agreement to implement a new excess heat tax based upon a certification scheme to dictate the taxation on excess heat implemented from 2020. The certification enables a differentiated taxation which will differ from 9.0 øre/kWh or 3.6 øre/kWh dependent upon if the company is certified (Skattestyrelsen, 2019). To increase the flexibility for the consumers in relation to the heat supply, the Danish Parliament have removed the mandatory connection for new urban areas established from the beginning of 2019 and forward (Energi-, Forsynings- og Klimaministeriet, 2018). This means that the municipality can no longer enforce the consumers to be connected to the collective heat supply through the local plan. This is heavily discussed by Michael Damm from the KTC group (Association of Technical Directors in Danish Local Authorities), who argues that there is a direct link between the mandatory connection and a green transition. The DH companies are also not very satisfied with this change, since the DH network is only feasible in areas with high enough heat demand density. If less consumers are connected, it will increase the cost per consumer due to the annual fixed costs being divided upon less consumers. The heat loss in the network increase per energy unit sold and it becomes harder to integrate excess heat into the DH system due to it requiring a large consumer base (Moesgaard, 2019). It is however important to point out that even before the removal of the mandatory connection, new households established as low energy buildings were not required to be connected to the DH system (Retsinformation, 2016).

The biggest challenge for the DH systems with the new framework conditions and the urbanisation tendency which are occurring and will increase in the future is that the DH systems are not dimensioned to supply all these new consumers without making investments in upgrading measures. These upgrading measures are however often time consuming, long lasting and implies high investments, which is why the planning process must be carefully planned in the long term (Lauritzen, 2012). It can therefore be argued that the mandatory connection and remain connected obligation (obligation to pay an annual fee for being a member of the collective supply network) are important for the DH systems to upgrade their system to make the best possible assessment of how to supply the current and future consumers. But at the same time if the heat demand density is not high enough, due to either consumers moving away from the city or leaving the DH network as seen on Figure 1.1, then the deficits of DH can outweigh the benefits, and make individual solutions worth considering in these areas.

A municipality that has experienced a decrease in the population from 2010-2018 of 2% is Vesthimmerlands Municipality (Danmarks Statistik, 2019). Vesthimmerlands Municipality contains around 37,227 inhabitant and is located around 51 km from Aalborg. Vesthimmerlands Municipality is therefore defined as a municipality located further away from large cities. Their main city is Aars, which contains around 8,302 inhabitants in 2018 and over the last 8 years, they have experienced an increase in population with around 390 citizens during this period and is right now in the middle of expanding the city area.

1.3 Aars District Heating System

Aars City have a collective DH distribution network which is illustrated on Figure 1.2, where Aars City is marked with a black circle, whereas lines scattering from Aars indicates the transmission lines to the merged cities Hornum, Haverslev and Suldrup.

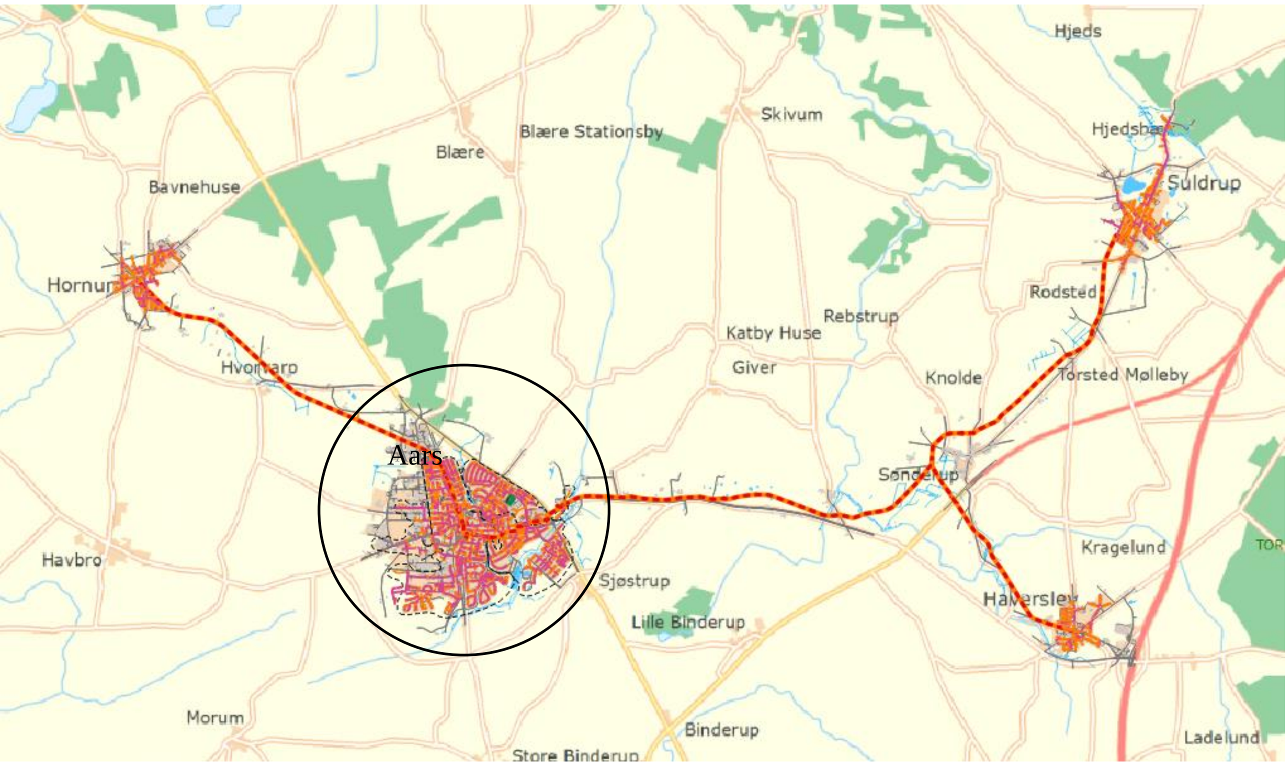


Figure 1.2 - Map of Aars DH system from QGIS (Black circle illustrate Aars), (Aars Fjernvarme, 2019b)

In 1955, Aars DH was established with only 70 consumers supplied by fuel oil boilers. Aars DH is a non-profit organization owned by the consumers, which implies that a surplus or deficit will be financed by the consumers equally. In 1985, Aars DH implemented a new heat central consisting of a waste incineration plant, coal boiler and two oil boilers, which covered around 66% of the city's heat demand. But with the implementation of the heat supply act in 1986 and focus on utilisation of natural gas and waste in co-production of heat and electricity, Aars DH implemented a new waste to energy CHP plant with a turbine to co-produce electricity and heat (Aars Fjernvarme, 2019a).

In 2009, Aars DH merged with Hornum DH and connected the two systems through a transmission pipe on 8 km. This was done to reduce the administrative costs and to secure a stable and competitive heat price by increasing the utilisation of waste. Two years later, Aars DH expanded their transmission network to Haverslev and Suldrup, which connected the two systems through a 14 km transmission pipe. This was done to reduce the utilisation of natural gas in these cities. The natural gas engines in Suldrup, Haverslev and Hornum now only operates when the electricity price is high enough for it to be feasible. The mergers also enabled Aars DH to utilise more of the excess heat from the waste incineration CHP plant that would otherwise be cooled away especially during the summer period (Aars Fjernvarme, 2019a).

Aars DH system supplies more than 5500 consumers with CO_2 neutral energy and have a total annual heat production of 138,971 MWh/year in 2018. 98% of the cities heat demand is covered from the waste incineration plants consisting of furnace 1, which is a boiler and furnace 2, which is a CHP plant. The rest of the heat demand is secured through wood pellets, natural gas peak load boilers. A more detailed description of the energy system will be described in Section 4.3.

In the period from 2010-2018, Aars City have increased with around 5% corresponding to around 390 more citizens, whom have all been connected to the DH system. The index of population development is illustrated on Figure 1.3 below.

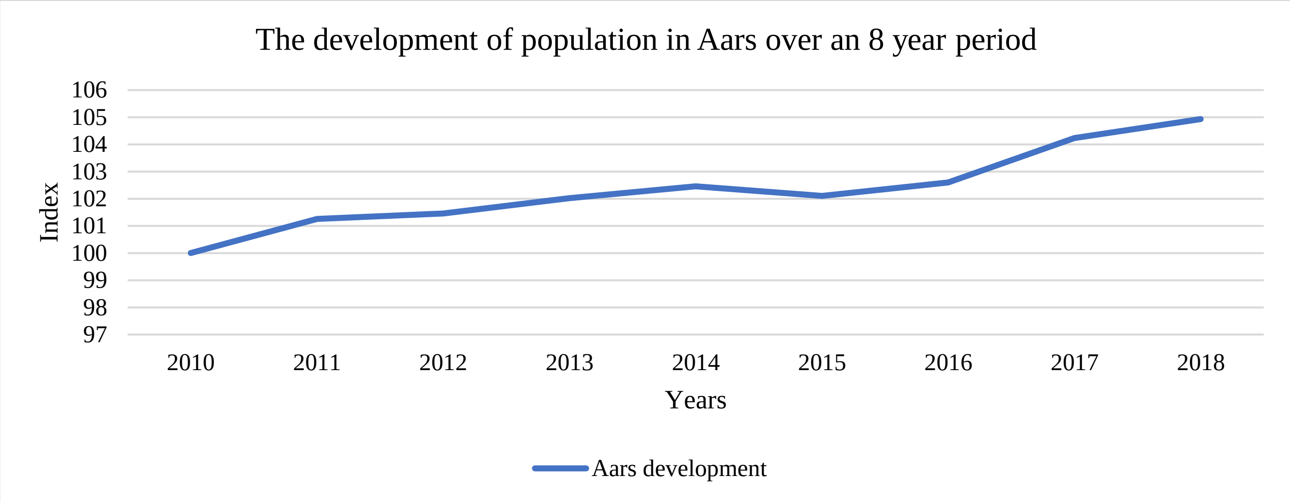


Figure 1.3 - Development of population in Aars from 2010-2018 (Danmarks Statistik, 2019)

The growth in population have increased the demand for expanding the city, which is why Vesthimmerlands Municipality is planning a new urban area. The new urban area under construction is called Aars West, which consist of two district plans no. 1050 and no. 1070. Close to the project area, the iron foundry industry MAT, Dania is located and in 2015 Aars DH and Dania were considering utilising the excess heat produced by Dania's furnaces in the DH system. However, due to the old framework conditions containing a barrier for business economy, as described in Section 1.2, and uncertainties related to the development of Aars West, it was not feasible to utilise the excess heat from Dania. Now, with the new framework conditions from the Energy Agreement, and the energy saving subsidy from the Energy Saving Scheme expiring in 2020, further described in Section 3.3, Aars DH and Dania want to reinvestigate the old project proposal. This is mainly due to the limitations within Aars DH's current distribution network, meaning that depending upon the different constructions and heat demands, the pipe on Markvænget, illustrated on Figure 1.4 below, supplying the kindergarten in Aars West might not have enough capacity to secure the future heat demand in the area during peak load hours (Aars Fjernvarme, 2019b).

Aars West will be developed as an area for public purposes (institutional area) based upon the district plan 1050 illustrated on Figure 1.4 below, where the Iron foundry MAT, Dania is marked with a black circle east of Støberivej.

Figure 1.4 - Map of Aars West institutional area, 1050 (MAT Dania marked with black circle)

The purpose of local plan 1050's content is to give access for public and recreative purposes. The idea with Aars West is based upon the municipality's development plan that describes a desire to establish a new public school and sports hall in the area south of Løgstørvej. Vesthimmerlands Municipality have already implemented a new day-care centre in the area in 2017 (Vesthimmerlands Kommune, 2016). The institutions within the area is still not finalised and it is not certain when the area is expected to be fully developed and what it will include. It is however agreed upon that a new indoor public swimming pool will be established (Vesthimmerlands Kommune, 2018a). The other urban area included in Aars West is called Galgehøjen, which will be built in 3 stages.

The purpose of local plan 1070's content is to create new attractive housing options for e.g. families, since the area is located right next to the area of Aars West. The housing options in district plan 1070 consist of parcel households, individual households and terraced houses (Vesthimmerlands Kommune, 2018b). The area of Galgehøjen Stage 1 and 2 is illustrated below on Figure 1.5.

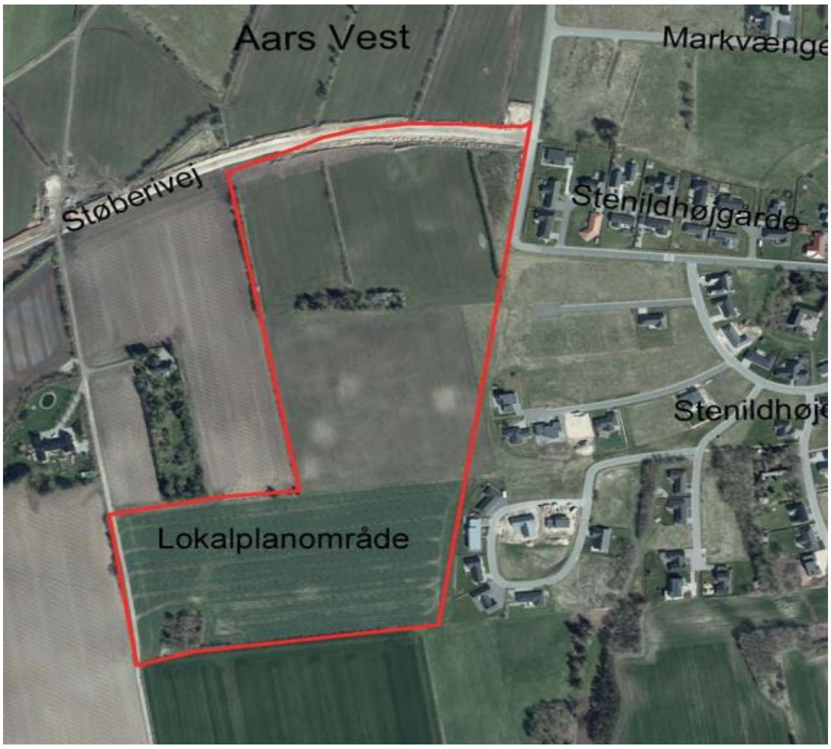


Figure 1.5 - Map of Aars West house complex area (Galgehøjen), 1070.

The main idea with establishing Aars West and Galgehøjen is to expand the city area and better connect the outskirts of the city with the main center, which have expanded further and further away from the city centre (Engerstrøm, 2019). Aars West is close to the popular parcel house area Stenildhøj and by implementing the institutional area, they hope to expand the city area further west in the future (Vesthimmerlands, Kommune, 2018b).

Galgehøjen (Stage 1 & 2) is already approved to be supplied by DH, where the DH were compared with individual air to water and ground source HP's. The heat supply in the area must be the most feasible solution in relation to the socio-economy for it to be implemented. However, if it does not apply the highest business economic value, then the project proposal will not be realised because it is the company who must finance and establish the heat supply.

Aars DH would like to investigate if their current distribution network can supply the new urban area of Aars West and if any upgrading measures are needed. They are also interested in reinvestigating the old project proposal with utilising the excess heat from Dania to see if this under the framework conditions can provide a positive business and socio-economic value in relation to supplying Aars West with DH (Aars Fjernvarme, 2019b).

2. Research Question

"How can Aars District Heating ensure the security of supply in the new urban area Aars West from a technical, - business- and socio-economic perspective?

2.1 Sub questions

1. What is the expected heat demand in Aars West and how should the distribution network be dimensioned?

2. What are the technical limitations within Aars DH network and what upgrading measures are needed to ensure the security of supply in Aars West?

3. What technical alternative provides the highest business- and socio-economic value for Aars DH?

4. How sensitive are the alternatives towards changes in the chosen assumptions?

2.2 Research Question Clarification and Delimitation

The thesis will focus on investigating Aars DH current distribution network and production side to ensure the security of supply in Aars West and the feasibility for the DH system. To ensure the security of supply in the new urban area Aars West different alternatives will be investigated. The alternatives consider different supply options in relation to implementing new production units and upgrading the distribution network. The technical perspective includes an analysis of the hydraulics and production side in Aars DH system to investigate the capacity in the network and production units. The different alternatives must be in accordance with the municipality's energy plan, which means that fossil fuel based units will not be included. Due to the removal of the mandatory connection to the DH system, the analysis will include individual solutions, but the individual solutions investigated will be based upon recommendations from the entrepreneurs developing the area and the municipality. The upgrading measures which will be investigated consist of upgrading the pipe dimensions, new heat centrals and supply temperatures.

2.3 Report structure

The overall structure of the report can be seen on Figure 2.1. The main structure is illustrated by the order of chapters in the middle of the figure. The lined boxes on the right side of the figure is an elaboration on where the different theories and methods are applied throughout the thesis by following the arrows. The lined box on the left side of the figure explains where the four sub questions are answered, which are used to answer the research question.

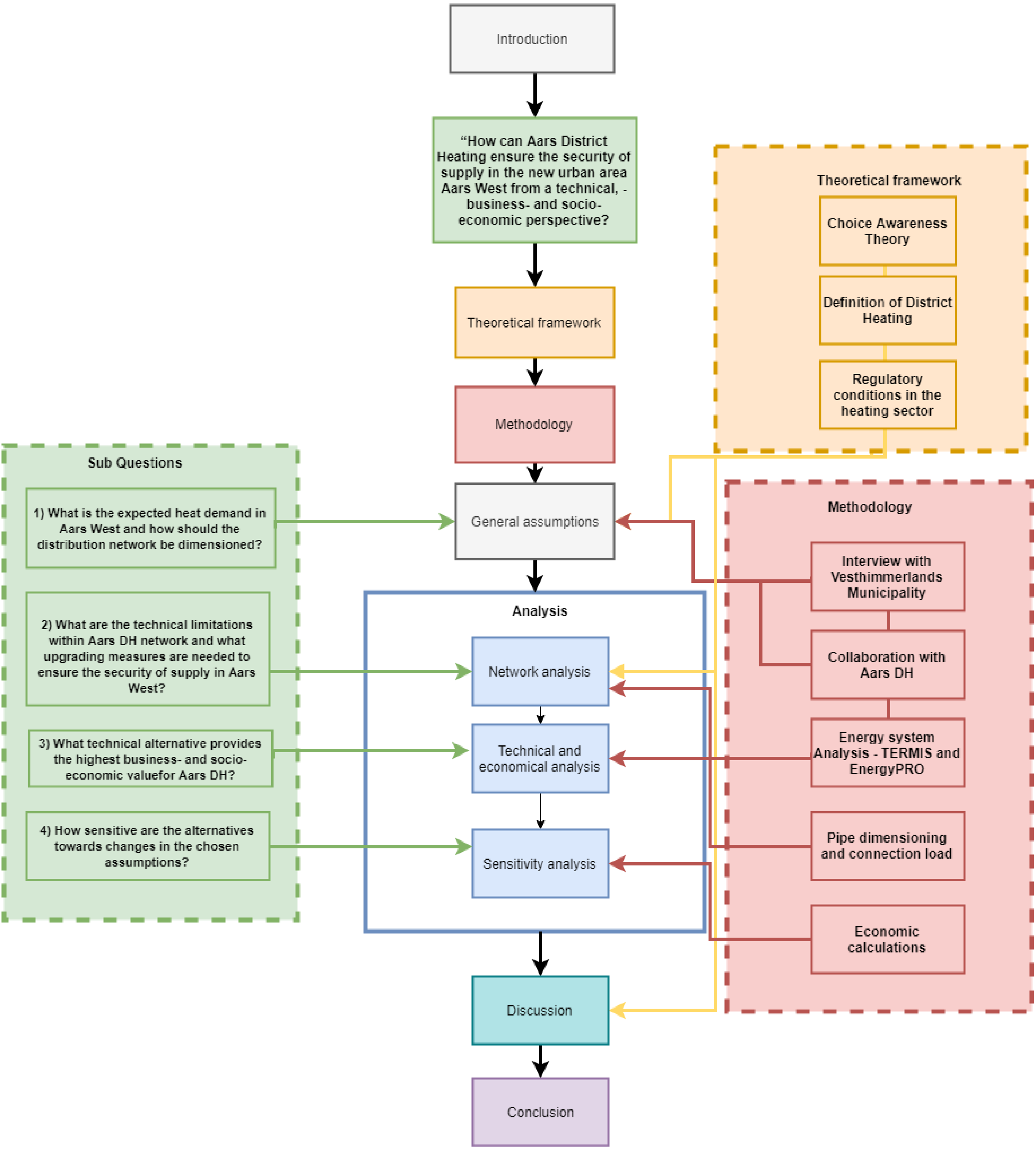


Figure 2.1 - The structure of the project with applied theories, methods and tools throughout the thesis

3. Theoretical framework

This chapter describes the different theories used in the thesis to give an understanding of what a DH system is, its different components and how it functions. The theoretical framework from the choice awareness theory will be used to structure the analysis.

3.1 Definition of a District Heating System

District heating can be defined and classified in different ways, but according to Eurostat, DH or city heating is the distribution of heat through a network to one or several buildings using hot water or steam produced centrally, often from co-generation plants, utilisation of waste heat from industries or from dedicated heating systems (European Commission, 2019a). A DH system can vary in size from covering a large area to covering a small village or even a few households. Every DH system have a unique element in terms of their specific local conditions hereby size, temperature level, network, piping, available fuel suppliers, consumption patterns etc. However, what all DH systems have in common, and what defines a well-functioning system can be characterized through the value chain, as seen on Figure 3.1. The value chain describes what must be present for a DH system to be functional, but also what determines the size and efficiency of the system. Many of the parameters in the chain correlate with each other e.g. if the number of connected consumers is high, then the distributed energy is high, and the investment costs is high to ensure the security of supply (Rutz, et. al. 2017). It is important to assess the actual conditions of the complete DH system and to optimise upon the technical conditions such as production, distribution and consumption which is illustrated on Figure 3.1 below. The overall optimisation of the DH system is a complex process, since it is long lasting and implies high investments.

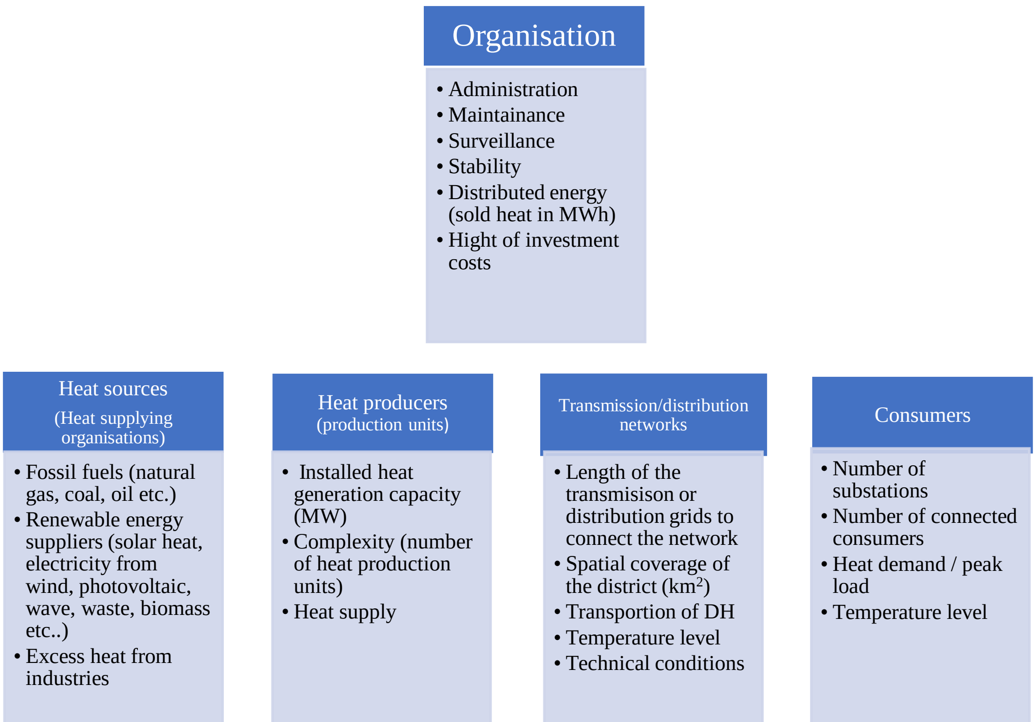


Figure 3.1 - Definition of a District Heating system. Based upon (EA Energianalyse, 2017) and (Rutz, et al. 2017)

A DH system must consist of an *organisation,* who are administrating the distributed energy to secure the demand at the consumers. The organisation must also maintain the production units, so they are functional and do surveillance on the distribution and transmission network to ensure the security of supply and optimisation of the network. The organisation is dependent on stability, in relation to the consumers, to make the best assessment as possible in relation to deciding upon expanding the DH system and securing the supply. The organisation's ownership nature can differ in relation to if it is publicly, privately owned or mixture of both. In Denmark the organisation is chosen on behalf of the consumers to maintain their interests and provide as cheap heat as possible while maintaining a high security of supply and often a high focus on the environment. This means that the risk of investments is covered by the municipality or consumers and the project is implemented by the public utility company (EA Energianalyse, 2017). Aars DH system is consumer owned and therefore it is the organisations goal to reduce the overall heat price as much as possible.

A DH network can consist of many different *heat sources* and therefore also heat suppliers. The decentralised DH systems in Denmark were mainly based upon heat sources as natural gas or oil in rare cases, but with the integration of RE, the energy system will include more heat sources such as solar power, excess heat to operate HP's and biomass etc. In Aars DH the system is primarily built upon waste incineration, and then Aars and the surrounding towns use natural gas for the spare production units. To increase the flexibility and reduce the CO_2 emissions within the DH system, Aars DH wants to include a new heat source, which is the excess heat from Dania.

The *heat production units* are used to generate heat, which in the traditional DH system often involves CHP plants, boilers and heat storages. The production units must be upgraded to support the overall energy goals and to integrate the RE energy the heat generation is expected to be produced on HP's, biomass boilers or CHP plants, geothermal energy etc. In Aars DH the current production units include a rather simple energy system, even though the number of heat production units are high, because the heat generation is mainly from the waste incineration CHP plant and furnace. The efficiency on these units are increased through flue gas condensation. All towns have spare capacity available to produce if the waste incineration plants cannot cover the heat demand.

The *distribution network* distributes the heat through the piping network, where the generated heat from the production units is transferred to the consumers. The heat transfer medium can be either steam or hot water, and in Denmark hot water is utilised with varying temperature levels. The technical specifications in relation to the distribution network is highly dependent upon the grid length, temperature level and the amount of water transported. The consumer density is also very important, because it has a large effect on the overall efficiency within the network. It is important to consider when selecting the right temperature level within the DH network. The temperature level is often based upon the consumer requirements, meaning the DH system want to lower the supply and return temperature as much as possible. A high differential temperature will reduce the mass flow, piping dimensions, electrical pumping costs and heat losses in the network (Rutz, et al. 2017). In Aars DH their specific network consists of four different networks connected through the transmission line at the main central located at Dybvad Møllevej in Aars. In this thesis, only the influence on Aars

City's distribution network will be investigated since this must be expanded with the establishment of Aars West.

The consumers are the most important component in the DH system, since they are the main source of revenue for the DH system. The temperature level requirements from the consumers determines the operation of the DH system, since the minimum required consumer's supply temperature correspond to the minimum supplying temperature of the DH. The temperature level at the consumer is dependent on insolation and heating installation installed (radiators or floor heating). Therefore old buildings will require higher supply temperatures of e.g. 80°C compared to newer buildings, which often only require around 60°C. The DH system's supply temperature varies during the year compared to summer and winter, because during summer the supply temperature must correspond to the temperature level for domestic hot water production whereas during winter at minimum outside temperatures, the flow temperature has the highest level (Rutz, et al. 2017). The consumers energy consumption in EU households are primarily used for space heating and water heating (European Commision, 2019b). Today, many DH systems are investigating low temperature DH systems, which means a supply temperature of 65°C or below, since it reduces heat losses and enables the utilisation of other heat producing technologies such as HP's or waste heat from industry. One of the challenges with low temperature DH is the legionella bacteria occurring below 55°C, which requires additional devices such as heat exchangers for hot water supply (Rutz, et al. 2017).

The focus in this thesis will mainly be put upon the *"heat producers", "transmission/distribution network" and "consumers"* values in the chain, since these aspects cover the heat generation, distribution and use. To make the right assessment of the future heat supply in Aars West, it is important that the alternative is beneficial for the consumers.

3.2 Choice Awareness Theory

The Choice Awareness Theory emphasises that different organisations and stakeholders have different points of views, which is illustrated through their interests and actions, driven by the respective discourse. The different interests influence the potential alternatives investigated and evaluated. Aars DH, Dania, project developers and the municipality all have different interests in relation to the development of Aars West. In this thesis the main stakeholder is, the consumers, because Aars DH is a non-profit consumer owned organisation implying they have their consumers best interest in mind. It is however important to consider the pros and cons related to multiple alternatives, before finalising a decision. The selection of one of those alternatives will be based upon what is considered the best alternative in relation to company goals, economic benefits and environmental impacts (Lund, 2014). The core element in Choice Awareness is that the decision maker must have a true choice when evaluating alternatives. In this thesis, having a true choice represents having more than one "real" alternative available and analysed. Having a wide choice of alternatives enables the decision-maker to judge the merits between the alternatives in relation to how sensitive each are to changes in the framework conditions, local conditions and economic conditions. By considering all these aspects, then the best alternative presented for the specific DH system can be chosen (Lund, 2014).

The Choice Awareness theory constructs counter strategies to enable the decision-maker to make an adequate choice. In this thesis creating a true choice will be based upon only three of the four counter strategies from the Choice Awareness Theory, as shown on Figure 3.2. The first counter strategy is chosen to design the concrete technical alternatives through modelling of energy system analysis. The second strategy involves constructing feasibility studies to evaluate the business and socio-economy in all alternatives and then the third strategy discuss the sensitivity of each alternative in relation to changes in the chosen framework conditions and public regulations. The third strategy will not be applied in relation to give a detailed suggestion toward changes in the public regulation but instead used to discuss the influence of the regulations and assumptions. The fourth strategy concerns promoting new democratic infrastructure into the DH sector. This will require changes towards the framework conditions, and this strategy deals with who should make these changes happen and how they can be implemented into the framework conditions (Hvelplund, 2011). In this thesis the DH system is already a rather democratic infrastructure and the purpose is not to determine what democratic process that is needed or how to further promote it into the DH sector, which is why it is not further included.

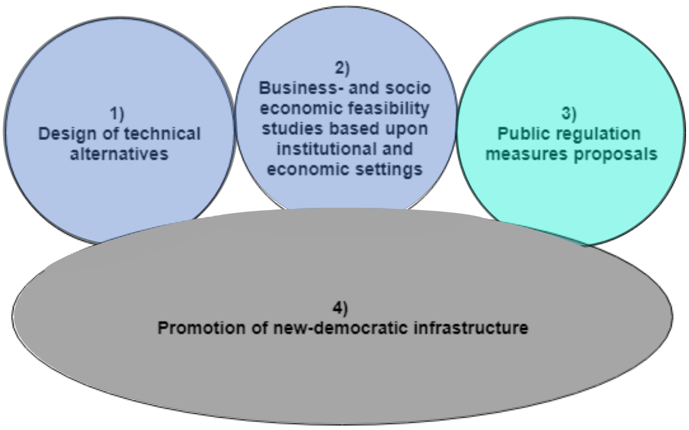


Figure 3.2 - Choice Awareness theory – based upon (colour illustrate Chapter) (Lund, 2014)

The counter strategies will be used as a guideline to structure the analysis and discuss the results on how to ensure the security of supply in Aars West from a technical, business and socio-economic perspective. The first part of the analysis will deal with a thermodynamic/hydraulic analysis of Aars DH's current network to give a detailed insight into the operation of the network. This will indicate the limitation and barriers in which the design of alternatives must consider related to ensuring the security of supply. The second part of the analysis will include the design and modelling of the reference system and technical alternatives, which will be presented in Section 4.1, as the first counter strategy. The second counter strategy will investigate the business- and socio-economic feasibility within all alternatives. This is done to investigate how sensitive the different alternatives are to changes in the assumptions. The sensitivity analysis will be conducted on both the business- and socio-economic calculations. The third part of the counter strategies involve a discussion of the results and chosen assumptions to validate the choice and include more parameters into the decision making than only quantitative data. The three counter strategies will then have highlighted the most important pros and cons related with each alternative investigated and hereby a true choice is ensured (Lund, 2014).

3.3 Regulatory framework conditions in the heating sector

Every project proposal within the heat sector is subjected to be in line with the different regulation and framework conditions. The most important laws within the heat sector are the Heat Supply Act and Project Declaration, which provide the overall regulation for consumers, fuel suppliers and DH organisations.

Heat planning

All DH companies are subjected to fulfilling the purpose of "The Heat Supply Act" (Retsinformation, 2017a). The Heat Supply Act's purpose is described in §1 unit 1, which emphasise the promotion of the most socio-economic and environment friendly energy source is used for heating buildings and hot water supply and within this framework decrease the dependency on fossil fuels (Retsinformation, 2017a). To enforce the Heat Supply Acts regulation, the municipalities are chosen as the planning authority, and they can therefore only approve a project in relation to these guidelines. The Project Declaration concerns the municipalities planning of heat supply, requirements for the approval of projects in relation to collective heat supply units and processing of cases in relation to the Heat Supply Act (Retsinformation, 2017b). The Project Declaration enforces the requirements from the Heat Supply Acts purpose criteria through its §6, which explains that the project proposal must include a concrete assessment of what the most socio-economic feasible project is. The assessment must be based upon an energy, societal and environmental assessment of the project before the municipality can approve the project proposal, in relation to The Project Declaration's §26 unit 1 (Retsinformation, 2017b). When planning for a new area that is not included in the collective heat supply, a project proposal must be constructed to change the areas status to a collective heat supply area. These project proposals are subject to approval in relation to the Project Declaration §3 unit 1 and appendix 1, which concerns establishment of new supply areas (Retsinformation, 2017b).

Requirements for production units in large District Heating areas

With the Energy Agreement from 2018, as described in Section 1.1, the small decentralised DH systems have received permit to deviate from the co-production requirement and fuel commitment. The large decentralised DH companies will therefore in this thesis consider the decentralised DH companies that did not receive the permit to deviate from the CHP- and fuel commitment in the Energy Agreement (Energi-, Forsynings- og Klimaministeriet, 2018). The large DH companies are subjected to restrictions in relation to what production unit that can be implemented due to the co-production requirement from the Heat Supply Act (Retsinformation, 2017a). The municipality can only approve production units over 1 MW capacity if they are installed as CHP plants and are the most socio-economic feasible solution, in relation to §12 in the Project Declaration (Retsinformation, 2017b). The DH company can get dispensation, if the production unit is installed as peak load or reserve unit to secure the heat demand. The dispensation is only granted if the current production units cannot cover the heat demand and the expansion of production capacity happens in connection with a concrete project proposal of extending the distribution grid. HP's are not part of these requirements, since they utilize electricity as fuel, and can be implemented into the energy system if it is socio-economic feasible (Retsinformation, 2017b).

The Energy Saving Scheme subsidy

The DH sector together with the electricity sector and gas sector committed themselves to realise energy savings in accordance with the Danish Energy Agency. In 2018-2019 the goal is 4.31 PJ, whereas in 2020 the goal is adjusted based upon the energy statistics (Dansk Fjernvarme, 2017b). The agreement involves that the companies within these sectors must realise energy savings in relation to the individual company's energy consumption (Dansk Fjernvarme, 2017b). In Aars DH, they must realise energy savings of 4414 MWh in 2019 (Dansk Fjernvarme, 2019). The energy savings can be among other things obtained by implementing a new electricity or gas driven HP. If the company cannot utilise the energy savings generated by implementing a HP for DH to fulfil their own energy saving goal in one or more years, then the saving can be sold to other companies on a market price.

The energy saving scheme will expire by the end of 2020, which makes it attractive for DH companies to implement HP's within the DH systems before the expiration to receive the subsidy. If the DH company can utilise e.g. excess heat to reduce the company's net energy consumption, it is counted as an energy saving. If the company can supply excess heat at a temperature level, where it can be directly utilised in the DH network through a heat exchanger, then the energy saving is given to the company supplying the excess heat (Holm, 2019). The energy saving subsidy depends upon the annual heat production, which is calculated as the expected full load hours deducted with the energy consumption from the unit and electricity consumptions from the pumps required etc. This is then multiplied with the relevant conversion factor.

When installing an electricity driven HP for DH production then the electricity consumption is multiplied with the relevant conservation factor which is 1, because it utilises electricity. The energy saving subsidy is given as an investment subsidy for the HP in the first year. The heat production from the HP is calculated through an estimation of the annual average heat production during the first 10-year period of the production unit's life time (Energi-, Forsynings- og Klimaministeriet, 2016).

4. Methodology

This chapter includes a description of the methodology, why the given methods are chosen and how they are applied and complement each other throughout the thesis to answer the research question.

4.1 Collaboration with Aars District Heating and the different alternatives investigated

The collaboration with Aars DH has been conducted through meetings, phone calls and emails to determine the technical conditions used to construct the baseline alternative in EnergyPRO, described in Section 7.1. Aars DH have assisted with determining the technical assumptions in relation to the current heat demand, production units, transmission losses, efficiencies and heat losses. Aars DH have also provided data for the construction of the TERMIS model, described in Section 4.3, in terms of consumer data, piping, alternative routes, GIS data, height curves and pressure gradient level within the network.

The design of the technical DH alternatives is constructed in collaboration with Aars DH to make sure that the alternatives can be implemented in their energy system. Aars DH wants to investigate, if the excess heat from Dania can be utilised within their network to obtain the energy savings before it expires in 2020, as described in Section 3.3. The other alternatives are also constructed in collaboration with Aars DH to ensure the security of supply, but also the highest business and socio-economy value.

The alternatives that will be investigated in this thesis are the following:

- Reference Scenario: Current energy system of Aars DH with a new pipeline
- Alternative 1: Excess heat unit Dania and Danpo pipeline
- Alternative 2: Water to water HP Dania and heat storage
- Alternative 3: Excess heat unit Dania and heat storage
- Alternative 4: Danpo pipeline and heat storage
- Alternative 5: Wood chip boiler at Dania
- Alternative 6: Individual air to water HP's

(Aars Fjernvarme, 2019b)

The individual solution is constructed to secure the highest socio-economic value by investigating other solutions than DH. To find out what individual solution that is expected to be implemented in Aars West, then Vesthimmerlands Municipality and project developers in Aars West are included. They conclude that an air to water HP solution is the most possible, due to it requiring less space and it being a technology available for all households with the lowest investment costs (Vesthimmerlands Kommune, 2019). Aars DH expects to maintain their current energy system throughout the planning period and it will therefore function as a baseline for all DH alternatives to see what new production unit that can provide the lowest heat price and highest socio-economic value within the existing production setup (Aars Fjernvarme, 2019b).

4.2 Interview/Meeting

To estimate the future heat demand, expected construction, development alternatives and technical assumptions related to the heat supply in Aars West an interview/meeting was conducted with Kristin Engerstrøm, Rasmus Jensen, Kristina Ginnerup, Peter H. Staun and Charlotte S. Jensen, who are all involved with the urban, - environmental- and energy planning in Vesthimmerlands Municipality. The reason for involving these many actors from the municipality was to make the best possible assumptions and determine the expectations related to the future planning in Vesthimmerlands Municipality. The future heat demand in Aars West depend upon what type of buildings that are expected to be constructed in the area. To make the right dimensioning of the piping in the area, it is important to clarify the overall expectation in the area. Vesthimmerlands Municipality is the authority with the most knowledge about what is going to happen in the area, which is why an interview with them is necessary to make the best estimation possible. The interview is conducted to determine the temperature level required for the institutional area and Galgehøjen Stage 1, 2 and 3. This is because the project developers must construct the consumer installation after this. Another important aspect to discuss at the meeting is when the different constructions are expected completed, because it is important for the feasibility of a new production unit. Due to the removal of the mandatory connection, the municipality can no longer enforce mandatory connection, and therefore it is important to include the project developers to clarify the alternatives. Vesthimmerlands Municipality wants to compare individual air to water HP with the DH alternative. The knowledge and data provided by the interview are used in the hydraulic analysis to determine the future heat demand and therefore dimensioning of the piping in the area. It is also used to determine the technical/economic analysis in relation to modelling the production distribution for the gradually increased heat demand.

The interview/meeting with the different stakeholders from Vesthimmerlands Municipality is conducted as a semi structured interview. To make an agenda for the meeting an interview guide consisting of a guideline of questions is constructed, which the meeting revolves around answering. The interview guide's questions are constructed as general and open, which emphasize a broad discussion, but also follow up questions from the interviewer to structure the direction and enable the interviewed individuals to elaborate on points made. This method is chosen to give the interviewed individual more room to answer the questions with an elaboration behind and to create a strong discussion of the pros and cons related to the heat supply of the area (Kvale & Brinkmann, 2009).

4.3 Energy System Analysis

To investigate the overall influence on the DH system it is important to investigate both the network conditions and heat production conditions within the DH system to ensure the security of supply and feasibility of operating the energy system. To make this assessment two modelling tools are chosen.

Termis Software

To model the thermodynamic and hydraulic influence, the new urban area Aars West will have, on the transmission and distribution grid in Aars DH, Termis has been chosen. Termis is a hydraulic modelling tool used for DH networks, which simulate flow, pressure and thermal behaviour in the distribution network (Schneider Electric, 2016). Termis conducts hydraulic simulations that can be used to optimize the DH supply and utility production within the energy system. Termis can be used for calculating flows, temperatures, pressures, pumping head, load on pipes, pressure loss gradients, temperature losses, costs, renovation plans etc. The hydraulic analysis is based on real time data from the DH's SCADA system that allows the DH companies to obtain more information about their entire network and operation. The DH company also have access to historical data, enabling the DH company to go back in time and check the operation within the network. This allow them to make smarter and better decision making leading to optimizing cost-effectiveness and overall efficiency. It also increases the orientation for the consumer, because they can be informed about potential renovations (Østergaard, 2018). Termis is a useful tool when assessing the technical impacts of changes related to installing a new heat production unit and heat supply within the DH network. The modelling in Termis take size and operational parameters of a new heat unit into account and can be used to assess how the entire network will operate with proposed changes. Termis is typically used for designing DH networks hereby dimensioning new pipelines to fit the system, to meet future demands, avoid bottlenecks and comply regulations (Schneider Electric, 2018). This makes Termis a good tool for the technical analysis of the DH network in this thesis, because it can investigate the limitations within the network and ensure the security of supply in Aars West.

Termis allows the DH system to look at the network on a broad and detailed level and gives access to knowledge about what is happening within the distribution network after the hot water leaves the heat central. Interventions such as supply changes, opening or closing of valves, turning pumps and plants on and off, and assessing the impact on consumer supply can be simulated (Schneider Electric, 2016).

Aars DH's Termis model is shown on Figure 4.1

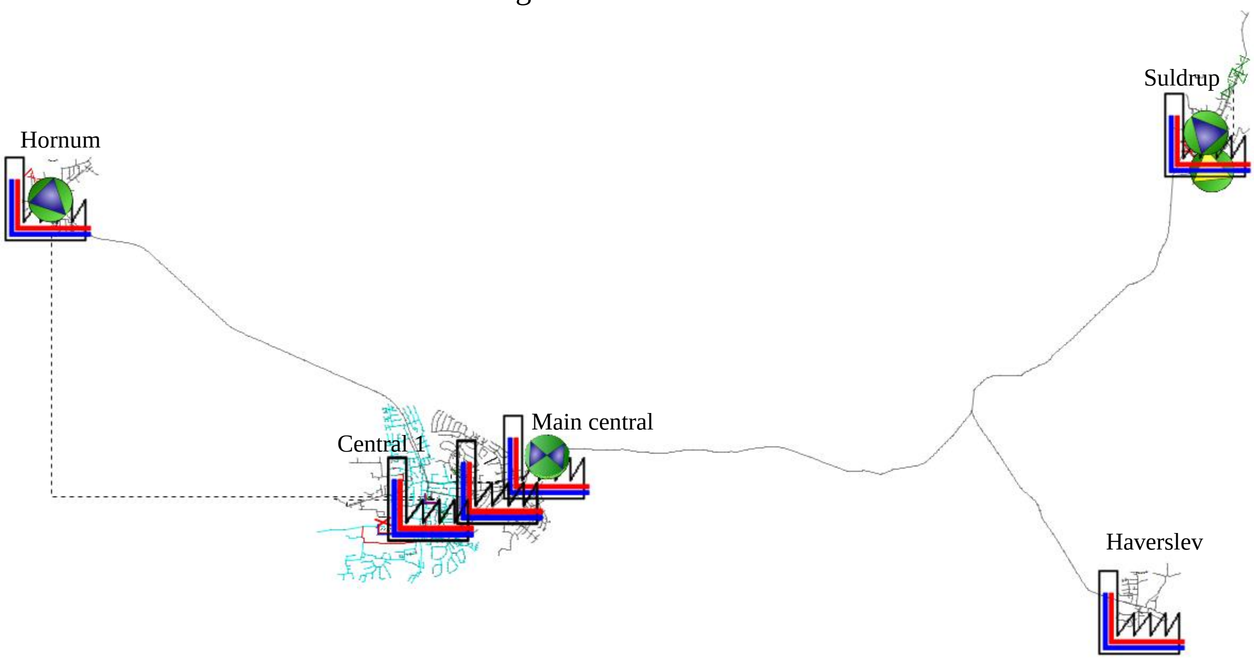


Figure 4.1 - Termis model of Aars DH network

Figure 4.1 illustrates the network of Aars DH and the transmission pipes to the nearby cities. Aars DH is divided into different zones in Termis to make a faster calculation for the specific area. Aars West will therefore be placed in zone "Central 1, Gislumvej".

Termis will be used to dimension the distribution network in Aars West in relation to the given assumptions, described in Section 5.3. Termis will also calculate the influence of gradually connecting Aars West onto the existing network in relation to differential pressure, supply pressure, supply temperature, flow and pressure loss per meter. This is done to get an indication of, if the current network can supply the new area or if reinvestments in e.g. the piping must be conducted to ensure the security of supply in the area. Termis can also give an indication of points within the network where additional pumps should be installed to maintain the pressure in the network, but this will not be investigated in this thesis. Termis illustrate the piping dimensions in the DH network, which will be used to determine the investment costs related to the new distribution area or illustrate where the reinvestments in the existing network must be conducted to supply the heat demand (Schneider Electric, 2016). To make an adequate analysis of the influence on the network, it is important to calibrate the Termis model for a real time situation, which is done through configurating the global load factor, consumer temperature cooling, heat loss correction factor and ambient temperature to fit the real time situation measured in the DH network (Østergaard, 2018).

Termis will be used to calculate the piping length, dimension, network limitation in relation effect and heat losses in Aars West. Termis can however not calculate the production distribution or operation costs within the energy system to optimise it for lowering the annual operation costs. To make the economic assessment for each alternative another tool must therefore be chosen to complement for this.

EnergyPRO

To model the technical DH alternatives, EnergyPRO has been chosen. EnergyPRO is a modelling tool that can build a model of the heat supply options interrelations. EnergyPRO is typically used for DH systems where a combined techno-economic analysis is relevant. EnergyPRO can optimize complex energy projects with a combined supply of electricity and thermal energy from multiple energy producing units (EMD International, 2013). EnergyPRO is also chosen, because this thesis seeks to find the alternative that provides highest business economic and socio-economic value. EnergyPRO calculates the annual operational costs for the system in relation to each production unit's operation over the 20-year period. The calculation period is chosen due to the technologies expected life time, starting from 2021. To make these calculations, EnergyPRO have different modelling setups, and the “finance module” is chosen to account for the developing heat demand, fuel- and electricity price. This is done to see if the different alternatives can ensure the security of supply through the period and how the production distribution is influenced by the varying fuel and electricity prices and heat demands developing during the period (EMD International, 2018).

The modelling setup of Aars DH system, in EnergyPRO, is illustrated on Figure 4.2.

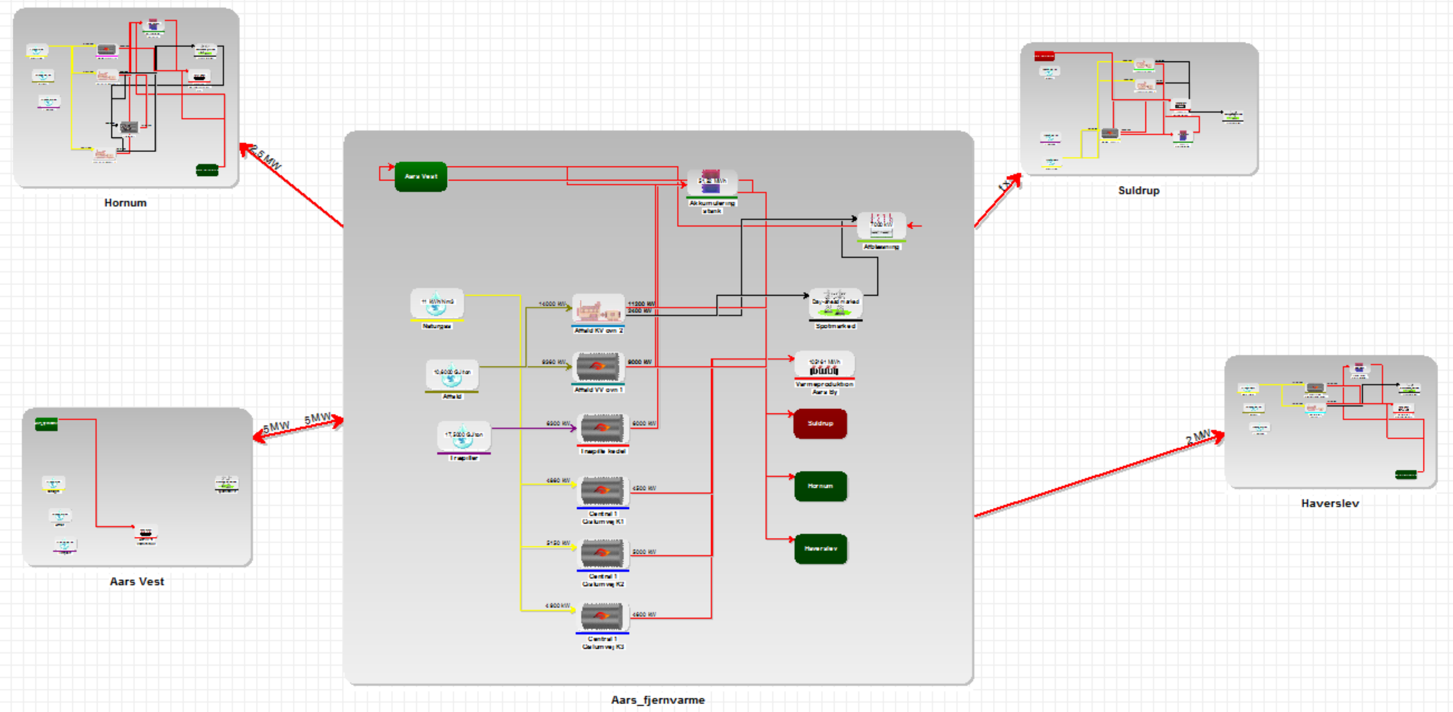


Figure 4.2 – EnergyPRO model of Aars DH system baseline for all alternatives

Aars DH current system primarily consists of two waste incineration plants, a boiler on 9 MW and turbine on 11.2 MW heat capacity and 2.4 MW_{el} capacity. Aars DH also has flue gas condensation on both furnaces on 4.5 MW, which is illustrated by an increased efficiency. Aars DH also have a wood pellet boiler on 6 MW. Around the cities which are connected to Aars main central, they have natural gas boilers and motors to secure the heat demand. Aars city has three natural gas boilers with a total capacity of 14.1 MW.

EnergyPRO depends on several inputs to calculate the heat production price for the system:

- Time series with hourly values of the specific weather data for the area and electricity prices for the day ahead market to regulate after in relation to buying/selling.
- Fuel costs related to operating the production units to optimize the energy system and the development of these prices throughout the calculation period, which is done through an index covering the 20-year calculation period.
- Taxes, tariffs, subsidies and O&M costs related to the specific fuels and production units.
- Technical properties and efficiencies for the different production units and a heat demand to fulfil.

(EMD International, 2013)

In a system with a combination of different technologies, the heat production price will determine the number of operation hours in each unit after lowering the annual expenses while securing the heat demand from a business economic perspective (Rutz, et al. 2017). This is done through creating an operational strategy, which determines the production and consumption of the different production units. EnergyPRO calculates the production unit's operation costs within each specific hour and the unit with the lowest production costs per MWh of heat is then chosen to operate as 1st priority to produce heat. The operation strategy will use the 1st priority as much as possible, but if it cannot cover the heat demand, then the unit with the 2nd lowest production costs per MWh operate in that specific hour and so on, which is illustrated on Figure 4.3 (EMD International, 2018).

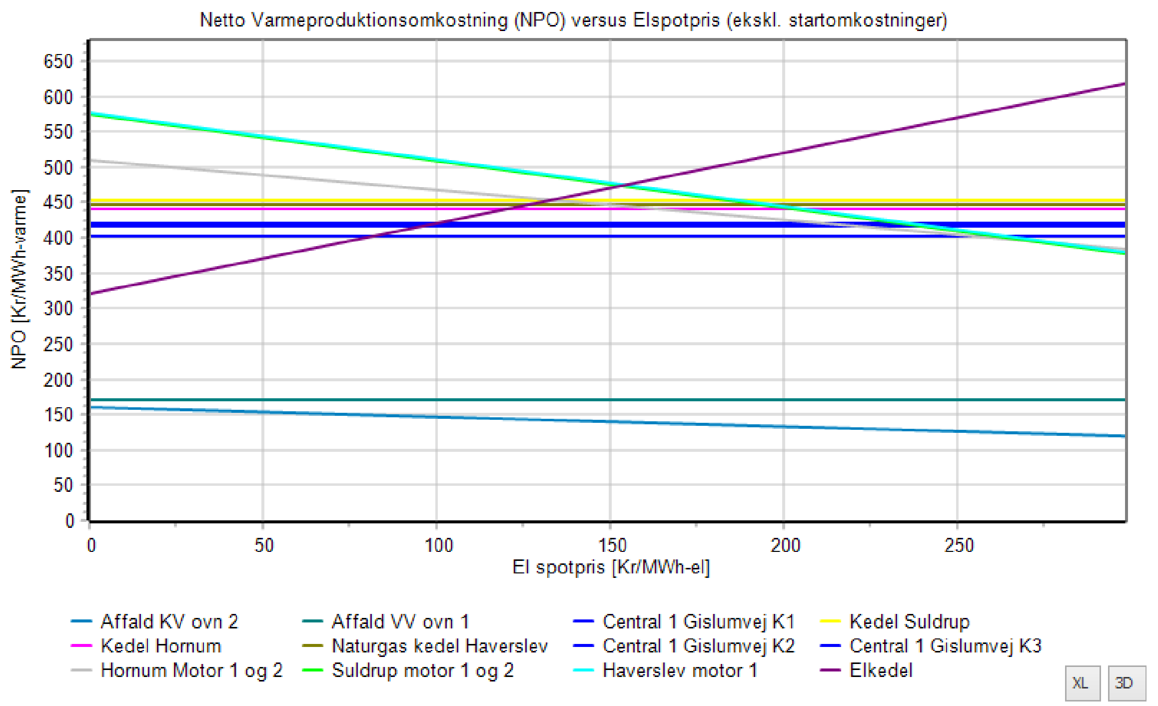


Figure 4.3 - Operational strategy of the production units in Aars DH illustrating the net heat production costs

The operational strategy indicates that the waste incineration CHP plant is the cheapest unit to operate even at an electricity price of 0 DKK/MWh. It is therefore given a high priority to enable as much production on this unit as possible, in Chapter 7. This is due to the unique conditions related to the utilisation of waste, which the company is paid to dispose of (Aars Fjernvarme, 2019b). When investigating the alternatives, there can be hours where it is more feasible to utilise the new production unit and dispose the surplus energy from the waste incineration plants through the cooling tower. Some of the alternatives will involve utilising excess heat from Dania, and due to the substitution principle's purpose, which secures that the heat consumers will have the lowest heat price as possible. The price level for the utilised excess heat can therefore not be above the substitution price for the unit it replaces. The substitution price is estimated annually (Mikkelsen & Kristensen, 2017). The wood pellet boiler on the main central is given low priority. This is due to in 2018 the load on the transmission pipe from the main central was pressured to the limit in the winter period. To secure the heat demand the natural gas boilers was operating instead of the wood pellet boiler (Neve, 2019).

EnergyPRO can optimise the operation of the DH system after incorporating a heat storage, and since Aars DH wants to investigate the influence of a heat storage in some of the alternatives, this is another reason why EnergyPRO is chosen as modelling tool. The heat storage capacity is utilized through a prediction on how the future preconditions are expected to develop, from the time series (electricity prices, temperature profile, fuel price development etc). EnergyPRO will on behalf of these conditions estimate when to storage the heat, utilize the hot water in the tank and when not to. This creates a very flexible unit, but also increases the flexibility within the other production units who regulate after the varying fuel and electricity prices in the spot market. The operational strategy operates on hourly values, which are important in a system like Aars DH. This is because Aars DH is connected to the Day Ahead Spot Market, where the electricity price is distributed on hourly intervals, and therefore can the operation strategy vary every hour depending on the electricity price.

Termis and EnergyPRO are two modelling and simulation tools, who complement each other, since Termis focus on the DH network and EnergyPRO's focus on the production side. The technical network limitations calculated in Termis are therefore required input for EnergyPRO to know how much heat that can be distributed to Aars West and to know the heat losses in the network to calculate the production distribution for each alternative. The different economic evaluation tools used in this thesis will be described in Section 4.5.

4.4 Piping dimensioning and connection load

To optimise the DH network in relation to lowering the total costs, it is necessary to find the optimal velocity for a given pipe dimension. When transporting DH water, it is necessary to have the right pressure level to account for the pressure losses related to pipe resistance, individual resistance in pipe bending, valves, compensators etc occurring at the central and the differential pressure at the consumers. The pressure gradient dimensioning criteria (Pa/m) is 100 Pa/m meaning that if the pressure loss per meter is above 100 Pa/m then the piping must be upgraded technically speaking (Lauritsen, 2012).

The dimensioning of the pipelines in Aars West is calculated through the following formula

$$\Delta P_{pipe} = \frac{\lambda * \rho * v^2}{2 * d_i} \quad [Pa/\,m]$$

$\triangle P_{pipe}$ = The pressure loss in the pipe (Pa/m)
λ = the friction coefficient (-)
ρ = the medias density (kg/m^3)
v = the medias velocity (m/s)
d_i = the internal pipe diameter (m)

(Lauritsen, 2012)

The dimensioning of a DH pipe is based upon the total connection load ϕ_t, which include the gross connection load for the network by including a summation of the connected consumers expected connection load, corrugated for variations in consumption and heat losses with the transportation.
The formula is illustrated below:

$$\Phi_t = s * \sum_{i=1}^{n} \Phi_i + \Phi_{tab}$$

ϕ_t = the total connection load (kW)
s = the actual simultaneity factor
ϕ_i = The connection load for the individual consumer
ϕ_{tab} = the heat loss within the DH pipe

(Lauritsen, 2012)

The heat demand is characterized by the annual heat demand (MWh) and the connection load (kW), which is used to denote the dimensioning effect of the consumption or the connection load value. The connection load for the individual consumer (ϕ_i) describes the heat effect needed to supply when the demand is highest. The connection load includes both space heating and utilisation of hot water.

A method to calculate the connection load is illustrated below:

$$\phi_i = \frac{Annual\ heat\ demand}{annual\ utilisation\ hours}$$

(Lauritsen, 2012)

The annual utilisation hours describe the hours per year where the heat demand is at its peak. The value is based upon an experience value, that is highly dependent upon climatic conditions, efficiency and insulation status of the buildings (Rutz, et al. 2017). For new buildings, it is determined to 2850 hours for households and 2500 hours for institutions based upon experience from COWI and tested in EnergyPRO on a daily average of -12^{o}C (Andersen, 2019). However, all consumers will not have peak loads at the same time, which is what the simultaneity factor accounts for (Lauritsen, 2012).

The heat demand for hot water can vary during a short duration of time and be significantly higher than the connection load factor. This has an influence on the dimensioning of the individual pipe installation and the dimensioning of service pipes for the individual consumers or DH pipe with a few connected consumers. The maximum hot water effect for a household is determined by the tapping water load, and since the new households in Aars West will utilise heat exchangers for the tapping water, the maximum hot water load is determined to 25 kW for an average household (Lauritsen, 2012). However, due to the hot water load only occurring in a short period of time, the maximum connection load for the service pipes will be dimensioned through the heat demand load or the hot water load depending on what value that is highest (Lauritsen, 2012).

The distribution piping will be dimensioned after the sum of connection loads multiplied with the simultaneity factor and with an add on from the hot water consumption.

The simultaneity factor's influence on the heat connection load is illustrated below on Figure 4.4

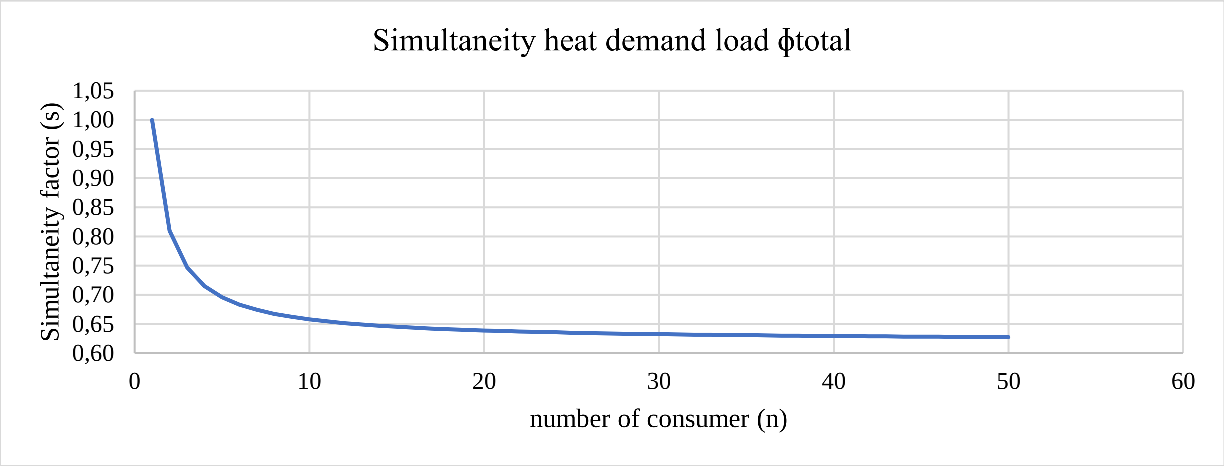


Figure 4.4 - Simultaneity factor heat demand load

The simultaneity factor for the heat connection load goes starts at 1 and with an increasing number of consumers then the simultaneity factor will be lowered until it is straightened out of around 50 consumers, where the factor will be constant around 0.62, even with more households connected. The value of 0.62 is based upon an empirical number. The calculation of the simultaneity factor for the heat demand is illustrated below:

$$s = 0.62 + \frac{0.38}{n}$$

s = simultaneity factor
n = number of consumers connected

(Lauritsen, 2012)

The simultaneity factor's influence on the added tapping water demand is illustrated on Figure 4.5 below.

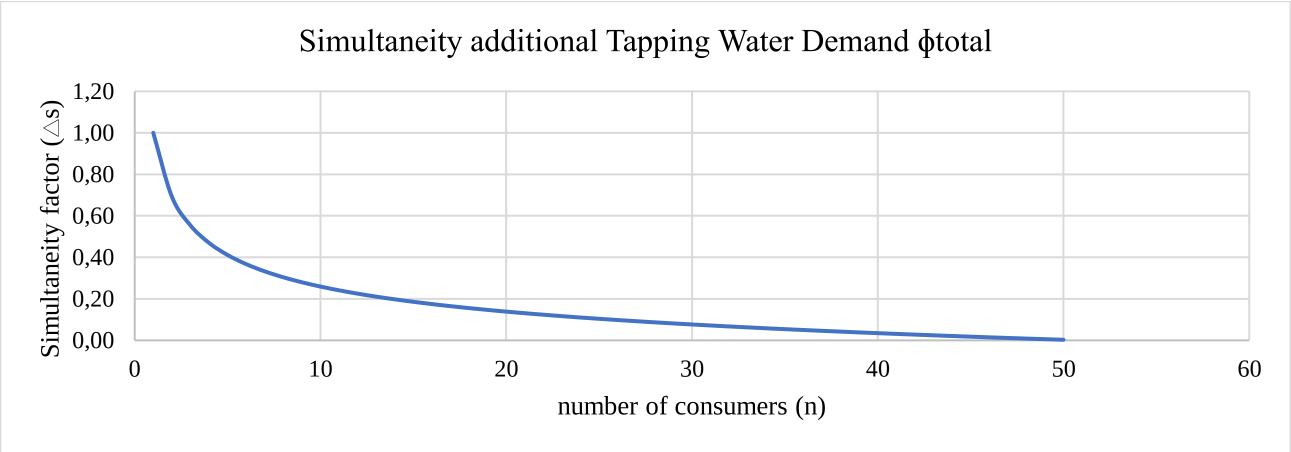


Figure 4.5 - Simultaneity factor Tapping water demand

In relation to the tapping water demand the simultaneity factor will be 1 for a household and 0 for more than 50 consumers supplied by the piping network, which means that the tapping water demand becomes irrelevant and the heat connection load will be the dimensioned effect inclusive the heat loss.

The calculation of Δs is illustrated below

$$\Delta s = \frac{51 - n}{50 * \sqrt{n}}$$

Δs = simultaneity factor
n = number of consumers connected

(Lauritsen, 2012)

The simultaneity factor is dependent upon building type and varies in relation to the DH area. An institutional area will however not have the same consumption pattern as a household and therefore the connection load can occur simultaneously meaning the factor will be 1 (Lauritsen, 2012).

4.5 Economic evaluation tools

When planning to change the heat supply in an area, a project proposal must be conducted. The project proposal with the highest socio-economic value when compared to other alternatives, must be chosen as it is described in the Heat Supply Act §2, from Section 3.3. The socio-economic analysis is a central element in the decision-making process, because it illustrates the socio-economic impact on the society. It is however also important to conduct an economic evaluation of a projects influence on the business economy for it to be realised, especially after the removal of the mandatory connection, as described in Section 1.1. The economic calculations involve many uncertainties related to predicting fuel prices, CO_2 quota prices, electricity prices, investment costs and the chosen interest/discount rate, which all influence the result. To account for these uncertainties a sensitivity analysis must be conducted involving the most uncertain parameters (Energistyrelsen, 2018a).

Socio-economic calculations

The socio-economic calculation will in this thesis be based upon the guidelines from the Ministry of Finance to create a common decision-making process that will be used to determine the alternative able to provide the highest socio-economic value (Finansministeriet, 2017). The socio-economic analysis will be based upon the Cost Benefit method, which investigates the costs and benefits related to a project and then the alternative with the highest socio-economic value in DKK is chosen. The Cost Benefit method is linked to the welfare oriented neoclassical model, which emphasise profit maximisation for the society by accepting the market prices without taking the developing costs and benefits for different technology developments into account (Hvelplund, 1995). The costs and benefits for the society is illustrated through operating the different alternatives optimally for the DH system according to the operational strategy from EnergyPRO.

Socio-economic calculations must price set all the effects a project have on the society to evaluate the cost and benefits. To do this it is important that all valuable effects are measured in the same price level. The socio-economic value is often first calculated in *factor prices*, which concerns the direct costs for the society related to operating the energy system with the cost and benefits for the company. The factor prices must be recalculated to *market prices*, which concerns the prices that the consumers pay for services incl. taxation but subtracted with subsidies. The market price illustrates the production factors that are used within a project and how they could be used differently from the consumers point of view. This is done because the socio-economy concerns the consumers' willingness to pay and not the actual cash flows (Finansministeriet, 2017).

The societal costs will be considered by including the *net tax factor,* which convert the factor price to a market price. The net tax factor illustrates how much of the consumers private consumption that are influenced by indirect taxes, direct taxes and subsidies and is calculated to 32.5%. When tax changes occur it often result in a changed net revenue for the public finances, and if a project proposal include a loss of revenue in the public finances, then this loss must be financed elsewhere (Finansministeriet, 2017). *The tax distortion factor* is therefore applied in socio-economic consequence calculations and it represents the marginal socio-economic cost, which occur due to general financial taxation. The tax distortion factor accounts for a potential socio-economic income loss for the society due to another allocation of resources from a project. The tax distortion factor is equal to 10% and is also used to convert the factor prices to market prices to indicate the total cost of an initiative (Finansministeriet, 2017). When evaluating a project, the socio-economic calculation takes the discount rate into consideration, because it illustrates the potential loss of an alternative revenue, which the invested resources could have given elsewhere. *The discount rate* has a large influence on the socio-economic result, because it is also used to make future cost and benefits comparable to costs and benefits today. This is because the costs and benefits in the future are given a lower importance, than today, due to the uncertainties. The discount rate in socio-economic calculations is politically determined and symbolises the "price on capital". The discount rate is today 4% without inflation during the project period of 35 years and then it decreases if the period is longer (Energistyrelsen, 2018a).

The socio-economic calculations include energy and environmental consequences from price setting fuel prices, CO_2 quotas, and a societal value setting of the emissions SO_2, NO_x and $PM_{2.5}$. The environmental consequences with changing the fuel consumption will be calculated for the air emission pollution considering CO_2, CH_4, N_2O, NO_x, SO_2 and $PM_{2.5}$. The CH_4 and N_2O will be calculated as CO_2 equivalents. The socio-economic impact assessment of what is feasible and not must be seen in relation to the economic and political goals for the development of the society, since the price settings are politically determined. The alternative with the highest socio-economic value is not determined to also be the most business economic alternative, which is why there should be an instrument which secures the connection between what is socio-economic feasible also must be business economic feasible (Hvelplund, 1995).

Business economic calculations

The business economy within a project shows the total economy from the utility companies' perspective. There is not a specific guideline on what the raw fuel prices and discount rates included in the business economic analysis must be, since it can vary due to the size of the company and area. There are however elements that must be the same in the business and socio-economic calculations, which are the investment, energy saving subsidy and operation assumptions. To compare the calculation method for business- and socio-economy Table 4.1 is constructed to illustrate the similarities and differences.

	Business economy	Socio economy (nonvalue-based costs)
Investment costs & O&M	Yes	Yes
Fuel costs	Aars District Heating	The Danish Energy Agency
Electricity costs (2020)	The Danish Energy Agency	The Danish Energy Agency
CO2 quotas (2019)	129 DKK/ton	119 DKK/ton
Other emission pollution	-	Yes
Taxes and subsidies	Yes	-
Energy savings	350 DKK/MWh	350 DKK/MWh
Tax distortion losses	-	10%
Net tax factor	-	132%
Discount factor	3%	4%

Table 4.1 - Economic calculation assumptions based upon (Energistyrelsen, 2018a)

The discount rate in the socio-economic calculations differs the longer the calculation period is and due to the calculation period being within the interval of 0-35 years, then the discount rate is 4% (Finansministeriet, 2017). The business economic discount rate is determined by the market and interest rate. DH projects can receive a municipality loan of 3%, which will be used in the business economic calculation (Vesthimmerlands Kommune, 2019). The energy saving price is estimated to 350 DKK/MWh (Aars Fjernvarme, 2019b). A socio- and business economic analysis can include more aspects, but these are the most important factors which will be included in this thesis.

Net Present Value Calculation and Annuity Payment

To evaluate the business- and socio-economy of each alternative in this thesis, a Net Present Value (NPV) calculation will be conducted. The NPV is a method to determine the current value of all future cash flows including the investment costs. The cash flow will involve discounted values of the costs and benefits which are expected to influence the society or company during the life span of the alternative. The alternatives are business economic feasible if the discounted benefits (cash inflows) are higher than the initial investment and costs (cash outflows) during the calculation (Østergaard & Lund, 2010). The socio-economic calculation investigates the socio-economic impacts total costs for each alternative in comparison with the reference, where the costs and benefits are discounted with the socio-economic discount rate. Therefore the alternative with the lowest socio-economic costs provides the highest socio-economic value.
The formula for the NPV calculation is given below:

$$NPV = \sum_{t=0}^{n} NP_t * (1+r)^{-t}$$

NP_t = Annual net payments at time t
t = calculation time horizon
r = discount rate

(Østergaard & Lund, 2010)

The NPV calculation is chosen, because it is well suited for evaluating projects with a long-term investment. The NPV includes all payments that are related to an investment and it accounts for the temporal distribution of payments through the discount rate, which discount the payments to the present point. There is no universally correct discount rate in the business economy, it depends on liquidity, risk and alternative projects which could have been implemented during the calculation period. This means that with a higher discount rate the more uncertain the feasibility of the given project is. This is because a high discount rate disfavours high initial investments and long-term benefits within a project (Østergaard & Lund, 2010).

To see the influence of an alternative related to the total production costs in DKK/MWh, another method will be used, the annuity payment method. The annuity payment method is used to describe the annual average costs related to the investment. This is done to illustrate a rather stable heat price which only differs due to annual operation costs during the calculation period. To finance an investment, the company must often obtain a loan to a given interest rate. The loan costs associated to the investment will be equally divided upon the 20 years and put in addition to the annual operation costs. The total liquidity effect over the 20 years is then divided with the total heat production, illustrating the annual average heat production costs. The interest rate accounts for the time dimension in relation to the loan costs and is the same of 3% as in the NPV calculation (Lauritsen, 2012).

The formula for the annuity payment calculation is given below:

$$Annuity\ Payment = Investment\ costs * \frac{\frac{r}{100}}{1-\left(1+\frac{r}{100}\right)^{-t}}$$

r= discount rate
t = time horizon

(Østergaard & Lund, 2010)

The heat price is calculated as the overall production costs related to operating the different alternatives in DKK/MWh. To make sure all alternatives are comparable, a scrap value is calculated for the alternatives where the investment in e.g. the production unit or piping have an expected life time of above 20 years.

Scrap value calculation

The calculation period is expected to cover a 20-year period and if the new production units or pipelines do not have the same life time horizon, a scrap value for the remaining years for the specific alternative will be calculated to account for the discrepancy between the alternatives. The scrap value is placed in year 20 as a positive value. The scrap value calculation is illustrated below.

$$NPV_{t_{20}} = \frac{Investment\ costs * \frac{20}{life\ time}}{(1+r)^{20}}$$

(Finansministeriet, 2017)

The scrap value is important to consider in DH projects both in the socio- and business economy, because the pipelines are expected to have a longer life time than a production unit and involve high investment costs, which are not required with individual solutions.

5. Determining the general assumptions

This chapter includes an overview of the technical and economic assumptions that will be used to create the operational strategy for each alternative in the analysis. There will also be constructed an estimation of the expected heat demand in the new urban area of Aars West in relation to what buildings and sizes they are expected to be established in.

5.1 Technical assumptions

The technical specifications for Aars DH's current energy system will be presented in Table 5.1. The total annual average heat demand is today 108,302 MWh, but due to heat losses in the DH network, the total heat production from the heat centrals are 138,849 MWh (Aars Fjernvarme, 2019b).

The heat demand of Aars West is expected to increase throughout the 20-year calculation period dependent upon when the different buildings in Aars West is established. The current heat demand in Aars DH system will remain the same, since there are no planned renovations in the consumer households (Aars Fjernvarme, 2019b). The peak load production in Aars DH was in 2018 around 29.3 MW and the heat demand is modelled daily where the peak load occurs from 6 o'clock to 8 o'clock in the weekdays.

Heat demand specifications District heating in 2018	
Yearly Heat production	138,849 MWh
Yearly heat demand	108,302 MWh
Peak load production	39.5 MW
Heat Dependent fraction	60%
Hot water dependent fraction incl. heat loss	40%
Period dependent on weather conditions	01-09 to 31-05
Reference Temperature	17°C
Distribution loss in the grid	22 %
External conditions (DRY data)	Zone 2
Consumers	5553

Table 5.1 - Heat Demand specifications for Aars DH

The heat dependent fraction is highly influenced by the external conditions since 60% of the total fraction depends upon the ambient temperature. This is due to in Aars DH's system, around 22% of the heat production is heat losses in the transmission and distribution grid and 18% is used for domestic hot water, which leaves the 60% for space heating. The reference temperature is the ambient temperature, and it determines the consumers requirements for space/room heating. The reference temperature is based upon standards used in Denmark (EMD international, 2013).

In Aars DH the new consumer installations will be dimensioned to 65°C supply temperature and a cooling of minimum 30°C at -12°C outdoor temperature. The supply temperature will vary during the year due to climatic conditions (outdoor temperature and wind speed) from 85°C to 70°C in the primary grid. Aars DH have committed themselves to secure a differential pressure of a minimum of 0.2 bar and a supply pressure of maximum 7 bar at the consumer (Aars Fjernvarme, 2014).

To determine the amount of excess heat, which are rejected from Dania's furnaces and Dania's production pattern, a temperature and flow measuring is conducted. The given excess heat production is illustrated on Figure 5.1 below.

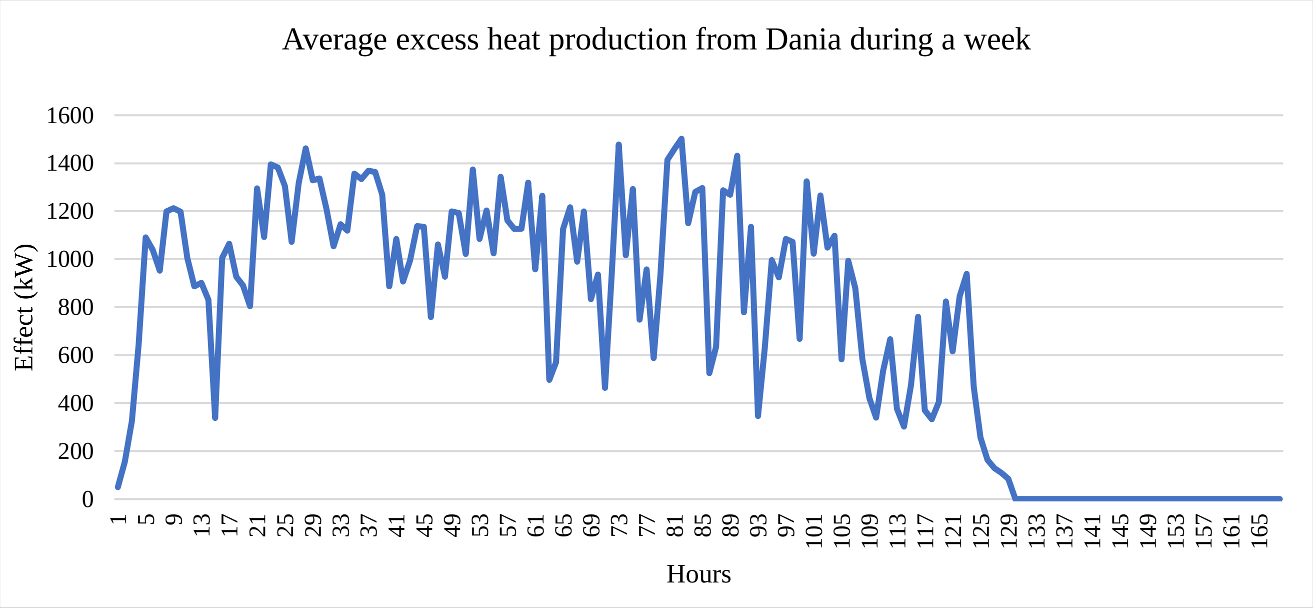


Figure 5.1 - Excess heat production from Dania in an average week

Figure 5.1 illustrates the excess heat production from Dania on an hourly basis from Sunday 18.00 to Sunday 17.00. This weekly average is used as the production pattern from Dania throughout the year. Dania's production is however also closed in the holidays. The temperature level of the excess heat is measured to 24°C with a constant flow of 211 m³/h, because the pumps are not frequency regulated and therefore operating at max load constantly (Tidemand, 2019).

External weather conditions

The external conditions include a weather profile with outdoor temperatures on an hourly basis to illustrate the variations in the heat consumption. The weather profile included in the modelling is based upon the Danish Reference Year (DRY) data. The weather data represents a typical Danish calendar year which varies in relation to the specific location in Denmark, since the profile differs in some areas. To account for this, DMI has divided Denmark into different industrial zones and Aars is located within zone 2's weather profile (DMI, 2012). The ambient temperature profile can be seen on Figure 5.2

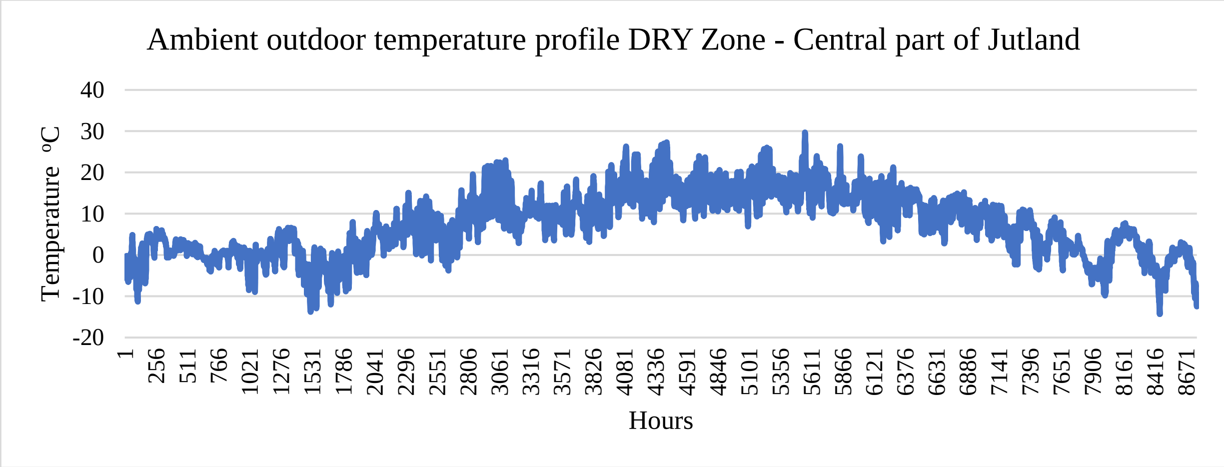


Figure 5.2 - Outdoor temperature profile in the central part of Jutland

The peak load demand often occurs during the coldest day of the year and in the reference year, the lowest temperature was around -14.3°C, which indicates the peak load capacity of around 39.5 MW. The hot water demand is however not directly dependent upon the outdoor temperature, due to consumer habits, and it is therefore not expected to change drastically during the year.

The technical specifications related to the different alternatives production capacity will be further described in Chapter 7 under each alternative. The modelling in EnergyPRO must include both technical inputs to operate, but also some economic assumptions to create an operational strategy, as described in Section 4.3.

5.2 Economic assumptions

The economic assumptions include varying prices such as fuel and electricity prices, but also fixed prices in relation to the fuels and taxes, tariffs and O&M costs per MWh. The electricity price profile is based upon the 2018 electricity price distribution, which will be used throughout all DH alternatives. The electricity price distribution is illustrated on Figure 5.3.

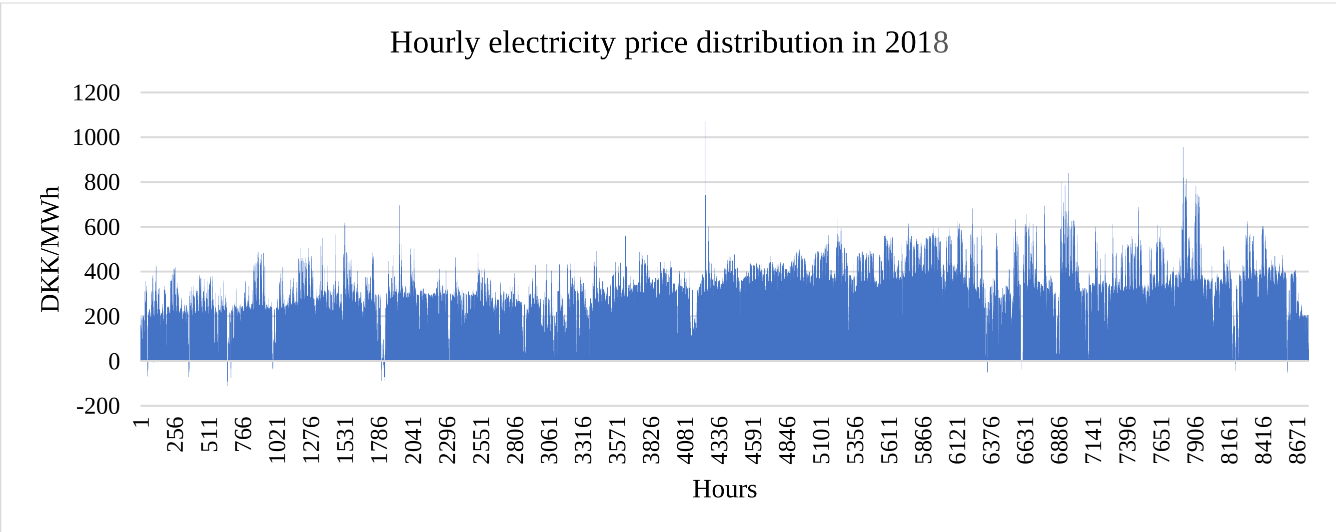


Figure 5.3 - Hourly Distribution of the Danish western electricity price in 2018

The average electricity price in 2018 was around 326 DKK/MWh, whereas the highest price in one hour was 1073 DKK/MWh and lowest -112 DKK/MWh (Nord Pool, 2018). Figure 5.3 illustrates few hours with an electricity price below 200 DKK/MWh. The 2018 electricity price distribution will be used in the 20-year calculation period, but the projected average price from 2021-2040 will be based upon the Danish Energy Agencies projected price levels. The price on waste is not included in the guideline, and it will therefore be based upon data informed by Aars DH on Figure 5.5.
The relevant fuel prices are illustrated on Figure 5.4. The average natural gas, wood pellet, electricity and wood chip price will be fixed annually during the years in both the business- and socio-economic calculation (Energistyrelsen, 2018b). The natural gas price operates on the European Spot gas market but will in this thesis be fixed annually together with the wood chip and wood pellet price. Aars DH expects their annual natural gas consumption to be 107,404 m³ in 2019 (SEAS-NVE, 2018).

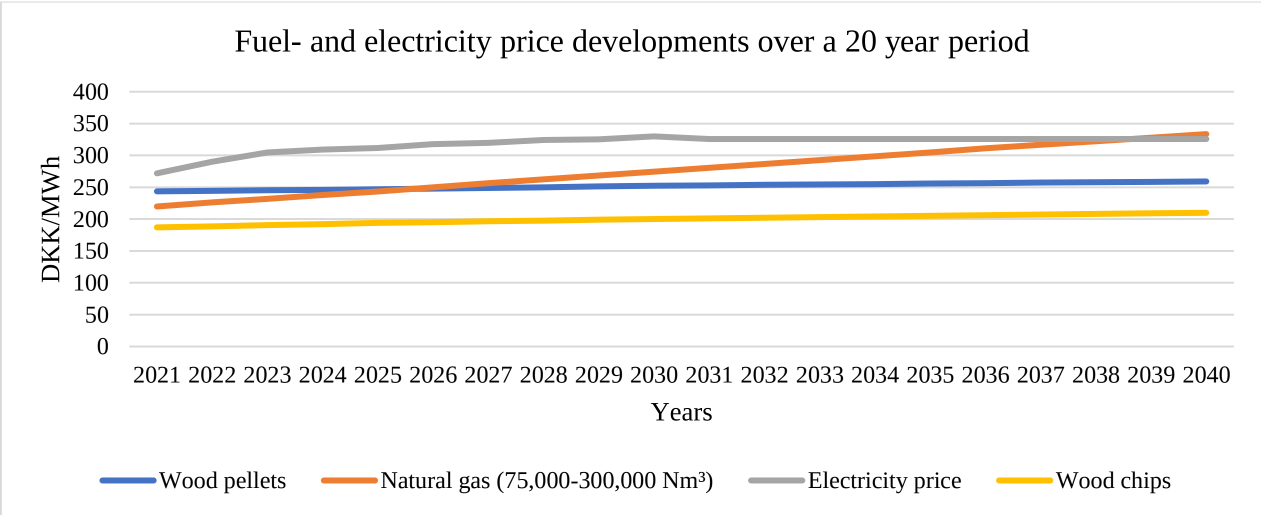


Figure 5.4 - Development of fuel and electricity prices over 20 years

The Danish Energy Agency projects that the electricity will decrease to 272 DKK/MWh in 2021 compared to the 2018 average price of 326 DKK/MWh. From 2021, the electricity and fuel prices are projected to have a linear transition towards the price level of 2040 (Energistyrelsen, 2018b). The average waste price is determined to vary monthly dependent upon the supply and demand of the waste. The annual variations in the waste price is illustrated on Figure 5.5 below.

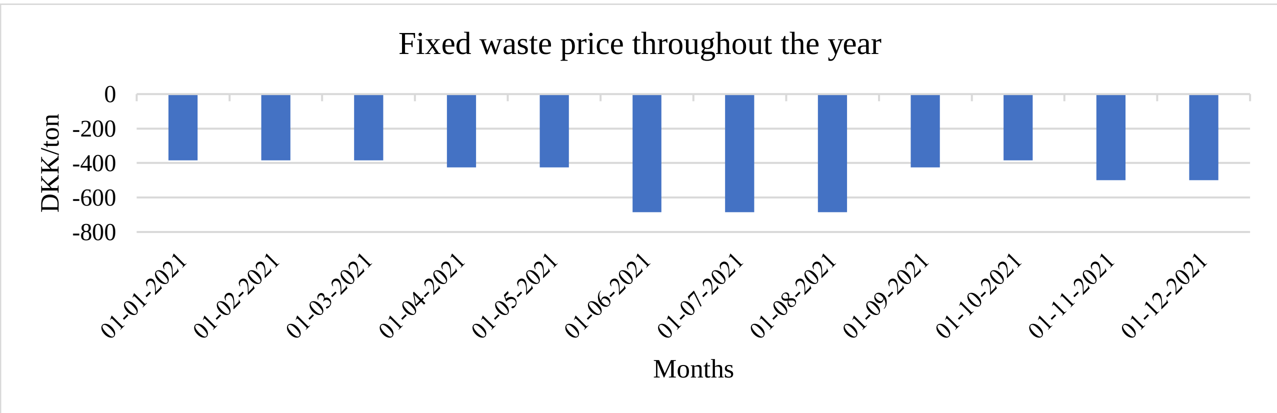


Figure 5.5 - Monthly average waste price throughout 2018

The price level of waste is highest in the summer period, where the heat demand is lowest and in November and December Aars imports waste from the UK, meaning the waste price is higher compared to October. The average waste price is -485 DKK/ton and the waste price level are fixed throughout the calculation period due to uncertainty of development and variations during the year. The price levels are raw prices, meaning that taxes and tariffs are not included in the price. An overview of the different taxes related to the fuels utilised in Aars DH in 2019 together with O&M costs are illustrated on Table 5.2.

	Taxes and tariffs 2019	**Price in DKK/MWh**	**Sources**
Natural gas Energy tax (boiler and CHP)	2.225 DKK/Nm³	202.30	(SKAT, 2019a)
Natural gas CO_2 emission tax (boiler & CHP)	0.396 DKK/Nm³	36.00	(SKAT, 2019b)
Natural gas NOx emission tax (boiler)	0.008 DKK/Nm³	0.73	(SKAT, 2019c)
Natural gas NOx emission tax (CHP)	0.029 DKK/Nm³	2.64	(SKAT, 2019c)
Natural gas Methane emission tax (CHP)	0.068 DKK/Nm³	6.18	(SKAT, 2019d)
Electricity for heat tax	0.155 DKK/kWh	155.00	(SKAT, 2019d)
Waste incineration tax	46.8 DKK/GJ	168.5	(SKAT, 2019e)
Waste incineration CO_2 tax	173 DKK/ton CO_2	26.82	(SKAT, 2019e)
Waste incineration NOx tax	5.1 DKK/kg NOx	1.22	(SKAT, 2019e)
Electricity tariff (local)	0.112 DKK/kWh	112.00	(Aars Fjv., 2019c)
Electricity tariff (transmission)	0.080 DKK/kWh	80.00	(Energinet, 2019)
Biomass tax: NOx	0.5 DKK/GJ	1.80	(SKAT, 2019c)
CO_2 Quotas	127 DKK/ton	40.70	(Aars Fjv., 2019c)
Excess heat taxation	25 DKK/GJ	90.00	(Skatteministeriet, 2019)
Operation and maintenance costs for the production units			
Natural gas CHP plant	-	El – 65.00	(Aars Fjv., 2019c)
Natural gas boiler	-	8.50	(Aars Fjv., 2019c)
Waste incineration turbine & boiler	-	50.00	(Aars Fjv., 2019c)
Electrical heat pumps	-	25.00	(COWI A/S, 2019)
Wood Chip boiler	-	10.00	(COWI A/S, 2019)
Excess heat unit	-	17	(COWI A/S, 2019)

Table 5.2 - Overview of taxes related to fuel types and O&M costs for the different production units

The Energy tax and CO_2 tax for natural gas CHP plants are not required to pay the full tax, and to account for this, the E formula is chosen for the calculation of the refund (SKAT, 2019f). The waste incineration plants are double taxed in relation to CO_2, since they must pay both CO_2 tax and CO_2 quotas. The biomass alternative is interesting from a business economic perspective, since it is currently almost exempt from taxation. The electricity for heat tax will be reduced to 155 DKK/MWh, and excess heat tax 90 DKK/MWh as described in Section 1.1. The rest of the tax structures will follow the 2019 price level due to uncertainties on how they will change from 2021 and forward.

5.3 Determining the heat demand in Aars West

To estimate the heat demands for the different new buildings in Aars West, SBI made an analysis of different building types' heat demand in 2014, which will be used in this thesis as an estimation guideline to determine the projected heat demand related to the different household constructions (SBI, 2014). The heat demand for the new institutions in Aars West will be based upon current data from existing institutions in Aars and compared to the SBI guidelines.

The new urban area in Aars West must be built after the energy framework from 2018 (BR18). The BR18 register describes a theoretical value of the expected heat demand for each construction, which include a heat conversion factor dependent upon heat supply (Bygningsreglementet, 2019). An investigation, made by Verdo in 2015, investigated the energy consumption within different households of 160 m² built under the BR08-BR15 framework in the Danish city Randers. The results are illustrated on Figure 5.6 and it shows that the measured heat demand is significantly higher than the theoretically calculated heat demand in the buildings from the framework 2008-2015 (Verdo, 2015).

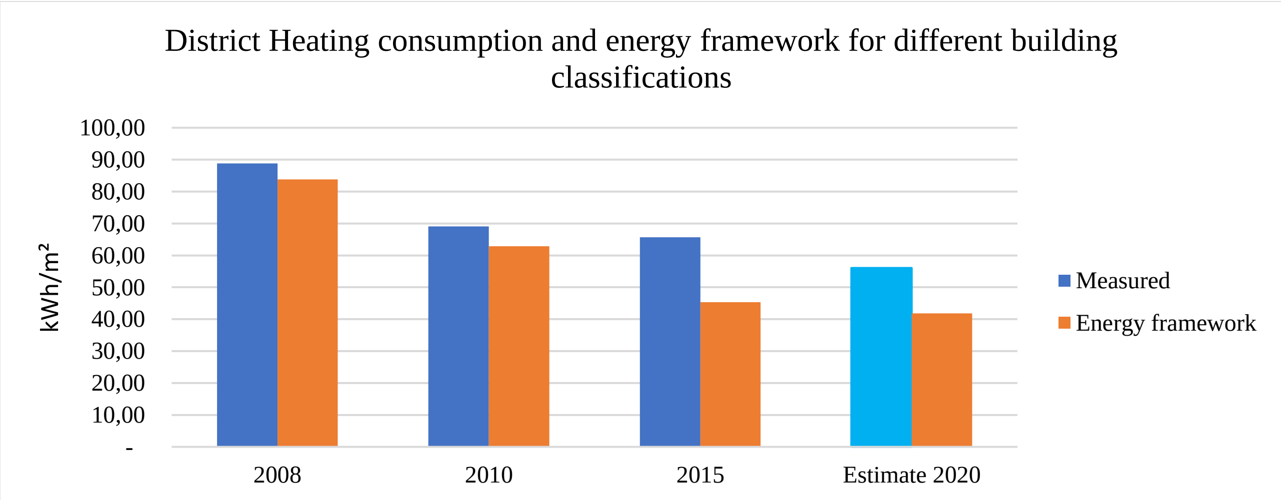


Figure 5.6 - DH consumption and energy framework for different construction classes based upon (Verdo, 2015)

Figure 5.6 illustrates that the lower the energy framework is, the higher deviation between the theoretical and investigated value there is, in relation to the heat demand. This tendency is also confirmed in an SBI report 2016:09, (SBI, 2016). The energy framework does therefore not symbolise a true indication of the heat demand for new buildings. From 2010-2015, the heat demand is saturated with a decrease of only 5%, which could indicate that the buildings have reached a level where the heat demand is not able to decrease much further. This is mainly due to the hot water demand, which is independent upon investments in insolation etc (Busk, 2019).

The BR15 classification's measured average heat demand is 5% lower than the measured BR10 classification and 45% higher than the energy framework. On behalf of these indications an estimated value for the measured data in 2020 is constructed. This is done to illustrate a more accurate heat demand in the area that accounts for a hot water demand and rebound effect occurring in new well insolated households. This is done to make sure that the distribution network and service pipes are not under dimensioned (Eriksen, 2017). The estimated heat demand for a standard building is illustrated on Figure 5.6 with an estimated value of 56 kWh/m² for 2020 instead of the theoretical value from BR18 of 41.8 kWh/m². Galgehøjen Stage 1 and 2 have already received permit from the Municipality back in the beginning of 2018 under the BR15 framework with a 45% increase of the heat demand to match the measured values. The different households will have a different heat demand (kWh/m²) and the expected construction and heat demand in Aars West, Galgehøjen Stage 1 & 2 is illustrated in Table 5.3.

Aars West - Galgehøjen Stage 1 & 2 (local plan 1070)						
Construction (type)	Amount (number)	Area per building (m²)	Heat demand (kWh/m²)	Heat demand per building	Total Estimated heat demand (MWh)	Heat load (kW)
Parcel house	47	180	64.4	11.6	545	191
Indv. house	8	180	64.4	11.6	93	33
Terrance house	12	90	64.4	6.7	80	28
Total	67	-	-	-	718	252

Table 5.3 - Determined assumptions related to Galgehøjen Stage 1 & 2 in Aars West

The planning process of Galgehøjen Stage 3 in Aars West is already being discussed and this area will consist of the same number of households as Galgehøjen Stage 2, but with more individual households (Engerstrøm, 2019). Galgehøjen Stage 3 will differ in relation to heat demand and temperature supply, since these buildings will be constructed as low temperature households (zero energy households) (Vesthimmerlands Kommune, 2019). The heat demand in Aars West Galgehøjen Stage 3 will be based upon the BR18 theoretical classification for zero energy households meaning the theoretical heat demand must not be higher than 27 kWh/m² per year. However, The Danish District Heating Association have investigated the energy consumption in these low energy households as well, and the same tendency from the Verdo investigation occurs. Therefore, the theoretical value will be multiplied with 34% to match the same tendency from the normal households, but the energy consumptions are still lowered by half (Eriksen, 2017). The estimated heat demand and heat load for Aars West Galgehøjen Stage 3 is illustrated in Table 5.4 below.

Aars West - Galgehøjen Stage 3						
Construction (type)	Amount (number)	Area per building (m²)	Heat demand (kWh/m²)	Heat demand per building	Total Estimated heat demand (MWh)	Heat load (kW)
Parcel house	16	180	36.5	6.6	105	37
Indiv. house	10	180	36.5	6.6	66	23
Total	26	-	-	-	171	60

Table 5.4 - Determined assumption related to Galgehøjen Stage 3 in Aars West

The total households in Galgehøjen will consist of 63 parcel houses, 18 individual houses and 12 terrace houses.

The constructed assumptions for the institutional area in Aars West are based upon the interview conducted with Vesthimmerlands Municipality in relation to the institutions expected to be constructed and their respective size in m². The estimation of the heat demand for the institutional area in Aars West will be based upon both measured values from existing institutions in Aars, the estimated values from the SBI report and compared to the estimated value of 2020, from Figure 5.6. This is done to make the most adequate estimation for the new institutions as possible (SBI, 2014). The estimated values for Aars West institutional area are illustrated in Table 5.5

Aars West – Institutional area (local plan 1050)						
Construction (type)	Amount (number)	Area per building (m²)	Heat demand (kWh/m²)	Heat demand per building (MWh)	Total Estimated heat demand (MWh)	Heat load (kW)
Swimming Pool	1	4,500	267	1,200	1,200	480
Outdoor Pool	1	1,125	267	300	300	120
Sport hall	1	3,661	98	360	360	144
School	1	8,446	71	600	600	240
Total	4	-	-	-	2,460	984

Table 5.5 - Determined assumptions related to the industry area in Aars West

The different areas will develop gradually during the calculation period from 2021, since this is when Galgehøjen Stage 1 and the Swimming Pool are expected to be fully constructed. The estimated development of the area is illustrated in Table 5.6 below. The construction of the DH distribution network will follow the development gradually in relation to Galgehøjen whereas the institutional area will be built in 2021 and the other institutions will connect to the primary grid through a service pipe.

Area	Connection load (kW)	Year
Galgehøjen 1 & Swimming pool	754	2021
Galgehøjen 2	98	2023
Sports hall	144	2025
School	240	2028
Galgehøjen stage 3	60	2030
Total	**1296**	**2030**

Table 5.6 - Estimation of construction development and heat load in Aars West

These assumptions will be used to indicate the expected heat demand in the area, connection loads, construction of the distribution network and load on the existing network and production units during the calculation period.

6. Aars District Heating network analysis

This chapter includes an analysis of the piping dimensioning in Aars West in relation to the pressure loss criteria and Aars DH's technical regulations. There is also conducted a hydraulic analysis of the influence with connecting Aars West onto the existing network to see and if any reinvestments or upgrading measures in the network are needed.

6.1 Construction of distribution network in Aars West

To supply the new urban area Aars West, a distribution grid within the area must be constructed. The new urban area is expected to be connected to the existing DH network through the pipe DN80 located at Markvænget in Aars, which is illustrated on Figure 6.1. The distribution grid will be constructed in Termis, since this tool can assess how the entire network will operate with the expected changes and if the pipes/pumps are large enough to distribute the heat from the main central to the connected consumers in the network. Aars West (Galgehøjen) is already under construction but to assess the overall load on the network, the piping must be dimensioned to supply the entire area. This means that the piping will be over dimensioned in the beginning, since it is too expensive to upgrade the piping dimensions gradually.

The expected piping dimensions and a tracé of the area is illustrated through the Termis model on Figure 6.1. Aars West (public institutional area) will be dimensioned after the criteria from the institutions, since their consumption pattern deviate from a standard household in relation to full load hours. The temperature levels for Aars West's Galgehøjen Stage 1 & 2 and the institutional area is expected to require around 65^{o}C supply and 35^{o}C in return temperature meaning the consumers will have a cooling of 30^{o}C. Galgehøjen Stage 3 will be constructed as low temperature DH, meaning the buildings will only require a supply temperature of 55^{o}C supply and 30^{o}C in return equal to a cooling of 25^{o}C. The piping will be dimensioned as traditional DH, since the units must be able to handle 75^{o}C in supply in the coldest hours and when Dania's production is closed.

By connecting Galgehøjen Stage 3 with Galgehøjen Stage 1 & 2, a shunt will be established to control the temperature in the area. This is done because the temperature cannot be lowered as much in the other buildings due to the existing consumer installations and requirements. The shunt function to connect the return and supply side in the network, meaning that it allows water from the return side to mix with water from the supply side to maintain a predefined supply temperature at the location of the shunt (Schneider Electric, 2018). The constructed distribution grid in Aars West together with the pressure loss Pa/m in the piping is illustrated on Figure 6.1 below, calibrated for a peak load situation at -12^{o}C.

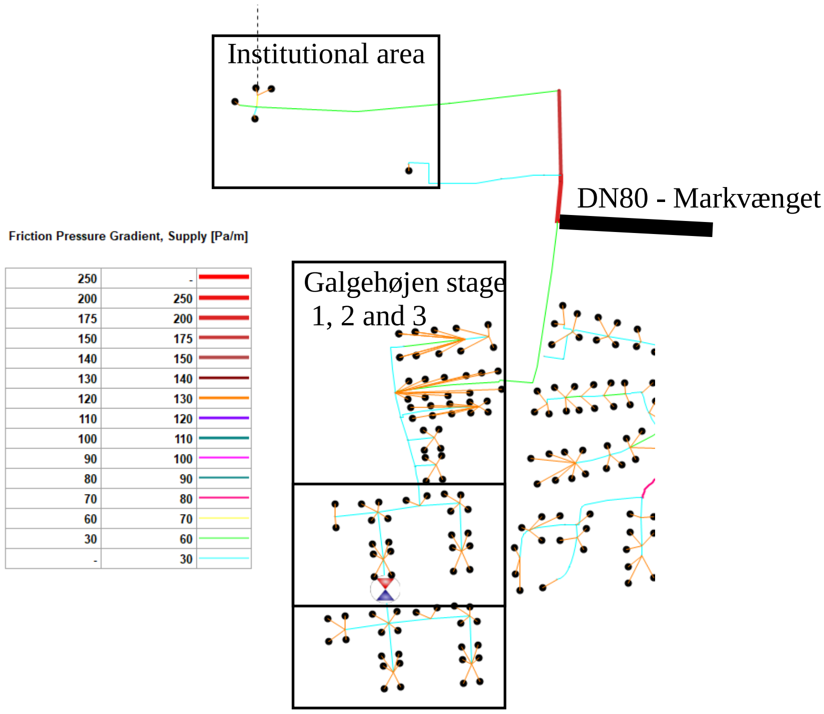


Figure 6.1 - The piping and number of consumers (black dots) in Aars West, the boxes indicate the areas

Figure 6.1 illustrates that the pressure loss per meter (Pa/m) in the area is below the 100 Pa/m, which is the dimensioning criteria. Aars West is divided into two areas. One pipe leading to the institutional area is above the criteria with a pressure loss of 171 Pa/m, meaning it is over loaded. It is however not considered a problem in relation to it being upgraded, since the alternatives will provide an alternative route or heat central, which will reduce the pressure on that pipe. With the full development in Aars West, then the pressure load on Markvænget will increase to 268 Pa/m, which is critical. The different piping dimensions, lengths and prices on unconsolidated areas for the rest of Aars West are illustrated in Table 6.1 below. Due to Galgehøjen Stage 1 & 2 already being under construction, the costs associated to this area will not be included in investment.

Dimension	**Length (m)**	**Price (DKK/m)**
Service pipe (household)	312	1170
Service pipe (institutions)	80	1607
DN25	70	1171
DN32	156	1232
DN40	182	1314
DN50	27	1466
DN65	14	1550
DN89	161	1664
DN100	485	1866
Total	**1487**	**2,608,316**

Table 6.1 – Aars West distribution network incl. piping dimensions, lengths and price level in Aars West (COWI A/S, 2019)

The piping price (DKK/m) includes new twin pipes series 3 and included in the price are materials, welding, constructions work, counselling and unforeseen extra costs on 10% of the total price (COWI

A/S, 2019). The service pipes for the household are estimated to 12 m in average and for the institutions 20 m in average.

6.2 Hydraulic analysis of the current district heating network

Aars West will be developed from 2021 to 2030, which means that the investment in upgrading the DH network and new production units will happen gradually. The current DH network in Aars DH will utilise a DN80 pipe to supply Aars West located on Markvænget (red circle). The connection loads influence on the DH network is illustrated on Figure 6.2. In 2018, the waste incineration plants could in a peak load situation supply 13.34 MW at a temperature set of 80/40°C to the zone from Central 1 at Gislumvej, located at the right corner of Figure 6.2, which the Termis model is calibrated after.

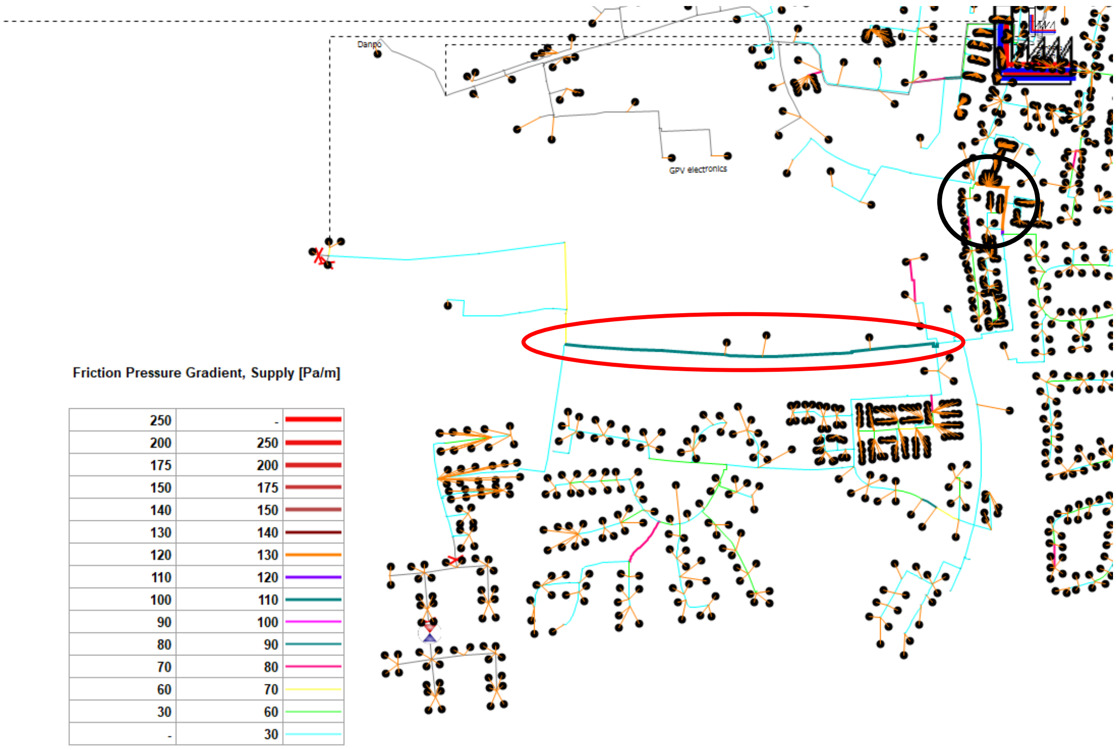


Figure 6.2 – Aars DH current DH network with the expansion of Aars West (Circles outline high Pa/m)

Figure 6.2 illustrates that by connecting Galgehøjen Stage 1 and the indoor swimming pool in Aars West equal to a connection load of 754 kW, then the pressure loss in the DN80 pipe will be 102 Pa/m, which is marginally above the dimensioning criteria, but not problematic, since it is in a peak load situation. However, the main pipe marked with orange (black circle), has a high pressure loss of 124 Pa/m, meaning it is already critical for the system to supply the area, so the piping must be upgraded. The DN80 at Markvænget can distribute a volumetric flow of 17.02 m^3/h equal to a heat load of 0.75 MW with a $\triangle t$ (difference between supply- and return temperature) of 38.1°C. This will be used further in the technical and economic analysis in Section 7.1.

The high pressure losses in the pipes, influence the supply pressure from the central and if the pressure losses are too high, the pumps on the central must increase their critical speed, to ensure that the differential pressure at all consumers always are above 0.2 bar. The supply pressure cannot be below 0 due to the hydrophore which secures that the pressure within the pipe is higher than the pressure from the surroundings. The hydrophore pressure in the network is essential to have installed in times with pump failure to make sure a vacuum in the piping is not occurring (Iversen Trading, 2019).

The high pressure loss is caused by a high DH water velocity, since the higher velocity, the higher pressure loss. With a higher media velocity, it can cause a challenge in relation to noise and pressure surge in the network. The differential pressure is used to dimension the DH installation to make sure that the necessary flow can run through the consumer installation to ensure the supply temperature and cooling of the DH water. In Aars DH they have a minimum requirement of 0.2 bar at the consumer installation, but they are typically operating after 0.3 bar, which will be used in this thesis (Aars Fjernvarme, 2019b). The differential pressure (pressure difference between supply- and return pressure) is created by the pumps implemented in the DH network, and it indicates how much DH water that can run through the internal heating installation at the consumers. The higher differential pressure, the higher flow possible. To increase the differential pressure, pumps must increase their critical speed, which is illustrated on Figure 6.3. If the current network should supply the area in 2021, then the supply pressure on the central must increase to 6.3 bar to make sure that the differential pressure is above 0.3 bar at the critical point. This is still within the accepted supply pressure maximum of 7 bar in the network, as described in Section 5.1. However, if more consumers are connected to the grid it will be problematic. It is therefore important to investigate what can be upgraded, since the pumps on Central 1 at Gislumvej will be pressured to the limit as Aars West is gradually developed.

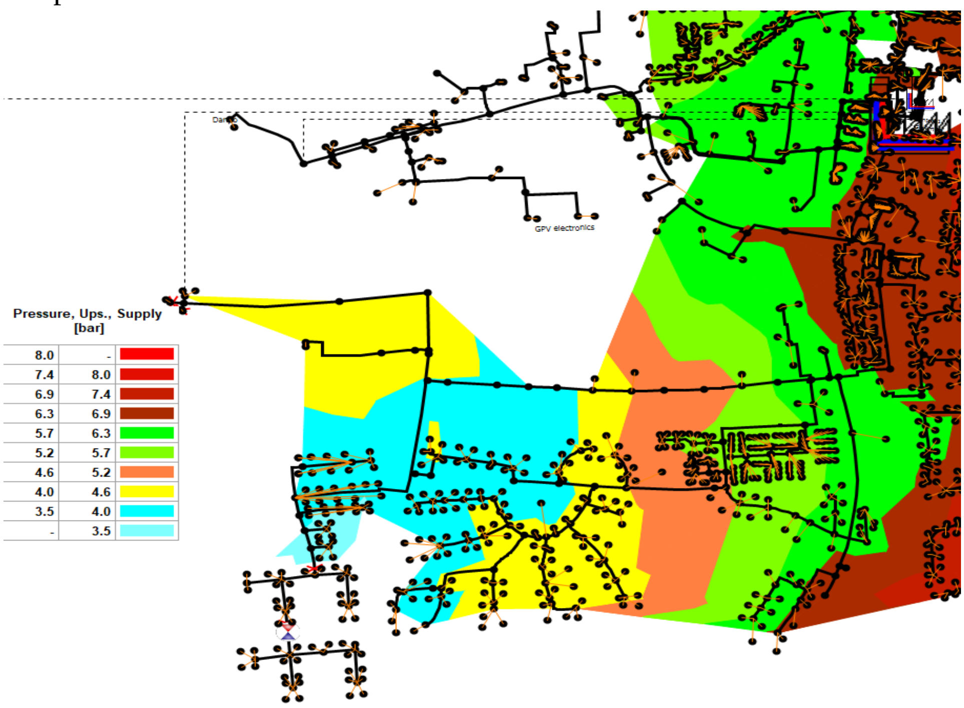


Figure 6.3 - Termis supply pressure for the DH network

Another parameter that could secure the demand in the area is to increase the supply temperature to 90ºC, since it will increase △t and therefore decrease the flow because of less m³/h needed to secure the heat demand. Flow indicates how many litres of DH water that circulates through the unit an hour (Schneider Electric, 2018). By increasing the supply temperature the network will become less efficient due to an increased heat loss, as described in Section 3.1. The high load on the DN80 must be solved to supply Aars West in the future and after discussion with Aars DH, it is not feasible to upgrade the DN80 pipe since it is only three years old (Neve, 2019). Therefore, an alternative route for the reference scenario will be constructed to secure the heat demand in Aars West.

6.3 Hydraulic analysis of the reference system

The alternative route constructed will be implemented through Markedsvej and will be dimensioned to supply the entire area due to the relatively short time horizon of the estimated constructions, which is illustrated on Figure 6.4. The temperature from Central 1 at Gislumvej is 80.2/37.3ºC.

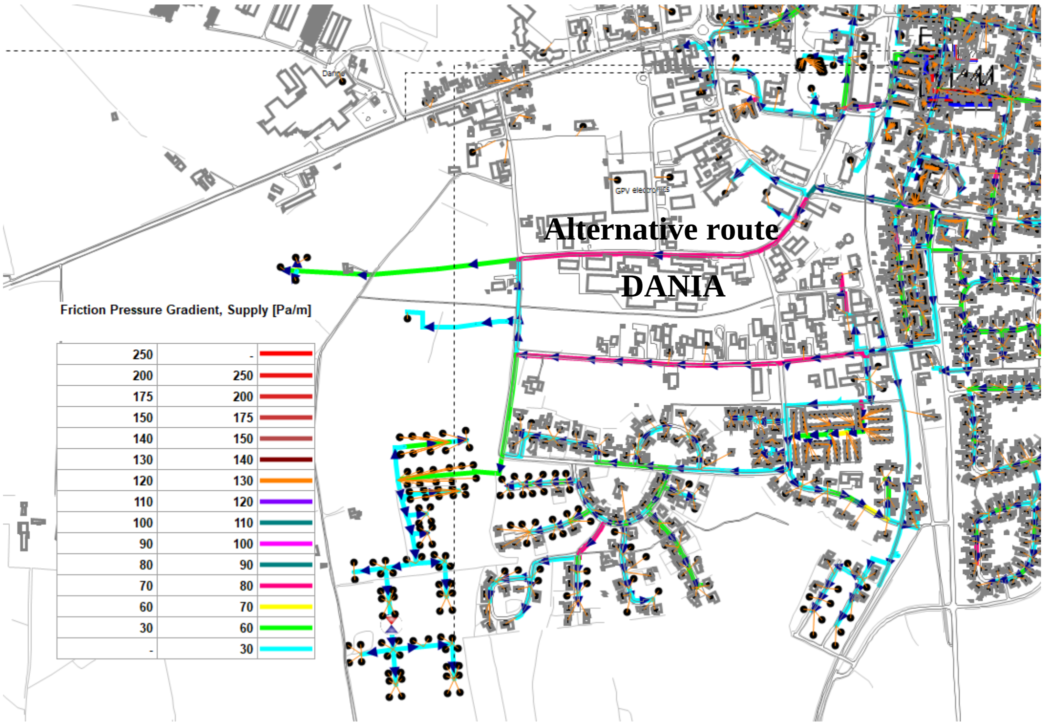


Figure 6.4 – Alternative supply piping route to supply Aars West illustrating piping network, pressure gradients and flow direction

By implementing a new supply pipe connection (Alternative route), the load on the DN80 on Markvænget (red line with arrows) is decreased from 268 Pa/m to 70 Pa/m, and the alternative route will have a pressure loss of 77 Pa/m, which is illustrated on Figure 6.4. The dimension, length and price level for implementing the alternative route is illustrated in Table 6.2 below and it includes materials, welding, constructions work, external counselling and unforeseen extra costs on 10 % of the total price (COWI A/S, 2019).

Dimension	Length (m)	Price (DKK/m)
DN80	678	1665
DN200	160	2909
Total	**838**	**1,928,755**

Table 6.2 – Supply pipe to Aars West incl. piping dimensions, lengths and price (COWI A/S, 2019)

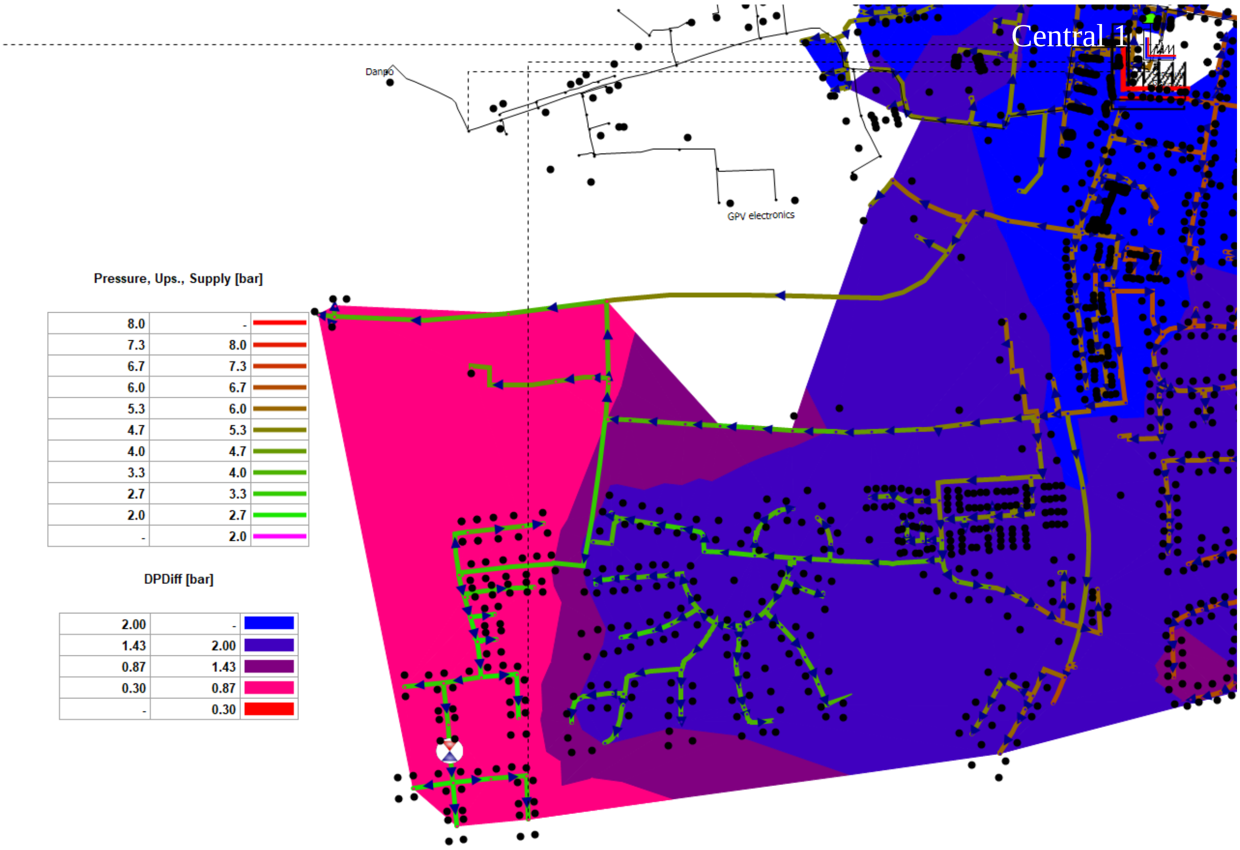
The installed pipe is a DN80 with a length on 678 m running through the road close to Dania (Markedsvej). The reference scenario includes upgrading a DN150 with a length on 160 m close to Central 1 at Gislumvej, which were over pressured, as described in Section 6.2. The total investment costs related to installing the alternative route are 1,928,755 DKK and will be placed in year 2021 due to the swimming pool and Galgehøjen Stage 1's influence on the network. The development of Aars West will also influence the heat loss, which is illustrated in Table 6.3.

Area	Connection load (kW)	Additional heat loss (kW)	Pressure loss (Pa/m) on DN80 - Markvænget	Pressure loss (Pa/m) on Alternative Route
Galgehøjen stage 1 & swimming pool	754	62	23	32
Galgehøjen 2	98	17	30	37
Sports hall	144	3	42	49
School	240	4	66	72
Galgehøjen stage 3	60	11	71	76
Total	**1296**	**90**	**71**	**76**

Table 6.3 - The influence of gradually connecting Aars West unto the DH network (Reference system)

By installing the alternative route, the load on the DN80 on Markvænget will be reduced significantly and gradually. As more buildings are constructed the connection load is increased together with the heat losses in the network due to increased size of network. With a full development of Aars West, the heat loss will be 90 kW. The DH network will have pipes that are a bit over dimensioned in the beginning, which will give a higher temperature drop in the pipes from the central to consumers due to low velocity. The minimum velocity is calculated through looking at the supply temperature at the consumer furthest away from the central to make sure that the temperature loss is not too high before reaching the consumer (Lauritsen, 2012). The capacity needed from the central to supply Aars West will then be 1386 kW incl. heat losses in the DH network, which will be used in EnergyPRO to calculate the production distribution in Section 7.1.

The temperature levels in the reference scenario are all above the required temperature of 65°C and varies from 75-78°C at the consumers. The high supply temperature is due to the heat production coming from the waste incineration plants and natural gas boilers from the main centrals, which distribute it into the DH network with around 80°C. The differential pressure and supply pressure are illustrated on Figure 6.5 below.



8.0	-	
7.3	8.0	
6.7	7.3	
6.0	6.7	
5.3	6.0	
4.7	5.3	
4.0	4.7	
3.3	4.0	
2.7	3.3	
2.0	2.7	
-	2.0	

2.00	-	
1.43	2.00	
0.87	1.43	
0.30	0.87	
-	0.30	

Figure 6.5 - Aars West Reference - differential- and supply pressure (map colour illustrates DP and pipe colour SP)

Figure 6.5 illustrates that the institutional area has a supply pressure of around 3.8 bar whereas Galgehøjen's supply pressure is 2.7 bar. By installing the alternative route with the full development of Aars West then the supply pressure from the Central 1 will increase to 5.9 bar. The differential pressure will be 2.4 bar to secure a differential pressure of minimum 0.3 at the critical point, which is illustrated on Figure 6.5's map colour representing the differential pressure. The technical conditions are therefore met in the DH network for securing the distribution of DH water in a peak load situation, as described in Section 5.1.

6.4 Hydraulic analysis of installing an alternative at Dania

Aars DH wants to investigate some alternatives utilising the excess heat from Dania. After consultation with Dania's Bent Tidemand and Aars DH's Kasper Neve, it is possible to utilise the excess heat from the furnaces at Dania with a temperature of 65°C resulting in an alternative, where there is no need to boost the temperature with a HP. However, this alternative is dependent upon more technical and organisational specifications in relation to securing the cooling demand at Dania and receiving agreement. Therefore, the HP alternative will be investigated in comparison. The excess heat load from the heat central at Dania must be utilised first in the system, when possible with a temperature set of 65/29°C.

An illustration of the piping network, location of heat central and pressure gradients with the full development of Aars West is illustrated on Figure 6.6 below

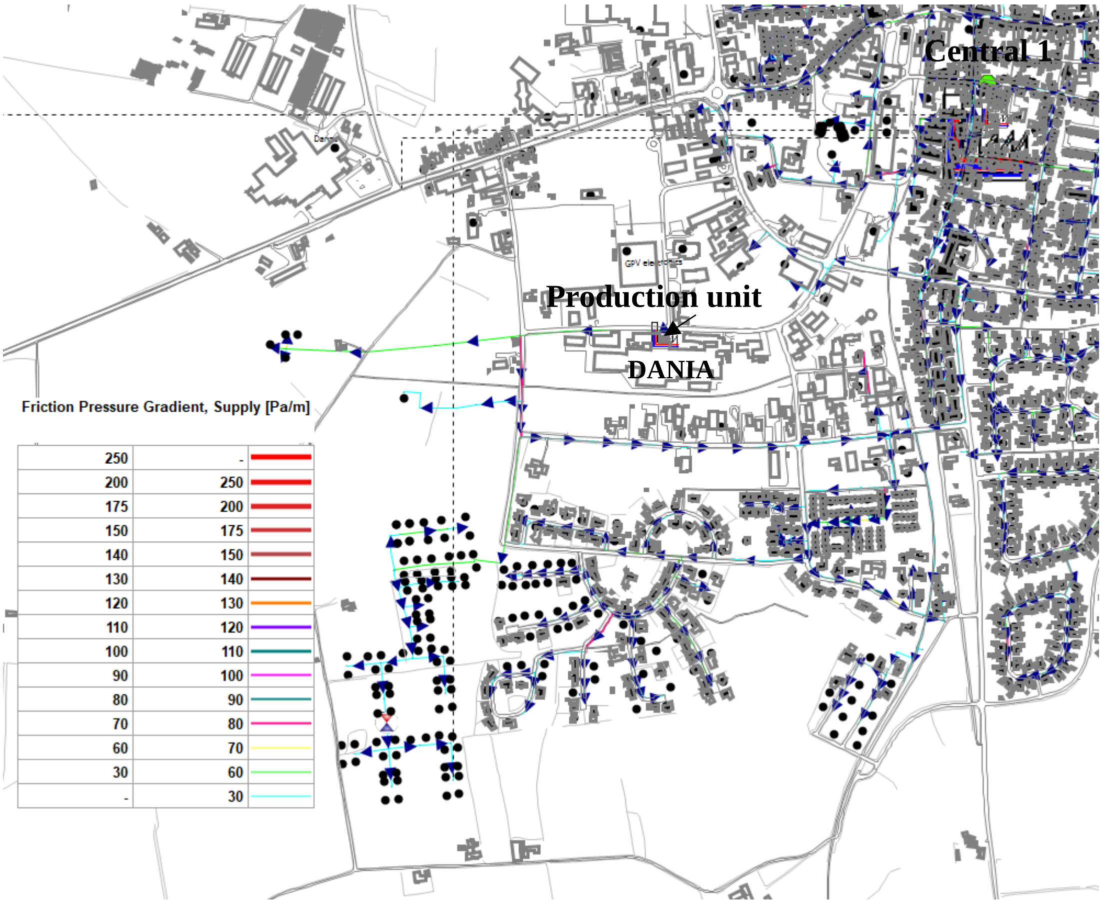


Figure 6.6 - Alternative with excess heat from Dania illustrating pressure gradients and piping network and flow direction

Figure 6.6 illustrates that the supply pipe from Dania will be able to supply the area and have a pressure loss of around 40 Pa/m. The challenge with utilising the excess heat from Dania is that the production is closed during the weekends, and it is therefore necessary to incorporate a solution to supply the heat demand during the weekend in Aars West, if the pipe on Markvænget does not have enough capacity.

The dimension, length and price level for implementing the piping network from Dania is illustrated in Table 6.4 below and it includes materials, welding, constructions work, external counselling and unforeseen extra costs on 10 % of the total price (COWI A/S, 2019).

Dimension	Length (m)	Price (DKK/m)
DN125	334	2160
Total	**334**	**872,908**

Table 6.4 - Supply pipe from Dania incl. piping dimensions, lengths and price (COWI A/S, 2019)

The installed pipe is a DN125 with a length on 334 m running from Dania to Aars West. By implementing the supply pipe at Dania and the heat central, the pressure on the piping close to Central 1 at Gislumvej is reduced and will therefore not require an upgrade unlike the reference scenario. This is due to Dania being able to supply both Aars West, but also utilise the capacity on the

Markvænget pipe to supply more of Aars. The costs related to installing the DN125 supply pipe from Dania will be 872,908 DKK.

The influence on the DH network with utilising the excess heat from Dania to supply Aars West's gradually developing heat demand is illustrated in Table 6.5.

Area	Connection load (kW)	Additional heat loss (kW)	Pressure loss (Pa/m) on DN80 - Markvænget	Pressure loss (Pa/m) on Dania supply pipe
Galgehøjen stage 1 & swimming pool	754	15	82	31
Galgehøjen 2	98	12	66	32
Sports hall	144	5	50	35
School	240	13	31	41
Galgehøjen stage 3	60	6	22	40
Total	**1296**	**51**	**22**	**40**

Table 6.5 - The influence of gradually connecting Aars West unto the DH network with a supply pipe from Dania (Alternative)

By installing the supply pipe from Dania with a new production unit, the load on the DN80 on Markvænget will increase from the beginning to 82 Pa/m. This is due to the production from Dania must be utilised and therefore it will be transmitted through the Markvænget pipe to Aars city. However, as the heat demand gradually increase, the more heat can be utilised within Aars West and therefore the heat load is decreased on the Markvænget pipe. The Dania supply pipe's pressure loss increases a small amount throughout the period. It is important to clarify, that Dania do not have 1.5 MW available constantly due to the varying excess heat production, as described in Section 5.1. The additional heat loss is reduced from the beginning of the period to 15 kW compared to the reference system of 69 kW. By increasing the heat demand then the heat losses also increase due to more piping being installed, but overall the heat losses are reduced with 39 kW compared to the reference system. The heat load needed from the centrals to supply Aars West will then be 1347 kW incl. heat losses in the DH network at -12^{o}C. This effect will be used in EnergyPRO to calculate the production distribution and test if the heat demand is secured throughout the calculation period in Section 7.1.

To utilise the heat from Dania, the supply temperature must be 65^{o}C to provide the consumers in the institutional area and Galgehøjen Stage 1 and 2 with the right supply temperature. Figure 6.7 illustrates the temperature level in Aars West and which unit that supplies what area through the flow direction.

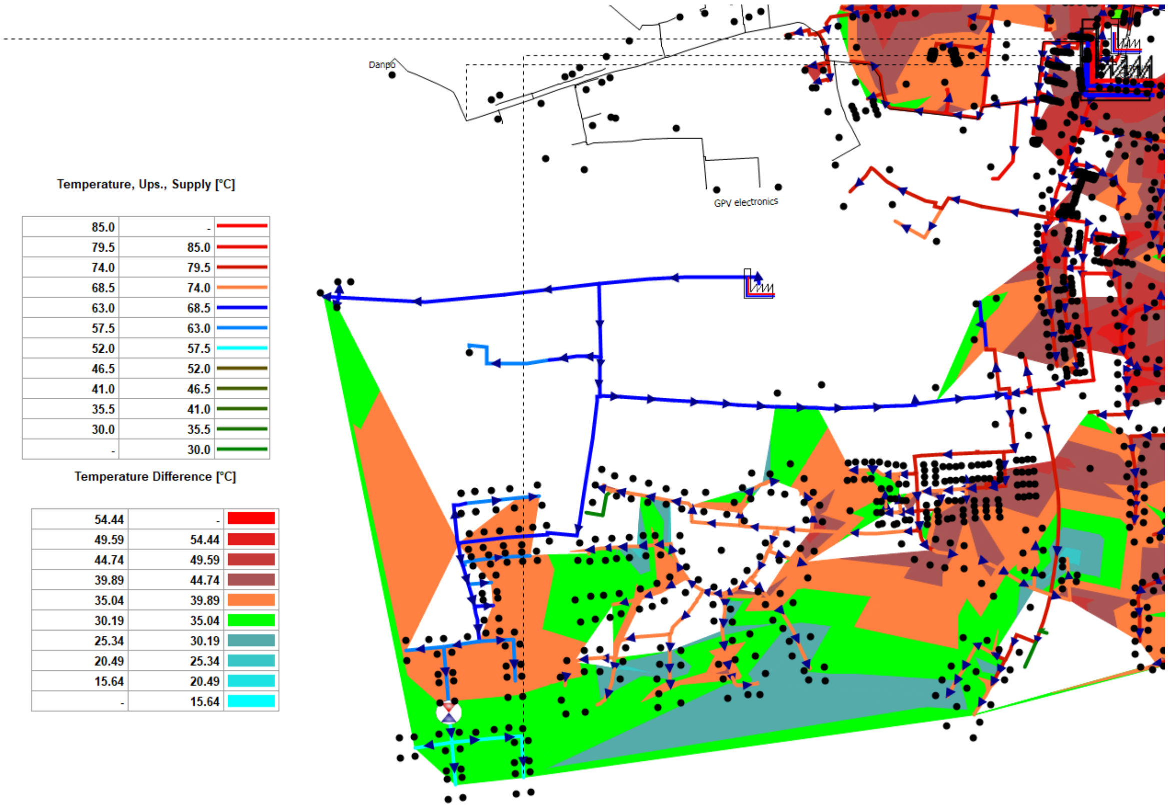


Figure 6.7 – Dania supply pipe supply temperature and temperature difference (arrows indicate flow direction)

Figure 6.7 illustrates that the production unit at Dania can supply Aars West with heat in a peak load situation, since the supply temperature is 65°C. With the 1.5 MW heat capacity it can also transmit heat through Markvænget with the condition of Central 1 at Gislumvej is mixing the hot water to increase the temperature to secure the consumers temperature requirements of 68-76°C. The consumers must secure a △t of a minimum of at least 30°C, which is secured in the area and some consumers have a higher cooling of 35°C. The high △t is important, because the pressure loss often increases by lowering the supply temperature from the heat central. This is because it becomes harder for the consumers to cool the return water, which leads to a decrease of △t and therefore higher media flow. The cooling is dependent upon consumer installations (radiator size in relation to heat demand) and comfort level for hot water usage. To increase the temperature difference, the supply temperature can be increased, or the return temperature can be decreased. It is most economic beneficial to lower the return temperature, because a higher supply temperature results in a higher heat loss in the network (Rutz et al., 2017).

The differential pressure and supply pressure in Aars West are illustrated on Figure 6.8 below.

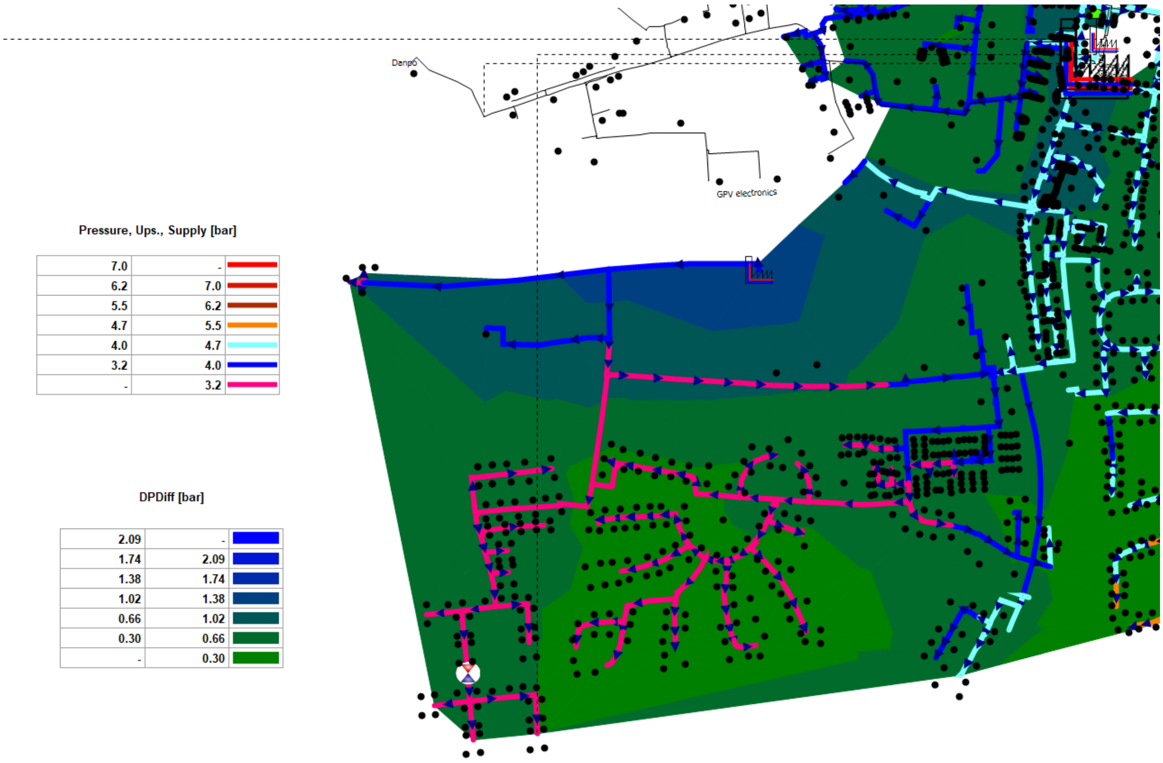


Figure 6.8 – Dania Supply pipe with differential and supply pressure (supply pressure - lines, differential pressure - map colour)

Figure 6.8 illustrates that to ensure a differential pressure above 0.3 bar in Aars West, then the Dania central will have a supply pressure of 3.4 bar and a return pressure of 2.1 bar equal to a differential pressure of 1.35 bar. Central 1 at Gislumvej will have a supply pressure on 4.3 bar and a return pressure of 3.5 equal to a differential pressure of 0.76 bar to secure the heat demand in Aars West and the consumers around. The differential pressure is higher at Dania, because this heat load must be utilised, before Central 1, and it is transmitted through the pipe at Markvænget. However, to mix the DH water from Dania and Central 1 at the end of the Markvænget pipe, the differential pressure must be the same. The technical conditions are met in the DH network for securing the distribution of DH water in a peak load situation, as described in Section 5.1.

Danpo pipe during the weekend

Some of the alternatives will investigate utilising the spare capacity in the Danpo pipe during the weekends. This is done to secure the heat demand in Aars West in the weekends, when Dania's production is closed, as described in Section 5.1. The spare capacity in the Danpo pipe is equal to around 1 MW from Friday at 19.00 to 20.00 Sunday, where Dania's production is closed from 03.00 Saturday to 18.00 Sunday. This is almost the same period that Dania's production is shut down, which creates a good synergy (Neve, 2019). A pipeline trace is illustrated on Figure 6.9 below.

Figure 6.9 - Pipe trace from Danpo pipe to Aars West

The Danpo pipe will have a dimension of DN100, since it will distribute 1 MW at a supply temperature of 90^{o}C and return temperature of 40^{o}C equal to a pressure loss of 33 Pa/m. The Danpo pipe will function as a transmission pipe available in the weekends. By installing the Danpo pipe into the Dania's supply system, the heat losses will increase with an additional 5 kW compared to Dania's distribution network without the Danpo pipe. The costs associated with implementing the Danpo pipe are illustrated in Table 6.6 below.

Dimension	**Length (m)**	**Price (DKK/m)**
DN100	350	1866
Total	**350**	**790,245**

Table 6.6 - Supply pipe from Danpo incl. piping dimensions, lengths and price (COWI A/S, 2019)

The costs related to installing the Danpo pipe without the heat exchange central is equal to 790,245 DKK including materials, welding, constructions work, external counselling and unforeseen extra costs on 10% of the total price (COWI A/S, 2019)
The pumping effects and electricity consumption is illustrated on Table 6.7 below

Pump specifications	**Reference**	**Dania**	**Dania and Danpo**
Pump effect total (kW)	25	13	17
Pump consumption total (MWh)	70	37	49

Table 6.7 - Pump effects during a peak load situation and electricity consumption

The pump effect illustrates the needed effect to transport the given flow and securing the differential pressure at the consumers. By installing a new pumping central at Dania, the pump costs will be reduced because electricity consumption (MWh) is reduced. The operational savings from the pumps are considered insignificant in relation to the total costs and will therefore not be included further. The different pipeline costs related to each alternative will be used in the economic analysis and the heat losses calculated in Termis will be used in the technical analysis in Chapter 7.

7. Technical and Economic analysis

This chapter includes a technical calculation of the production distribution in Aars West for each alternative to determine how it is supplied and optimised from a business economic perspective. The production distribution is used in the business, - and socio- economic assessment of the different alternatives.

7.1 Technical analysis of ensuring the security of supply in Aars DH system and Aars West

The technical analysis in EnergyPRO will determine if the security of supply is ensured in Aars West, and how much the annual operation costs are during the 20 year calculation period. All alternatives will operate after lowering the annual operation costs as much as possible as described in Section 4.3. To give an indication of how the different production units are influenced by the chosen assumptions and mechanisms within the system Figure 7.1 is constructed.

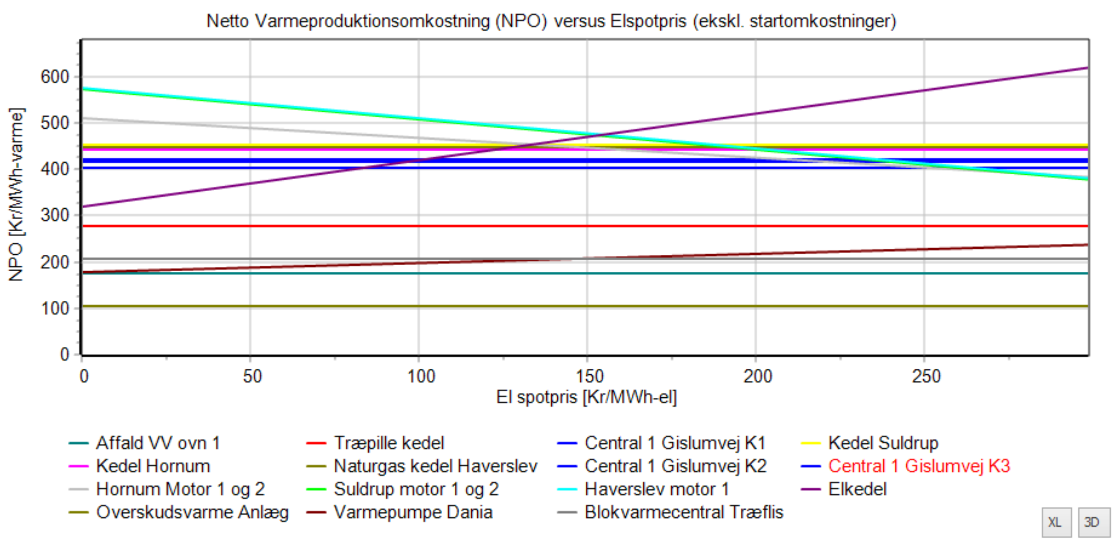


Figure 7.1 - Overall net heat production costs related to operating the production units in Aars DH in january

Figure 7.1 illustrates the net heat production costs in relation to the electricity spot market in DKK/MWh. All the individual costs associated to operating the different production units occurring throughout the investigated alternatives are presented. This strategy will determine what unit covering the heat demand in the specific hour for each alternative. It is important to notice the waste incineration CHP plant furnace 2 is not included, since it is given high priority in all alternatives, as described in Section 4.3. All boilers, waste incineration plant furnace 1 and the excess heat unit's production costs are fixed due to a fixed fuel cost level per month and taxes. The HP is dependent upon the electricity price, but due to the high COP value, the electricity price will not influence it as much as e.g. the electric boiler which increases linear with the electricity price. The cheapest unit to operate is the excess heat unit with a NPC of 105 DKK/MWh. The waste incineration furnace 1's NPC will vary monthly due to the waste price.

Reference scenario

The reference system will not include any reinvestments in production units, since the current energy system have enough capacity to secure the demand in Aars West. It is however necessary to upgrade the existing distribution network to ensure the security of supply in the area, as described in Section 6.3. The technical specification and investment costs related to upgrading the reference system are illustrated in Table 7.1 below.

Reference system technical specifications	
New production unit capacity	-
Pipeline investment	1,928,755 DKK
Scrap value	-533,952 DKK

Table 7.1 - Technical specifications and investments costs

Aars DH is mainly built upon utilising waste for their incineration plants and to supply Aars West with DH it will mainly be from waste to energy or natural gas in peak load situations. Figure 7.2 illustrates how the heat demand in Aars West is supplied by installing a new pipeline and if the security of supply in peak load situations are ensured with the full development of Aars West from 2030.

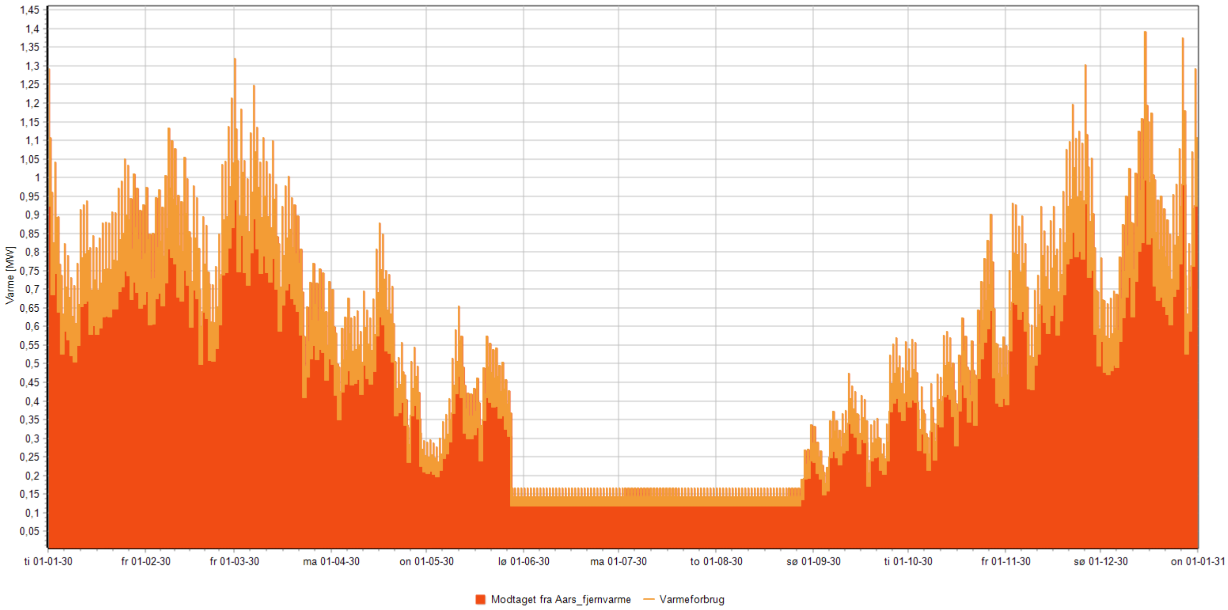


Figure 7.2 - Heat production of Aars West supply in 2030 (Reference System)

Figure 7.2 illustrates that it is not a problem to supply Aars West from Aars DH with the installation of a new DN80 pipeline on Markedsvej and the DN80 pipe along Markvænget, as described in Section 6.3. The peak load in 2030 for the entire DH system is estimated to 39.5 MW and the capacity on the waste incineration plants are in total 26 MW in Aars. Therefore, other production units, from Figure 7.1, must produce to cover the remaining heat demand in the system. The wood pellet boiler is located at the same central as the waste incineration plants, meaning that the wood pellet boiler can only operate if the waste incineration plants are not producing at max capacity due to the limitation in the transmission pipe from the main central at Dybvad Møllevej (Neve, 2019). The reference system will be used to compare the influence on both Aars West and the total DH system from installing another alternative supply. To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.3 below.

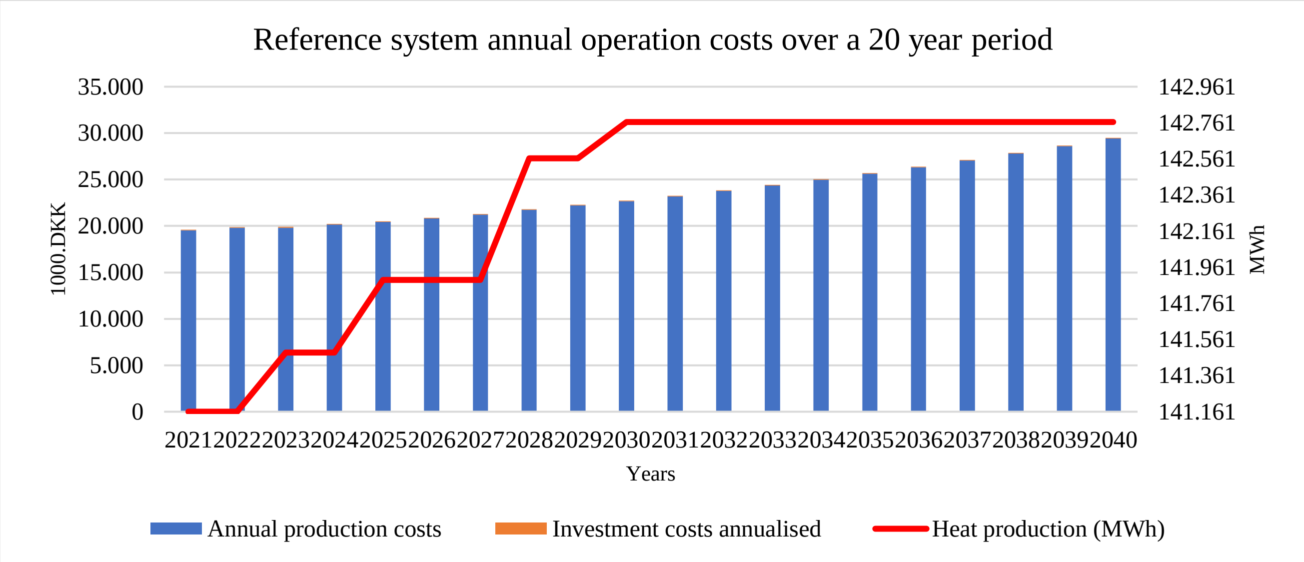


Figure 7.3 - Annual operation costs, investment costs and heat production over 20 years (Reference System)

Figure 7.3 illustrates that the annual production costs are increasing during the period, which is due to the extra heat demand, which will provide a higher production, but also due to increased costs from CO_2 quotas, fuel costs on natural gas etc. as described in Section 5.1. The CO_2 quotas have a large influence on Aars DH's system, because the waste incineration plants production covers such a large part of the heat demand, and waste includes fossil and non-biodegradable fractions (Grøn Energi, 2017). The electricity price is also expected to increase throughout the period, which enables the system to lower their production costs through an electricity sale from the waste incineration CHP plant furnace 2. The annual production costs from the reference system will be used as comparison with the other alternatives to test if any of them can provide a positive cash flow of yearly savings compared to the reference system during the 20-year calculation period.

Alternative 1 – Excess heat Dania and Danpo pipe

The technical specifications for Alternative 1 are illustrated in Table 7.2 below.

Alternative 1 technical specification	
New production unit capacity	1.5 MW at full capacity
Temperature from excess heat	65ºC
Pipeline investment	1,663,153 DKK
Heat central with pumps	1,288,748 DKK
Heat exchange central	748,455 DKK
Scrap value (pipe)	-460,424 DKK

Energy Saving Scheme - 350 DKK/MWh	-1,232,231 DKK

Table 7.2 - Technical specifications and investment costs related to Alternative 1

Alternative 1 will utilize the excess heat from Dania during the week, which requires a heat central with new frequency regulated pumps. The Danpo pipe during the weekend requires a heat exchange central, when Dania's production is closed, as described in Section 6.4. The specific investment costs related to implementing the alternative is illustrated in Table 7.2. The synergy with the utilization of the excess heat from Dania and the Danpo pipe's extra capacity during the weekends enable Aars DH to ensure the security of supply, which is illustrated on Figure 7.4 below.

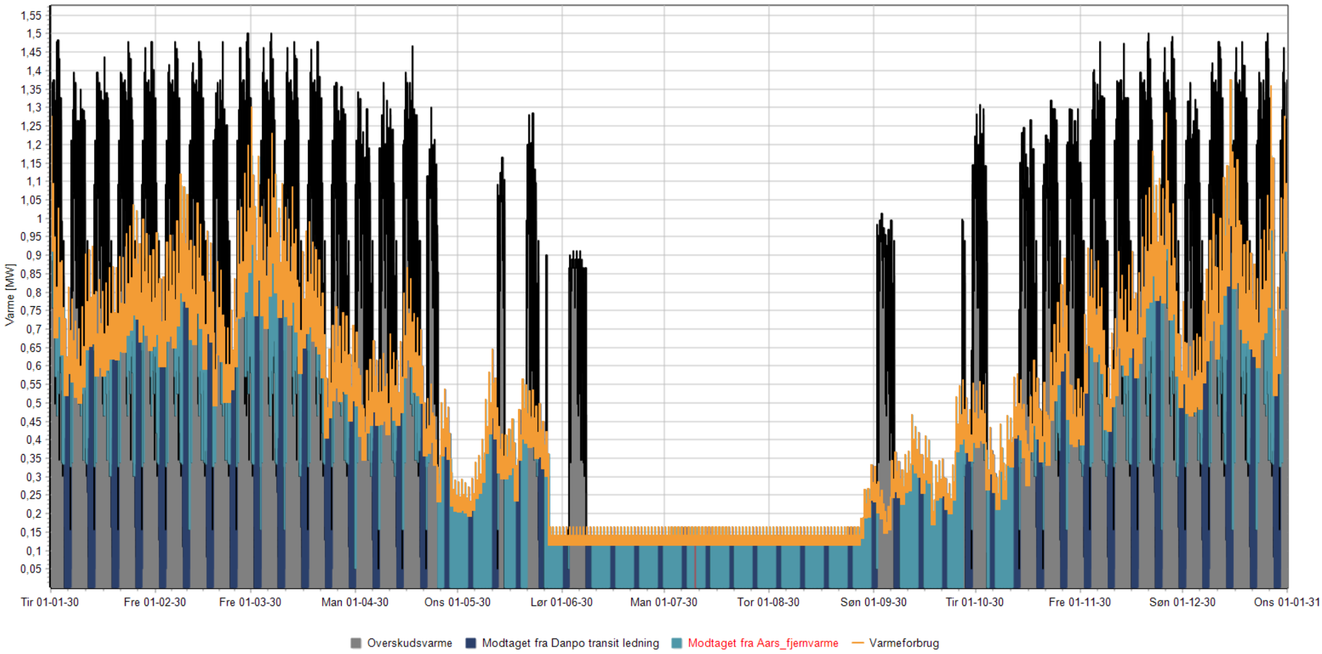


Figure 7.4 - Heat production of Aars West supply in 2030 (Alternative 1)

Aars West's peak load demand of 1.36 MW can be secured by utilizing the excess heat from Dania and the pipe on Markvænget during the week with the assumption that Dania's furnaces are operating as illustrated in Section 5.1. During the weekend it is Aars DH who secures the demand through both the pipe on Markvænget and Danpo. The pipe on Markvænget is often used to transmit heat from Aars West instead of transmitting to Aars West, unlike the Danpo pipe which can only transmit to Aars West. The overproduction available from Dania's excess heat is utilized in Aars DH, because it is a cheaper production unit to operate than the waste incineration plant furnace 1 except in the summer from June to October, where the waste price is -685 DKK/ton. The reason for the utilization of excess heat in June and August is due to scheduled maintenance on the waste incineration plant furnace 2, making it unable to produce.

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.5 below.

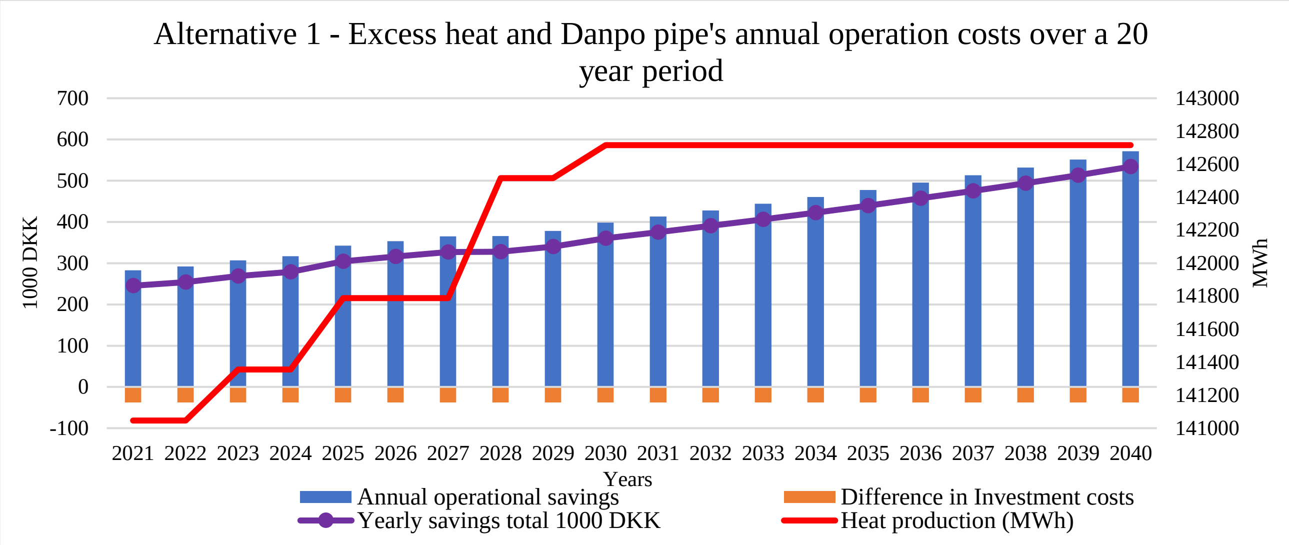


Figure 7.5 - Annual operation saving, investment costs and heat production costs over 20 years (Alternative 1)

Figure 7.5 illustrates that Alternative 1 can reduce the annual production costs more than the reference system in all years during the calculation period. This is mainly due to reducing the operational costs from the natural gas boilers and CHP plants in the system, electric boiler and waste incineration plant furnace 1 compared to the reference system by utilising the excess heat from Dania and storage. The yearly savings increase from 2030-2040, which is mainly from the savings in CO_2 quotas.

Alternative 2 – Excess heat driven HP with heat storage

The technical specifications for Alternative 2 are illustrated in Table 7.3 below.

Alternative 2 technical specification	
New production unit capacity	1.6 MW at full capacity
Temperature from excess heat	24°C
Pipeline investment	872,908 DKK
Heat pump investment	6,903,204 DKK
Heat storage 600 m³	1,613,736 DKK
Scrap value (pipe)	-539,483 DKK
Energy Saving – 350 DKK/MWh	-188,522 DKK

Table 7.3 - Technical specifications and investment costs related to Alternative 2

Alternative 2 will utilize the excess heat from Dania during the week. Today Dania cools their excess heat in average from 24°C to 21°C with an almost constant flow of 211 m³/h, which causes operation costs for the pumps. By using the Lorentz formula with the assumption of an inlet temperature of 30°C and outlet temperature of 65°C, a COP value is calculated to 5.05. The heat capacity is increased by utilising the HP due to the electricity consumption used to increase supply temperature. These assumptions will be used as an alternative to the utilization of the excess heat at a temperature of 65°C. The heat storage is dimensioned to 600 m³ with a temperature in the bottom of 35°C and top of 65°C. The specific investment costs related to implementing the alternative is illustrated in Table 7.3.

Figure 7.6 below illustrates how the heat demand in Aars West is supplied by installing the HP and a heat storage and it indicates if the security of supply in peak load situations are ensured with the full development of Aars West from 2030.

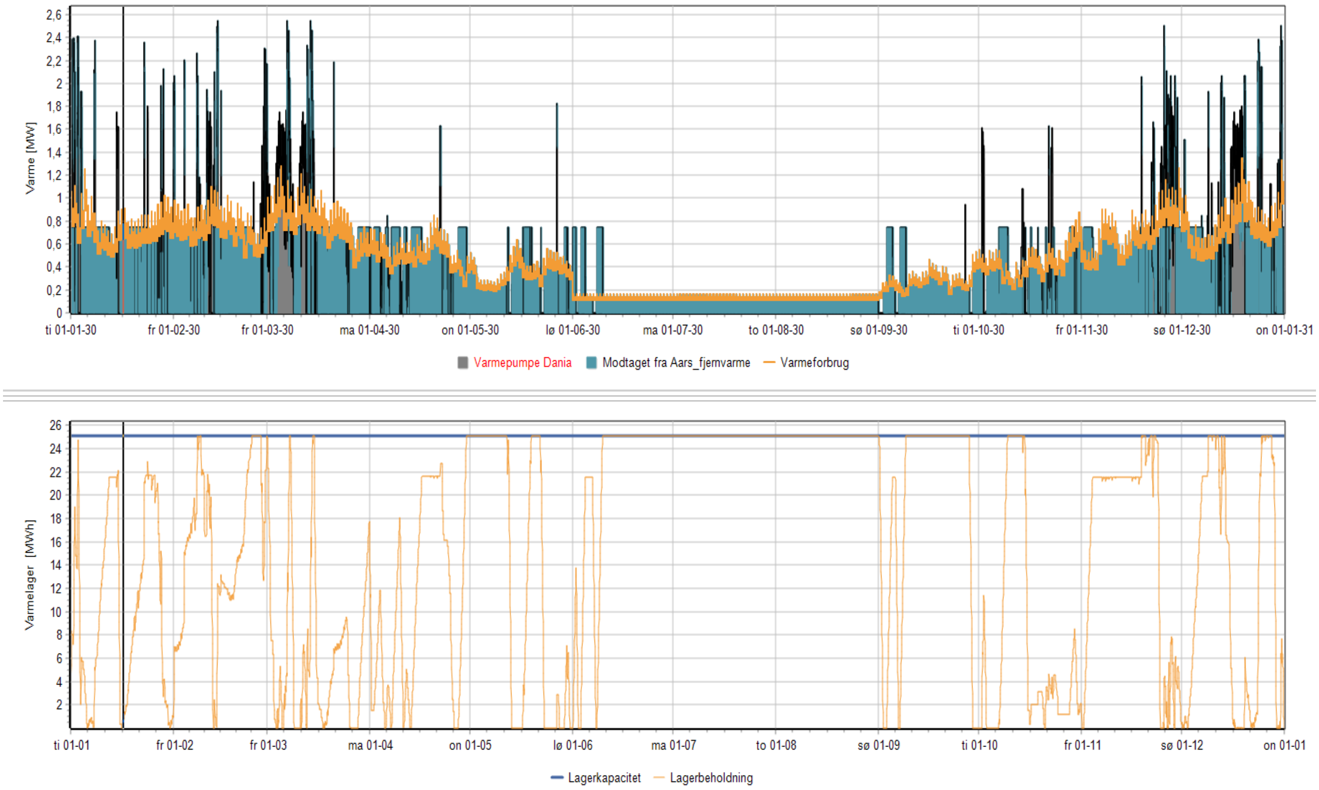


Figure 7.6 – Heat production of Aars West supply in 2030 (Alternative 2)

The heat demand throughout the year is secured through utilizing the heat from the HP, heat storage and Markvænget pipe. The HP does not have many production hours, it is primarily used to secure the peak load demand in Aars West, when the pipeline on Markvænget cannot. In some hours, the HP transmit some of its production to Aars DH, which can be further transmitted to Hornum instead of utilizing the electric boiler, when the electricity is low. The HP does however not have as many production hours compared to utilizing the excess heat directly from Dania's furnaces. This is due to the HP having extra operational costs in relation to taxes, tariffs and dependency on the electricity price. The higher the electricity price, the higher operation costs will the HP have, as illustrated on Figure 7.1. The limitation in the pipe at Markvænget does however require an additional production unit in the area to secure the heat demand, which enable the HP to produce as second priority when Aars DH cannot transmit enough heat. The heat storage is primarily used to store the transmitted heat from Markvænget. The heat storage is therefore stealing production hours away from the HP in the periods where the Markvænget pipe cannot supply the area. Hence, instead of providing a higher utilisation of heat from the HP, it enables more production on the waste incineration plants. However, in hours with very low electricity prices, the heat can be stored, if not utilized within Aars West or transmitted to Aars DH. The stored heat from Markvænget enables more of the heat rejected during the summer to be utilized instead of cooled away.

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.7 below.

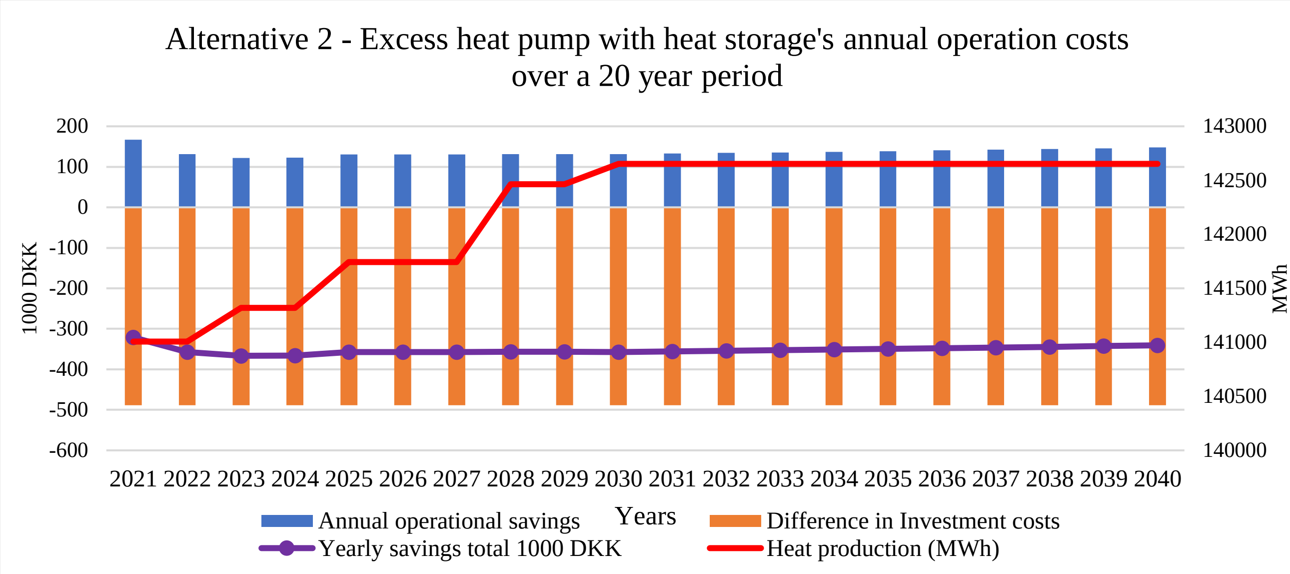


Figure 7.7 - Annual operation saving, investment costs and heat production costs over 20 years (Alternative 2)

Figure 7.7 illustrates that the HP alternative can lower the annual operation costs compared to the reference system throughout the calculation period. This is mainly because the utilization of the electric boiler is reduced, when the electricity prices are low, since the HP is more efficient. The heat rejected during the summer is also decreased, because it is stored and utilised when furnace 2 is under maintenance and therefore is the heat furnace 1 also reduced. The annual operation saving is almost constant through the calculation. Overall the annual operational savings are very small, and when the difference in investment costs is added, then the alternative becomes unfeasible compared to the reference system.

Alternative 3 – Excess heat Dania with heat storage

The technical specifications for Alternative 3 are illustrated in Table 7.4 below.

Alternative 3 technical specification	
New production unit capacity	1.5 MW at full capacity
Temperature from excess heat	65°C
Pipeline investment	1,663,153 DKK
Heat central with pumps	1,288,748 DKK
Heat exchange central	748,455 DKK
Scrap value (pipe)	-455,425 DKK
Energy Saving – 350 DKK/MWh	-1,235,706 DKK

Table 7.4 - Technical specifications and investment costs related to Alternative 3

Alternative 3 will utilize the excess heat from Dania during the week, which means a heat central with new pumps must be implemented. The excess heat will be delivered at 65°C directly from the furnaces. This requires Aars DH to make an agreement in relation to securing the cooling demand at Dania and implement new frequency driven pumps to regulate the flow and temperature. The heat storage will have the same technical specifications as in Alternative 2 of 600 m² with a temperature in the bottom of 35ºC and top of 65ºC. The specific investment costs related to implementing the alternative is illustrated on Table 7.4.

Figure 7.8 illustrates how the heat demand in Aars West is supplied during the year by installing the excess heat production unit and heat storage.

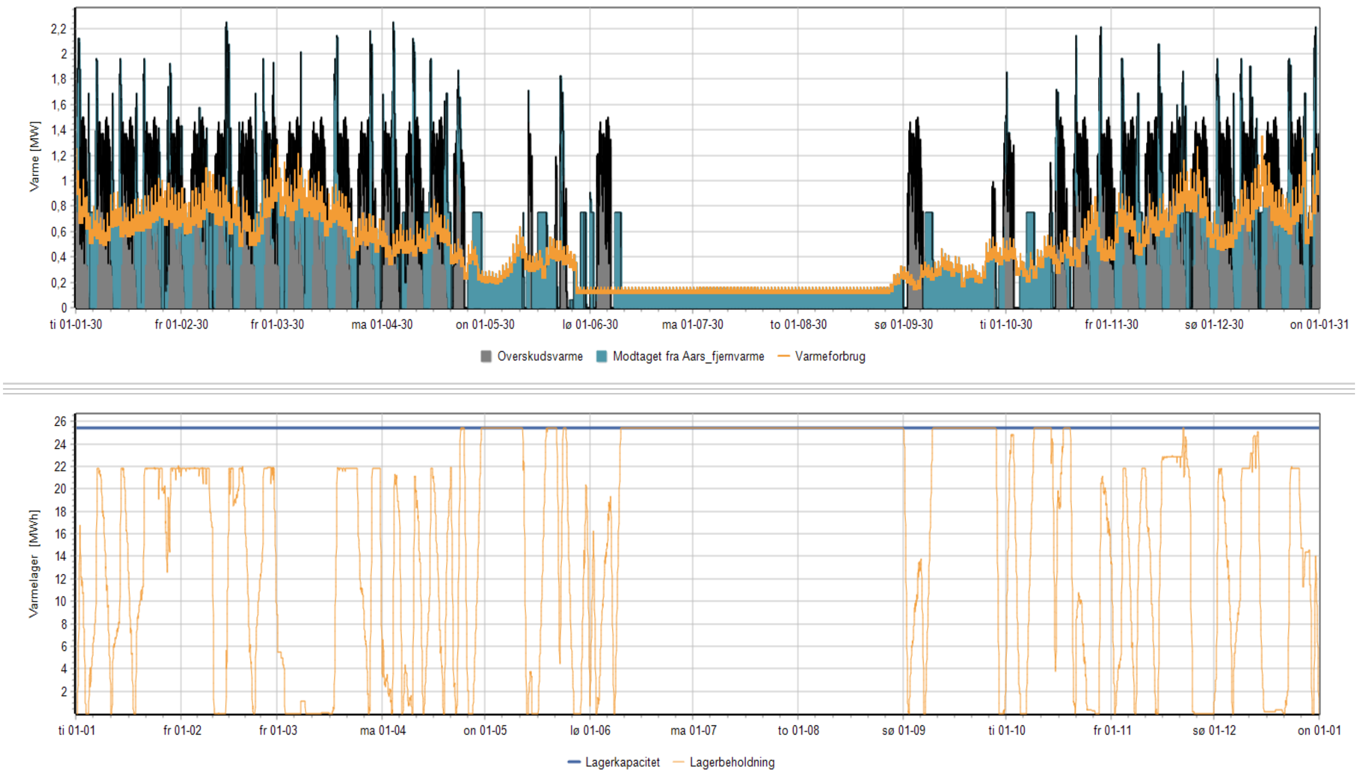


Figure 7.8 - Heat production of Aars West supply in 2030 (Alternative 3)

The heat demand in Aars West is secured in Alternative 3, and it is primarily supplied by the excess heat from Dania, and the waste incineration plants during the winter period. The excess heat unit also transmit heat to Aars DH system as well as obtaining production from Aars DH and storing the excess heat. The heat production from the heat storage can either be utilised within Aars West, but also be transmitted to Aars DH's current network. The heat storage is often utilised in the weekends to compliment the heat received from the Markvænget pipe to secure the heat demand, which is indicated on Figure 7.8 through the varying production pattern in the storage graph.

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.9 below.

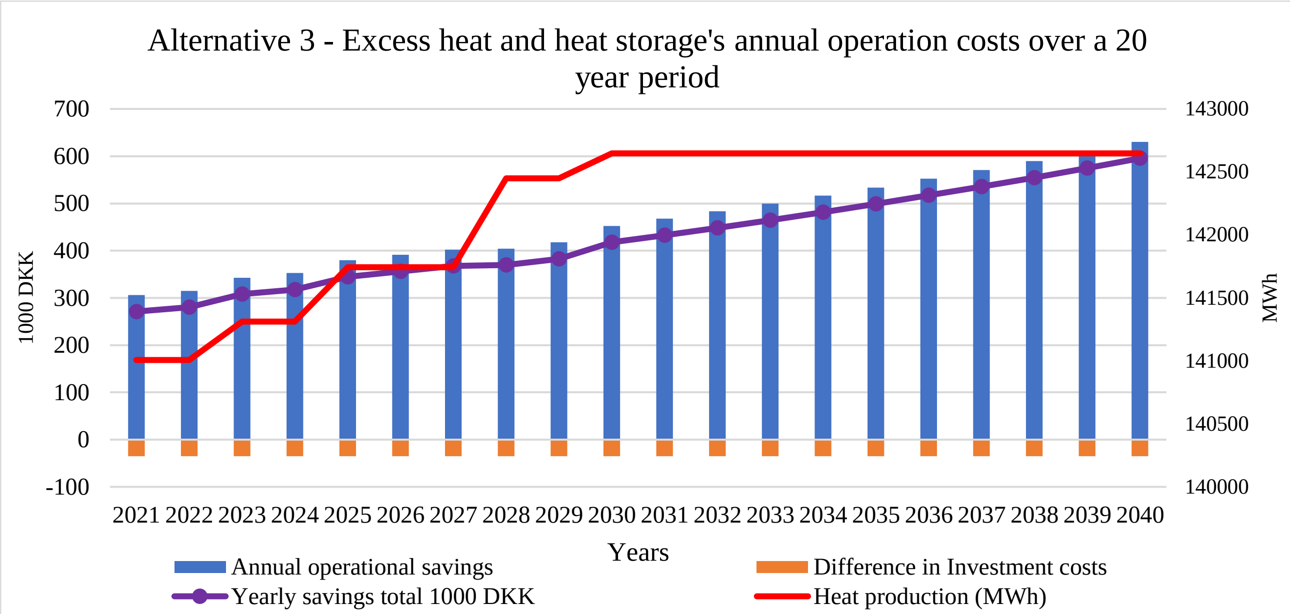


Figure 7.9 - Annual operation saving, investment costs and heat production costs over 20 years (Alternative 3)

Figure 7.9 illustrates that Alternative 3 can reduce the annual production more than the reference system throughout the calculation period. This is mainly due to benefits from Alternative 1 and 2 in relation to the utilization of the excess heat and heat storage to decrease the production on the more expensive units as the electric boiler and natural gas CHP plants. The utilisation of the excess increases together with the heat demand, which also decreases the production on furnace 1. This is because the excess heat unit is cheaper to operate than furnace 1 and is therefore given a higher priority. The annual operational savings are increasing almost linear throughout the calculation period, and even with the added investment costs, the yearly savings are still providing a surplus. In 2028, the annual operational savings decrease, due to a saturation point on the utilisation of the excess heat from Dania, but due to increases in fuel costs and CO_2 quotas the savings increase. The revenue is highest in the end of the calculation period, which also improves with an increase of the heat production and CO_2 reduction.

Alternative 4 – Danpo pipe with heat storage

The technical specifications for Alternative 1 are illustrated in Table 7.5 below.

Alternative 4 technical specification	
Pipeline Investment	790,245 DKK
Heat exchange central	784,455 DKK
Heat storage 545 m³	1,465,810 DKK
Scrap value (pipe and storage)	-533,052 DKK

Table 7.5 - Technical specifications and investment costs related to Alternative 4

Alternative 4 will utilize the extra capacity of 1 MW in the Danpo pipe in the weekend from 19.00 Friday to 20.00 Sunday. The heat storage is implemented to store some of the heat from the Danpo pipe and Markvænget pipe during the weekend to help secure the heat demand throughout the week. The specific investment costs related to implementing the alternative is illustrated in Table 7.5.

Figure 7.10 below illustrates how the heat demand in Aars West is supplied by installing the Danpo pipeline and a heat storage, and it indicates if the security of supply in peak load situations are ensured with the full development of Aars West from 2030.

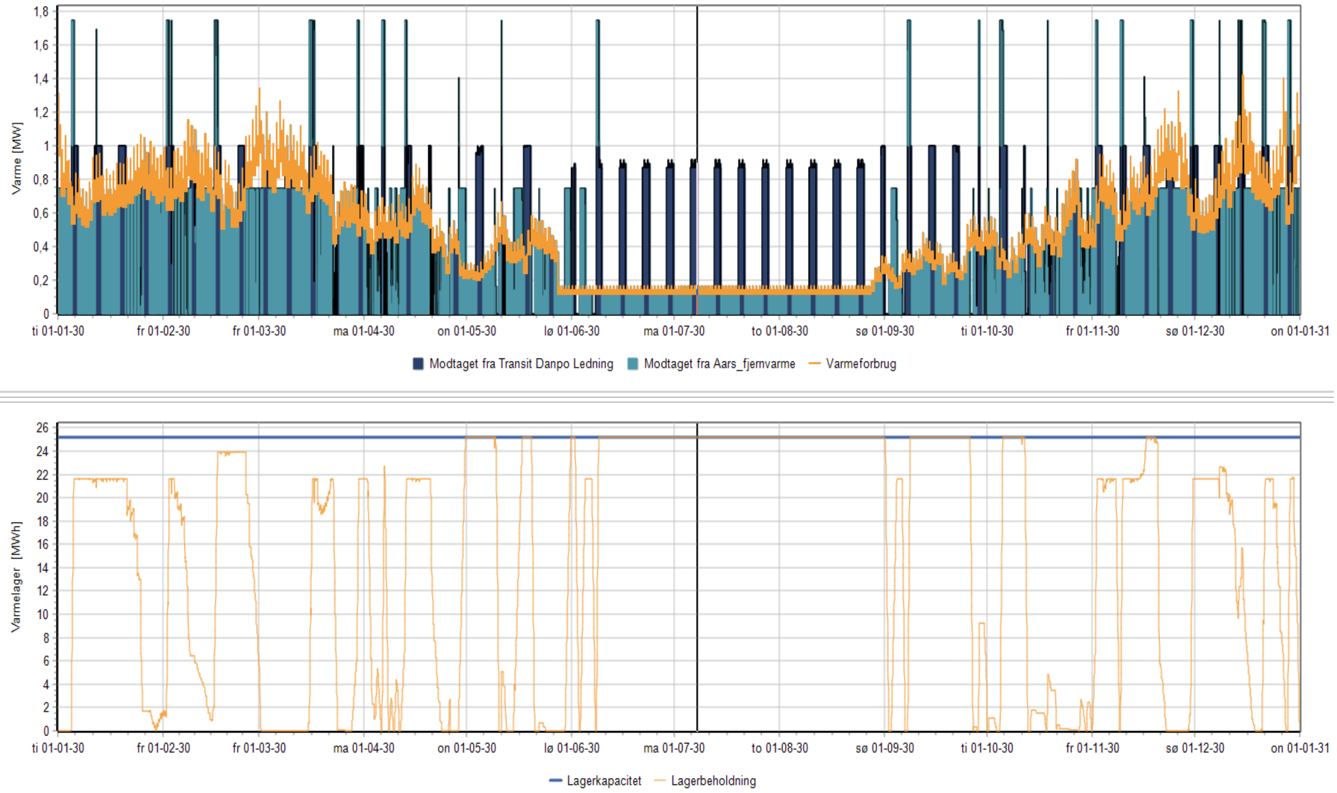


Figure 7.10 - Heat production of Aars West supply in 2030 (Alternative 4)

Aars West's peak load is around 1.35 MW and therefore is the extra capacity from the Danpo pipe required to secure the heat demand. However, there are some hours where there is not enough capacity to supply the entire heat demand. The total heat production required in Aars West Alternative 4 is 3844 MWh, but there is only enough capacity to secure 3795 MWh. This is however not critical because the DN80 pipe on Markvænget can be pressured a bit more to provide a higher flow and therefore more capacity in the most critical hours (Neve, 2019). The system's heat storage provides more flexibility for Aars DH, but the storage capacity is not fully charged in the winter period before being utilized, meaning that a larger heat storage would not ensure the security of supply.

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.11.

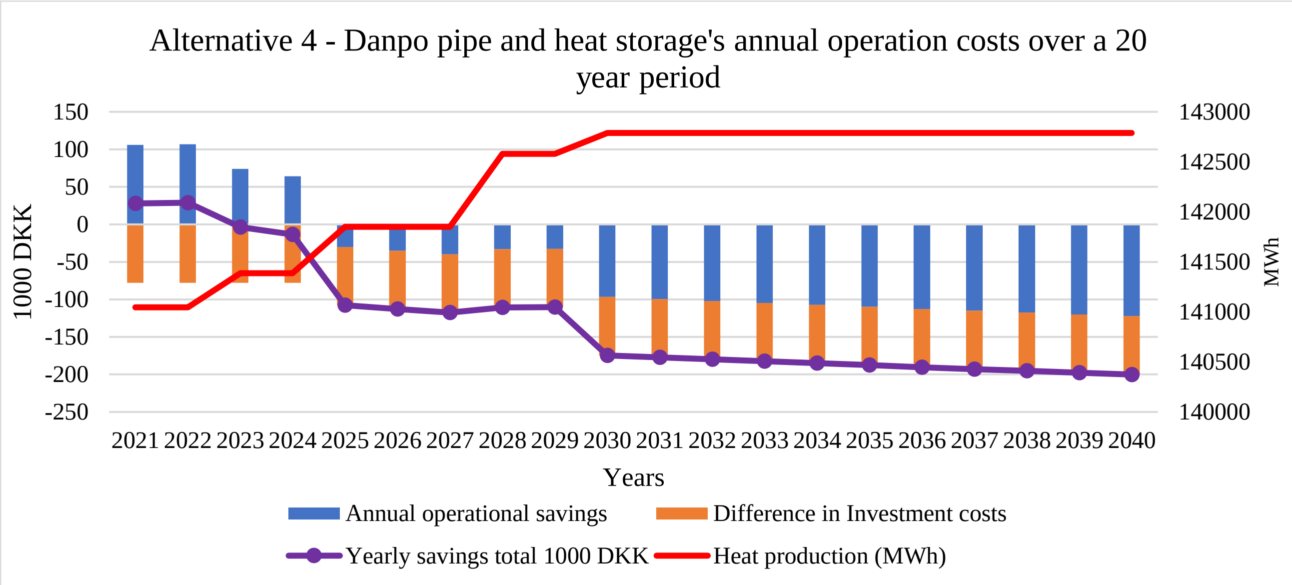


Figure 7.11 - Annual operation saving, investment costs and heat production costs over 20 years (Alternative 4)

The annual operation costs related to operate Alternative 4 in comparison to the reference system provides an annual operational saving from 2021-2024, it is however gradually decreasing with the increase of the heat demand. This is because of the capacity limitation in the DH network, meaning that more of the expensive natural gas boilers and CHP engines produce more compared to the reference system. From 2025 the annual operational savings and investment costs are both negative meaning it not feasible to implement.

Alternative 5 – Wood chip boiler

The technical specifications related to installing a WCB is illustrated in Table 7.6 below and the boiler will be placed at Dania with the assumption of them renting Aars DH some space.

Alternative 5 technical specifications	
New production unit capacity	1,4 MW
Efficiency	95 %
Production unit investment	7,000,000 DKK
Pipeline investment	872,908
Scrap value (pipe)	-289,985

Table 7.6 - Technical specifications and investment costs related to Alternative 5

Alternative 5 involves implementing a 1.4 MW wood chip boiler with the purpose of ensuring the heat demand in Aars West. The WCB is dimensioned after securing the heat demand in Aars West even in hours where the pipe on Markvænget is under maintenance. The specific investment costs related to implementing the alternative is illustrated in Table 7.6.

Figure 7.12 below illustrates how the heat demand in Aars West is supplied by installing a WCB, and it indicates if the security of supply in peak load situations are ensured with the full development of Aars West from 2030.

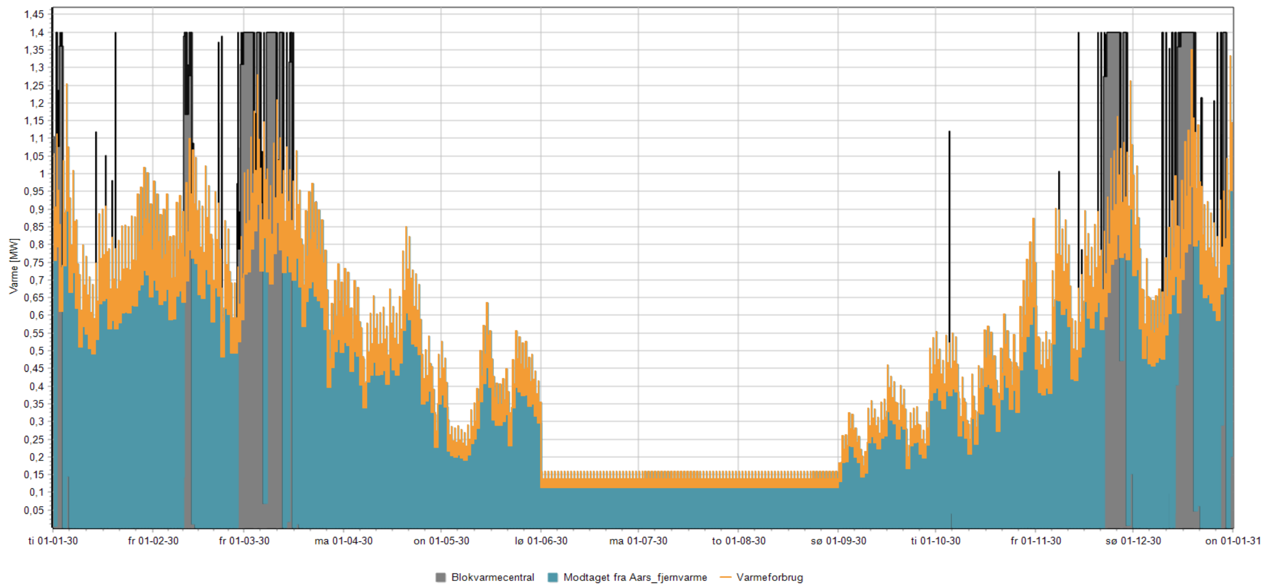


Figure 7.12 - Heat production of Aars West supply in 2030 (Alternative 5)

By installing the WCB in Aars West, the heat demand of 1.35 MW is ensured with the full development of the area. The heat demand of Aars West is primarily supplied by Aars DH through the DN80 pipe on Markvænget. The WCB is only producing to secure the heat demand in times where there is not enough capacity on Markvænget. During peak load situations the WCB supplies the entire demand in Aars West and transmit some surplus heat to Aars DH system to replace the production from the natural gas boilers. The WCB does not provide the same amount of flexibility as the HP, since the price level is fixed and independent upon changes in e.g. electricity prices, as illustrated on Figure 7.1.

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.13.

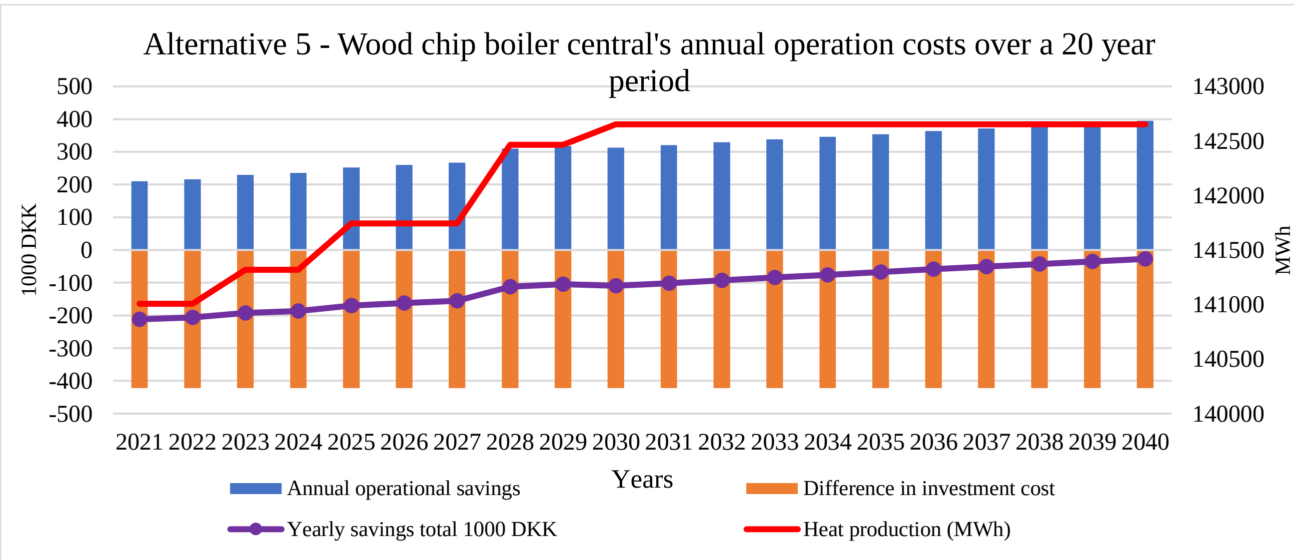


Figure 7.13 - Annual operation saving, investment costs and heat production costs over 20 years (Alternative 5)

By installing a 1,4 MW WCB, the annual operational savings are providing a surplus compared to the reference system, which only increases with the development in the heat demand. The operational saving is mainly due to the WCB replacing production from natural gas boilers in Aars and the natural gas CHP and boilers in Suldrup, Haverslev and Hornum is also decreased. This is because the WCB is cheaper to operate than the natural gas units dependent upon the electricity price. The WCB can be used to secure the heat demand in Aars West and transmit to Hornum, which is located close to Aars. The total yearly savings are not high enough to account for the large investment costs related to the WCB, and therefore is the WCB not feasible to implement.

Alternative 6 – Individual air to water HP's

Alternative 6 involves converting all consumer installations in Aars West to individual air to water HP's while maintaining the current DH system. This is done to compare the different alternatives and see how the individual solution would compare.

Table 7.7 is constructed to indicate the price level of an individual air to water HP per kW in relation to households and industry and the expected COP values these units can obtain.

Individual HP specifications	Investment (DKK/kW)	O&M costs (Fixed)	O&M costs (Variable (DKK/MWh)	COP
Household	13,074	2174	-	3.25
Institutions	3502	9874	3.90	3.90

Table 7.7 - Individual air to water HP specifications (Energistyrelsen, 2018c)

To secure the increasing heat demand in Aars West, the development in the annual production costs to supply the total Aars DH system and investment costs are illustrated on Figure 7.14.

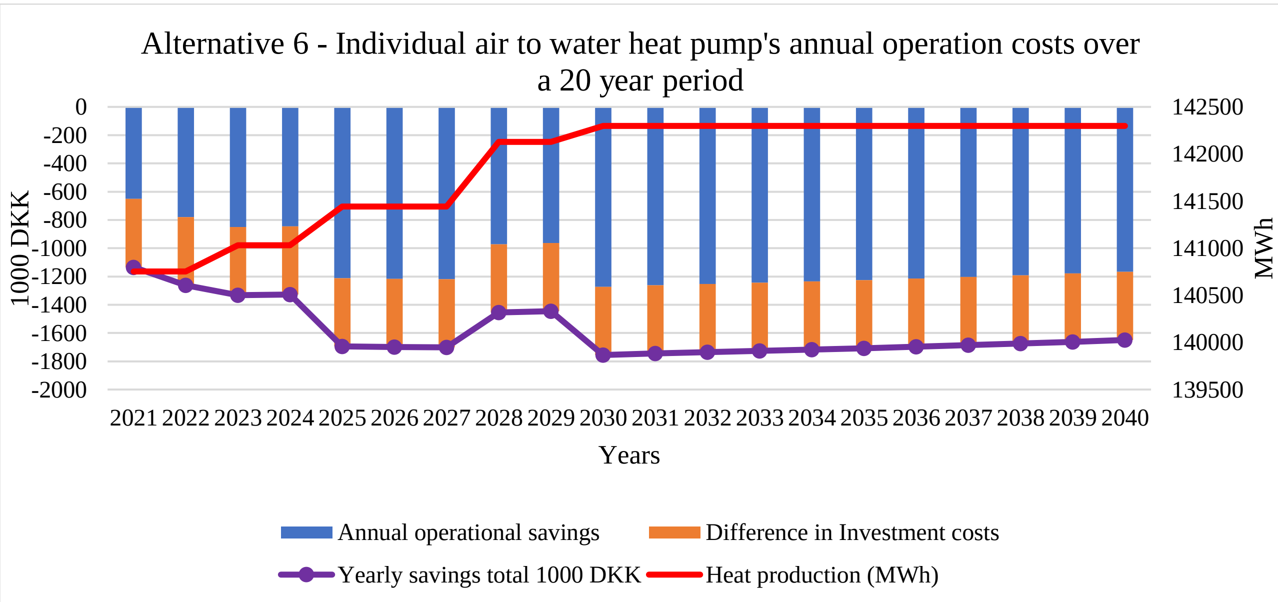


Figure 7.14 - Annual operation costs during the calculation period (Alternative 6)

By converting Aars West to individual air to water HP's, the annual operational savings will be negative compared to the reference system. This is due to the low heat prices occurring in Aars DH, since their waste incineration plants are depreciated, high waste prices and high electricity prices. The individual HP's will be based upon air to water energy source, which is varying throughout the year, indicating that the seasonal COP value will be lower compared to the excess heat. The individual HP's also have high taxes and tariffs related to their operation, which makes it hard to compete with the benefits of the DH system in Aars. The investment costs are also high, but due to operational costs resulting in a deficit compared to the reference system, it only provides an extra cost for the consumers making it even more unfeasible.

Summary of the production distribution for each alternative

To sum up the technical analysis an overview is illustrated below:

- Reference Scenario: Current energy system of Aars DH with a new pipeline
- Alternative 1: Excess heat unit Dania and Danpo pipeline
- Alternative 2: Water to water HP Dania and heat storage
- Alternative 3: Excess heat unit Dania and heat storage
- Alternative 4: Danpo pipeline and heat storage
- Alternative 5: Wood chip boiler at Dania
- Alternative 6: Individual air to water HP

The total production distribution for each of the alternatives is illustrated on Figure 7.15 below. The waste incineration CHP plant furnace 2 are contributing to supplying over 70% of the heat demand in all alternatives. It is therefore the last 30% which are interesting to investigate, since the different units are in direct competition with the waste incineration plant furnace 1, natural gas boilers and CHP plants, electricity boiler and wood pellet boiler, throughout the year.

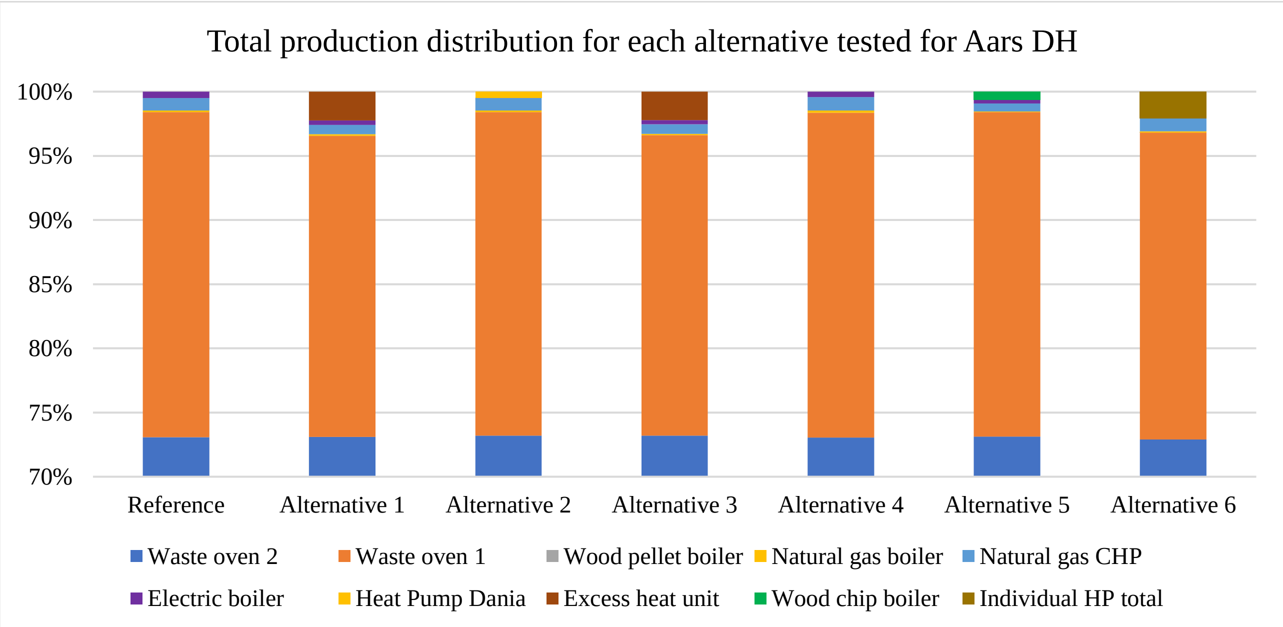


Figure 7.15 - Overview of the production distribution for each alternative

Figure 7.15 illustrates that Alternative 1 and 3 can compete with the waste incineration plant furnace 1 and obtain more production hours compared to the reference system. In these alternatives the excess heat also substitutes the production from the natural gas boilers and CHP engines. Alternative 2 does not obtain many production hours, the production distribution is almost identical with the reference systems. This indicates that the HP only operate to cover the peak loads in Aars West and substitute the heat production on the electric boiler and a little natural gas. Alternative 4 is very similar with the reference system, but the natural gas boilers and CHP plant's production is increased together with the electric boilers production. In Alternative 5 the electric boiler, natural gas CHP and natural gas boiler production is reduced in relation to the WCB producing. In Alternative 6 the individual HP's are covering the entire heat demand in Aars West and the rest of the production is used to cover the heat demand in Aars DH. All the investigated alternatives, except Alternative 4, were able to ensure the security of supply with the full development of Aars West in 2030. An overview of the liquidity effect, meaning the annual operation costs including the annual loan costs for each alternative in comparison with the reference system, is illustrated on Figure 7.16 below.

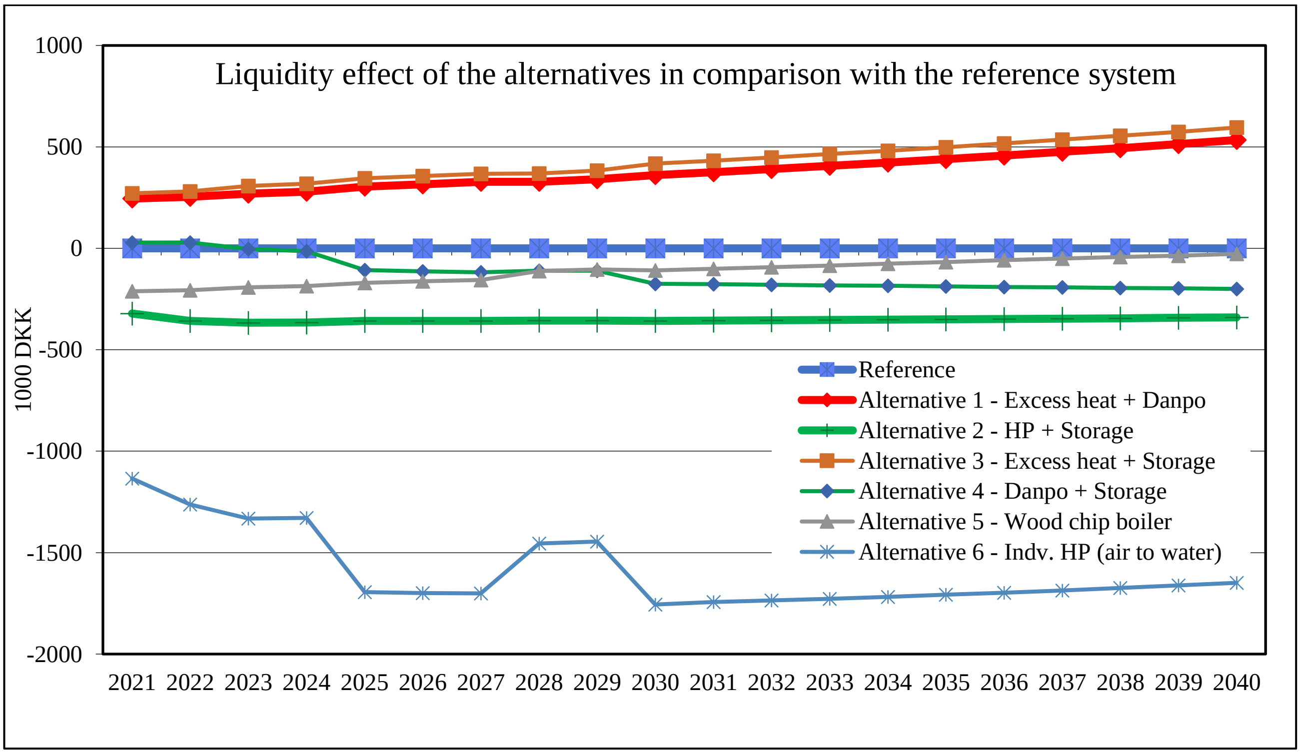


Figure 7.16 - Overview of the annual operation costs with investment costs (liquidity effect) of the different alternatives in comparison with the reference system

Both Alternative 1 and Alternative 3 improves the liquidity for Aars DH the most. This is because the excess heat unit are cheaper to utilise than the existing production units in Aars DH in many of the hours during the year. Even with the included investment costs, Alternative 1 and 3 provide a positive liquidity effect. Alternative 2, 4, 5 and 6 cannot improve the liquidity effect in comparison with the reference system. This is primarily due to the annual operational saving are not high enough to account for the large investment costs.

7.2 Business economic calculation of each alternative

The influence of the total operational and investment costs inclusive loan costs during the calculation period are recalculated as an annual average heat price in DKK/MWh of each alternative to compare what alternative that can provide the highest business economic value, as described in Section 4.5. Figure 7.16 illustrates an overview of the annual average heat price for the different alternatives investigated to supplying Aars West.

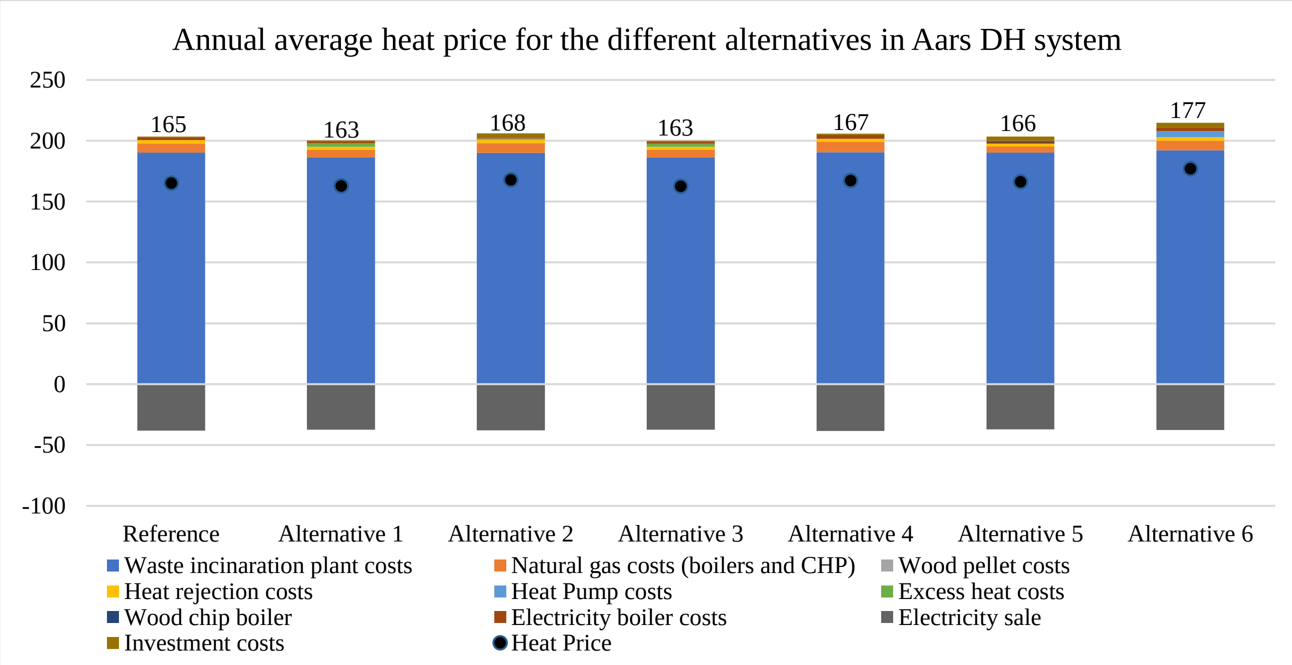


Figure 7.17 - Annual average heat price for the different alternative

When comparing the annual average heat price for the different alternatives only two alternatives can reduce the heat price more than the reference scenario. Alternative 1 and 3 both provides the lowest heat price of 163 DKK/MWh. Alternative 4 provides a heat price of 167 DKK/MWh and Alternative 5 provide a heat price of 166 DKK/MWh. Alternative 4 was not able to cover the entire heat demand of Aars West with the full development in 2030, which means that there will be extra costs associated to secure the demand in relation to pump and production costs. The alternative with the highest heat price is Alternative 6 with 177 DKK/MWh.

The annual average heat price gives an indication of the benefits related to each alternative throughout the entire calculation period with an investment cost equally divided throughout the years, considering the loan costs with an interest rate. The NPV calculation measures the time aspect differently, because the main investments are placed in year 0, and the annual operational savings are then discounted. (Østergaard & Lund, 2010). The annualization method emphasised that both Alternative 1 and 3 provides the highest business-economic value, but to ensure this a NPV calculation of all alternatives compared to the reference system is illustrated on Figure 7.18 below.

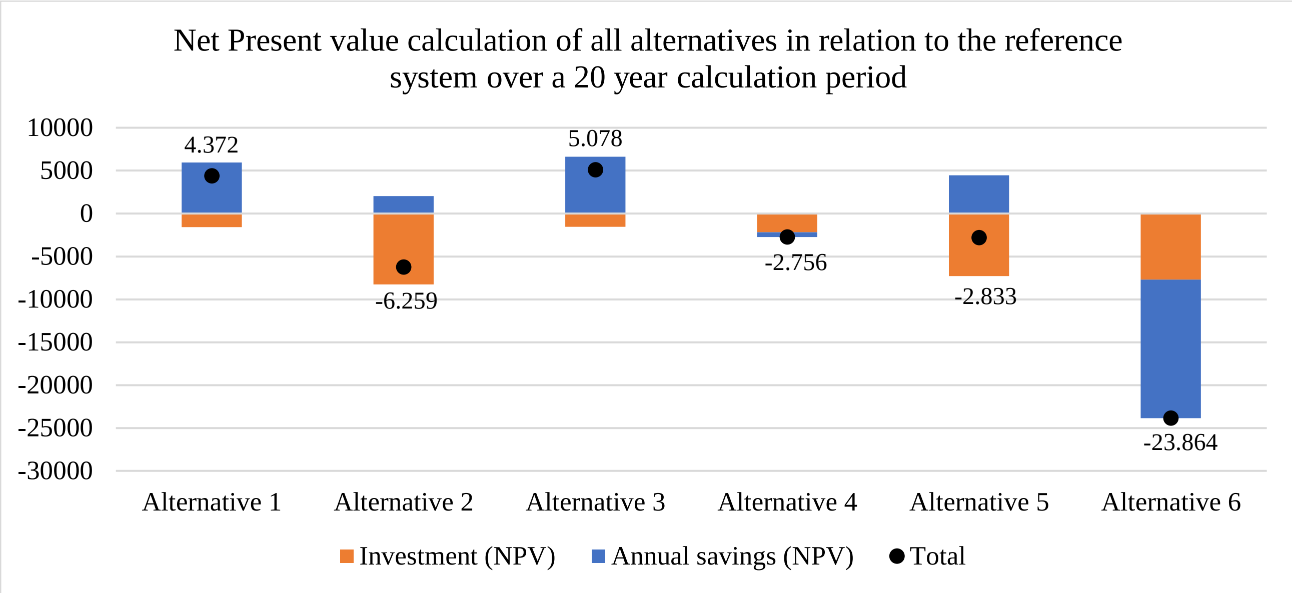


Figure 7.18 - Net Present Value calculation of the different alternatives

Figure 7.18 illustrates that the alternative able to provide the highest NPV is Alternative 3 of 5,078,000 DKK, and the second best is Alternative 1 with 4,372,000 DKK. Alternative 3 provides the highest annual operational saving of all alternatives, and Alternative 3's investment costs are also lower than Alternative 1's with the business economic scrap value included. Alternative 2 and 4 cannot provide a positive NPV due to the high investment costs whereas Alternative 4 and 6 have both negative investment costs and annual savings. However, the business economy does not dictate what project that will be implemented, it is also highly dependent upon the socio-economic impact each alternative has on the society, as described in Section 4.5.

7.3 Socio-economic calculation of each alternative

The socio-economic analysis will be used as an evaluation tool to see what alternative that can be implemented and approved by the municipality. The socio-economy can however not determine if the project will be realised, since it is the company that must finance and implement it. The environmental emission impact related to each alternative is illustrated in Table 7.8 below.

Emissions (tons)	Ref	Alt.1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
CO_2 electricity consumption and production	-15,960	-16,018	-16,607	-16,057	-16,252	-16,105	-15,670
CO_2 fuel consumption	475,112	465,053	474,593	464,780	497,880	470,864	469,612
CO_2 net impact	459,152	449,035	457,986	448,723	481,629	454,759	453,942
CO_2 equivalents (CH4 and N2O)	5,921	5,268	5,880	5,272	6,303	5,092	6,028
SO_2	78	76	77	76	82	78	77
NOx	698	680	697	679	733	688	691
PM2,5	3	3	3	3	3	4	3

Table 7.8 - Overall environmental impact of operating the different alternatives (abbreviated Alt.)

The highest emission exposure comes from the waste incineration plants, since they produce the most as Figure 7.15 illustrates, which is why the CO_2 net impact is high in all alternatives. The alternative able to lower the CO_2 net impact the most is Alternative 3, since it reduces the fuel consumption the most. Alternative 1 reduces the CO_2 equivalents more than Alternative 3, but Alternative 5 reduces the CO_2 equivalents the most. Alternative 3 reduces the emissions of SO_2, NO_X and $PM_{2.5}$ impact the most. To account for the socio-economic impact for the company an evaluation of the cost is conducted in factor prices, illustrated on Figure 7.19.

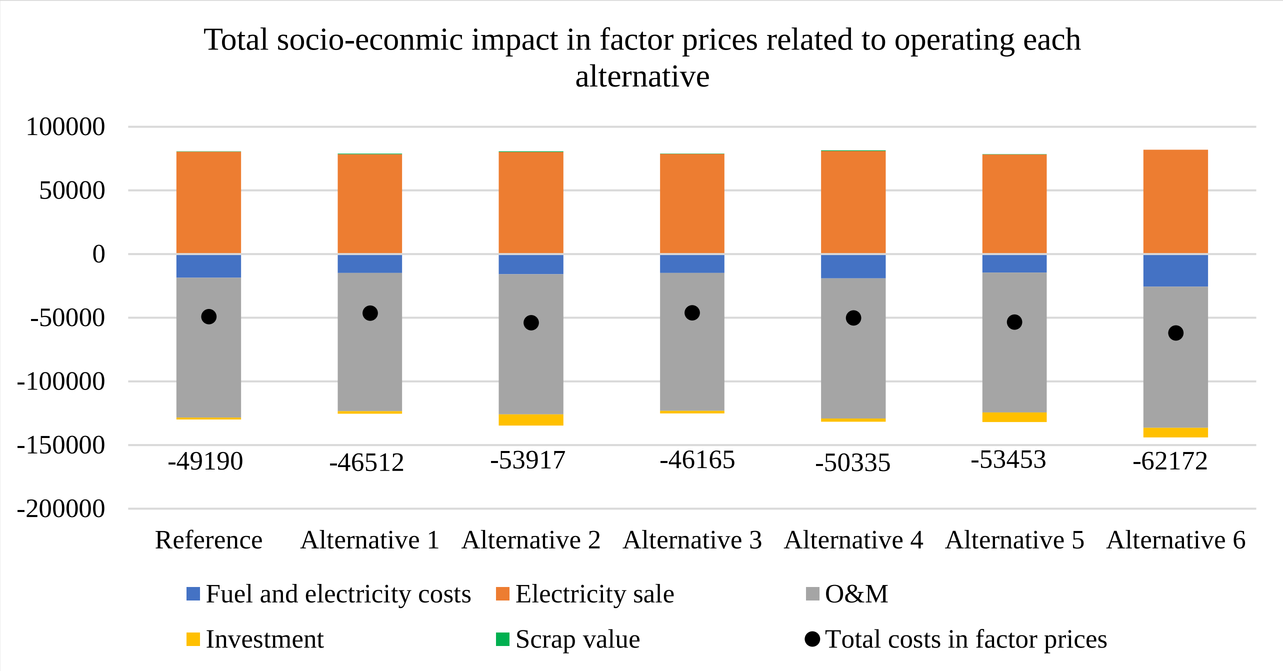


Figure 7.19 - Socio-economic impact in factor prices

The alternative, which provides the lowest socio-economic impact in factor prices is Alternative 3 of -46,165,000 DKK, whereas Alternative 1 has a socio-economic impact of -46,512,000 DKK. The main difference between Alternative 1 and 3 is the investment costs, which is higher in Alternative 3, but the savings in fuel consumption, O&M and a higher electricity sale are enough to compensate. Alternative 2 provides the second highest socio-economic impact in relation to the company prices, which is mainly due to the O&M, fuel and investment costs. Alternative 6 provides the highest socio-economic impact, where the same tendency from Alternative 2 is present with the large O&M, fuel, and investment costs causing a large socio-economic impact.

To assess what the socio-economic impact related to operating the different alternatives are for the society, the factor prices will be converted into market prices and the environmental emission impact will be calculated as a societal cost, as described in Section 4.5. The total socio-economic impact in market prices are illustrated on Figure 7.20 below.

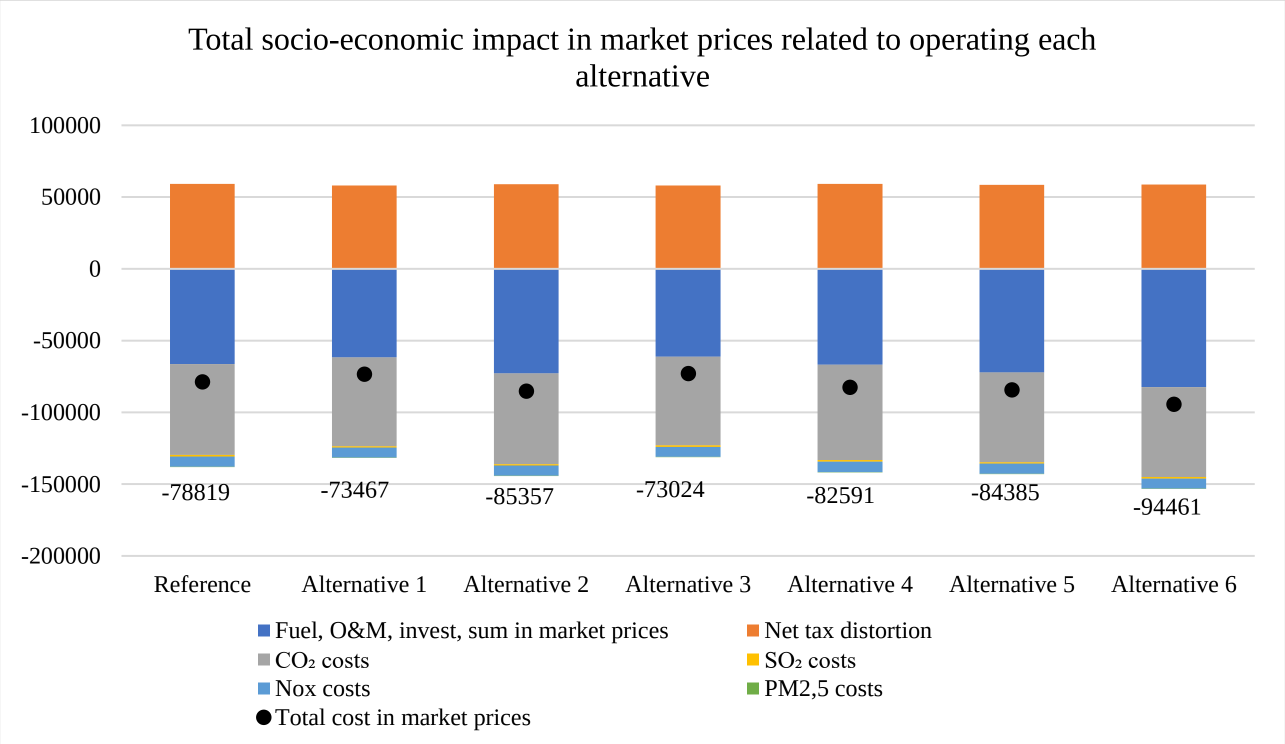


Figure 7.20 - Socio-economic impact in market prices

Figure 7.20 illustrates that the alternative, which can provide the lowest overall socio-economic impact is Alternative 3 of -73,024,000 DKK. Alternative 1 provides the second lowest socio-economic impact of -73,467,000 DKK. Alternative 3 could both lower the factor prices and emission exposure the most, and therefore is it also the alternative providing the highest socio-economic value. Alternative 1 does however provide a higher net tax revenue for the society, because of the higher utilisation of waste, which counts as a positive effect. Alternative 2, 5 and 6 all lower the CO_2 costs compared to the reference system, but due to the high investment costs, these alternatives do not provide a positive socio-economic value, and can therefore not be implemented. Alternative 6 provides the highest socio-economic impact of all alternatives.

The different alternatives are based upon many assumptions that are uncertain, and therefore a sensitivity analysis is conducted in Chapter 8 to test how robust the alternatives are to changes in the used assumptions.

8. Sensitivity analysis

This chapter includes a sensitivity analysis of the most uncertain parameters chosen in the analysis to see how they influence the different alternatives. The sensitivities are divided under specific parameters investigated. For each parameter both the business- economy and socio-economy is presented.

8.1 Heat demand

The heat demand calculations are based upon an estimate in relation to the consumers consumption patterns and the degree of insulation. The heat demand is hard to estimate especially in low energy buildings due to the hot water demands influence, as described in Section 5.3. Therefore, a sensitivity for the heat demand is conducted to test the influence of increasing the heat demand with +20% and decreasing the heat demand with -20% for both the business- and socio-economic calculations. First, is the influence on the business economy illustrated on Figure 8.1.

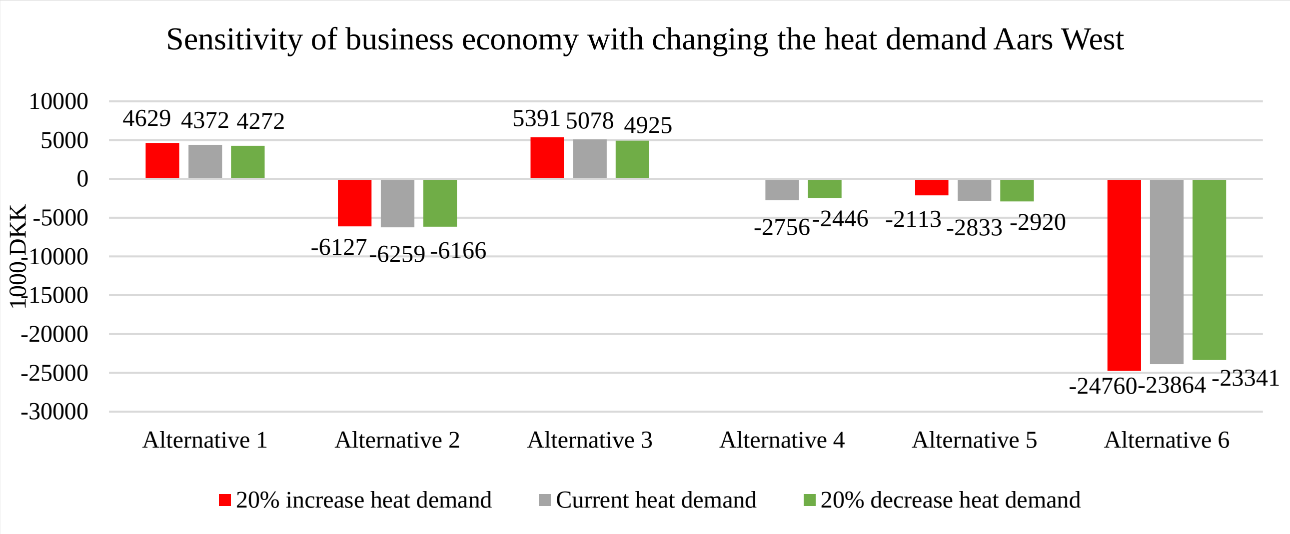


Figure 8.1 - Sensitivity of the heat demand's influence on the business economic value

Alternative 4 will not have its heat demand increased, since it could not ensure the security of supply under the current assumptions. By increasing the heat demand then Alternative 1, 2 and 3's NPV increase, which is due to more excess heat being utilised from the beginning, which enable a higher production from the excess heat unit and HP. This also results in a higher energy saving subsidy. Alternative 6's NPV is however increased with the heat demand, which is mainly because it provided negative annual operational savings, as illustrated on Figure 7.14. Alternative 3 still provides the highest NPV of 5,391,000 DKK. The alternative which benefits the most from the increase in the heat demand is Alternative 5, which reduce the negative NPV to -2,113,000 DKK. This is mainly due to the large investment and capacity related to the WCB which is better utilised from the beginning creating a larger annual operational saving.

The influence on the business-economy is now presented, and then the heat demands influence on the socio-economic impact is illustrated on Figure 8.2.

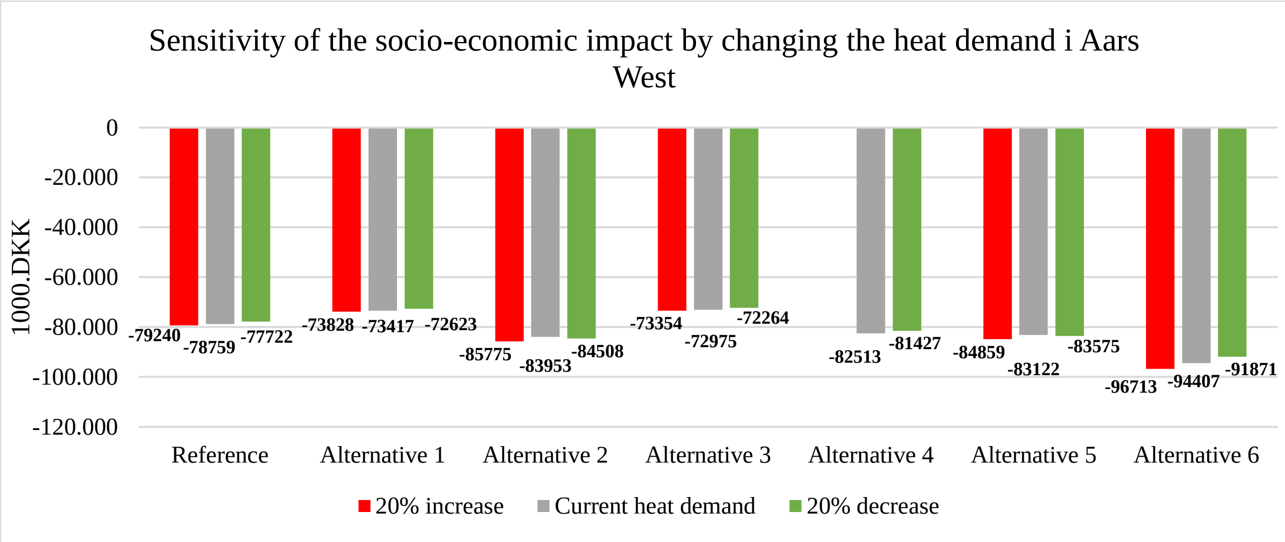


Figure 8.2 - Sensitivity of the heat demand's influence on the socio-economic value

By increasing the heat demand it results in a higher socio-economic impact, which is due to the extra costs in relation to fuels, O&M and emission exposure and vice versa with the decrease. Alternative 3 provides the lowest socio-economic impact in all tested heat demands. With a 20% decrease in the heat demand it provides a socio-economic impact of -72,264,000 DKK and with a 20% increase a socio-economic impact of 73,354,000 DKK. This is mainly due to the flexibility which the heat storage provides by integrating more excess heat in the DH system and reducing the natural gas consumption.

8.2 Investment costs

To test how robust the business- and socio-economic calculations for the different alternatives are to changes in the investment costs an increase of 20% and 40% together with a decrease of -20% and -40% is investigated. First, the influence on the business economy is illustrated on Figure 8.3.

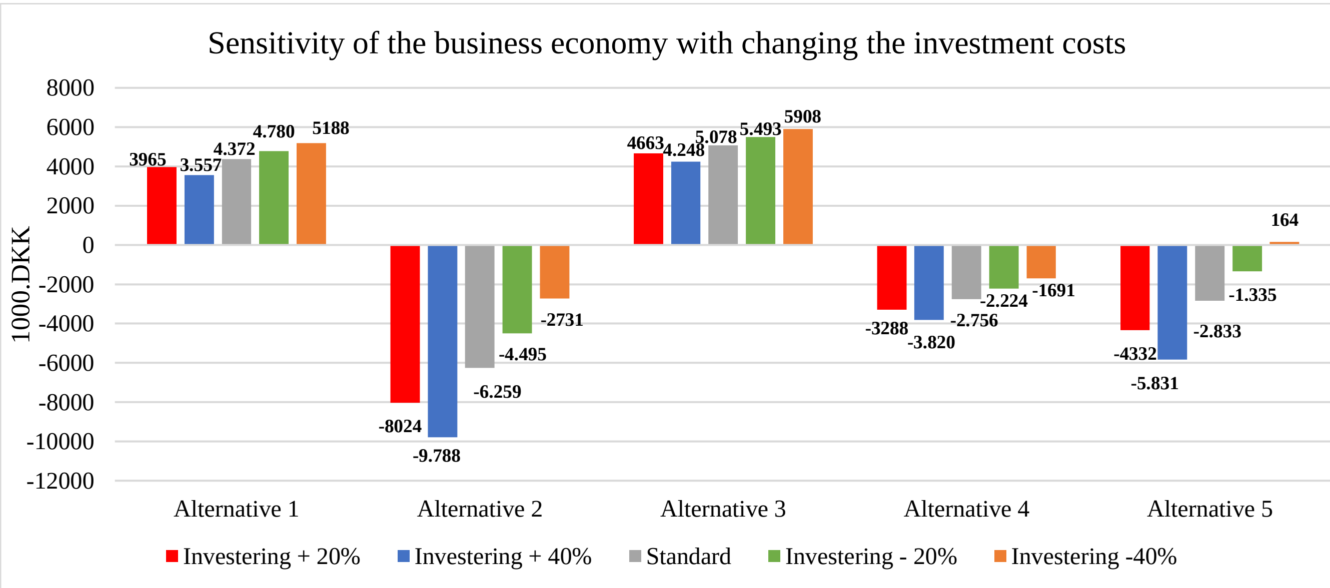


Figure 8.3 - Sensitivity of the investments costs in the business economy (NPV)

By increasing the investment costs with either 20% or 40 %, Alternative 3 will still provide the highest NPV. The same tendency is occurring when reducing the investment costs with -20 % and -40 %. It is however interesting to see that Alternative 2 and 5's deficits are significantly reduced compared to the other alternatives, which indicates how much of an influence the investment costs have on these alternatives. Alternative 5 provides a positive NPV of 164,000 DKK with a 40% reduction in the investment costs. Alternative 6 is not included, because of the negative annual operational savings.

The influence of increasing and reducing the investment costs in the socio-economic calculations are illustrated on Figure 8.4.

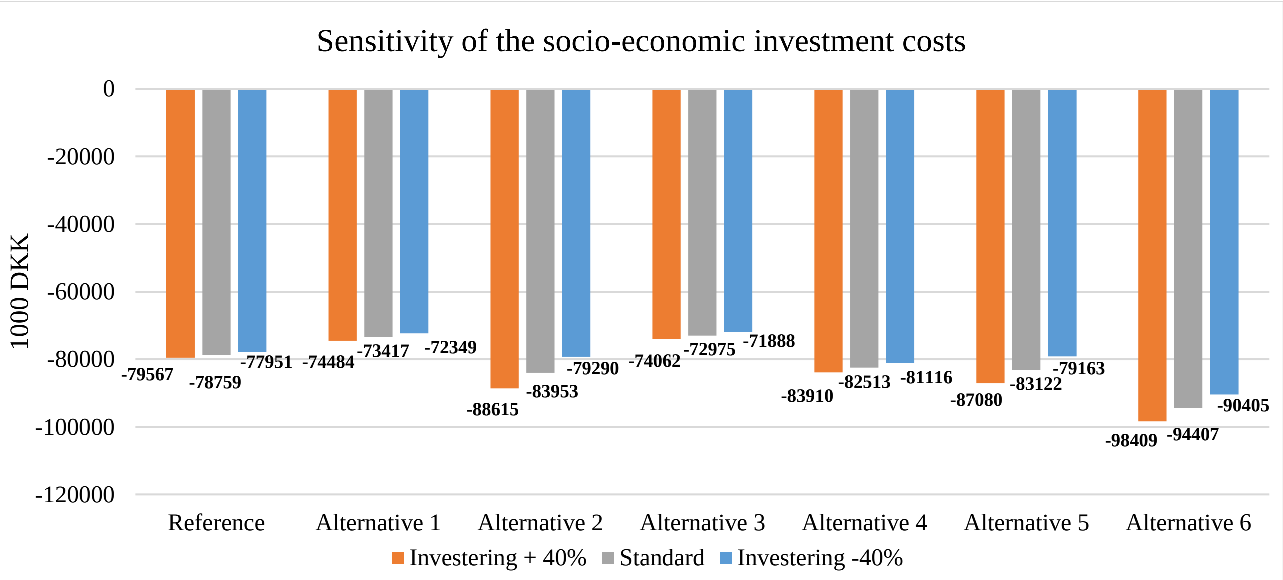


Figure 8.4 - Sensitivity of the investments costs in the socio-economy (NPV)

By increasing and decreasing the investment costs with ±40%, Alternative 3 still provides the highest socio-economic value. Alternative 1 and 3 are however not very sensitive towards changes in the investment costs unlike Alternative 2, 5 and 6, which socio-economic impact are highly influenced.

8.3 Discount rate

To test the influence of the discount rate on both the business- and socio-economic calculation different discount values are investigated. The discount rates are different in the business- and socio-economy, as described in Section 4.5. First, the influence of increasing the business economic discount rate from 3% to 6% and 9% is investigated on Figure 8.5. This is done to test how robust the alternatives are to the uncertainty related to the annual operational savings.

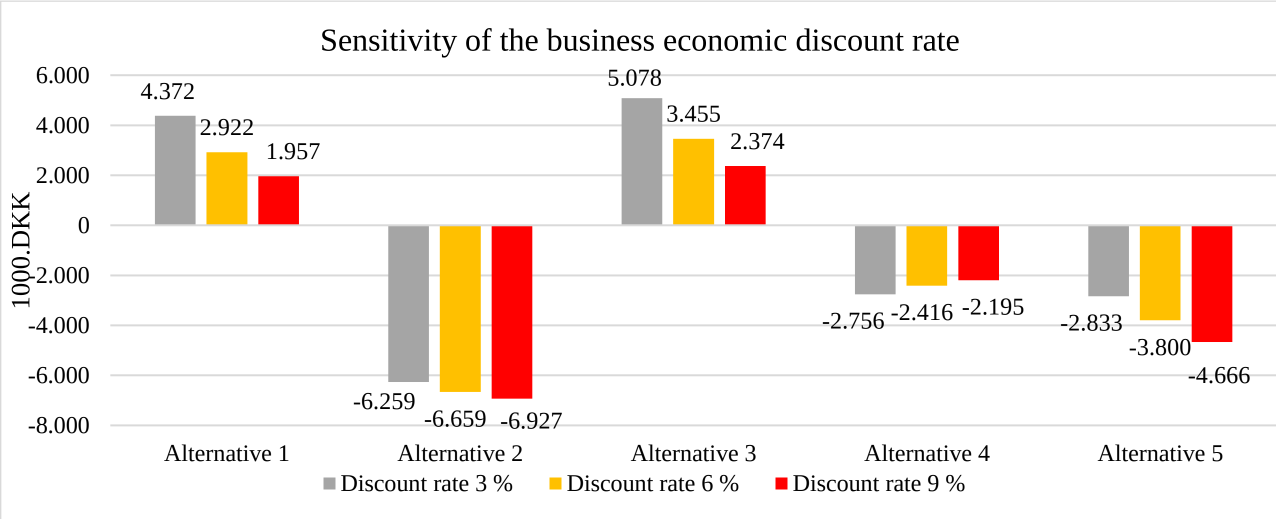


Figure 8.5 - Sensitivity of the business economic discount rate

By increasing the discount rate, the different alternatives NPV's have become less feasible, which is because of the annual operational savings in the future are given a lower value. In Alternative 1, 2, 3 and 5 the largest annual operational saving occurs later in the calculation period. In Alternative 4 a higher discount rate provides a better result, which is because of the annual operational savings occurring in the beginning of the calculation period and the costs occurring later are given a lower value. A higher discount rate devalues the future revenues and costs by giving them a lower value than today. So, the revenues in the beginning of the project is given a higher value than the costs occurring later in the calculation period. Alternative 6 is not included in the sensitivity of the discount rate, because it provides negative annual operation savings and negative investments costs, meaning it will never provide a positive result. By increasing the discount rate, Alternative 3 still provides the highest NPV of all alternatives of 2,374,000 DKK compared to Alternative 1 of 1,957,000 DKK. Now the influence of changes in the discount rate for the business economic calculations investigated, it is important to test how robust the socio-economic impact calculation is to changes in the politically determined discount rate. The influence of changes in the discount rate in the socio-economic calculation is illustrated on Figure 8.6 below.

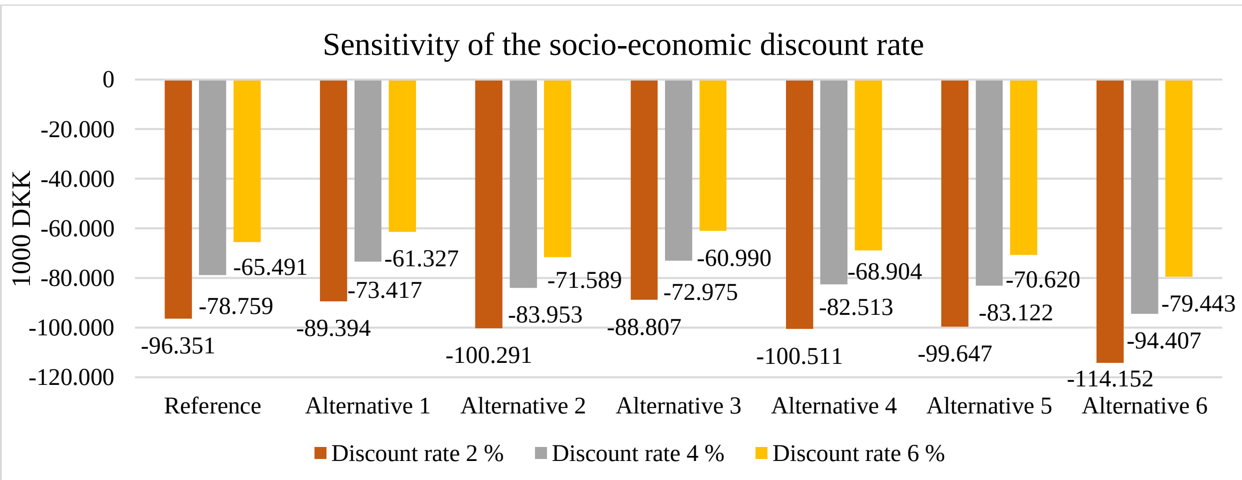


Figure 8.6 - Sensitivity of the socio-economic discount rate

Figure 8.6 illustrates that by lowering the discount rate in the socio-economy, the impact is increased, because the uncertainty about the future impacts are given a higher value and vice versa a higher discount rate reduces the costs in the future. This has the opposite effect in comparison with the NPV of the business economic calculation, which is due to the socio-economic calculation is constructed as a total impact assessment of the societal costs. Alternative 3 provides the lowest socio-economic impact in all the tested discount rates in comparison with the other alternatives.

8.4 Sensitivity of the electricity price

To test how robust the alternatives are to changes in the electricity price, which is the main revenue in the DH system, a reduction of the electricity price with 50% is investigated. First, the influence of decreasing the electricity price with 50% in the business economic calculation is investigated on Figure 8.7

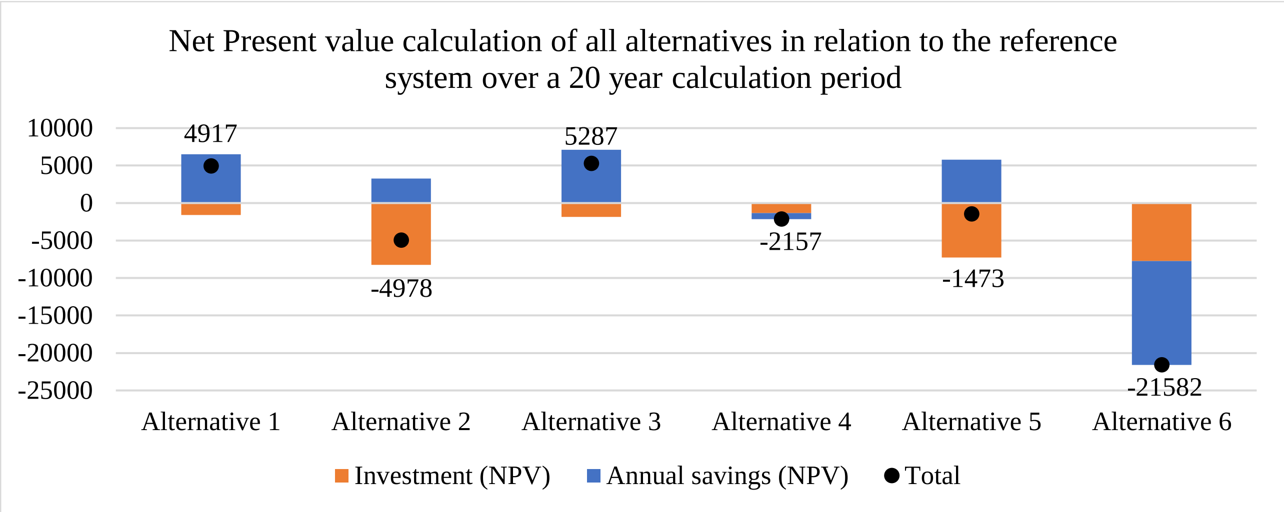


Figure 8.7 - Sensitivity with a 50 % reduced electricity price on the business economy

The NPV calculation shows that Alternative 3 provides the highest business economic value of 5,287,000 DKK compared to Alternative 1 of 4,917,000 DKK. This is mainly due to the natural gas CHP units in the DH system will have less production hours and be replaced with the natural gas boilers and electric boiler. The benefits with the heat storage are also reduced, since the waste incineration CHP plant furnace 2 receives less revenue from the electricity produced. However, the waste price is still high during the summer and when the electricity price is high enough for the electricity sale and disposal of waste to provide negative NPC, the heat rejectors are still utilised.

Additionally, the influence of reducing the electricity price in the socio-economic calculations is investigated. It is important to test how robust the socio-economic impact assessment is to the same reduction. The influence of reducing the electricity price with 50% in the socio-economic calculation is illustrated on Figure 8.8 below.

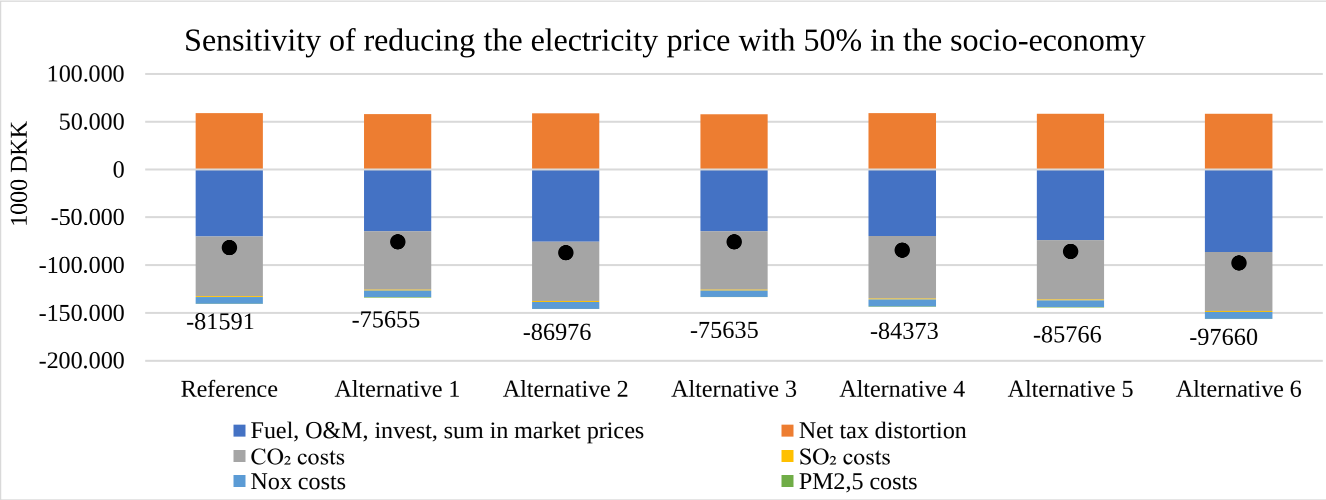


Figure 8.8 - Sensitivity with a 50 % reduced electricity price on the socio-economy

The 50% reduction of the electricity price results in Alternative 1 and 3 to have almost the same socio-economic impact, but Alternative 3 still provides the lowest impact of 75,635,000 DKK. This is due to Alternative 3 has lower CO_2 costs and total fuel, O&M and investment costs.

8.5 Sensitivity of the business economic impact of changes in the excess heat price

The excess heat from Dania is currently given to Aars DH free of charge, therefore to see the influence on the business economic result, different excess heat prices are illustrated on Figure 8.9.

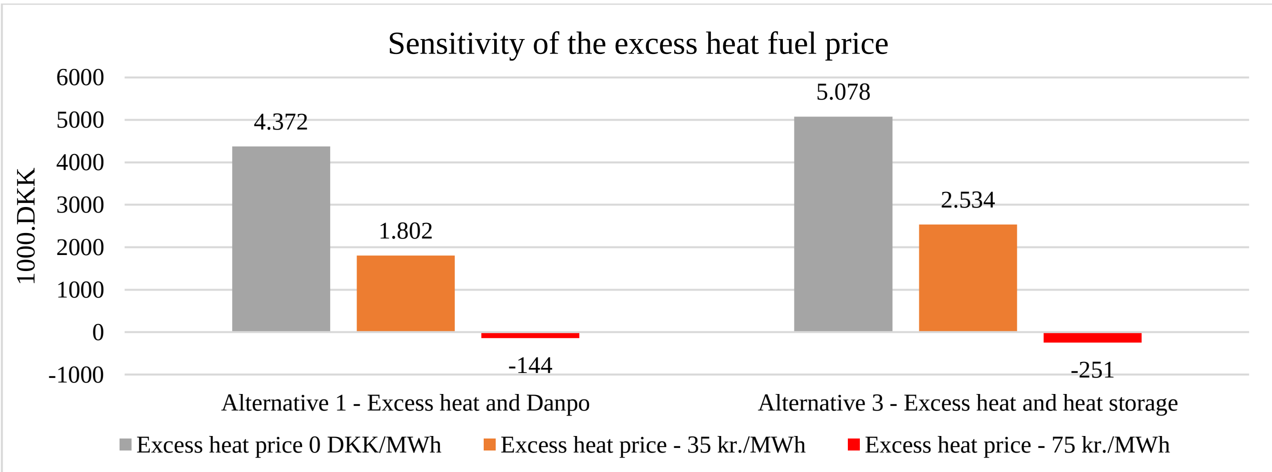


Figure 8.9 - Sensitivity of the excess heat fuel price level net present value calculation

By increasing the price level on the excess heat then the alternatives become less feasible, because it becomes harder to compete with the waste incineration furnace 1. By increasing the excess heat fuel price with 75 DKK/MWh, both alternatives provide a negative NPV. Alternative 3 has a higher NPV compared to Alternative 1 with a fuel price on 35 DKK/MWh, which is due to more excess heat being utilised. However, with a price on 75 DKK/MWh, the excess heat production unit produce more in Alternative 1 than Alternative 3. This is due to the heat storage is filled with heat from the waste incineration plants as often as possible unlike Alternative 1, where the excess heat is needed to secure the heat demand due to no storage options. The fuel price can be increased further for Dania, if they are certified, since this reduce the excess heat tax with 54 DKK/MWh, as described in Section 1.1.

9. Discussion

The chapter includes a discussion of the results presented in Chapter 7 and Chapter 8, and the influence of the chosen assumptions. Thereafter, the socio-economic calculations will be discussed in relation to the changes in framework conditions and the future role of DH in relation to ensuring the 2050 goals.

9.1 Discussion of chosen assumptions

Through the analysis and sensitivity Alternative 3 provides the highest business- and highest socio-economic value in all tested sensitivities. Alternative 3 also ensures the security of supply in the area even with a 20% increase in the heat demand. This means that Alternative 3 is the best alternative to implement from a technical and economic point of view. However, there are many risks and uncertainties related to utilising the excess heat from Dania, because the higher the price level are on the excess heat, the worse the business economy becomes. The risk with Alternative 3 is that by utilising the excess heat from Dania, without making any upgrading measures in the pipelines, then Aars West becomes reliant upon Dania to secure the heat demand. If Dania's production is shut down or production pattern changes, it will affect the consumers in Aars West and lead to higher investments in e.g. new production units or pipelines to ensure the heat demand in the area unlike the Reference System or Alternative 5. This is because the production is controlled by Aars DH.

There are also some uncertainties related to increasing the dependency of waste to energy. If the framework conditions change for the waste incineration plants e.g. higher taxation (CO_2 quotas, CO_2 emission tax etc) or waste price reductions, then it will have a large influence on the overall DH system due to the dependency on one resource. By implementing more resources into the DH system e.g. excess heat, WCB or HP's, then the flexibility is increased and dependency on one resource limited. This makes the system more versatile towards changes in the framework conditions and prices, due to the diversity both the production units and heat resources in the energy system provide (Bæk, 2017).

Fuel price settings for the future

The waste price is simulated as a fixed price monthly. The waste price has a large influence on the feasibility of the system, because around 96% of production distribution in the reference system is covered by the waste incineration plants furnace 1 and 2, as illustrated on Figure 7.15. The production distribution does not represent the heat demand. This is because the waste incineration plant furnace 2 heat rejects when the net production costs are negative, which often occur during the summer period and the heat is therefore not utilised by the consumers. The waste price is very uncertain, because it is highly dependent upon supply and demand both domestically and internationally, since Aars DH imports waste from the United Kingdom. The increased focus on recycling and reuse of waste management makes it hard to predict the amount of waste in the future. However, Jesper Bo Jensen from Dakota says that the amount of waste has been overall increasing the last years. Even with the high focus on recycling in Denmark, the amount of waste will not decrease soon due to the consumption's patterns and the available amounts internationally (Jensen, 2018). An analysis from the Copenhagen Resource Institute also indicates that the amount of waste will increase in the future, but the overall capacity on the waste incineration plants will decrease (Copenhagen Resource Institute, 2017). However, the UK have decreased their waste production with 12% from 2004-2016 (Eurostat, 2019). If the waste price is lowered, then many of the alternative will be able to obtain more production hours, because they would be able to compete with the waste incineration plants. Another parameter which is uncertain in the analysis is the natural gas price, which is fixed annually in the simulation. The natural gas price is not fixed, it is traded daily on Gaspoint Nordic Spot. By having a flexible natural gas price, the different production units will compete more individually both in relation to the electricity price but also natural gas price. The natural gas consumption is however very low in Aars DH and the influence will therefore be minor, since it is only utilised as peak load units, where they must produce no matter the costs.

9.2 District heating and individual heat pumps role in the future energy system

To realise the Danish energy goals for 2035 and 2050 as described in Section 1.1. The Danish Energy Agency made analysis where they predict that the future heat production in 2035 will be primarily based upon electricity to heat and biomass. The utilisation of waste is expected to decrease whereas the utilisation e.g. excess heat will increase (Energistyrelsen, 2014). To utilise the renewable energy resources such as electricity for heat or excess heat, the DH systems must upgrade their current energy systems, since these energy resources are most efficient at a low temperature of 55-65^{o}C. This will challenge the DH systems existing distribution network in relation to reinvestments in the infrastructure. Because a lower supply temperature often leads to a lower $\triangle$T, and therefore a higher flow in the pipes (possible upgrade) and pump costs (Paaske, 2015). Another challenge is at the consumer level, because the existing consumers must also lower their temperature requirements. This is done through investments in building renovations e.g. insulation, new larger radiators (underfloor heating) and tap water units to maximise their cooling, which also require a high investment. These changes are however hard to implement in the private sector, even though building regulations, policy and incentives are implemented to improve the energy efficiency (Wittchen et al. 2014).

The consumers are the ones dictating the temperature level, and if some consumers require higher supply temperatures than 55-65^{o}C e.g. during the winter, the temperature can be boosted or covered through additional production units such as biomass boilers or waste incineration plants as in Aars DH. If these units are not present in the DH system and the temperature level requirements are too high or only a few consumers require the temperature level, it might be feasible to investigate installing an individual production unit or not connect them to the DH system. This is because the heat losses increase with higher supply temperatures (Rutz, et al. 2017).

The biggest challenge with DH is the heat losses in the network, as described in Section 1.2. If the supply temperature cannot be lowered due to the existing consumers temperature requirements, it becomes less feasible for the new households to be connected to the DH grid compared to installing an individual HP, which are more efficient at a lower supply temperature. This is because the DH sector is transitioning towards heat only producing units (boilers and HP's), which can also be installed individually. The benefits of scale must therefore be high enough to outweigh the deficits of heat losses in the DH networks to outcompete the individual solutions. It is therefore important to motivate the existing consumers to reduce their supply temperature as well as their return temperature to increase the efficiency within the DH network.

With the removal of the mandatory connection and remain connected obligation for new urban areas, the DH systems are exposed towards making these heavy investments in upgrading the DH network or implementing new production units. This is because there is no guarantee that the consumers will connect or remain part of the DH system, after the investments are made, which often have a life time horizon of 20-40 years. The free choice of heat supply can also have a negative influence on consumers who want DH but are deselected by the DH company due to the uncertainties and risks (KTC, 2018). It can also be argued that some DH systems are not dimensioned to supply the large increase/decrease of consumers that are occurring due to the urbanisation without making many heavy reinvestments, which might increase the heat price. These DH systems can be challenged in relation to supplying the consumers with a competitive heat price in comparison with individual HP's. It is therefore important to evaluate, if the DH system should fusion with a surrounding DH system to create a more competitive heat price or transition towards an individual solution.

When looking at the overall energy system from a holistic point of view then the individual HP's should only be implemented in areas outside of the collective distribution grid where it does not make sense economically to connect the consumers to the DH system. This is because of the future challenges which are expected to occur with the increased implementation of more renewable energy resources such as wind and solar power. These challenges consider a reduction in regulative electricity capacity, since wind and solar power have low marginal costs which the regulative CHP plants cannot compete with (Djørup, 2016). The renewable energy resources production patterns are highly dependent upon the weather conditions and when the wind is not blowing, and the electricity peak load demand is increased due to electric vehicles, HP's etc. then the security of supply can be challenged (Lund, 2018). The expected development is illustrated on Figure 9.1.

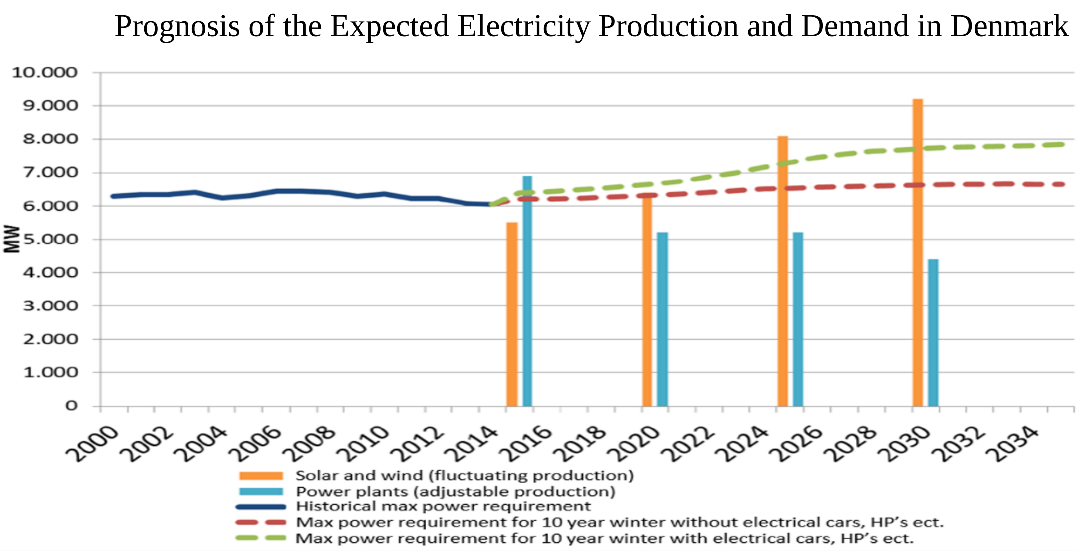


Figure 9.1 - Prognosis of the expected electricity production and demand in Denmark (Dansk Energi, 2016)

The DH systems can obtain higher HP efficiencies than individual HP's, which reduce the electricity consumption, and DH also provides more flexibility in relation to heat storages. These heat storages can be utilised in hours where the supply exceeds the demand of electricity and reduce the peak load in other hours and stabilise the electricity system (Djørup, 2016). To reduce the electricity peak load, it is important to either minimise the electricity consumption or create a more flexible energy system with focus on both the demand side and production side management (Lund et al, 2015). In Aars DH it was not feasible either socio-economic or business-economic to implement individual HP's instead of DH. However if consumers choose to implement individual HP's instead of connecting to the DH system, many of the benefits provided by DH such as benefits of scale, flexible storage solutions, integration of excess heat, geothermal energy, waste incineration plants and biomass CHP plants can be lost. These benefits are based upon synergies within the heat and electricity sector to ensure a cost-effective transition towards a CO_2 neutral energy system (Energinet, 2018). Therefore, the socio-economic calculations are important to conduct in relation to the business economy, because even though it might be profitable to implement individual solutions from a business economic point of view, it is not necessarily the best solution from a societal point of view. The socio-economy indicate the impact an alternative will have on the society, hereby the costs/benefits related to the electricity consumption and production in the future.

9.3 The influence of the socio-economic calculation

With the removal of the mandatory connection, the municipalities have lost an important planning tool to enforce the implementation of the most socio-economic beneficial solution and conduct strategic energy planning (KTC, 2018). New urban areas have been given the free choice of heat supply, which means that project proposals for these areas have lost their significance in the planning process. This is because the municipality cannot enforce a consumer to choose a specific heat supply. This leaves a question in relation to who should construct these project proposals in the future to ensure the highest socio-economic alternative, as the Heat Supply Act enforces, as described in Section 3.3.

The highest socio-economic value is in this thesis only based upon a cost/benefit analysis, as described in 4.5. However, more aspects, which are not given a market price in the Cost/benefit analysis can be included in the socio-economic calculation. These aspects could be job creation, security of supply or externalities such as social effects (visual) and environmental effects as noise from the cooling devices rotating fans etc. These are all important aspects to consider even though they cannot be directly price set. But the overall value can still be evaluated and included as a positive/negative side effect to each alternative in relation to the cost/benefit assessment (Finansministeriet, 2017). By assessing these aspects, it can be discussed what alternative that provides the highest socio-economic value in relation to what should be given the highest merit when comparing the quantifiable and qualitative aspects related to the socio-economic impact.

10. Conclusion

This thesis seeks to address the influence of the urbanisation, occurring within e.g. the larger cities in the municipalities, in relation to the existing DH systems. Many of the DH systems were implemented or retrofitted with the oil crisis in 1970's, where the Heat Supply Act was implemented. These DH systems are therefore old and under constant development to supply both existing and new consumers with hot water. The urbanisation increases the demand for heat in the cities, but it also enables the cities to utilise new CO_2 neutral energy resources such as excess heat from industries. The energy planning has changed with the new framework conditions in relation to the removal of the mandatory connection for new urban areas established after 2019 and tax reductions in e.g. excess and electricity for heat. This have increased the competition between individual solutions and DH, because of the energy efficiency requirements for buildings, policy and incentives making individual solutions more competitive than before. A city expanding is Aars and Aars DH are looking to expand their current distribution area to include the new urban area being developed in Aars West, which have led to the following research question and sub questions.

> ***"How can Aars District Heating ensure the security of supply in the new urban area Aars West from a technical, - business- and socio-economic perspective?***

To answer the Research Question the following sub questions are answered and concluded upon before an overall conclusion is made. The different alternatives investigated are the following Reference system – New pipeline, Alternative 1 – Danpo pipe and Dania excess heat unit, Alternative 2 – Water to water HP and heat storage, Alternative 3 – Excess heat unit and heat storage, Alternative 4 – Danpo pipe and heat storage, Alternative 5 – WCB and Alternative 5 – Individual air to water HP's. These alternatives are constructed in collaboration with Aars DH and Vesthimmerlands Municipality to find the best technical, business- and socio-economic alternative to supply Aars West.

1. ***What is the expected heat demand in Aars West and how should the distribution network be dimensioned?***

To ensure the security of supply in the new urban area, an estimation of the different construction types and expected heat demand is made. To clarify what construction and when it is expected to be developed, an interview with the municipality of Vesthimmerland was conducted and illustrated that Aars West will consist of different households and new institutions such as an indoor swimming pool, kindergarten, sports hall and a public school. The estimation of the heat demand related to the different constructions is based upon recommendations from SBI, building regulations, building entrepreneurs and historic data from Aars DH from similar constructions. The total heat demand in Aars West is 3484 MWh equal to an effect of 1.29 MW excl. heat losses, since it will vary from the alternatives. The different heat loads from the consumers are utilised to dimension the DH distribution grid with consideration of the simultaneity factor in Aars West. The total costs of the distribution network without new supply pipes in Aars West is estimated to 2,608,316 DKK with the total development.

2. ***What are the technical limitations within Aars DH network and what upgrading measures are needed to ensure the security of supply in Aars West?***

To ensure the technical regulation within Aars DH network, then the differential pressure must be above 0.2 bar and the supply pressure below 7 bar at the consumer installation. The DH network will technically operate after securing a minimum of 0.3 bar, since this is what Aars DH use. This is done through a hydraulic investigation of upgrading the pipelines, increasing the pumps critical speed on Central 1 at Gislumvej or build a new heat central at Dania. The alternative supply pipe in the reference system will be a DN80 running through Markedsvej. To secure the differential pressure at the consumers in Aars West, the pumps at Central 1 must increase the supply pressure to 5.9 with a differential pressure of 2.4 bar. To utilise the excess heat from Dania another supply pipe is built together with a new pumping station. The pumps on Central 1 will then decrease the supply pressure to 4.3 bar with a differential pressure of 0.76 bar. The heat central at Dania will have a supply pressure of 3.4 bar with a differential pressure of 1.35 bar. The differential pressure from Dania is higher than Central 1, due to the heat generated from Dania must be utilised first in Aars West.

3. ***What technical alternative provides the highest business- and socio-economic value for Aars DH?***

To evaluate on the business economy both an NPV calculation and an annualization calculation are constructed to calculate the influence of future costs and benefits together with the repayment amount of the investment. This is done to make sure that the alternative with the highest business economic value is chosen. The six tested alternatives show that only two can lower the annual average heat price and provide a positive NPV through the 20 year calculation period. The alternative providing the highest business economic value is Alternative 3 with an annual average heat price on 163 DKK/MWh and NPV of 5,078,000 DKK. To evaluate the socio-economy an NPV calculation is conducted on the impacts through a consequence assessment. The six tested alternatives are then compared with the reference system to indicate what alternative that provides the lowest societal impact. Only two out of the six alternatives can lower the societal impact in relation to the reference system and Alternative 3 provides the lowest socio-economic impact on the society in market prices of -72,975,000 DKK. The reference system provides a socio-economic impact of -78,759,000 DKK.

4. ***How sensitive are the alternatives towards changes in the chosen assumptions?***

To evaluate the sensitivity of each alternative the most uncertain parameters have been investigated. Throughout all the sensitivities conducted, then Alternative 3 provides the highest business and socio-economic value. By changing the heat demand with a ±20% the most sensitive alternatives are Alternative 5 and 6. Another uncertain parameter is the investment, which is based upon prices from the Danish Energy Agency. By changing the investment costs then Alternative 2 and 5 are the most sensitive, which is due to the high investment cost and few operational hours. By increasing the discount rate, then Alternative 3 is the most sensitive, which is mainly due the largest operational savings occurring later in the calculation period. The excess heat utilised from Dania is given to Aars DH free of charge. By increasing the excess heat price with 35 DKK/MWh, then the feasibility is already halved and at 75 DKK/MWh both Alternative 1 and 3 provide a negative NPV. It can therefore be concluded that Alternative 3 provides both the highest business- and socio-economic value in all tested sensitivities and is therefore the least sensitive alternative under the given assumptions.

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