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COST DRIVERS IN DISTRICT HEATING: COMPARISON OF CAPEX COSTS BETWEEN THE NETHERLANDS AND DENMARK

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COST DRIVERS IN DISTRICT HEATING: COMPARISON OF CAPEX COSTS BETWEEN THE NETHERLANDS AND DENMARK

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CONTENTS

1. EXECUTIVE SUMMARY

This research is conducted by Ramboll for the Danish Energy Agency (DEA) and Netherlands Organisation for Applied Scientific Research (TNO). For this research a comparison of CAPEX and cost drivers for district heating projects in the Netherlands and Denmark has been conducted. The results are shared with the Ministerie van Economische Zaken en Klimaat (MINEZK) in the Netherlands. The Netherlands is in the process of changing away from a district heating tariff scheme which is linked to the natural gas price to cost-based tariffs. Consequently, CAPEX and related cost drivers will affect the tariffs in the future. Learning from Denmark and selected Danish cases for district heating projects, results and recommendations can help to secure lower district heating tariffs in the Netherlands, which in future will reflect the costs of district heating.

Three cases for the Netherlands were studied using quantitative data from three district heating projects: East Wageningen, Amsterdam and Groningen. In addition, five workshops were held to discuss and compare Dutch and Danish cases; one with practitioners, one with financial institutions, two with the municipalities of Groningen and Amsterdam and one with cooperatives. Relevant actors from Denmark were participating in the five workshops as well. From the quantitative analysis of comparing CAPEX for Dutch and Danish district heating projects and qualitative analysis of the discussions in the five workshops, the following results emerged:

- There is low transparency in Dutch district heating resulting in a lack of knowledge sharing and missing best practices within project design. In The Netherlands, district heating companies are not obliged to reveal their real costs, for example when they start a project or for tariff setting.
- The low transparency leads to lower efficiency and higher project CAPEX costs. By contrast, in Denmark district heating knowledge hubs have been developed, which disseminate recommendations and analyses on best practices, and, e.g., contribute to the national technology catalogues. The catalogues contain the costs of technologies and can be used as a benchmark. It allows district heating companies and municipalities to compare their costs with the costs as listed in the catalogue.
- The non-profit basis of the Danish district heating companies is an important factor that has facilitated the extensive knowledge sharing. As Dutch district heating companies are rarely in direct competition, they should also have a strong interest in strengthening knowledge sharing.
- Establishing new district heating networks in the Netherlands has often resulted in the use of centralized production with a single heat source, requiring greater investment in back-up capacity, peak load and bigger pipes than Danish equivalent schemes. In Danish schemes multiple heat sources also enabled operators to use load dispatch to optimise the cost of heat supply as prices fluctuate over time. Danish district heating systems have developed this large diversity of heat production over years. This development has been promoted by the open access to new heat production as part of the Danish heat regulation. Integration of external heat sources is possible when heat can be offered at a price lower than what the district heating company can otherwise produce. The large available capacity today allows for many Danish district heating systems to expand more easily.
- Analyses of the Dutch case studies regarding establishing district heating distribution systems have revealed that Dutch general costs (these are costs which are not included in the main direct costs such as material and labor, they do include for example risk) seem to be twice the Danish general costs, which indicate that Dutch contractors find significant risks and uncertainties in these types of projects. These risks may be associated with various elements of the implementation process, including the design of the contract,

regulatory requirements and cooperation with authorities, and planning the construction work.

- Further, the analyses uncovered that Danish experiences with changing from single pipe pairs to twin pipes has kept network construction prices low in Denmark despite general price increases in the economy. Dutch assessments, however, are that twin pipes appear to be too expensive. This might be due to limited experience with twin pipes, but nevertheless there is an incentive for Dutch project planners and entrepreneurs to keep investigating the economic benefits of using this method.
- The mandatory Danish heat infrastructure planning processes organized with the relevant heat planning authorities and district heating companies have created a larger amount of district heating schemes in Denmark, along with greater certainty of the pipeline of future projects. The socio-economic requirements, standardized guidelines for new projects and specific loan conditions have created a safe investment environment for new district heating projects. All this has resulted in project cost savings and product discounts - a context that was not available in the Netherlands in the same way.
- In Denmark a socio-economic analysis has to be conducted before a district heating project can start. In this socio-economic analysis the real costs and tarrifs which the consumers will pay are compared with other heating sources, e.g. heat pumps. Only if district heating is the best option, can a district heating project start. There are public tools available which help in conducting this socio-economic analysis. There is a source planning tool, which shows which how combinations of heat sources can work together. Furthermore, there is the beforementioned cost catalogue, which can serve as a benchmark for costs.
- Investors of Dutch district heating projects often required a high IRR to profit from district heating projects. District heating companies in Denmark are run as non-profits and are not allowed to profit from the sale of district heating.
- In Denmark, district heating is financed by a non-profit mortgage provider with a long payback time, with the financial risk underwritten by the municipality, which is not possible in the Netherlands today. In the Netherlands the financial institutions have limited experience about district heating projects, resulting in requirements for a higher interest rate, resulting in higher financial costs. The experience and knowledge from existing district heating schemes in the Netherlands are build up in the large district heating companies. However this experience and knowledge are not shared with new and smaller companies, with financial institutions or with municipalities, which means there seems to be a lack of transparency on this build-up knowledge. Heat regulation in the Netherlands does not encourage transparency whereas in Denmark the regulation has furthered and required transparency of costs also being reflected in transparency of knowledge.

Only a limited number of cases were analysed during the project. Furthermore, each project is unique. Still, general conclusions were found based on these cases, leading to 5 overall recommendations to reduce cost drivers affecting district heating CAPEX in the Netherlands:

1. Design engineers, and those commissioning network design work, should explore international design best practices and seek to develop design norms used in projects at present (e.g. use of twin pipes and optimising the level of pipe insulation for a system, looking to countries such as Denmark, Sweden, Germany and the UK to understand opportunities to reduce project CAPEX).
2. Network developers and operators should explore opportunities for diversifying the use of heat sources within networks, facilitating access to new cheap heat production sources and enabling heat supply cost minimisation both in terms of CAPEX and heat supply costs.

Subsidies, encouraging diversification, could be adapted. Also, third party access for cheaper resources helps this diversification.

3. The Dutch government has tasked municipalities with a new responsibility to lead the transition to sustainable heating, including identifying the lowest costs sustainable heat supply approaches at district level. Although the government has developed technical guidelines and designated funds to assist the municipalities, the question remains whether municipalities have sufficient capacity, resources and necessary enforcement mechanisms to fulfill the new task. In Denmark, useful experience has been gained from municipalities having had a central role as the local heat planning authority for several years. The standardized socio-economic approach to specific project proposals in Denmark has also played a key role in strengthening the municipalities in their role as the local heat planning authority. Lessons from this experience could be studied and transferred to the Netherlands. For example, the (voluntary) planning tool: municipal strategic energy planning from 2012 illustrates how Danish cooperation on joint efforts and goals on least cost and tariff planning was strengthened with other local actors, such as the local district heating companies.
4. Financial institutions should look to develop their knowledge of the district heating sector further and establish standardised processes for assessing and approving finance for district heating projects. In parallel, there are opportunities to utilise public financing and/or offer government underwriting of project loans by national or local governments to enable larger scale, strategic projects to overcome the perceived financial risks of this developing part of the energy system.
5. Finally, there is an opportunity to increase transparency as regards to formulating, justifying and reporting investment plans, heat purchase agreements and tariff decisions, i.e. pursue objectives that district heating companies' economic decisions and environmental goals and tariff composition should be publicly disclosed and explained better, thus to increase trust amongst consumers in the cost and operational efficiency of networks. It is expected that high consumer trust can be translated into a high connection level to district heating schemes and thus a high degree of utilization of the invested assets, i.e. low CAPEX per customer.

The recommendations should be seen in the light of physical conditions for district heating being reasonably comparable between Denmark and the Netherlands. Danish consumers use more heat on average than Dutch consumers, among others because the number of low temperature days is around 10% higher in Denmark. Conversely, the higher population density in the Netherlands (around 402 vs 132 inhabitants in Denmark per km^2) means that there is generally a higher building density, which theoretically should promote district heating solutions.

2. INTRODUCTION

This report presents the findings from research conducted by Ramboll for the Danish Energy Agency and TNO, looking to identify and compare potential cost drivers of district heating (DH) projects related to CAPEX in the Netherlands and Denmark.

An international comparison of district heating tariffs in several EU countries (Huygen et al. (2021))[1] has revealed that tariffs in the Netherlands are higher compared to other EU countries. Due to the increases in gas prices, this difference has grown in 2022. Whereas a Danish apartment pays on average €1352 for a heating demand of 54 GJ, a Dutch household would pay €2610 for this demand. This is almost twice as much. For a typical Dutch demand of 26 GJ, a Dutch household pays €1536. Of the 386 analysed Danish district heating supplyers, 1 has higher tariffs than the maximum tariffs as imposed by the ACM and 6 higher than the average tariffs of the main Dutch district heating companies.[2,3]

Today, the Netherlands uses a tariff scheme linked to the natural gas price. However, this approach will in the new Heat Act be changed to a cost-based system, where CAPEX costs will have a direct influence on the resulting heat tariffs experienced by customers. This research seeks to identify the potential cost drivers related to the CAPEX of district heating projects, using a comparison between Denmark and the Netherlands.

2.1 Research aim

In summary, this research aimed to identify the differences in CAPEX of district heating projects between the Netherlands and Denmark and identify potential cost drivers of CAPEX.

2.2 CAPEX characteristics

CAPEX refers to large, long-term, up-front costs when developing a new district heating system. CAPEX can be funded by internal financing or external financing via a bank loan. The financial scheme or cost of capital to finance the CAPEX has a strong influence on the annualized investment cost (yearly capital costs). CAPEX contrasts with operating expenses (OPEX), which are ongoing expenses that are inherent to the operation and maintenance of the assets. CAPEX is depreciated every year by a certain amount across a time period depending on a lifetime and a depreciation schedule.

CAPEX must be seen as part of the total project cost over the life of the system. Especially when investing in renewable energy systems, the district heating company typically chooses to accept high plant costs, as the company expects that this choice will mean utilization of cheap / free renewable energy such as solar, geothermal, or ambient heat, and thus the total costs will be lower over the total economic life of the plant.

[1] https://esb.nu/esb/20062702/warmte-is-in-nederland-een-stuk-duurder-dan-in-andere-europese-landen

[2] Danish data: Priser pr. 1. januar 2022 (forsyningstilsynet.dk)
Dutch data: Welke tarieven mag ik vragen voor het leveren van warmte? | ACM.nl
Warmtetarieven Eneco blijven ruim onder maximum van ACM
Tarieven stadswarmte 2022 Amsterdam | Vattenfall Warmte
Tarievenblad 2022 ENN 01-07-2022.pdf (ennatuurlijk.nl)
warmtetarieven HVC in 2022 (hvcgroep.nl)
199.46-Tariefkaart_A4_standaard_Jul22_web.pdf (svpparticulier.nl)

[3] The Dutch yearly bill is calculated by first calculating the average fixed and variable rates from the 6 district heating companies. Next, the yearly bill is calculated: yearly bill = fixed rate + variable rate * 54 GJ.

As a DH system is divided into 3 system parts: production plants, distribution system and customer installations, CAPEX can be separated into these 3 parts. If a completely new district heating system is installed, the full investment will be required in all 3 system parts. However, in the case of an expansion of a DH system, the CAPEX is mostly concentrated on the distribution system and customer installations. These are characteristics of the Danish DH projects that are analysed in this report.

Typically, a Danish district heating project replaces the natural gas supply in an area with district heating. In many cases the new area is located next to the existing district heating network. Therefore, the supply to the new area can take place through existing heat production units combined with a smaller investment in new production capacity.

In the Netherlands this is usually not the case, because the share of existing DH supply is lower than in Denmark. A new network has to be built as well as production capacity. Building a new district heating system from scratch therefore often results in higher investment costs. However, this also offers the opportunity to built the most modern and efficient district heating system.

2.3 District heating in the Netherlands and Denmark

Around 0.5 million households in the Netherlands are currently connected to district heating systems (approximately 6% of Dutch households)[4]. In comparison, approx. 1.7 million Danish households have district heating (64% of Danish households), and a further 0.2 million households, equivalent to half of the households that currently have natural gas or oil boilers, are planned to be connected to district heating in 2028 the latest.[5,6]

District heating in the Netherlands

District heating in the Netherlands is supplied from various heat sources. The use of different heat sources configures different DH systems and costs, but all are based on hot water. Of the households connected to district heating the distribution is as follows[7]:

[4] CBS/TNO (2020): "Warmtemonitor 2019"
[5] DEA (2020): "Energistatistik 2020"
[6] The Danish Parliament (2022): "Danmark kan mere II"
[7] SIRM (2019): "Tariefregulering warmtebedrijven voor kleinverbruikers".

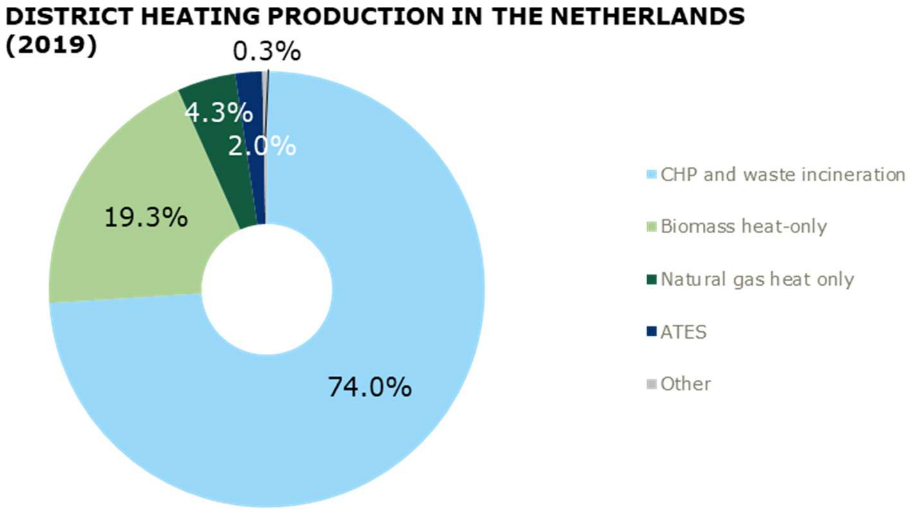


Figure 2-1 Distribution of types of district heating production in the Netherlands (2020)[2]

Depending on the district heating system and heat source, the district heating systems in the Netherlands are either high-temperature systems (supply 90-130 °C) or medium temperature systems (supply 70-75 °C).

The Netherlands has 19 large district heating systems (which supply more than 0.15 PJ) and distributes a total of 20.4 PJ to approximately 355,000 connections. In addition, there are 100-200 small collective heating networks that distribute a total of 2.4 PJ to approximately 64,000 connections.[4]

The Dutch market is also characterized by the presence of [8,9]:

- Six major heat suppliers (Eneco Warmte & Koude, Ennatuurlijk, HVC, District heating Purmerend, Vattenfall and Westpoort Warmte) that are responsible for 90% of DH supply.
- Housing associations (including large housing associations) that operate traditional gas-fired heating systems in small DH networks.
- Others: Institutions and owners 'associations (for the purpose of providing heat at an affordable price to residents), commercial properties (supplying heat to rented buildings), energy service companies (acting as a service provider and not owning the grid) and local suppliers (government and citizens' initiatives with local sustainable energy targets).

District heating in Denmark

Most Danish district heating systems are operating on a medium-temperature level and are supplied by heat from a combination of several heat production plants to always secure the cheapest heat production possible, e.g. with fluctuating electricity prices. At high electricity prices a heat pump or boiler get more expensive, so a source such as CHP will perform better. At low electricity prices heat pumps and boilers can outperform a CHP. Being able to choose, depending on electricity prices, enables a district heating company to offer the lowest prices to its customers. This is not only the case in the six largest central district heating systems in Denmark but also in most of the approximately 400 smaller district heating systems. The "large" central district heating companies all have/have had a large-scale CHP unit which supplied heat to most of the

[8] ECORYS (2017) "Rendementsmonitor warmteleveranciers 2015 en 2016". Report for the ACM.
[9] ACM (2020) "Rendementsmonitor warmteleveranciers 2019 en 2020"

given supply area. Having these large-scale CHP units are defined by law. However, in Denmark there is no legal definition of what defines a large or small district heating area.

Denmark has six large areas in which multiple district heating companies distribute a total heat production of approximately 74 PJ per year (56% of the total). In addition, there are approximately 400 decentralized, medium-sized and small-scale, district heating systems with an annual heat production of approximately 58 PJ (44% of the total) which are spread throughout the country[10].

The district heating production comes from large, centralized cogeneration plants (mainly based on biomass and waste), decentralized cogeneration plants, heat-only units, and surplus heat from third-party producers such as industrial companies. The largest contribution to district heating production comes from centralized, large-scale CHP plants. CHP plants supplied nearly 70% of the heat demand in 2020, of which the large-scale CHP units contributed half of the total. The geothermal plants cover only 0.4% and ATES is negligible and only related to large commercial building complexes[9].

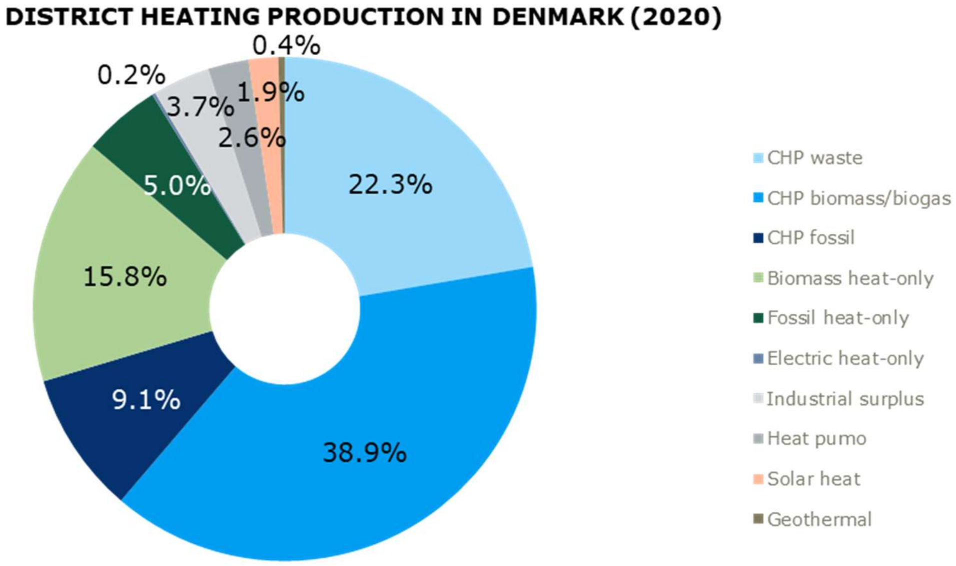


Figure 2-2 Distribution of types of district heating production in Denmark (2020)[2]

2.4 Research method

The research used a mix of quantitative and qualitative analysis. Wherever possible, CAPEX data for projects were sourced to enable a quantitative comparison between different types of project case studies across the two countries. In addition, qualitative data were collected through a series of five workshops with key groups of industry actors to inform both the quantitative analysis and to identify the broad range of factors that influence project CAPEX, from regulations and incentives, technical specifications and finance. The role of the municipality in the Netherlands and Denmark was also discussed in workshops with representatives from municipalities.

The project sought to facilitate co-learning between Dutch and Danish stakeholders. This approach enabled effective comparison across the two district heating markets to inform understanding of the reasons why and under what conditions project costs are as high as they are in the Netherlands. Furthermore, Dutch and Danish stakeholders had the opportunity to co-learn best practices – aiming to support future cross-country collaboration.

Figure 2-3 summarises the workshops undertaken within the project.

Workshop 1	Workshop 2	Workshop 3	Workshop 4	Workshop 5
Practitioners	**Municipalities**	**Financial institutions**	**Cooperatives**	**Municipalities 2**
12-11-2021	*07-02-2022*	*18-03-2022*	*12-05-2022*	*20-05-2022*
Themes The Dutch district heating market Retrofitting of houses for district heating Tariffs and legislation Planning and design of district heating Different types of cost drivers	**Themes** The municipality's role and capacity for district heating Project ownership and governance Laws and regulations Comparison of municipalities' CAPEX models	**Themes** Skills and experience in different types of financial institutions Financial risk in district heating projects Community owned cooperatives Role of national and local governments in relation to finance	**Themes** Presentation of different district heating systems in Denmark System design Heat production Network infrastructure and connection of customers	**Themes** A follow-up on the first workshop with the same municipalities. Focus on specific costs and comparison of project costs for Dutch and Danish projects. Comparison of heat supply, network infrastructure and customer connection
Participants EES, Heijmanns, Hillerød Utility	**Participants** Warmtestad (owned by Groningen Municipality) Amsterdam Municipality Rune Nielsen representing Danish municipality	**Participants** Energie samen, VNG, BNG Bank, Fynske Bank	**Participants** Coöperatie Warmtenet Oost Wageningen (WOW), Warm Heeg	**Participants** Warmtestad (owned by Groningen Municipality), Goningen Municipality, Amsterdam Municipality

Figure 2-3 Summary diagram of conducted workshops

2.5 Disclaimer of research method

This research is a case study, comparing cost drivers related to CAPEX in the Netherlands and Denmark. By using a case study approach, it is possible to get a greater understanding of each case and what trends are general or different in the two countries. However, it can be difficult to compare DH projects as no two projects are the same, even if they are in the same country. Even though Denmark is used as a benchmark, CAPEX still varies from project to project. Comparing quantitative data in the form of CAPEX in DH projects between two countries can be even more difficult.

Through this case study it has been difficult to compare average costs in DH projects and to conclude that the average cost in the Netherlands is higher than in Denmark as the amount of data has been limited to few cases. Still, by analysing these cases and the conducted workshops with both Dutch and Danish stakeholders, it has been possible to get a deeper understanding of what causes the differences of CAPEX costs between DH projects in the Netherlands and Denmark.

2.6 Structure of this report

The main goal of this report is to compare and see if there are differences in CAPEX costs for district heating projects in the Netherlands and Denmark and to show the related cost drivers. Furthermore, this report is intended to provide an evidence base to support Dutch district heating stakeholders to create more competitive customer propositions, gain efficiency and facilitate the envisioned growth of the Dutch district heating market.

The rest of the report is structured as follows:

- Section 3 presents the quantitative analysis undertaken in this research, showing a comparison of the different aspects of CAPEX costs in a number of district heating cases in the Netherlands and Denmark.
- Section 4 presents the findings of the qualitative analysis of the workshop discussions, identifying potential cost drivers for CAPEX.
- Finally, Section 5 summarises the key findings of the research and makes recommendations for key stakeholders about opportunities for reducing district heating costs in the future.

To support orientation of the reader throughout the report, the discussion of CAPEX costs and cost drivers in each section is structured around the three themes of heat supply costs, network infrastructure costs, and customer connection costs which were identified as key themes in the workshops.

3. QUANTITATIVE ANALYSIS: COMPARISON OF CAPEX COSTS IN DISTRICT HEATING PROJECTS IN THE NETHERLANDS AND DENMARK

This section presents a quantitative comparison of CAPEX costs across comparable case study district heating projects in the Netherlands and Denmark, discussing the identified reasons for these differences. A main part of the quantitative analysis was presented and discussed at the workshops.

3.1 Description of analysed data

The Danish data sources come from district heating projects that Ramboll has been involved in, in connection with the project development the recent years:

- Key data from Danish district heating projects for heat supply of 2 new building areas and 6 existing residential areas.
- Detailed accounting data from construction work carried out by 2 Danish district heating companies.
- Ramboll's key figures from project tenders and project planning projects (district heating network and production facilities).

The Dutch data sources come from three project cases, which have been grouped into two case studies:

Dutch data sources – case study #1

- District heating network Benedenbuurt, a residential district in the town Wageningen (Figure 3-1): Cost estimate for the Oost-Wageningen heat grid (dated 14-07-2021).
- Heat generation plant Benedenbuurt, Wageningen: Variant 3: Amminia (NH_3) air source compression heat pump with gas boiler backup and heat accumulator (no ATES).

Dutch data sources – case study #2

- WarmteStad cost model – municipality of Groningen.
- Amsterdam district heating project analysis model with cases based on: district heating system with 1,000 multi-family houses (new built) and 10 office buildings up to 5,000 m2 (age from 1920-1950).
- Cost summary for district heating system variants Amsterdam. Identical customer basis as in the model: 1,000 new multi-family houses, 10 office buildings up to 5,000 m2.
- The models/projects have data for the different themes as analysed in this report: infrastructure, heat sources and connections. The Groningen project is used to compare infrastructure costs with Denmark, based on a fictive district heating grid. The Amsterdam case is used for the other themes.

A data aggregation / processing has been performed to make the available material usable for the comparative analysis:

- Detailed cost items from projects have been aggregated and summed up to key values and compared - Danish versus Dutch key values.
- All prices are exclusive VAT and adjusted to 2021 price level.

Note that by choosing price level 2021, the quantitative analysis does not include the sharp price increases that occured during 2021 as a result of the Corona epidemic and intensified in 2022 with the war in Ukraine.

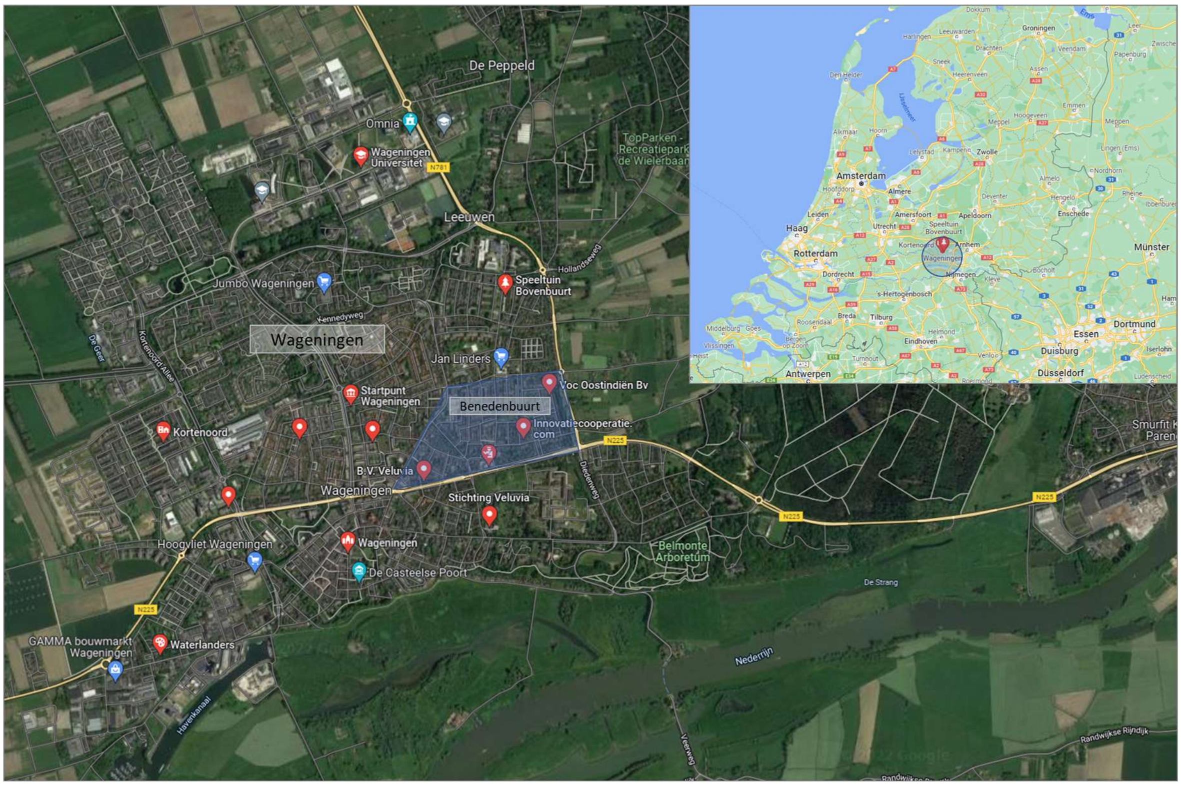


Figure 3-1 Location of Benedenbuurt in the town Wageningen.

3.2 Presentation and analysis of case studies

In this section, the following two Dutch case studies are described and analyzed

1. Case Study #1: Project Benedenbuurt – East Wageningen
2. Case study #2: Project municipalities

They form the basis of workshops 4 and 5 and quantitative analysis.

3.2.1 Case Study #1: Project Benedenbuurt – East Wageningen

3.2.1.1 Project basis

The urban area planned for district heating is an existing residential area from the 1950s, consisting of a total of 490 homes, of which 380 are houses (duplex, detached, terraced) and 110 are apartments. In terms of ownership, it is predominantly privately owned houses but also a proportion of rental housing.

Today, the area is supplied with natural gas with an average annual gas consumption of approx. 1500 m^3 (approx. 15 MWh/year or 54 GJ/year per home). As an urban structure, it may look like a Danish suburban residential area, where conversion from natural gas to district heating is also high on the agenda in these years.

The initiative to get district heating comes from the area's own residents, when the municipality a few years ago announced that the sewer system in the area needed to be replaced. By coordinating the district heating project with the replacement of the sewer system, the idea is to be able to save on the district heating project's construction costs. The existing gas network can also be shut down within the same project framework. However, it requires efficient project coordination, and a collaboration was established between the local resident group and the municipality. Furthermore, different stakeholders and professional developers were involved to assist to mature the project.

A connection level is calculated as shown in Table 3-1. No connection of other buildings in the vicinity is expected, e.g., larger public or commercial buildings that could benefit the project's finances.

Table 3-1 The planned customer connection level for project Benedenbuurt

Type	Number of connections
Apartments	108
duplex	18
terraced houses	16
2 under 1 hoods	296
Detached houses	6
Total	**444**

At the project's current planning stage, the residents' group has completed a feasibility study, has generally chosen the technical setup, and has asked a professional consultancy firm for an offer for the construction of the district heating project. The planned technical-financial framework of the project is described below.

3.2.1.2 Heat production plant

Technical description

As a heat production plant for the district heating project, an approx. 1 MW ammonia (NH_3) air-water heat pump had been chosen as the base load and with the gas boiler system as the peak load and backup. See Table 3-2. The heat pump is designed in 2 steps to reach the design supply temperature of 75ºC. The estimated efficiency of the HP is SPF[11] = 2.95. Other possibilities for heat production plants have also been investigated, including the use of ATES (Aquifer Thermal Energy Storage), biomass and connection to a larger district heating system in the vicinity.

Table 3-2 Technical key figures for Project Benedenbuurt heat production plant

Benedenbuurt Wageningen DH Heat production	Peak MW	Load factor H	Production GJ/year
DH System ΔT= 70/40 ºC, T max 75ºC	1.76		19,000
Ammonia air/water HP (coverage 86-90%)	0.84	3,000	16,720
Gas boiler (capacity 100%, coverage 10-14%)	1.76	5,500	2,280

**) HP is designed for around 1 MW, but at winter peak the HP has reduced capacity.*

[11] Seasonal Performance Factor (SPF) of Heat Pumps also named Seasonal Coefficient of Performance (SCOP).

The selected heat production plant (heat pump system with gas boiler backup) is technically comparable with similar Danish projects. See assumed load distribution on Figure 3-2 (source: workshop). This figure shows the number of hours in a year that a certain load is used. On the left-side of the figure the high loads are shown, this is mostly during the winter. At the right-side of the figure the low loads are shown, this is mostly during the summer. A challenge - environmentally and politically - is the choice of the natural gas boiler as backup, but there are no obvious alternatives. An electric boiler with a larger heat accumulator might be possible as an alternative if the boiler could also produce cheap heat in (sufficiently long) periods with cheap electricity in the public grid system.

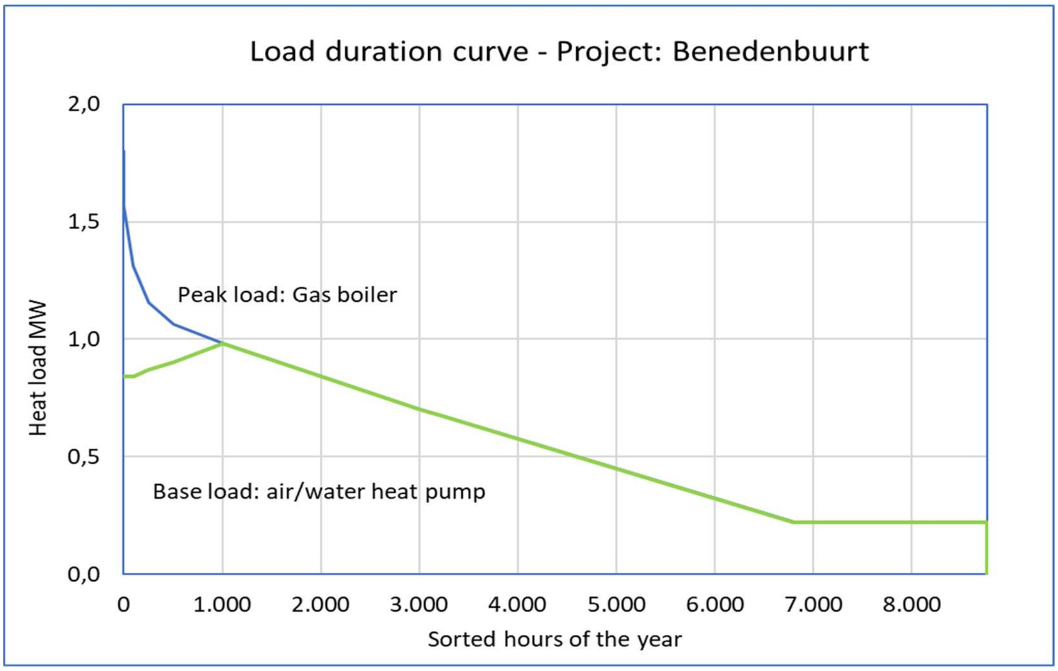


Figure 3-2 Assumed load duration curve for Project Benedenbuurt (source: workshop).

Economic assessment

Aggregated data on CAPEX costs per kW for 10 smaller ammonia air/water 2 step heat pump projects (below 3 MW heat) in which Ramboll has been involved, are shown in Figure 3-3. It shows a large cost variation, but with planned cost mostly within a range of 1,300-1,600 EUR / kW. If a gas boiler plant is added as peak and full reserve, the total turnkey plant project from scratch in Denmark can be estimated to approx. 2,100-2,400 EUR / kW. Thus, the Benedenbuurt heat production plant should in Denmark cost 2.1-2.4 MEUR. The Dutch cost estimate is 2.24 MEUR, which corresponds well to what a similar turnkey plant would cost in Denmark.

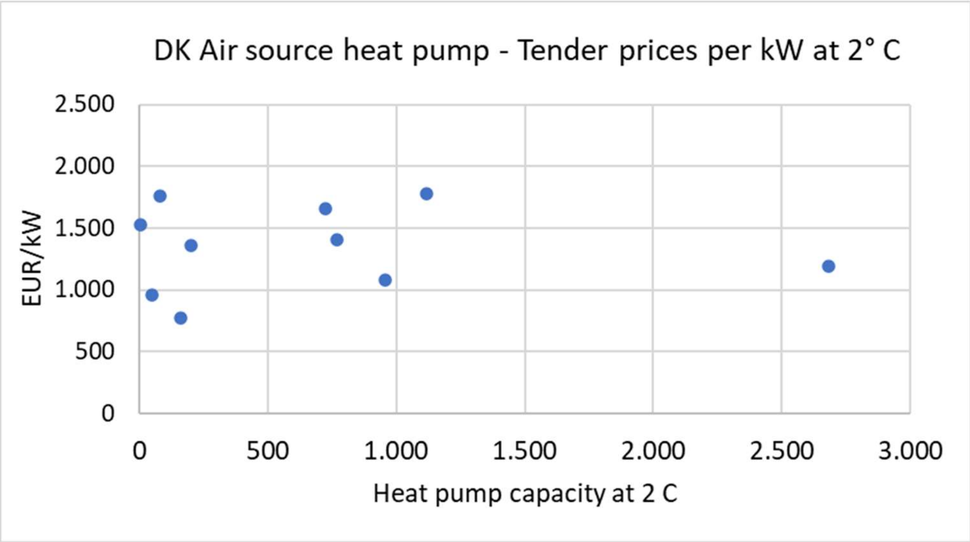


Figure 3-3 Danish Ammonia (NH3) air/water HP construction cost (source: Ramboll)

3.2.1.3 District heating distribution network

Technical description

The district heating network's technical design framework is summarized in Table 3-3. This corresponds well to a Danish design of a district heating network. A good CAPEX comparison with a similar Danish construction project is therefore assumed to be possible.

However, according to received information the construction/work conditions include:

- The construction of the heat pipelines will run in parallel with the construction of the municipal sewage system and reorganization of the topsoil. The costs do not include a delay in the construction of the heat network due to sewage work.
- Traffic measures by municipality of Wageningen, during construction.
- Removal and replacement of street furniture by the municipality of Wageningen.

Such conditions are theoretically unusually favorable and are something that is only very rarely seen in Denmark. However, it is Danish experience that it requires very effective planning to in practice take economic advantage of such synergies between different construction projects. But assuming a successful planning and coordination, the cost of the heat distribution infrastructure must be expected to be significantly lower than the costs for a similar network in Denmark.

Table 3-3 Technical design of the planned Benedenbuurt DH network

Network design basis - Project: Benedenbuurt, East Wageningen	
System type	Bonded pre-insulated pipe system
Diameter heat pipe:	DN20 to DN400
Pipe insulation class:	3
Design temperature:	85°C (95°C)
Design pressure:	6-10 bar
Standardization:	EN13941
Standard material:	Steel-PUR-PE - single pipe
Standard execution method	Open trench or drilling

Economic assessment
The technical-economic key figures of the planned district heating network based on the Dutch project developer's estimates are summarized in Table 3-4, and compared with typical Danish cost levels in Table 3-5.

Overall, construction costs are at the high end, the subtotal construction is similar to a Danish level, however a large part of the costs - such as reconstruction of the road top - are not included gin the Dutch numbers, as it is taken on by the municipality, but included in the Danish numbers.

The material costs seem to be similar, and the limited construction work are assessed to be within the expected level that it would cost in a Danish context in the suburbs near a large city.

The reason why the total construction costs nevertheless are relatively high seems to be due to the additional costs that are added to the total project costs, and which include:

- Other non-recurring costs: 4%
- Implementation costs: 8%
- General expenses: 10%
- Profit and risk: 4%

Table 3-4 Technical-economic key figures of the planned Benedenbuurt DH network

Project: Benedenbuurt	Value	Unit	1000 EUR	EUR/conn	EUR/m*	Share
Misc. construction	40	M	98	283		4%
Digging trench	4,195	M	88	255		4%
Laying pipes	4,225	M	178	514		7%
Sleeves & sockets	1,252	pcs	71	206		3%
House connections	3,014	M	211	610		8%
House throughputs	346	pcs	415	1,200		17%
Audit, control etc.			111	320		4%
Subtotal construction			**1,172**	**3,388**	**162**	**47%**
Material and delivery			782	2,261	107	31%
General project costs			542	1,565	74	22%
Total construction costs	**7,239**	**M**	**2,496**	**7,214**	**345**	**100%**
Contingencies 10%			250	721	34	
Total incl. contingencies	**7,239**	**M**	**2,746**	**7,935**	**379**	**110%**

*EUR/m = costs per meter of pipe

Table 3-5 Technical-economic key figures compared to typical Danish cost share.

Cost group	Danish typical share			Benedenbuurt	
	Low	Middle	High	Share	1000 EUR
Construction costs					
Materials/pipes	19%	15%	13%	31%	782
Excavation+pipe works	55%	55%	55%	47%	1,172
Top reconstruction	13%	17%	19%		
Sum construction part	87%	87%	87%	78%	1,954
Overall costs					
Design	2%	2%	2%		
Consultancy	4%	4%	4%		
Other/Inhouse costs	8%	8%	8%	22%	542
Sum additional	13%	13%	13%	22%	542
Total before contingencies	100%	100%	100%	100%	2.496
Contingencies 10%	10%	10%	10%	10%	250

In a Danish project context, the general additional costs (including risk) will typically be around half of the costs in the Benedenbuurt project. The high costs in the Dutch projectis assumed to be because a considered high front-end risks, resulting from adding risk on risk on risk. In a well-planned Danish project, a professional district heating company will handle the start-up framework and defines the construction work precisely in the tender material, so that the project's contract holder can save/reduce on these risk-related costs.

3.2.2 Case study #2: Project municipalities

3.2.2.1 Project basis

This project assessment is based on the Amsterdam district heating project analysis model with a project case consisting of developing a district heating system to supply heat to 1,000 new multi-family houses together with 10 office buildings of up to 5,000 m2 (1920-1950). Thus, as a model the case is not as realistic as the Wageningen case. Furthermore, as the project is mostly to be regarded as a case study, there may be risks and cost elements that are not fully described and therefore may have significant uncertainty.

In the assessment the Amsterdam district heating project analysis model is used together with the WarmteStad cost model (from Groningen municipality), which in detail corresponds to the contractors' tender lists when tendering for projects.

The project is characterized by containing both a heat supply part and a cooling part: it is planned that the same energy system will supply the building with both comfort heating (space heating and domestic hot water) and comfort cooling in the summer. Combined heat and cooling production is generally the most cost-effective way to use a heat pump as a production plant. The technical setup is shown in the table below for four different designs of the heat production.

Table 3-6 Assumed technical setup for the Amsterdam case study

Amsterdam Model	Heat supply							Cooling supply		
Unit: MWh th / MWh e	SH	HTW	Net	Loss	Gross	Elec	SPF	Net	Elec	SFP
B: ATES + Dry cooler MT	2,167	1,414	3,581	26%	4,811	2,247	2.14	639	121	5,3
C: ATES + TEO MT	2,167	1,414	3,581	26%	4,811	2,083	2.31	639	113	5,7
D: Datacentre (30°) MT	2,167	1,414	3,581	26%	4,811	1,387	3.47	639	213	3,0
E: Stadswarmte (70°)	2,167	1,414	3,581	26%	4,811			639	213	3,0

Note: SH= Space heating, HTW =Hot tap water, Elec = Electricity consumption

An overall assessment of the construction costs extracted from the Amsterdam model and converted to the construction costs per consumer is shown in Table 3-7. It can be seen from the table that since gas was otherwise planned for use in cooking, a cost is included to convert the gas to electricity.

Table 3-7 Assessed construction costs per customer

Amsterdam Model EUR ex VAT/customer	Central	Network	Customer*)	Sum	Cooking adjustment	Total
B: ATES + Dry cooler MT	3,127	5,132	2,025	10,285	2,160	12,445
C: ATES + TEO MT	3,428	6,570	2,025	12,023	2,160	14,183
D: Datacenter (30°) MT	6,609	7,111	2,025	15,745	2,160	17,905
E: Stadswarmte (70°)	0	12,190	2,025	14,215	2,160	16,375

**) Exclusive cooking adjustment*

3.2.2.2 Heat production plant

Among the alternatives, an ATES system with dry cooler or alternatively with TEO[12] has been chosen. ATES is applied to provide heating and cooling to the buildings. The system operates in a seasonal mode where storage and recovery of thermal energy is achieved by extraction and injection of groundwater from aquifers using groundwater wells.

There are no similar ATES systems for the supply of new homes in Denmark that can be used for a comparison. Therefore, the table below sets out the construction costs for the choice of alternative heat production plants with the purpose of assessing whether the choice of technology in terms of cost level is reasonable based on Danish plant price experience, as the Danish technology catalog from DEA is used as the equivalent Danish plant price basis.

It can be seen from

[12] TEO = Dutch: Thermische Energie uit Oppervlaktewater = Thermal energy from surface water with the purpose to use a lake, canal or river to increase the heat amount stored in the warm well of the ATES.

Table 3-8 that the specific costs for ATES, as expected, are between the Danish costs of an ammonia electric air / water heat pump system and an ammonia ground water heat pump with 1.2 km boreholes.

Table 3-8 Assumed technical-economic key figures for the Amsterdam case study

	Unit	Danish heat production plants				Amsterdam	
		Wood chips boiler w/ absorp-HP	NH_3 electric Air/water heat pump	NH_3 Ground water HP 1,2 km (lime)	Electric boiler w/tank	B: ATES + Drycooler	C: ATES +TEO
CAPEX	MEUR					3.2	3.5
Capacity	MW					1.6	1.6
Specific CAPEX	EUR/kWth	840	1,340	2,650	210	1,970	2,160
Technical life	year	30	25	25	30	30	30
Load factor	h	5,000	5,000	5,000	1,400	3,000	3,000
Cost per energy supplied	EUR/MWh	7.5	13.7	27.1	6.7	29.3	32.1
Annual efficiency		120%	3.40	4.00	100%	2.14	2.31

On the other hand, there is an interesting observation linked to the size of the plant and thus to the load duration factor, which impacts the cost of capital as part of the total operating costs. The ATES system appears to be oversized on the heat supply side, as the load duration factor is estimated at around 3,000 hours, where a load duration factor of at least 5,000-5,500 hours is recommended based on a Danish rule of thumb, since an ATES system must be regarded as a base load plant. A base load plant typically covers 80-90 % of the demand of a year.

However, the oversizing must be seen in the light of the following: The ATES system's heat pump is dimensioned for the cooling demand, and for the highly insulated new residential buildings, the heat demand is so limited that the heat pump's corresponding heat capacity becomes too large. But consequently, the conclusion is that the costs per energy supplied are higher for the Amsterdam case than for comparable Danish cases. Note that with lower full load hours, the cost per energy supplied would also increase for Danish heat pumps. In this comparison the different numbers are used, because different designs were used for the district heating systems.

3.2.2.3 Distribution network

Technical description

In the Amsterdam project, a pipe pair network with insulation class 1 is assumed. The insulation of district heating pipes is standardized in classes (also called series). The lower the class, the less insulation but cheaper pipe. The insulation classes 1 to 3 (or Series 1 to 3), which are defined in the European norm EN 253, is the most common in district heating, where insulation class 1 with the lowest insulation layer results in a relatively high heat loss in the district heating distribution network (26% in the Amsterdam project according to Table 3-6), but can result in cheaper construction costs due to lower pipe prices and less excavation work.

If twin pipes with insulation class 3 are chosen instead, it is assessed that this construction costs would be higher, as shown in Table 3-9. Instead the distribution heat losses will be lowered to the half (see Table 3-13), which will improve the overall system efficiency in a positive direction. But as the table shows, the Danish experience is that the total construction costs depend significantly on the project size, as large project volumes provide construction savings both in the pipe procurement and in the construction work.

It should be noted that prices from the WarmteStad model are default values for model use, and in practice there can be a price variation depending on the often significant discounts that are usually negotiated between manufacturer and buyer. It is likely that the prices or negotiation of prices is more established in Denmark, because the market is more mature, which is likely leading to lower prices. Large discounts are particularly dominant in the Danish market for pipes, which may be due to a mature market with high competition.

Table 3-9 Assumed total costs of different pipe systems

DN	Single insulation class 1		Single insulation class 3		Twin insulation class 3	
	Warmte Stad *)	Denmark		Denmark		Denmark	
	EUR/m	Smaller EUR/m	Larger EUR/m	Smaller EUR/m	Larger EUR/m	Smaller EUR/m	Larger EUR/m
25	21	19	11	25	15	23	14
32	17	23	14	31	19	27	16
40	18	25	15	33	20	28	17
50	21	30	18	40	24	37	22
65	25	34	20	45	27	43	26
80	29	43	26	56	34	53	32
100	38	59	36	78	47	79	47
125	46	70	42	93	56	111	67
150	56	86	52	114	68	131	74
200	80	123	74	163	98		

Note: Variation in Danish costs are related to smaller or larger projects. (DN = diameter of the pipe in mm)

Economic assessment

As the default district heating network design – and therefore also the construction costs - is considered to be too simply described in the Amsterdam model, a model calculation has been made instead, where a similar Danish pipeline project has been used as input to the WarmteStad (Groningen) cost model. The construction costs can be considered as too simply described because the network design in the model has only one pipe dimension in the primary and the secondary network. This cannot be used for construction cost assessment. The result of this calculation is shown in Table 3-10.

As the table shows, the comparison uncovers some notable differences between a Danish and a Dutch pipeline project, with the construction costs of the Warmtestad model generally on the high side of Danish projects:

- The general project costs are much higher in the Warmtestad case, than is usual in Denmark. This indicates that the Dutch project is assessed to have a high risk including several uncertainty factors.
- Top reconstruction, especially asphalt work, is extraordinarily high in the Dutch project, which can be attributed to regulatory requirements, as asphalt contains environmentally harmful substances (tar, oil and heavy metals) that may require special precautions.

Consequently, the total costs of infrastructure are higher in Warmtestad (Groningen) than in Denmark. The construction costs of Warmtestad is in general comparable with Danish high cost level, where actually it is expected be comparable with Danish mid cost level, because of the similar context of the Groningen and Danish mid cases.

As emphasized in the report's introduction, it should be noted that when generalizing based on one project comparison, the conclusions must be taken with caution.

Table 3-10 Economic key figures extracted by using the WarmteStad cost model

Construction costs	DK cost	Equal project cases		
Unit: 1000 EUR ex VAT	**variation**	**DK High**	**DK Mid**	**WarmteStad**
Construction costs				
General	8-12%	583	510	395
Excavation	47-54%	2,741	2,485	2,644
Piping	11-14%	666	599	432
Welding mounting	6-12%	319	351	513
Pipe work control	2-3%	146	127	176
Top reconstruction	8-20%	1,104	861	1,549
Others	2-4%	236	184	60
Sum construction	100%	5,794	5,118	5,769
Materials		421	421	431
General project costs		575	512	1,038
Material surcharge *)				17
Wage supplement				408
Unforeseen contractor costs		679	605	681
Totals		**7,469**	**6,655**	**8,345**

3.3 Differences impacting CAPEX

In connection with cost drivers, a number of characteristics have been observed from the quantitative analysis of two case studies, which are assumed to represent a general trend for Dutch district heating systems. The observed characteristics are discussed further in this chapter, based upon additional evidence and perspectives gathered from the stakeholder workshops.

3.3.1 The high general costs in Dutch projects

We have observed from the cases that the contractors make up a large share of the general costs. This indicates that the contractors assess that there is a high risk in the construction project. On the bottom line, it results in construction costs being at a high level compared to similar Danish projects - assuming that the construction works are basically the same (digging a hole, laying a pipe and covering it up, and reconstructing the surface).

The workshop discussions indicated that the high general costs may be a sign that the construction project deals with a number of challenges, which include:

- The tendered contract is unclear and the work tasks are not well defined, which e.g. may be due to limited experience / knowledge with district heating projects.
- There may be insufficient information available about other underground infrastructure, areas with contaminated soil, high groundwater, etc.

- Best practices may not be utilized which may also impact the general costs in organising the construction works. In other words, laying techniques for district heating pipes may be more incorporated/developed without significant uncertainties in Denmark, especially in connection with the use of twin pipes, which in recent decades have been shown to have great potential for construction cost savings.

However, the workshop discussions also indicated that a particular element could have an impact: The high risk level may be a pre-work misjudgement by the contractor, and an efficient risk management and mitigation plan should make it possible to reduce the general costs, when the final bottom line of the project is determined after work has been completed.

3.3.2 Differences in need for production capacity

The quantitative comparison of CAPEX has drawn attention to assumed differences in the investment in production capacity in Denmark and the Netherlands when expanding district heating.

When expanding district heating networks in Denmark, it will often not be necessary to build new heat production capacity, as there is already sufficient existing capacity available. This is due to that production capacity has been installed continuously over time, because it has provided a financial benefit for consumers and thereby lower heat prices. The result today is that there is a widespread diversity of heat production plants even in smaller Danish district heating systems, but also that there is plenty of available capacity. (Estimates by Ramboll from the national heat production register thus show the total available heat capacity in Danish district heating is twice the total peak load demand. To this can be added the extensive short-term capacity provided by heat storages, which basically exist in almost all Danish district heating systems. The reason for this overcapacity is that the district heating companies prepare for future expansion of the network and also installs back-up capacity in case one of their units breaks down or is out for maintenance. This overcapacity is part of ensuring a high security of supply).

Despite ample heat capacity, the Danish district heating company still may choose to invest in new capacity. This is because an opportunity for an economic benefit is being assessed, typically if the marginal variable heating price when expanding is going to be undesirable high. It is strictly speaking not a necessary investment in new capacity, but to avoid too much of expensive heat production from existing peak load plants.

Thus, when expanding a Danish district heating system it is rare that there is a lack of heat capacity. But if this is the case, there will not only be a focus on providing peak load capacity to ensure the necessary security of supply, but also on investing in base load capacity that can keep the marginal heat production price low. In that way an expansion can provide an opportunity for a new base load plant to obtain a large annual utilization and thereby be economically attractive. Base load units often have higher CAPEX and lower OPEX, meaning that once they are in place, they can supply heat at a lower price. They also need to run at many full load hours for the investment to be beneficial. The opposite is relevant if peak load capacities are required. These units are less expensive to invest in, but have higher OPEX costs. (This is also a consequence of the Danish socio-economic calculation method, where it is the marginal price of district heating at the expansion that must be compared with a reference with individual heat production solutions). Only if a completely new district heating system is established, there will be a need to invest massively in new production capacity.

In contrast, Dutch district heating systems typically consist of fewer heat production plants, and when expanding existing district heating systems, it will much more often be necessary to invest in new heat production capacity, simply because there will be lack of capacity to ensure the required security of supply. In the Netherlands, there is also a general desire to establish new district heating systems in many new urban areas, which necessitates massive investments in new production capacity, while it is limited how many new district heating systems that will be established in Denmark, as district heating is already widespread throughout the country.

In Table 3-11, the alternatives described above to ensure production capacity by expansion of district heating are grouped into 4 action options. In Danish district heating systems, actions 1 and 2 will most often be chosen, where there will be no/limited burdensome CAPEX in new production capacity, while it is estimated that Dutch district heating systems more often will face actions 3 and 4, where CAPEX for new production capacity is considered a financial burden for the district heating project. The greater diversity in Danish district heating systems contributes to creating this difference, but also methods to focus on the marginal heat price during expansion can be recommended to make CAPEX in production capacity less burdensome in Dutch systems.

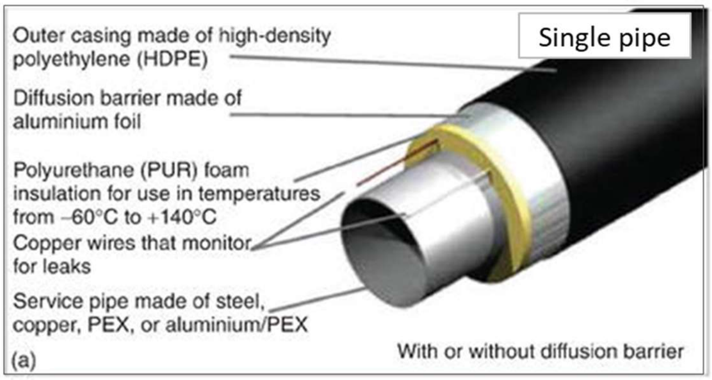
Table 3-11 Investment alternatives in new heat production capacity

Project type	Heat capacity to ensure adequate security of supply	Action option	Coverage of the new heat demand	Investment in new heat capacity
Expansion of existing district heating system	Existing capacity Sufficient	1	Utilisation of existing capacity	No need to invest in new capacity
		2	Supplement by new base load capacity	Investment to keep the marginal heat price low
	Existing capacity not sufficient	3	Supplement by new peak load capacity	Investment to ensure adequate security of supply
		2	Supplement by new base load capacity	Investment also to keep the marginal heat price low
New district heating system	No existing capacity	4	By new capacity	Massive investment in new capacity

3.3.3 General distribution network assessment

In the Dutch cases that are analysed in previous chapters, the chosen distribution pipe system is two single pipes (one pipe for heat supply and one return pipe). This choice of pipe system seems to be prevailing in the Netherlands. Furthermore, insulation class 1 has been chosen in the case from Amsterdam indicating a common trend to use a low insulation class to save pipe costs.

In the last decade, Danish DH companies have largely abandoned two single pipes and switched to a new system called double pipes or twin pipes that integrates the supply and return lines within one casing. The new system can be selected up to dimension DN150. For larger dimensions, the pipes are too rigid to be usable, unless a long straight pipeline is required. Both single and twin pipes are categorized in classes or series (usual 1, 2, or 3) depending on the insulation thickness.



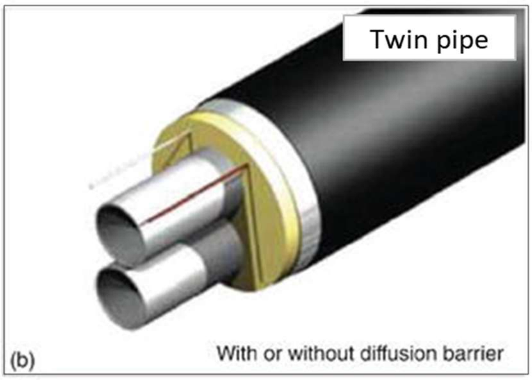


Figure 3-4 Branching of side pipes for single pipes and twin pipes, respectively
Source: standard vendor information

The shift to twin pipes is believed to have resulted in an improved efficiency in Danish construction works. Thus, the advantages of twin pipes are:

- the channel widths become smaller as illustrated in
- Table 3-12, which reduce the excavation works and is suitable in narrow streets and other places with limited space.
- pipe branches can be made at the same laying level, which reduces the digging depth.
- besides less soil has to be dug up, the surface area to be restored becomes smaller.
- twin pipes have significantly fewer joints / sleeves, and thereby less welding work.

This has contributed to the fact that Danish network construction prices have generally been unchanged in the decade before 2020-21, despite a general price increase in the economy.

It was mentioned at the workshops that both in Groningen and Wageningen analysis have been made whether twin pipes could be used, but they were found too expensive. This cost barrier is likely due to limited experience with twin pipes in the Netherlands. It is assumed that a threshold in sales volume and contractor experience has to be exceeded, before the economic benefits can unfold like in Denmark.

Table 3-12 Comparison of trench width between single pipes (pipe pair) and twin pipes

Dim	Minimum trench width using vertical walls [mm]					
	Pipe pair			Twin pipes		
	Serie 1	Serie 2	Serie 3	Serie 1	Serie 2	Serie 3
DN20	530	570	600	325	340	360
DN25	530	570	600	340	360	380
DN32	570	600	630	360	380	425
DN40	570	600	630	360	380	425
DN50	600	630	670	400	425	450
DN65	630	670	710	525	550	550
DN80	670	710	800	550	580	655
DN100	900	950	1,000	715	755	850
DN125	950	1,000	1,060	800	850	900
DN150	1,150	1,210	1,360	850	900	900
DN200	1,280	1,360	1,550			

In addition to the construction benefits, the twin pipes system has made it possible to reduce the distribution heat losses significantly. The relatively high heat losses in the district heating distribution systems is an issue that is often criticized. To reduce heat loss, two measures are used: Pipes and in particular twin pipes with more insulation (higher insulation class) are selected, and the operating temperature is lowered as much as possible, without violating customers' comfort requirements, including requirements for the hot tap water temperature.

In Denmark, twin pipes are chosen with at least insulation class 2, and most often insulation class 3. However, it can be questioned whether a high insulation class is needed if low-temperature district heating systems are being more common, i.e. where the heat supply temperature is below 55-60 ºC, which is the lower limit for producing hot tap water directly from district heating according to norms and comfort requirements. This is illustrated in more detail in Table 3-13 where the pipe heat losses are shown as a function of isolation class (series) and system temperature level. In addition to the fact that twin pipes significantly reduce the heat loss compared to two single pipes, the table shows that heat loss will also be low even without a high level of insulation, if low-temperature district heating is chosen.

Table 3-13 Pipe heat losses as a function of isolation class (series) and system temperature level

Pipe dimension DN40	Heat loss Factor W/mK	Water temperature T supply °C	T return °C	Annual heat loss kWh/m
Twin Pipe Series 1 (MT)	0.22	70	40	87
Twin Pipe Series 2 (MT)	0.18	70	40	73
Twin Pipe Series 3 (MT)	0.16	70	40	64
Pipe Pair Series 1 (MT)	0.32	70	40	125
Pipe Pair Series 2 (MT)	0.27	70	40	108
Pipe Pair Series 3 (MT)	0.24	70	40	97
Pipe Pair Series 0 (LT)	0.40	40	20	70
Pipe Pair Series 1 (LT)	0.36	40	20	63

Source: Logstor Calculator Model for insulation on pipes

However, it must be emphasized that the market share for low-temperature DH systems is very limited in Denmark. The all-dominating system in Denmark is today the mid-temperature level of 70/40 °C which has the advantages of simplicity:

- It can cover both new buildings and almost all older buildings, and the temperature level in adjacent new urban areas can be lowered to e.g. 60/25 °C using a simple shunt arrangement.
- Hot tap water can be produced directly without installing an individual booster heat pump.
- Both high-temperature heat sources and low-temperature heat sources combined with heat pump can be exploited in the same system.

These advantages are obvious when it comes to expanding existing mid-temperature district heating networks. However, when constructing completely new district heating systems from scratch, which is high on the agenda in the Netherlands, a technical-economic assessment of the alternative with a low-temperature network should always be made, especially if the dominant heat source also has a low temperature, or has the highest efficiency at low temperatures.

3.3.4 General customer cost assessment

Customer costs were discussed at the workshops. The topic is complex both in Denmark and the Netherlands, as connection costs can include various elements, depending on each district heating company's current connection tariffs, on the house type, and on the existing in-house heating installations.

Below principles for connection costs based on Danish best practice are presented and compared with Dutch cases. Thus, the customers connection costs can be divided into three levels:

1. Connection payment to the district heating company is in Denmark often based on the principle that other customers should not be burdened financially when connecting a new consumer. Thus, the new customer must pay for the branch line plus contribute to system costs due to an increased load on the district heating system. But since all the customers of a district heating company benefit from obtaining as high a connection level as possible, some Danish district heating companies also offer free connection (or a symbolic low connection fee), but often only during campaign periods where the contractor is laying pipe in the local street.

   The dominant cost element is the cost of the branch line (service pipe), which depends heavily on its length. In a Danish residential area with one-family houses, long service pipes of about 15-20 m from the street pipe to the house can contribute significantly to the total construction costs and may impact the connection payment depending on the connection tariff structure. Focusing on minimizing especially this cost element is important. This can be achieved in particular by aiming for as many connections as possible - and thereby lower cost per connection - at the moment when the contractor is laying pipe in the local street.

2. Payment for the customer’s heat substation unit for delivering space heating and producing hot tap water (HTW). As international products under EN standards, materials /equipment are assumed to cost the same, but the actual cost of a heat substation unit seems to be different due to differences in standards/comfort requirements in Denmark and the Netherlands. It seems that standards with very high performance or comfort requirements on the Danish heat substation units make them relatively more expensive (10-20%) in general than a similar Dutch one. This difference is observed for small one-family units, while the costs in the Netherlands and Denmark are assumed to approach each other for larger customer units.

3. Cost of inhouse refurbishment. Here, the costs in Denmark are considered to be much lower than in the Netherlands, as Danish houses usually have a utility room where the gas boiler is installed and can be relatively easily replaced with a heat substation unit without additional refurbishment costs. In the Netherlands, on the other hand, the existing gas boiler is often located in different places in the house, often in the attic. Furthermore, gas is also often used for cooking. When converting to district heating, there can therefore be some additional costs for Dutch house owners for both new pipes and installations, both inhouse and on walls that are not common in Denmark.

As for the customer heat substation unit, the building owner can buy it, rent it or lease it - when leasing, service is included in the total cost. These options are the same in Denmark and the Netherlands. But in Denmark, the financing by renting / leasing can be based on the district heating company's favourable loan options including a municipal guarantee, which benefits the consumer that may not be able to raise a loan on the same favourable conditions.

Figure 3-5[13] shows the typical Danish costs at the customer level for converting a single-family house to district heating.

As shown on Figure 3-5, the typical total replacement item cost will reach 4,000-5,000 EUR incl. Danish VAT of 25%, as the costs are typically only related to the replacement of the existing gas or oil boiler. Alternatively, all costs can be included in a substation lease contract of typically around 350-500 EUR per year incl. VAT, inclusive full service of the customer unit. Note that behind the payment is financing on favorable terms, here shown as a 2% loan over 25 years.

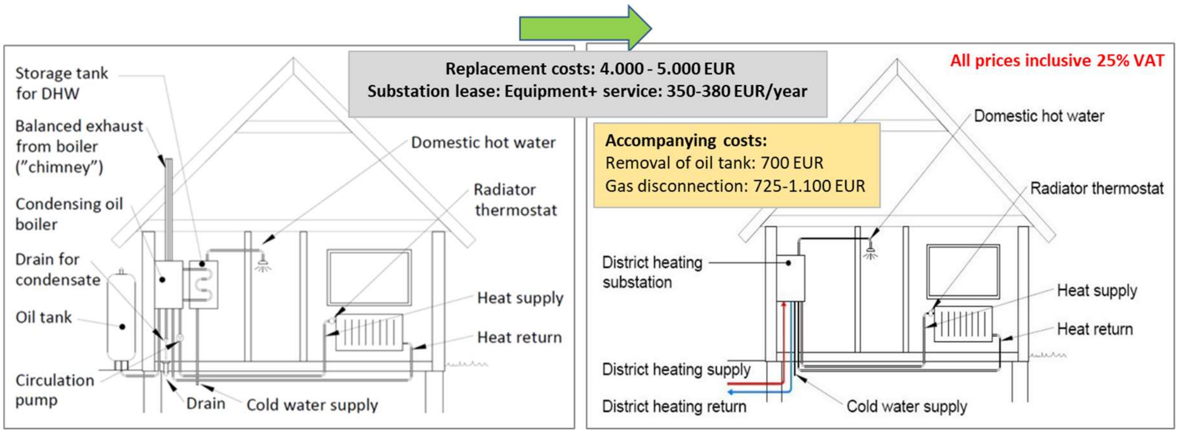


Figure 3-5 Heat substation cost

3.4 Summary of the quantitative assessment

The CAPEX elements for the two analysed Dutch case studies have been compared with examples from Danish district heating projects, and this quantitative analysis have revealed a number of significant cost differences that have been described. Below the results are summarized in three groups: heat capacity costs, heat distribution network cost, and customer connection costs:

Heat production capacity costs

District heating in Denmark typically expands on the basis of existing district heating systems, where there is often already sufficient heat production capacity for the expansion due to a high diversity of sources. If new capacity is established, it is usually not because of a lack of capacity, but because it is possible to install a new base load plant with the purpose of keeping the marginal heat price down.

The Dutch cases indicate a difference from the common Danish conditions. Dutch district heating systems typically consist of fewer heat production plants, which is an assumption backed by the Dutch cases used in this project as well as the discussions made in the workshops in this project. It is assumed more often to be necessary to invest in new heat production capacity, simply because there will be lack of capacity to ensure the required security of supply.

Furthermore, in the Netherlands, there is a bigger necessity than in Denmark to establish new district heating systems from scratch. In Denmark it is limited how many new district heating systems will be established, as district heating is already widespread throughout the country. Consequently, this necessitates investments in new production capacity in the Netherlands, which are not necessary in Denmark.

[13] Source: Ramböll

The construction cost level for production plants per thermal MW does not appear to be significantly different from Danish experience. However, the specific plant cost must also be seen in the light of how many full load operation hours can be achieved on the new plant, as a high number of operation hours is an indicator for an energy efficient investment that can contribute to keep the total district heating expenses down. Furthermore, the cost per MWh produced differs significantly per heat source. In Denmark cheap sources are the main providers of heat, e.g. biomass and residual heating. By diversifying their heat source portfolio, Danish district heating is able to choose the cheapest source at each moment.

For project Benedenbuurt the investment in new heat production capacity is significant. However, the investment is also being made with the possibility of making comfort cooling utilising the heat pump for cooling production to the extent that there is a demand for establishing a cooling system in the buildings. Using a heat pump for both heating and cooling and thereby maximising the operation hours of the new asset is an example of an energy efficient investment.

Heat distribution network costs

The analysis of the Dutch case studies regarding the costs of establishing a district heating distribution system has uncovered especially two significant cost elements that pull the total costs up to a very high level compared to typical Danish projects:

1. A large share of the general costs
2. Relatively high construction costs

Re 1: The Dutch general costs seem to be twice the Danish general costs, which indicates that Dutch contractors find significant risks and uncertainties in this type of projects. These risks may be associated with various elements of the implementation process, including the design of the contract, regulatory requirements and cooperation with authorities, and planning the construction work. It calls for a closer study of risk identification and risk mitigation.

Re 2: It is Danish experience that the change from single pipe pairs to twin pipes has contributed to the Danish network construction prices being generally unchanged in the decade before 2020-21, despite the general price increase in society. In other words: If Danish contractors had continued with single pipe systems, the construction costs would have been significantly higher. It can therefore be recommended that Dutch DH projects also switch to twin pipes to bring down the generally high cost level.

Note for both points that these were established in the two case studies, but are also supported by the work sessions which are discussed in more detail in Chapter 4.

Dutch assessments, however, are that twin pipes appear too expensive. It is the assessment that this cost barrier is due to limited experience with double pipes in the Netherlands. A threshold in sales volume and entrepreneurial experience must apparently be exceeded before the economic benefits can unfold as in Denmark.

Customer connection costs

The upfront costs for the heat consumers to connect district heating point in different directions:

The customer heat substation units seem to be more expensive in Denmark than in the Netherlands due to national Danish standards with very high performance or comfort requirements - at least for the smallest sizes of heat substation units for single-family homes.

Conversely, costs for in-house renovation in Denmark are estimated to be much lower than in the Netherlands, as Danish houses usually have a utility room, where the gas boiler is installed and can relatively easily be replaced by a heat substation unit without additional repair costs. In the Netherlands, on the other hand, the existing gas boiler can be located in different places in the house, often in the attic, which complicates the installation works.

The quantitative analysis has indicated that it is difficult to assess what the actual total cost is for the property owner, when converting from gas to district heating. This may well reflect a general challenge to present proper economic transparency to future customers and other stakeholders. As is also the case in Denmark, a distinction is made between what the district heating company assumes to cover of initial costs (costs which, however, are paid by the consumers over time through the tariffs), and what the new customer pays upfront/upon connection.

It can be added that the possibility for the district heating company to offer favorable loans to finance selected upfront costs for their new customers has in Denmark proved to be an effective means of achieving a high connection level.

In the Netherlands there is attention to lower the costs of connecting customers. A document has been written by the market ("Ambitiedocument voor haalbare warmtenetten" – "Ambition document for feasible district heating grid")[14], in which solutions to lower connection costs are worked out in four themes: improving cooperation; limiting risk of lack of connections; reduction of costs; and optimization of financing conditions.

[14] 220616-AL-Ambitiedocument-voor-haalbare-warmtenetten.pdf (warmtenetwerk.nl)

4. QUALITATIVE ANALYSIS: COST DRIVERS OF DISTRICT HEATING CAPEX COSTS

This section presents additional qualitative findings from the analysis of the five workshops. The workshop discussions were tailored to the specific experience and knowledge base of each group of actors but consistently structured around the three key elements of district heating systems: heat production, heat distribution and customer connection. CAPEX costs were considered within discussions both as direct material and construction costs of the network infrastructure (and the influence of system design), but also as the indirect costs of purchasing heat to supply the network and the influence of administration, operation and maintenance decisions over the resulting CAPEX costs. A thematic analysis of the workshop discussions is presented in the following sections.

4.1 Key cost drivers identified from qualitative analysis of the workshop data

The following sections present the findings from the qualitative thematic analysis of the workshop data, identifying cost drivers relating to the business models of district heating companies (section 4.1.1); the financing of projects (section 4.1.2) and the role and capacities of municipalities (section 4.1.3).

4.1.1 Business models of district heating companies

For DH markets in the Netherlands, there were five types of DH company business models discussed by the workshop participants:

- Traditional large utilities,
- Joint ventures between large utilities and local municipalities,
- Natural gas and infrastructure companies looking to diversify their activities into district heating,
- Newer small heat companies with small networks, and
- Fully publicly-owned heat companies.

The business models of companies within the Danish district heating market were distinct from the Dutch context. Danish district heating companies operate on a not-for-profit basis (regulated by the Danish Heat Act), with companies often owned by municipalities or communities. This ownership setup was seen by workshop participants as a driver of cost minimisation for consumers because the companies were ultimately owned or governed by the consumers they supplied.

In general when looking at which types of district heating business models supplies the majority of the district heating it is seen that the business models look very different in the two countries. The participants stated that the business model is influential over the CAPEX costs of projects. In the Netherlands the majority of the heat is supplied by commercial district heating companies whereas in Denmark the majority if heat is supplied by non-commercial companies. It is seen as a benefit for cost reduction that the district heating companies in Denmark must be transparent of their heat production costs. There is not the same requirement on transparency in the Netherlands. By being more transparent about project costs and procedures of work it could help shape investment decisions to lower costs. It could also offer an opportunity for municipalities and communities to shape the sustainability path of the system and the end-user heat tariffs.

4.1.2 Financing projects

It was clear from the stakeholder discussions that the cost of financing a district heating project in the Netherlands was higher than in Denmark. Dutch projects reported interest rates between 1-4% and also required a high level of equity (approximately 30% of CAPEX costs). In contrast, typical interest rates of project loans in Denmark were around 0.5% (with a maximum of approximately 3%). The reasons for the higher costs of finance were brought up within multiple of the stakeholder workshops. Table 4-1 compares the potential cost drivers identified within the discussions of financing district heating projects.

Table 4-1: Comparison of how financing of district heating projects is done in each country.

Potential cost driver for project CAPEX costs	The Netherlands	Denmark
Types of financial institutions that lend to district heating projects	Lending for district heating projects typically done by large financial institutions Large utility companies also financed their own projects	DH companies take loans through KommuneKredit for new DH projects. In short, KommuneKredit is a non-profit mortgage provider for municipalities and regions in Denmark that secures cheap funding for new projects. Easier administration because district heating projects are viewed as low risk as they involve a trusted business model.
Newly established DH networks	New (and often small scale) DH projects were seen as less attractive to large financial institutions. The reason why is that the connection risk is concentrated on fewer customers. If anchor load customers decide not to connect to the network the project becomes unviable.	DH networks have grown to large scales, de-risking either smaller or bigger expansion projects as the financial risk is spread across all customers on the network.
Familiarity of DH within financial institutions	Financing requirement from investors to earn a profit on district heating projects seems to lead to a higher need to include a higher risk premium associated with projects.	High level of familiarity, with established approaches and processes makes DH projects less risky investments for Kommune Kredit. Bankrupcy is not, or is rarely, seen in district heating in Denmark.

Potential cost driver for project CAPEX costs	The Netherlands	Denmark
Financial risk assessment of DH projects	Finance for newer, smaller district heating companies was assessed at the individual project-level, limiting the number of customers over which to spread the risk. There was a perceived high risk that customers will not connect to the network (high connection risk) – particularly with retrofitting into existing buildings. Perceived risks of a 'profit-ceiling' for heat tariffs, meaning that projects will not be able to recover sufficient costs to pay back loans. Perceived lack of knowledge of district heating within some DH actors – e.g. cooperatives. Timing of project roll-out is considered too slow by financial institutions.	The risk assessment is focused on the DH company as a whole, rather than the individual project. This enables financial risk to be spread across a larger number of customers. The risk of customers not connecting to DH is perceived as low. However, connection rates have slowed in recent years and there is a risk to companies that individual heat pumps will be adopted rather than district heating. At present financial risks are normally manageable across the wider network so this is not increasing the cost of finance.
Role of government policy support and subsidy	The majority of municipalities offer subsidy schemes for customer connection costs. Policy development taking place for district heating, including discussion of municipal guarantees to enable longer loan durations and lower interest rates, the new heat law, and the role of public vs. private ownership of networks. The Dutch public sector bank, BNG, is also expected to play a bigger role in project financing.	A municipal guarantee[15] is considered one of the most important 'subsidies' for projects by the workshop participants since it is cheaper and easier to apply. The Danish heat act encourages municipalities to grant guarantees.

The current analysis of project financing suggests that the relative low spread of district heating in the Netherlands is driving up the costs associated with financing district heating CAPEX costs. The biggest suppliers are commercial which means they keep closed books for competitiveness, and the regulation has not encouraged transparency of costs either. The market is characterised by new networks, high perceived risks and uncertainties, and a mix of actors made up of a few

[15] A guarantee that the municipality, and therefore the tax-payers, is held liable if the project cannot pay back the loan

(private) experienced parties or lesser experienced actors. In contrast, the mature Danish district heating market has well-established approaches to assessing and granting finance within a non-profit mortgage provider (Kommune Kredit), larger schemes and companies over which to spread financial risk, and underwriting of loans by municipal governments to ensure the costs of financing project CAPEX costs are minimised. The development was all the way facilitated by regulatory requirements for district heating companies to be non-profit and transparent.

4.1.3 The role and capacities of municipalities

The role and capacities of municipalities as a key influence over CAPEX costs of projects were discussed in several of the stakeholder workshops. A municipality's role, and supporting capacities to deliver this role, are well established in Denmark. The municipalities are the heat planning authorities in Denmark. In the Netherlands this is a developing area of work due to its history of natural gas networks in the past, use of building-level boilers for heating supply and the privatization of older DH networks. Table 4-2 compares the key characteristics of both countries across themes that were identified by the workshop participants as being likely to be influential over CAPEX costs of district heating projects.

Table 4-2: Comparison of the role and capacities of municipalities in the Netherlands and Denmark across key themes identified by workshop participants as being important for influencing CAPEX costs of district heating projects.

Role and capacity of the municipality	The Netherlands	Denmark
Heat planning	The benefit of long term planning of the heating system was also highlighted by research participants as offering potential benefits for reducing CAPEX costs of projects over the long term. This had the potential to influence project CAPEX costs by: - Leaving private companies to make investment decisions in isolation of a wider strategic or holistic vision for the area. - Increasing the challenges of coordinating with other energy programs such as energy efficiency retrofit.	It is standard practice that long term heat planning is undertaken by the municipalities, where a broader ambition is set, before design and planning of a specific part of a network. Concretely, every municipality must develop and maintain an updated heat plan. This ensures that planning of the future heat supply is in line with current national and local policies and strategic priorities. New heating projects are assessed on a socio-economic basis, using a methodology set at the national level to secure what is best for society in regards to price, emissions, local development plans etc. Further, it ensures that local heat sources and conditions are considered. The specific conditions for each project such as tariffs are considered. The municipality approves new heat projects and gives permission to expand existing networks.
Local powers	Municipalities are mainly responsible for approving development /	The municipalities are mainly responsible for approving development / standards / ensuring

Role and capacity of the municipality	The Netherlands	Denmark
	standards of new systems and supplying network permits.	compliance with local regulations (although some basic conditions that are set at the national level, e.g. the local area production plant) Municipalities either own networks or are on the board of the DH company so their role and influence are well defined. - The political priorities of the local area is into the DH company future planning through this route.
Skills and knowledge	Knowledge and experience of district heating energy planning and project development within municipalities is variable and exists mainly only within the big cities. This can lead to a lack of scrutiny and accountability of proposals made by private-sector DH companies. Where design of systems was being undertaken by a municipality (e.g. in new build areas), this often relied upon external consultancy expertise and did not always use optimum design approaches for minimising costs of a project. E.g. it was analysed by both municipalities if twin pipes should be used, but was found too expensive.	Most municipalities have knowledge of heat planning and design principles, but typically these tasks are undertaken by the DH company as the actor with the most accurate information for informed decisions. Twin pipes are most commonly used in Denmark as they reduce the CAPEX cost for the DH network.

Long term planning, supported by local coordination / implementation powers, was felt by workshop participants to have the potential to drive down CAPEX costs in projects in the Netherlands. In order for this to be implemented in the Dutch context, the skills and capacities within municipalities (or potentially at a national level such as the Expertise Centrum Warmte) would also need to be developed alongside the designation of suitable powers / policy interventions for enabling the delivery of long term plans.

4.2 Summary of qualitative analysis

The following cost drivers of district heating CAPEX costs in the Netherlands were identified through the qualitative workshop discussions:

- There is a lack of transparency of the economics on many schemes, making it hard to compare project proposals and assess value for money, and can potentially lead to high costs and tariffs.
- Dominant market actors in the Netherlands require a high return on project investments. This leads to higher tariffs given the same CAPEX.
- CAPEX costs appear to be magnified by a higher cost of finance in the Netherlands compared to Denmark. Workshop participants identified possible causes of this to be the perception of higher financial project risks within financial institutions. In particular, there was a higher customer connection risk due to the developing market and a lack of familiarity of district heating within financial institutions that contributed to this higher perception of risk.
- Some participants felt there was an opportunity for municipalities or other public actors to carry out long term planning of towns and cities. This was thought to have the potential to support projects in future proofing and coordination of wider low carbon programme delivery such as energy efficiency retrofit. Cost of twin pipes were found too expensive in the Netherlands even though they are used in Denmark to reduce cost of the DH network.

Finally, consideration was given to the impact of CAPEX costs on heat tariffs. In the cost-based approach to heat tariff calculation in Denmark, CAPEX costs can have a significant influence over the resulting consumer heat tariff. A transfer over to a cost-based system of heat tariffs in the Netherlands will accentuate the impact of CAPEX cost drivers, but will also provide an opportunity for reducing heat tariffs.

5. CONCLUSION AND RECOMMENDATIONS

This report has explored the differences in CAPEX costs of district heating projects in the Netherlands and Denmark. Where possible, cost drivers for CAPEX have been identified, with a particular emphasis on the Dutch context, where the district heating market is in an earlier stage of development than in Denmark. The following sections summarise the key differences observed between the CAPEX costs experienced in the two district heating markets and the drivers that were identified through analysis and discussions with stakeholders. Based upon these findings, recommendations are made about opportunities for reducing CAPEX costs for district heating projects in the Netherlands.

5.1 Key differences observed between Dutch and Danish Project Costs

Table 5-1 below provides a summary of the key CAPEX cost differences observed within Dutch and the Danish district heating projects. These range across material, construction and heat supply costs to administration, operation and maintenance costs.

Table 5-1 Summary of the key differences observed between the Dutch and Danish district heating set up that influence the resulting CAPEX costs of projects

Key differences	Description
Network specification	In Denmark, twin pipes were used more extensively within systems. Pipes were also generally specified at a higher insulation class than in the Netherlands.
Approach to heat source utilisation and production scheme	Networks established over time in Denmark make use of decentralised heat production with multiple and varied heat sources, enabling networks to optimise the cost of heat supply as prices change over time. Based on previous workshops on case studies, there seems to be a tendency for district heating networks to only utilize a single heat source in opposition to a diversified heat production.This requires greater investment in back-up capacity and peak load as well as bigger dimensions of pipes.
Material costs	The same cost levels for technologies and materials were observed in both countries. However, when district heating schemes start taking in a greater number of customer connections and supplying a larger quantity of heat demand, while showing greater certainty in the pipeline of future projects, product discounts are being offered in the Danish context that were not available in the Netherlands.
Profit margins	Danish regulations mean that district heating companies in general cannot make a profit from the sale of heat. This means that Danish district heating companies have a lower profit margin.
Experience/organisation	In general, district heating schemes in Denmark are longer-standing and more numerous than in the Netherlands. This has resulted in more experienced actors, established and standardised processes in areas such as financing of projects, and better organisation of resources resulting in lower project contingency requirements.

Key differences	Description
Risk assessment	High costs in Dutch projects are often a result of a considered high front-end risk, appearing when adding risk on top of risk. In a well-planned Danish project, a professional district heating company will handle the start-up framework and define the construction work precisely in the tender material, resulting in reduced risks and reduced costs.
Customer connection levels	Consumer familiarity with district heating in Denmark leads to higher customer connection levels to new areas of network than would currently be expected in the Dutch context. This lowers the specific costs of projects in Denmark. Further, district heating is often the cheapest alternative in Denmark in areas with a high heat density and is generally seen as payable and trustworthy from a consumer perspective.
Customer connection costs	In the Netherlands, high costs are experienced for retrofitting district heating into existing homes due to the set-up of existing heat systems, often in the upper section of households. In contrast, in Denmark it is more common to have a plant room on the ground floor of homes, enabling retrofitting of DH connections at a lower cost.
The role of long term planning	In the Netherlands, long term heat planning (i.e. setting a long-term vision for where district heating would be best placed) is an emerging practice. In Denmark, this has been a fundamental part of energy planning for decades. At present, it is predominantly carried out by Danish district heating companies, with oversight from the municipality.
Socio-economic calculation requirements	In Denmark every project proposal on district heating is calculated to assess the economic feasibility in regards to project economy, user economy and socio-economy. Especially the socio-economic requirements, which are defined by the Danish Government and supported by standardized guidelines and calculation methods, have made a difference in the Danish heating systems. All district heating companies have to ensure that their projects are the best option for society.

In summary, cost drivers for district heating CAPEX costs in the Netherlands were identified by considering the observed differences between the two countries' markets and practices.

- Overall, the costs associated with **network infrastructure** in the Netherlands were found to be higher than in Denmark, despite material costs being comparable across the two markets. These cost differences were attributed to general costs such as risk overheads placed on works by construction contractors, higher costs of finance and system design practices.
- In terms of **heat supply**, heat pump costs were seen to be equally expensive across the two markets. However, Denmark more commonly utilised other cheap heat sources such as waste heat from industry, allowing for use of the cheapest heat source at any time, ensuring lower heating costs. This diversification of heat sources in Denmark is not yet seen to the same extent in the Netherlands.
- **Customer connections** in the domestic retrofit sector was more expensive in the Netherlands than in Denmark. This was largely attributed to differences in the design of homes and existing heat systems and represented a cost that needed to be borne by Dutch projects.
- **Administration, operation and maintenance costs** were also found to be important influences on CAPEX costs:

- There was a lack of transparency of the economics on many schemes in the Netherlands, making it hard to scrutinize project finances.
- Finance costs were found to be higher in the Netherlands, partly caused by a lack of familiarity with district heating within financial institutions and a different risk perception.

5.2 Recommendations

This project has focused on the role of CAPEX costs in district heating projects and if CAPEX costs result in driving up the heat tariffs charged to customers if the Netherlands starts using a cost-based tariff scheme. Clearly, CAPEX will only be one element contributing to higher heat tariffs. The research highlighted a number of areas where the practices and market context in the Netherlands are likely acting as a cost driver on project CAPEX costs in comparison to the situation in Denmark. The many years of experience with district heating projects in Denmark mean that processes have become increasingly efficient. Although material costs have been rising, the costs of district heating projects overall have not risen over the past 15 years. The Netherlands also has experience with district heating, as seen on the amount of connections, but the stage of development is different from Denmark. The Dutch district heating market is characterized by high perceived risks and uncertainties, which are driving up the district heating CAPEX costs.

The analysis suggests the following key areas of opportunity for reducing these cost drivers affecting district heating projects' CAPEX costs:

1. Design engineers, and those commissioning network design work, should explore international design best practices and seek to develop design norms used in projects at present (e.g. use of twin pipes and optimising the level of pipe insulation for a system, looking to countries such as Denmark, Sweden, Germany and the UK to understand opportunities to reduce project CAPEX).
2. Network developers and operators should explore opportunities for diversifying the use of heat sources within networks, facilitating access to new cheap heat production sources and enabling heat supply cost minimisation both in terms of CAPEX and heat supply costs. Subsidies, preventing diversification, could be adapted. Also, third party access for cheaper resources helps this diversification.
3. The Dutch government has tasked municipalities with a new responsibility to lead the transition to sustainable heating, including identifying the lowest costs sustainable heat supply approaches at district level. Although the government has developed technical guidelines and designated funds to assist the municipalities, the question remains whether municipalities have sufficient capacity, resources and necessary enforcement mechanisms to fulfill the new task. In Denmark, useful experience has been gained from municipalities having had a central role as the local heat planning authority for several years. The standardized socio-economic approach to project proposals in Denmark has also played a key role in strengthening the municipalities in their role as the local heat planning authority. Lessons from this experience could be studied and transferred to the Netherlands. For example, the (voluntary) planning tool: municipal strategic energy planning from 2012 illustrates how Danish cooperation on joint efforts and goals on least cost planning was strengthened with other local actors, such as the local district heating companies.
4. Financial institutions should look to develop their knowledge of the district heating sector further and establish standardised processes for assessing and approving finance for district heating projects. In parallel, there are opportunities to utilise public financing and / or offer government underwriting of project loans by national or local governments to

enable larger scale, strategic projects to overcome the perceived financial risks of this developing part of the energy system.

5. Finally, there is an opportunity to increase transparency as regards to formulating, justifying and reporting investment plans, heat purchase agreements and tariff decisions, i.e. pursue objectives that district heating companies' economic decisions and environmental goals and tariff composition should be publicly disclosed and explained better, thus to increase trust amongst consumers in the cost and operational efficiency of networks. It is expected that high consumer trust can be translated into a high connection level to district heating schemes and thus a high degree of utilization of the invested assets, i.e. low CAPEX per customer.

The level of change implied by these recommendations is not something that can necessarily be implemented quickly but could be built into long term planning for the sector and monitored over time to understand the progress. It would also be beneficial to put these findings in the context of similar studies focusing on other elements of cost drivers on Dutch district heating tariffs to understand the CAPEX costs and the opportunities highlighted here for reducing them.