The Impact of Heat Load on the Business Case of a New District Heating System in the Netherlands

Thesis Energy Science - Willem van Rossum

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Summary

To evolve into a carbon-free society, the built environment needs to move to sustainable, natural gas-free heating by 2030. The PBL Netherlands Environmental Assessment Agency (PBL) has defined five strategies for sustainable heating. One of these strategies is to switch to medium-temperature district heating (MT DH) systems to heat buildings. Because DH systems take a long time to develop, there are uncertainties associated with the amount of heat that will be sold. The unknown influence of competing sustainable heat strategies, make these uncertainties bigger. This leads to the following research question:

'How does a change in heat load for DH systems due to competing heat strategies influence the business case of new MT DH systems for DH companies in the Netherlands?'

To answer this research question, an area in Delft, consisting of six neighbourhoods was chosen to analyse. For this area, using the business case template developed by TNO and commissioned by the ECW (expertise centrum warmte), the business case for the DH system was calculated under positive assumptions and energy demands. The resulting business case in the subject neighbourhood was **positive**. Next, scenarios were developed based on competing sustainability strategies, to evaluate the effect these strategies and behaviour have on the business case. These strategies were competing sustainable heating technologies and shell-improvements. Competing sustainable heating technologies affect the participation rate of the DH system, while shell-improvements affect the heat demand per connection. From this, five scenarios arose (excluding the reference scenario). Each scenario had a different combination of participation rates and insulation. The effect of these scenarios was evaluated from the national cost perspective and from the DH company perspective.

The results showed that the business case is strongly affected by the DH system heat load. When assumptions about participation rate and insulation levels worsened, the projected NPV and IRR declined. In every scenario, the IRR is positive and the investments are recuperated. However, only the reference scenario and the two least negative scenarios resulted in a positive business case. Higher insulation levels alone did not result in a negative business case for the DH company, but does strongly influences the national costs per avoided CO_2. An uncertainty analysis showed that the price for which heat is purchased and sold are the two most influential parameters for the business case. From this thesis, **it can be concluded that competing sustainable heating strategies have a significant influence on the heat load and the business case of DH systems**. There are scenarios where a DH system is still the strategy with the lowest national cost but is not a good investment for DH companies. Further research must point out whether or not it is efficient for the government to subsidise DH systems in these cases.

Preface and acknowledgements

This thesis is written in the context of completing my master in Energy Science. During the master's program, I developed skills and interests in energy technologies which eventually lead to the writing of this thesis. From February to July 2022, my research was facilitated by the PBL Netherlands environment assessment agency (PBL), where I had a position as a research intern in the built environment team. Hopefully, this thesis can help PBL with new insights, and serve society as a whole by contributing to a faster, smoother heat transition.

I would like to thank several persons who contributed to this thesis, and without who, this thesis would not have been the same. First of all, I would like to thank both my supervisors, Dr. Wen Liu from Utrecht University and Ir. Nico Hoogervorst from PBL, both sacrificed their time to give me important feedback and answered my questions every week. Both were always available to discuss ideas with me and elevate this thesis to a higher level. I also want to thank the rest of the built environment team from PBL for supporting me during this thesis and thinking along when needed. The Vesta MAIS support team from Ecorys also deserves special thanks, because they answered important Vesta MAIS related questions when I could not figure things out by myself. I also want to thank Geert de Lau from Ennatuurlijk for letting me interview him in the early stage of this thesis, giving me an insight into the functioning of DH companies and how they approach a business case. Last but not least, I would also like to thank Dr. Robert Harmsen for being the second reader of this thesis and providing feedback on the research proposal.

Finally, I want to thank everyone in my personal surroundings who supported me during the duration of this thesis. My housemates, family and friends all supported and believed in me the whole time, for which I am very grateful.

I hope you enjoy reading this thesis,

Willem van Rossum

Utrecht, 12/07/2022

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List of Abbreviations

Abbreviation	*Explanation*
ACM	Authority for Consumer and Market
CRC	Cost recovery contribution
DH	District heating
GHG	Greenhouse gasses
LT	Low temperature
MT	Medium temperature
HT	High temperature
NPV	Net present value
PBL	Planbureau voor de Leefomgeving
PBP	Payback period
IRR	Internal rate of return
MAIS	Multi Actor Impact Simulation

1. Introduction

1.1 Background and Societal relevance

Due to accelerated climate change, rising energy prices and the war in Ukraine, a clean and independent energy supply has risen to the top of policymakers' agendas. To mitigate climate change, the Dutch government formulated the goal of 49% CO_2 reduction in 2030 compared to 1990 (Rijksoverheid, 2022d). The built environment is an important sector to make more sustainable because around 40% of the energy consumed in the Netherlands is by this sector (Klimaatmonitor, 2022). Therefore, the Dutch government aspires to start cutting neighbourhoods of gas starting in 2030 and have a gas-free energy supply by 2050 (Rijksoverheid, 2022a). Five different strategies are identified to make the built environment carbon-free (van Polen et al., 2020): 1) all-electric (heating with electric heat pumps). 2) medium/high temperature (MT/HT) district heating (DH) systems. 3) low temperature (LT) DH systems. 4) Green gasses. 5) Hydrogen. Strategy 4 and 5 are considered not to be mature and robust for implementation by 2030. For strategy 4, only a variant with a maximum availability of 1.5 billion cubic metres (bcm) is deemed realistic. This makes DH systems and the all-electric strategy the most important. In densely populated areas with access to waste heat, the MT DH strategy is considered the most cost-effective and robust. In less densely populated areas, the LT DH strategy in combination with the all-electric strategy is considered the most viable (van 't Wout, 2021).

DH systems were first introduced in the Netherlands in 1923 in Utrecht (Utrecht.nl, 2015). Currently, 232 DH systems exist in the Netherlands, accounting for more than 430,000 connected buildings (ACM, 2021). These DH systems deliver more than 150 TJ of heat annually, of which over 50% goes to residential buildings, 15-20% to agriculture and 25-30% to services (Segers et al., 2020). DH systems are considered sustainable, especially LT DH systems, as these networks allow for the implementation of different sustainable heat sources like waste heat, geothermal heat and aqua thermal heat (Vermaat, 2018). However, current DH systems in the Netherlands are mainly fuelled by natural gas (76%). Only 7% of the energy delivered by DH systems in the Netherlands is from sustainable sources, and the other 17% is mostly from waste heat, which can be considered sustainable (Segers et al., 2020).

The Dutch government agreed upon implementing more DH systems to transition toward sustainable heating. From 2025 onwards, the government aspires growth in DH users by 80,000 per year, continuing to 2030 (Vermaat, 2018). However, the Dutch government does not only bet on DH systems to arrange the heat transition to sustainable heating. In the Netherlands, several subsidy schemes are available for building owners who want to invest building sustainability (for instance: SAH, SDE++, ISDE, EIA) (Ollongren, 2021). These subsidies help finance investments in things like insulation, more efficient heat supply and cheaper connections to DH systems (Rijksoverheid, 2022b). Some of these subsidies incentivise technologies that compete with DH systems. A subsidy for purchasing a heat pump can for instance lower the heat load (the amount of heat energy needed to maintain a certain building temperature (Calikus et al., 2019)) for DH networks, because a consumer with a heat pump has less demand for heat from a DH system, or might not want to be connected to a DH system at all (Lygnerud et al., 2021). Subsidies also promote technologies that lower heating demand like insulation, also influencing the heat load of DH systems, and the profits of DH companies (McDonald, 2021).

When the heat load for DH changes due to insulation or other sustainable heat suppliers, this can have societal consequences. DH systems require large initial investments, which often take decades to be paid back. To keep the fixed costs per connection low and to maintain profitability in the system, the number of connections in an area is important (ACM, 2021). When fewer people are connected to the DH system or demand less heat per DH connection, the DH company might need to take measures to ensure recuperation of the investment. For instance, a DH company can increase the fixed costs per connection, which can disincentivise sustainable use of heat because the portion of fixed costs increases compared to the variable costs. Or the DH company can charge more for the delivered heat, resulting in higher costs for consumers already connected to DH. This uncertainty in heat load for DH can also influence other stakeholders of DH systems. Since the heat demand through DH and the number of connections to the DH system are important for profitability, uncertainty about these parameters results in uncertainty for investors and suppliers. This can result in more slow decision-making for the development of new DH systems, which in turn can delay the heat transition and jeopardise the goal for growth in DH in the Netherlands.

1.2 Scientific background and knowledge gap

Previous studies regarding DH systems focussed on different aspects of DH systems. A state-of-the-art review of DH systems researched the main generation, transmission and storage technologies, as well as social aspects and barriers to be taken into account when developing DH systems. It also evaluated the biggest DH systems in Europe (the Netherlands was not taken into account) and the rest of the world (Mazhar et al., 2018). Lund et al. concluded that DH systems will have an important role in the future heat system (Lund et al., 2010). Multiple studies have been conducted on the next generation of DH systems and the challenges associated with the switch to this next generation (Buffa et al., 2019; Lygnerud, 2019). Also, different business models for DH systems have been researched widely, evaluating the effects of combining heat pumps with DH systems to make the system more efficient (Lygnerud et al., 2021), and developing business models to increase system efficiency (Leoni et al., 2020) and evaluating business models and barriers to investing in LT DH systems (Lygnerud et al., 2019). Different pricing mechanisms for DH systems also have been researched (Li et al., 2015).

Next to scientific research on DH systems, there is also research being conducted on the potential and functioning of the heat market. This type of research is often executed by governmental planning agencies or advisory companies and function to inform governments and test policies. For instance, TNO publishes a heat monitor every two years in which the use of heat, the fuel mix for heat and all heat networks are mapped and discussed (Segers et al., 2020). The authority consumer and market (ACM) publishes a financial performance monitor of all DH companies in the Netherlands to investigate the profits of DH companies and check whether DH companies are not gaining more returns on their investments than allowed (ACM, 2021). PBL reports yearly on the current status of climate and energy in the Netherlands, in the climate and energy outlook (klimaat- en energieverkenning). This report evaluates the energy consumption and greenhouse gas (GHG) emissions of different Dutch sectors and tests whether these sectors are underway to reach their climate targets (PBL, 2021). The most important piece of pre-research for this thesis, however, is the start analysis for gas-free neighbourhoods (Startanalyse aardgasvrije wijken). In this 'Startanalyse', for every neighbourhood in the Netherlands, it was calculated what the extra national costs are compared to doing nothing for each of the five gas-free strategies mentioned above (van Polen et al., 2020). What the 'Startanalyse' actually calculates, and how the results help this thesis, are explained further in section 2.2.3. in the theory section.

Next to these more explorative studies, limited studies have been conducted to evaluate the robustness of the business case of DH systems. When it has been calculated that a DH system is an option with the lowest national cost, it does not necessarily mean that the development of a DH system has a positive business case. A business case is considered positive when the revenues from a project, when discounted, are high enough to recuperate all expenses and get the desired profit margin during the lifetime of the project. The business case of DH systems is thus reliant on the revenue over time, which depends on the number of connections to the DH system, and on the amount of heat that is delivered per connection (Li et al., 2015). The development of a DH system is a process of multiple years. When the DH system is financed, certain assumptions are made regarding the projected sales of heat. Because the development takes a long time, these assumptions might not be correct anymore when the DH system is finished because individual consumers might have taken measures to reduce their heat demand. The stimulation of other sustainable heat strategies in the Netherlands increases this uncertainty, resulting in projects which are harder to finance, more expensive heat for consumers or higher required subsidies for DH companies. Which strategies can influence DH systems and how these strategies might influence the revenues of DH companies, is part of this thesis. How this change in heat load influences the business case of DH systems and how much of a change in heat demand DH companies can absorb is not clear from current literature.

Knowing how a change in heat load influences the business case of DH systems provides policymakers insights how different heat strategies interact. This results in more robust policies, assuring that each heating technology can flourish and the heat transition goes fast and cost-effective. It would also provide insights usable for countries with less developed heat strategies who are still unsure about what policy instruments to use for their heat transition. Analysing the robustness of the business case of DH systems gives insights into how costs are divided in the system and how much of a change in heat load the business case can take and remains positive. It also helps DH companies to understand how heat load influences the business case of DH systems as it helps to take uncertainties into account and helps to better predict future cash flows, resulting in a more robust business case with less risk.

1.3 Research objective and Research questions

Based on the discussion above, this thesis aims to carry out a quantitative analysis of the influence of a changing heat load for DH on the business case of new DH systems. This is done by analysing the effect competing sustainable heat strategies or sustainable behaviour has on both the national cost perspective for DH systems and the DH company perspective. For different heat loads, it is evaluated whether a DH system is a cost-effective strategy for policy makers and whether it is a logical investment for DH companies.

The main research question of this thesis is: *'How does a change in heat load for DH systems due to competing heat strategies influence the business case of new MT DH systems for DH companies in the Netherlands?'*. This research question will be answered using the following sub-questions:

1. What is the business case of new DH systems in a neighbourhood in the Netherlands where a DH system is likely to be developed without considering the impact of other competing strategies or shell improvements on heat demand?
2. What are the potential changes in heat demand due to the implementation of other heat strategies or shell improvements?
3. How and to what extent is the business case of the DH system in the subject neighbourhood influenced by the change in heat load?

1.4 Scope

Due to the time restrictions of this thesis project, it is not possible to take into account every aspect of DH systems. This thesis will therefore only look at the business case for new MT DH systems in the Netherlands. This is done from the perspective of the heat supplier and from a national perspective (the consumer perspective is out of scope of this research). Regarding building types, rental homes, owner-occupied homes and service buildings are in scope of this thesis.

1.5 Outline of this Thesis

The structure of this thesis is as follows: First, in the theoretical framework (chapter 2), it is discussed how DH systems function and how value is created. Next, the business case is described, followed by the used tools and methods. The theoretical framework and with the explanation of other used concepts. In the methodology chapter (chapter 3), first, the conceptual model is discussed, followed by the research approach. Then it is explained how a business case for a DH system is calculated. The methodology ends with a section regarding time scope, data collection and ethical concerns.

Next, the individual sub-questions are discussed. First, for sub-question 1 (chapter 4), a research area is determined and a DH system designed. Also, the business case is calculated for the reference scenario. Then, for sub-question 2 (chapter 5), policies are analysed resulting in different scenarios. In sub-question 3 (chapter 6), these scenarios are analysed and the results discussed. Following sub-question 3, Monte Carlo and sensitivity analyses are conducted (chapter 7) and the results are evaluated. Next, in the discussion section (chapter 8), the most important findings are discussed. Also, limitations, implications and suggestions for further research are discussed. This thesis ends with the conclusion (chapter 9). Here, the answer to the sub-questions and the research questions are given.

2. Theoretical Framework

In this section the concepts used in this thesis are described. It provides background information required to understand how the research is conducted and to put the research into context. First, DH systems are explained (2.1), followed by a description of models and tools used during this thesis (2.2). This section ends with an explanation the Monte Carlo uncertainty analysis (2.3).

2.1 DH systems

This section elaborates on the functioning and value creation of DH systems. First, section 2.1.1 explains how value is created by a DH system and how a DH system is typically designed. Section 2.1.2 elaborates on the different stakeholders in a DH system and what the interdependencies of these stakeholders are. Pricing mechanisms and the new Dutch heat law are discussed in sections 2.1.3 and 2.1.4. Section 2.1.5 describes the business case for DH systems from the DH company perspective. This chapter ends with section 2.1.6. Here, it is explained what other heat strategies/policies exist and how these could influence the business case of DH systems.

2.1.1 Value creation and design

DH systems aim to create value by creating a collective heating system, preferably utilising excess heat that otherwise would have gone lost. This heat is delivered to buildings to fulfil their heat demand for spatial heating and hot tap water (Persson & Werner, 2011). The value architecture necessary to deliver the heat to the end user consists of three sub-systems: heat production, heat distribution and the end-user (Osman, 2017). Figure 1 gives a schematic representation of a DH system.

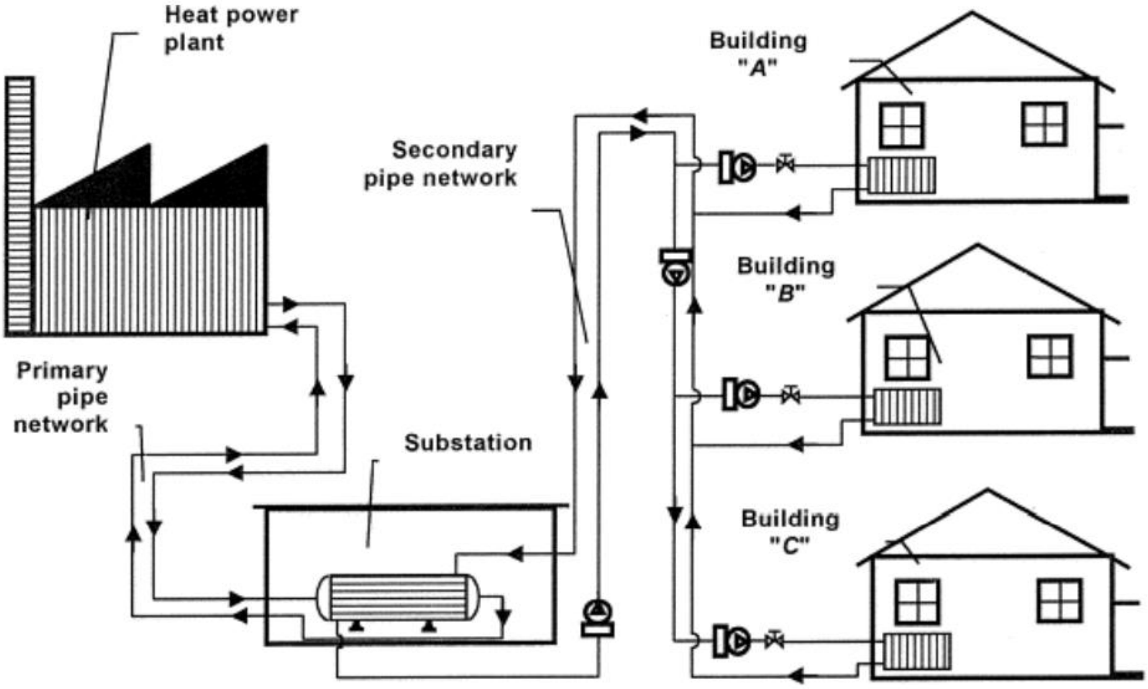

Figure 1: Schematic representation of an average DH system (source: Osman, 2017)

DH systems deliver heat to end-users by first generating heat by converting the energy contents of fuels, electricity or other energy sources to heat. It is also possible for DH systems to utilise residual heat generated by industrial processes, electricity generation or by burning waste. Then, using the primary network, heat in the form of hot water or steam is transported through insulated pipes towards distribution substations located close to the end-users. From the substation, the heat is transported through smaller pipes toward the individual buildings. In these buildings, a heat exchanger is used to exchange the heat in the DH system for heat in the buildings for the end-user. The water with most of the heat removed returns to the heat source to get reheated again.

2.1.2 Stakeholders

Typical stakeholders associated with a DH system are the heat supplier, DH network operator, municipalities and customers. The most common heat suppliers are industrial companies with waste heat, CHP plants and waste incineration plants (Schepers & van Valkengoed, 2009). The DH network operator (or DH company) is responsible for the heat delivery to the customer. In the Netherlands, it often is the case that the DH company is both owner and operator of the DH network and sometimes also the owner of the heat source for the system (Niessink & Rösler, 2015). Municipalities are stakeholders in DH systems because municipalities decide where DH systems will be implemented and need to give out permits to exploit DH systems. Sometimes, municipalities also fund and become co-owners of DH systems. Also, DH systems contribute to energy efficiency and CO_2 targets in the municipality (Osman, 2017). The customers for DH systems are project developers, housing companies, building owners and renters or home owners. Customers are not always the same as end-users, as the people using a building is the end-user of the heat, and that person does not always own that building. Often, the actual occupier of the building does decide whether or not he/she is connected to the DH system. This is because the DH network operator signs contracts with project developers or housing companies to deliver heat to the dwellings. A value network for DH networks as described above is given in Figure 2.

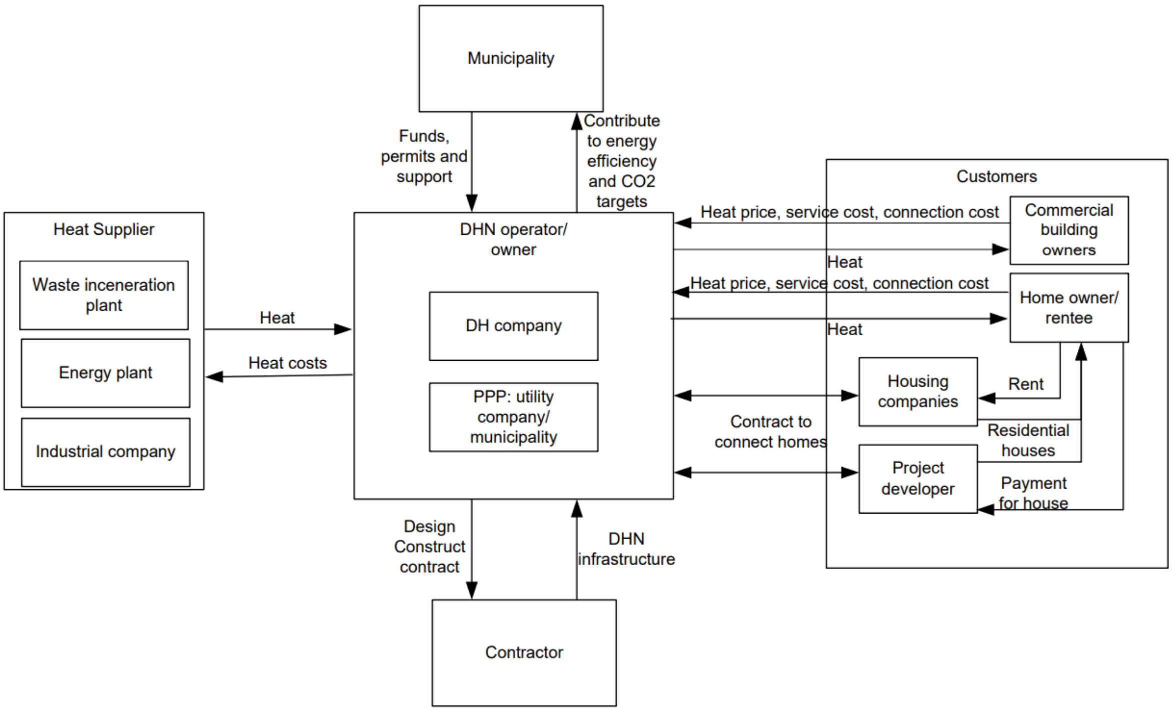

Figure 2: Value network of a DH system (source: Osman, 2017)

2.1.3 Pricing mechanisms

How DH is priced depends on whether the market is regulated or deregulated. The price components of DH however, are the same in a regulated and deregulated market. These price components are 1) the connexion costs, 2) the costs for the distribution network and 3) the heat production costs (Li et al., 2015). These costs translate to the price of heat comprising of a connexion fee, standing (fixed) cost and unit (variable) cost. In the Netherlands, the heat market is regulated. The maximum price DH companies can charge for heat is determined by the Authority Consumer and Market (ACM). Currently, the maximum price is determined in a way that users of a DH system can never pay more than a consumer in the same situation using natural gas for spatial heating (ACM, 2021). However, this pricing mechanism is subject to change in the new heat law. Instead of a price based on the gas price, the new price will be based on the actual, efficient made costs, plus an allowed profit (Wiebes, 2020).

2.1.4 New heat law

Currently, the Dutch government is finalising the new heat law which should go into effect in 2023 (de Ronde, 2022). The new heat law aims to facilitate the growth in DH systems by formulating new rules, providing more transparency in the pricing of heat, tightening requirements for the security of the supply of heat and ensuring DH sustainability (Wiebes, 2020). Another important change in the new heat law is that municipalities will be the directors of the heat transition by letting them define heat plots and choose which sustainable heating option is implemented for that plot. Additionally, a CO_2 norm is imposed on the delivered heat to ensure sustainability, which becomes more strict every year (Wiebes, 2019).

2.1.5 Business Case

This section elaborates on the business case for DH systems. First, a general description of a business case is given, followed by a more in-depth explanation of the business case for DH systems, explaining the different costs and benefits of the business case. It is also discussed how this business case is influenced by other strategies.

Multiple definitions exist for the term business case (or business model). Some definitions are focused on costs and profits, while some other definitions are more qualitative. Cambridge Dictionary defines a business case as “An explanation or set of reasons describing how a business decision will improve a business and how it will affect costs and profits and attract investments” (Cambridge Dictionary, n.d.), while Harvard Business Review defines it more qualitative as “assumptions about what a company gets paid for” and as “stories that explain how enterprises work” (Ovans, 2015). Investopedia defines a business model as “a company’s plan for making a profit” (Kopp, 2020) and the Association for project management (APM) says that a business case ‘justifies undertaking a project, programme or portfolio. It evaluates the benefit, cost and risk of alternative options and provides a rationale for the preferred solution’ (Dalcher, 2019). In this thesis, the last definition (APM definition) is used.

To evaluate the business case, indicators need to be defined. Blok & Nieuwlaar (2020) identified several financial indicators on which the business case can be evaluated, of which the net present value (NPV) is the most important. Beneath, the NPV is explained, according to two other indicators which are closely related to the NPV.

- Net present value (NPV)
  - Takes into account the lifetime of a project, (future) cash flows and the future value of money to see whether a project is profitable. Equation 1 describes the NPV and its components.

$$(eq.1)\ NPV = -I + \sum_{i=1}^{n} \frac{B-C}{(1+r)^{i}}$$

  - Where:
    - I is the initial investment

        - B represents the yearly project benefits
        - C represents the yearly project costs
        - r is the discount rate / project margin demand

- Payback period (PBP)
    - This is the time it takes for an investment to be recuperated. It is expressed in years and can be found by checking the moment in time the NPV passes the zero mark.

- Internal rate of return (IRR)
    - The internal rate of return is the discount rate or the desired profit margin that is required to get an NPV of zero. The desired profit margin is chosen by the DH company and is used to discount future cashflows, allowing for incorporating the desired project margin in the investment decision-making process. When the IRR is higher than the desired profit margin, the NPV, and therefore business case, is positive.

(Blok & Nieuwlaar, 2020)

2.1.5.1 DH business case – Cost components

Cost components for a DH system can be split into costs for infrastructure and costs for energy. Infrastructure costs are costs associated with the deployment of the DH system, such as the deployment of pipes for heat transport and distribution and the costs for heat transfer stations. The costs for pipes include the costs for opening and closing the ground. Other infrastructure costs can be the costs for internal adjustments in buildings and costs for heat delivery sets and measuring equipment (ECW, 2020). The costs for connecting a dwelling to the DH system is different based upon the type of connection, distinguishing ground-bound, stacked, collective and utility connections. Costs for delivery sets and measuring equipment are often charged to the end-user by incorporating it into the fixed component of the energy bill, while the internal adjustments costs are often paid by the building owner. These components, therefore, have no direct effect on the business case (ECW, 2020). Infrastructure costs for DH systems are often of great magnitude (millions) and are considered a yearly depreciation cost. Other costs associated with infrastructure are the yearly operation and maintenance (O&M) costs, expressed as a percentage of the investment costs, and costs for overhead and management expressed as a fixed amount per connection.

Energy costs are the costs associated with purchasing heat from third parties or the amortization of infrastructure that was built for the development of heat sources when the DH company has its own heat source. These costs include the costs of generating the thermal energy and the costs for the transportation of the heat towards the primary distribution station, connecting the heat source to the distribution network.

2.1.5.2 DH business case – Benefits

The benefits of the business case for a DH system consist of the heat sold to the end-user, fixed components associated with costs the DH company makes for delivering the heat and one-off contributions for connecting to the network. Often a DH company also charges a cost recovery contribution (CRC) to the building owner when connecting to the DH system. This CRC is a closing post of the business case and differs per DH system. The amount of heat sold is determined by the heat demand per connection and the number of connections. While the fixed and variable component is paid for by the end-user, the one-off contribution for connecting to the heat network is paid by the building owner.

2.1.5.3 DH business case – Other factors

Next to costs and benefits, there are also other factors influencing the business case of the DH network, influencing the costs and benefits and therefore also the business case. These are factors like vacancy rates in a neighbourhood, heat losses in the distribution pipes, the connection speed of a neighbourhood and participation rates.

2.1.6 The influence of competing sustainable heat strategies on the business case

Due to the gas grid being cut off in the future, high energy prices or sustainable behaviour, it is possible that housing corporations, landlords, private house owners or utility owners decide to lower their energy costs. Building owners can do this by either lowering their energy demand or by switching to cheaper energy sources. This can influence the business case of future DH networks, as DH companies will sell less heat when customer demand lowers, as the heat sold to customers is the main source of income for DH companies. Especially when these types of measures are taken while the DH network is being deployed, this can harm the business case. As most technologies experience economies of scale, it is expected that the more heat a DH company sells, the lower the average costs for the DH company are (Wang, 2018). However, research shows that for DH systems there is an optimal size and number of connections, based on the heating demand profiles and energy prices in that region (Chinese, 2008).The amount of heat sold to customers is likely to be influenced in two ways. 1) The government is promoting better insulation through subsidies and education in the national insulation program (Rijksoverheid, 2022e). Better insulation (shell-improvement) or more sustainable behaviour influences the heat demand per connection, resulting in less heat sold by the DH company. Although a lower heat demand per building theoretically allows for more budlings to be connected to a heat source, connecting more buildings also results in more pipes and maybe more distance between buildings, resulting in more energy losses. 2) The government also stimulates the use of hybrid heat pumps through subsidy schemes, and from 2026 onwards when a boiler needs replacement, it is only allowed to do this by replacing it with a hybrid heat pump (NOS, 2022). Measures like an all-electric or hybrid heat pump can make it obsolete for building owners to want to connect to the DH system because they already have sustainable heating.

To evaluate how these phenomena might influence the business case of a new MT DH system in the Netherlands, scenarios are developed in sub-question 2. To properly develop scenarios which can evaluate the effects of other sustainable heating strategies, it must be known how these strategies exactly affect the business case of DH systems. The created scenarios differ in some underlying assumptions, but most characteristics of the neighbourhood and other assumptions remain the same. Figure 3 shows how the two alternative sustainable options (alternative sustainable heating and shell-improvement) could influence the business case of DH networks. The cash flow in the business case is determined by summing the heat demand for all dwellings. The heat demand is determined by the number of connections and the heat demand per connection. The number of connection is influenced by building owners choosing a different sustainable heating alternative, like all-electric or a hybrid heat pump. The latter is influenced by building owners deciding to improve insulation in their buildings.

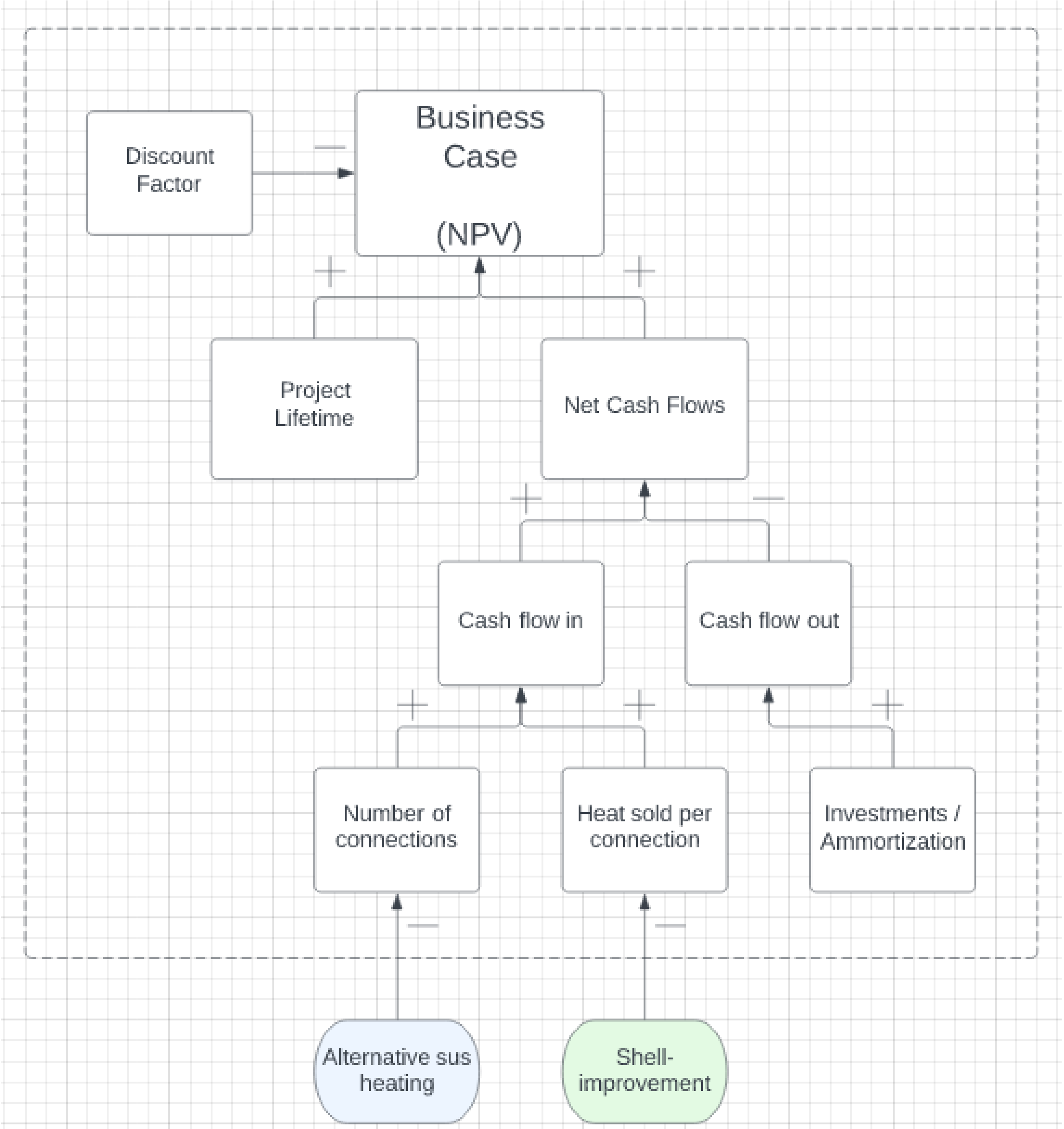

Figure 3: Schematic overview of how different sustainable strategies / behaviour affects the business case of DH systems

2.2 Tools and Models

To answer the sub- and research questions, certain tools and models are used. This section elaborates on what these tools and models are, and why they are appropriate to use in this thesis.

2.2.1 Vesta MAIS

Vesta MAIS is a techno-economic open-source spatial model, developed by the PBL. Vesta MAIS can calculate energy use and national costs for sustainable heat strategies in the built environment for the long term (to 2050). Based on the inputs, it calculates the energy requirements and costs for different sustainable heat strategies and evaluates which strategy is the best option on the building, neighbourhood or municipality level (Wesselman, 2019). For this thesis, the 'Leidraad' version is being used. This is the same version used for the 'Startanalyse' and is different from the normal version because it automatically applies strategies on the neighbourhood level and calculates the associated costs. The standard version applies energy measures on a building level, making the standard version less suitable to use for this thesis than the 'Leidraad' version. The model allows the user to evaluate the costs of different strategies under certain assumptions and allows for changing these assumptions to evaluate the effects. outputs the national costs of each strategy. It takes into account local circumstances and multiple aspects of the built environment (including building characteristics, policies and energy prices) to calculate different components of the energy system (primary focus lies on heat demand) accurately (van den Wijngaart et al., 2017). Although Vesta MAIS does not evaluate the business case of DH systems directly, Vesta MAIS calculations are often used by municipalities to decide where to apply which sustainable heating strategy. Analysing the effects of a change in heat load with Vesta MAIS gives insights into how municipalities in the future might decide where DH systems will be deployed. This indirectly affects DH companies and their businesses.

2.2.2 Template Business Case heat network

The Template Business Case is a template developed by TNO and commissioned by the ECW. It is developed for housing associations and DH companies, but can also give municipalities information about what costs are associated with the development of a DH system (ECW, 2022). This template can be used to calculate whether it is interesting for a DH company to invest in the development of a DH network by implementing specific data about the DH system. It can also be used by municipalities to gain more insight into the costs and benefits for DH companies to reduce information asymmetry between the DH company and the municipality. This strengthens the negotiating position of the municipality (ECW, 2022). This tool is appropriate to calculate and compare the scenarios because, like Vesta MAIS, it allows for changing certain scenario-specific parameters and evaluating the effect of this change on the business case. The main difference between Vesta MAIS and the template Business case is that Vesta MAIS calculates the national costs, whereas the template calculates the costs for the DH company.

The template consists of 9 sheets. Two sheets provide information on how to use the template. Two sheets are used to fill in the information regarding the DH network and underlying assumptions. The five remaining sheets are to check the input data and see the results. The most important input data and result sheets are the sheets 'uitgangspunten' (assumptions), 'aantallen & fasering' (numbers and phasing) and 'resultaten' (results). On the sheet 'uitganspunten', assumptions can be inserted about risks, subsidies, heat losses, pipe lengths and costs, CAPEX costs, OPEX costs and energy prices. The sheet 'aantallen & fasering' allows the user to insert different tranches for the DH network. Per tranche, the amount of housing equivalent, heat demand and type of tranche (individual ground-bound, stacked, collective or utility) can be inserted. On this sheet also the economic lifetimes of different parts of the DH system can be inserted. The sheet 'resultaten' gives the most important results of the analysis, like the NPV, PBP and IRR, but also shows the yearly cash flows and investments. All information which needs to be inserted into the model in these sheets is provided in Appendix A.

This template calculates how much of an extra cost recovery contribution is necessary to cover the unprofitable top of the investment. This is done by inserting a required project return, which is taken as the discount factor, and then letting the template calculate how large of a cost recovery contribution is necessary to get an NPV of zero. This makes the cost recovery contribution the closing post of the business case. When the cost recovery contribution is negative, the business case results in a higher project return than the inserted required return, making the business case positive. When the cost recovery contribution is positive, the revenues from selling the heat are not large enough to cover all expenses made over the lifetime of the project and make the desired profit. In this case, an extra contribution from consumers/building owners is necessary to make the business case positive.

2.2.3 'Startananlyse' PBL

The 'Startanalyse' is a study and report by the PBL where the extra national costs of five main sustainable heat strategies and several sub-strategies were calculated at the neighbourhood level using Vesta MAIS (Hoogervorst et al., 2020). The different strategies and a short description are listed in Table 1.

Table 1: Identified sustainable heating strategies and variants (Hoogervorst et al., 2020)

Strategy	Variant	Description
S1 – All-electric	S1a	Individual air source heat pump, insulation label B+
	S1b	Individual ground source heat pump, insulation label B+
S2 – MT/HT DH	S2a	MT/HT source DH, insulation label B+, residual heat
	S2b	MT/HT source DH, insulation label B+, geothermal heat
	S2c	MT/HT source DH, insulation label B+, geothermal heat – everywhere
	S2d	MT/HT source DH, insulation label D+, residual heat
	S2e	MT/HT source DH, insulation label D+, geothermal heat
	S2f	MT/HT source DH, insulation label D+, geothermal heat - everywhere
S3 – LT DH	S3a	LT source DH, insulation label B+, 30°C
	S3b	LT source DH, insulation label B+, 70°C
	S3c	Thermal storage LT source DH, insulation label B+, 70°C
	S3d	Thermal storage LT source DH, insulation label B+, 50°C
	S3e	Thermal storage + surface water LT source DH, insulation label B+, 70°C
	S3f	LT source DH, insulation label D+, 70°C
	S3g	Thermal storage LT source DH, insulation label D+, 70°C
	S3h	Thermal storage + surface water LT source DH, insulation label D+, 70°C
S4 – Green gas	S4a	Green gas with hybrid heat pump, insulation label B+
	S4b	Green gas with HR boiler, insulation label B+
	S4c	Green gas with hybrid heat pump, insulation label D+
	S4d	Green gas with HR boiler, insulation label D+
S5 – Hydrogen	S5a	Hydrogen with hybrid heat pump, insulation label B+
	S5b	Hydrogen with HR boiler, insulation label B+
	S5c	Hydrogen with hybrid heat pump, insulation label D+
	S5d	Hydrogen with HR boiler, insulation label D+

It is assumed that for 2030, strategies 4 and 5 are not robust enough for widespread deployment (van Polen et al., 2020). The most important results presented in the 'Startanalyse' are the head indicators, provided in Table 2, which are calculated per neighbourhood per strategy. These indicators are also standard Vesta MAIS outputs. Of these head indicators, the following are deemed the most important; H01 indicates expected energy demand per housing equivalent per year (GJ) H16 describes the extra national costs for implementing a strategy (€). H17 indicates the extra national costs per mitigated tonne of CO_2 (€/t CO_2). Extra national costs is the amount of money a certain strategy will cost society more compared to doing nothing. With these indicators, the 'Startanalyse' can provide information about in which neighbourhoods a DH system is the strategy with the lowest national costs. This allows for choosing the right neighbourhoods to perform the analysis on since it is assumed that municipalities choose the strategy with the lowest costs. This is also represented in a lot of heat transition plans made by municipalities, which often used the outputs of the 'Startanalyse'.

Table 2: Head indicators from Vesta MAIS and the 'Startanalyse'

Head-Indicator	Description	Unit
H01	Total energy demand	GJ / house * year
H02	Special heating demand	GJ / house * year
H03	Hot tap water demand	GJ / house * year
H04	Ventilation demand	GJ / house * year
H05	Cooling demand	GJ / house * year
H06	Appliances demand	GJ / house * year
H07	Total energy demand	100 kJ / m^2 * year
H08	Total energy input	GJ / house * year
H09	Natural gas input	GJ / house * year
H10	Green gas input	GJ / house * year
H11	Electricity input	GJ / house * year
H12	MT heat sources input	GJ / house * year
H13	LT heat sources input	GJ / house * year
H14	Balance ambience heat	GJ / house * year
H15	CO_2 emissions	Mg / year
H16	Extra national costs	€ / year
H17	Extra national costs	€ / tonne CO_2 avoided
H18	Extra national costs	€ / house * year
H19	Value green gas	€ / m^3
H20	Availability green gas	-

2.3 Monte Carlo uncertainty analysis

To better understand uncertainties and to evaluate the effects of these uncertainties, the results from the scenario analysis are evaluated by conducting a Monte Carlo analysis of the Excel extension @Risk, developed by Palisade (Palisade, n.d.). Using a Monte Carlo analysis, probability distribution functions (PDFs) are defined for uncertain input parameters. PDFs "explain the range of potential values of a given variable and the likelihood that different values represent the true value" (Mcmurray et al., 2017). PDFs can be represented graphically as distributions, of which common examples are the normal (Gaussian), triangular and lognormal distributions, which are shown in Figure 4.

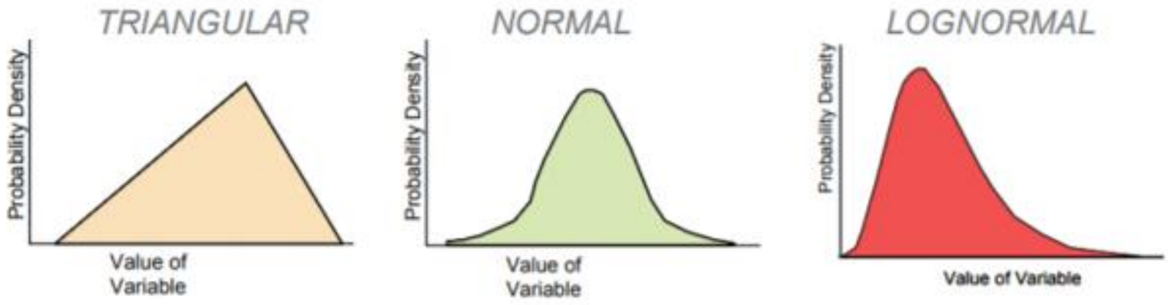

Figure 4: Uncertainty distributions (Mcmurray et al., 2017)

When uncertainty is small and symmetric around the mean, the normal distribution is the most appropriate distribution. The triangular distribution is the most appropriate when it is known what the upper and lower limits of the distribution are and when it is known what the preferred/most occurring value is. Triangular distributions can be symmetrical around the mean, but can also be asymmetrical.

When there are large uncertainties for a non-negative value, the lognormal distribution can be the most appropriate distribution. The Lognormal distribution is skewed and not symmetrical (Mcmurray et al., 2017). Table 3 gives the required information / settings for the three probability distributions.

Table 3: Required information per probability distribution

Probability distribution	Required information / settings
Normal	• Mean • Standard deviation
Triangular	• Minimum value • Most likely value • Maximum value
Lognormal	• Mean • Standard deviation • Mode • Maximum

Using @Risk software, a target cell (the NPV output) is calculated with thousands of iterations, where the software chooses random values for all uncertain parameters each iteration (Palisade, n.d.). This results in a probability distribution for the target cell, which can be used to make statements about the range of outcomes in a certain confidence interval. These probability distributions of the target cell can be used for risk assessment for investment projects (Platon & Constantinescu, 2014). The process of using probability distribution inputs resulting in a probability output and confidence interval is visualised in Figure 5.

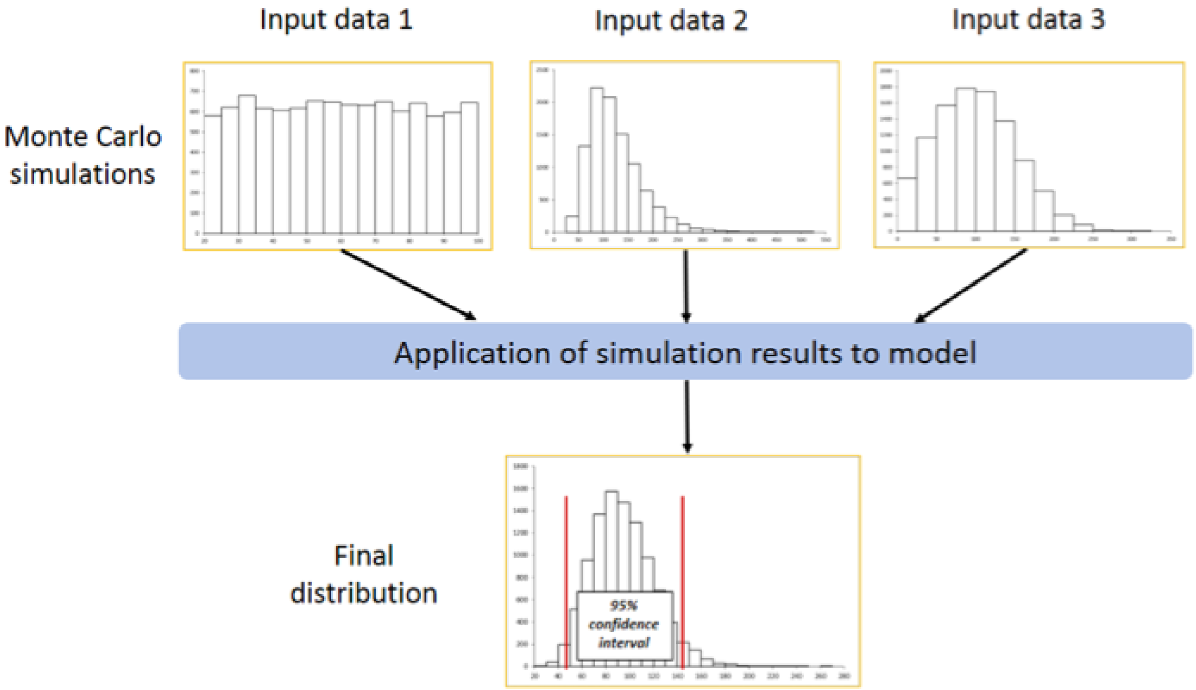

Figure 5: Illustration of the Monte Carlo approach (Mcmurray et al., 2017)

Next to the probability distribution for the target cell, the Monte Carlo analysis also provides figures indicating the influence of the uncertain input variables on the target cell. Useful output figures are the tornado diagram and the spider diagram. The tornado diagram evaluates how much each uncertain input parameter affects the result when the other input variables are kept constant. This provides insights into which parameters have the most influence on the output and might require further consideration (Raha, 2021). The spider diagram shows the change in the output as a result of percentile changes in the input variables.

Therefore, the Monte Carlo analysis provides more in-depth results, not only giving an outcome value but a range and probability distribution for values. This allows for a better analysis of the influence of uncertain variables on the model output. It is important, however, to keep in mind potential interdependencies between variables when choosing the parameters to conduct the uncertainty analysis. Some variables might be dependent on other variables, which means changing the probability distribution of one, also changes the distribution for the other. If interdependency is not carefully taken into account, the results of the Monte Carlo analysis might be less reliable.

3. Methodologies

This section describes the methods used to conduct the research and answer the research question properly. First, a general description of the method and the conceptual model of this thesis is given in section 3.1. Then, the research approach and detailed steps taken in this research are discussed (section 3.2). In section 3.3, it is explained how the business case is calculated. This chapter ends with a paragraph dedicated to time scope, data collection and ethical concerns (section 3.4).

3.1 Conceptual model

Figure 6 shows how the concepts explained in the previous chapter work together to answer the research question: '*How does a change in heat demand for DH systems due to competing heat strategies influence the business case of new HT DH systems in the Netherlands?*'. To answer the research question, first a research area needs to be identified and a reference scenario is calculated (SQ1). Following this, policies that may influence the business case are identified and scenarios are created (SQ2). Then, these scenarios are analysed and a Monte Carlo analysis and a sensitivity analysis

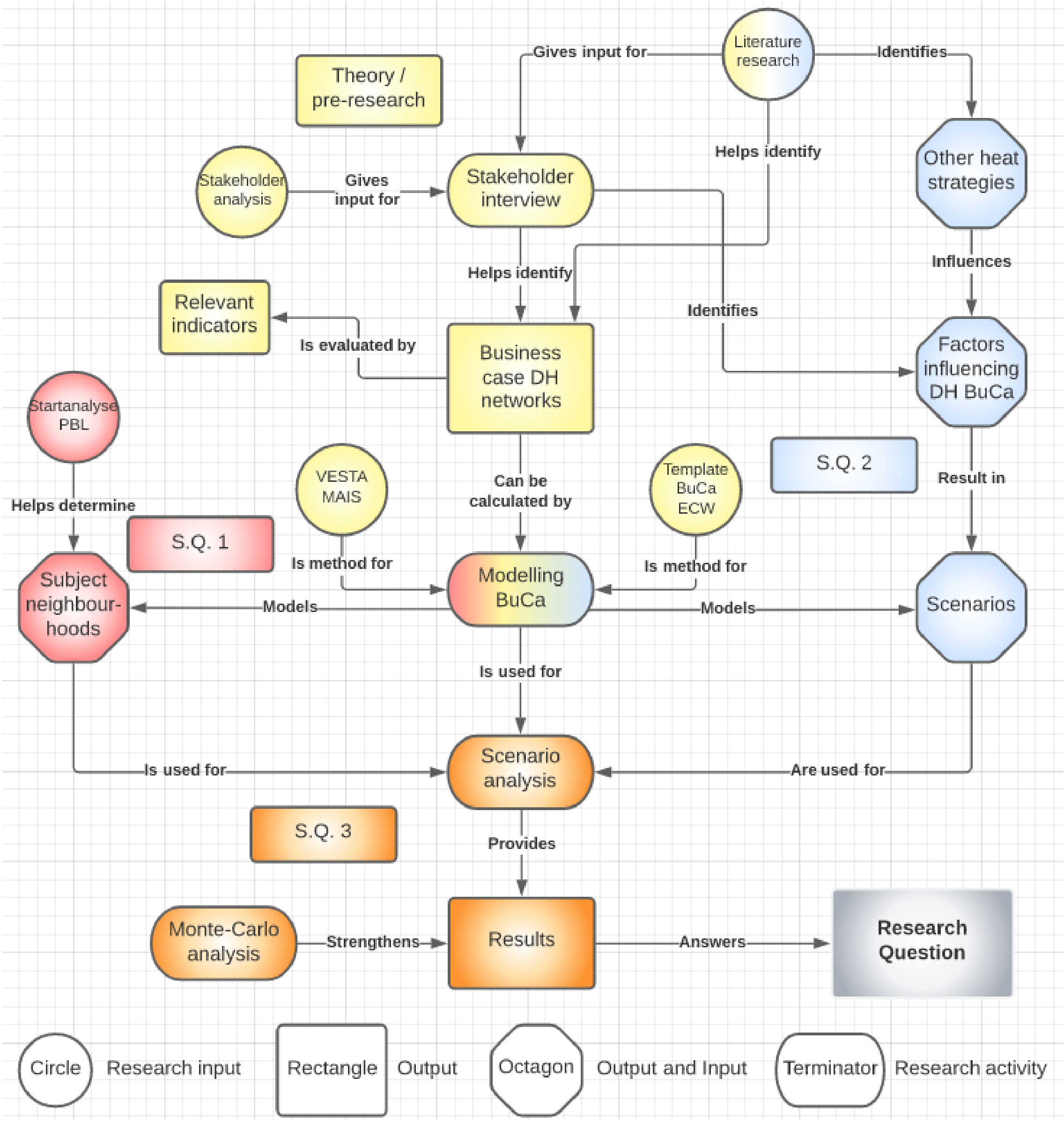

Figure 6: Conceptual model for the methodology used during this Thesis. The colours correspond to the different sub-questions (own work).

is conducted on each scenario. The research is divided into 4 phases; the yellow parts pertain concepts used for pre-research and theory, the red parts for sub-question 1, the blue parts for sub-question 2 and the orange parts for sub-question 3, which altogether leads up to answering the research question: *'How does a change in heat load for DH systems due to competing heat strategies influence the business case of new MT DH systems for DH companies in the Netherlands?'.*

3.2 Research approach

The following concrete research steps were taken to ensure this thesis' completion and the answering of the research question. Section 3.2.1 describes the steps associated with sub-question 1, sections 3.2.2 the steps associated with sub-question 2 and section 3.2.3 the steps associated with sub-question 3.

3.2.1 Sub-Question 1: Relevant neighbourhoods and reference scenario

1. Identify relevant neighbourhoods where DH is most interesting (S.Q.1)

The first step was identifying subject neighbourhoods to conduct the analysis. To select suitable neighbourhoods, the results from the 'Startanalyse' from PBL is used. It is evaluated what the extra national costs are for every sustainable heat strategy on the neighbourhood level. This was used to determine neighbourhoods where a MT DH system (Strategy 2) is the option with the lowest extra national costs. Although whether or not a DH system will be developed in a neighbourhood is dependent on various other factors, it is assumed that the cheapest strategy will be implemented in a neighbourhood.

The choosing process relies on one crucial assumption: *It is assumed that the neighbourhoods where the difference in extra national costs between the DH strategy and the second least costly strategy is the largest are the neighbourhoods where a DH system is most likely to be developed*. Or in equation form:

$$Likely\ neighbourhood = Max\colon \Delta Extra\ national\ costs(Strategy_2 - Strategy_{second\ best})$$

Since the green gas and hydrogen strategies are not deemed robust by 2030, only the 1.5 billion cubic meters variant of the green gas strategy was taken into account, while hydrogen was not taken into account (van 't Wout, 2021). Some neighbourhoods showed zero extra national costs for a sustainable heat strategy or had data missing. These neighbourhoods are dropped from the choosing process since having some strategies calculated as zero extra national costs interfered with the analysis method for choosing the best neighbourhoods.

When the neighbourhoods are chosen, it is also evaluated what the most likely heat source is for the chosen area. Information about the neighbourhoods is gathered and the potential DH system is designed using Google Maps and Kadaster. Using these tools, estimates of lengths of different types of pipes and substations are made. To create a realistic DH system, the following guidelines were maintained:

- Pipes try to follow roads as much as possible
- It is designed so that the number of pipes should be minimised
- There is one heat transfer station to transfer the heat from the heat source to the DH network
- There are substations to divide the heat from the primary pipe towards the secondary pipes leading into the neighbourhoods. Each neighbourhood has one substation unless the neighbourhood is too large for one substation (ECW, 2020).

2. Learn how to calculate the business case of DH networks
    a. From a national cost point of view (Vesta MAIS)
    b. From DH company's point of view (Template Business case ECW)

The next step was to learn how to properly use the modelling tools Vesta MAIS and the Template Business case to perform the analysis. Vesta MAIS is an advanced modelling tool with a steep learning curve. The creators of the model estimate it takes 20 to 30 working days to fully master the program (van den Wijngaart, n.d.). Vesta MAIS outputs the extra national costs of the scenarios for the chosen neighbourhood. The extra national costs of a scenario can be used to compare the DH system with other sustainable heating strategies. Although whether a DH system is developed in an area is dependent on more factors, this can be used to make prediction about where municipalities will choose to develop DH systems. The template is used to evaluate whether a DH system is an efficient investment from the DH company's point of view.

3. Calculate the reference scenario i.e. the business case under the current assumptions and strategy with the lowest national costs as calculated by PBL (S.Q.1)

The next step was to model the business case for the subject neighbourhoods without assuming a change in heat load due to competing heat strategies or shell improvement. This reference scenario is called scenario 0, as it is built on current assumptions and gives an idea of how the business case would look like if a DH system would now be implemented in the subject neighbourhoods. The alterations made in Vesta MAIS to perform the analysis are described in section 4.2. The data inputs for the business case template from ECW are given in Tables 8 and 9 in section 4.3 and are explained in detail in Appendix B.

Vesta MAIS performs as a black box and outputs the extra national costs per scenario with complicated model calculations. How the business case is calculated using the template, is described in section 3.3.

3.2.2 Sub-Question 2: Other sustainable heating strategies and scenario creation

4. Identify other heat strategies and evaluate how this might change the assumptions under scenario 0 (S.Q.2)
    a. Create scenarios based on policy instruments and behaviours that stimulate the heat transition

To evaluate the effects the sustainable heating strategies mentioned in Section 2.1.6 have on the business case of new MT DH systems in the Netherlands, it needs to be translated into scenarios. This is done by evaluating which parameters in the business case template and VESTA MAIS can be altered to represent the effects described. These scenarios are then analysed and compared to the reference scenario in sub-question 3. Scenario analysis is defined as “a process of examining and evaluating possible scenarios that could take place in the future and predicting the results or possible outcomes of these scenarios” (CFI, 2022).

As can be seen in Figure 3, alternative sustainable heating options influence the number of people willing to connect to a DH system. In the Template Business Case DH networks, this can be reflected by altering the participation rate of the neighbourhoods. This participation rate is defaulted at 100% but can be altered to evaluate the effects of fewer people connecting to the DH network on the business case of the new MT DH system.

In Vesta MAIS, it is not possible to evaluate the effects of a lower participation rate on the extra national costs for a strategy. Vesta MAIS calculates the extra national costs on a neighbourhood level and assumes that the neighbourhood as a whole follows a strategy, meaning that a participation rate of 100% is always assumed for every strategy. Therefore, the following workaround is created.

The most important indicator from Vesta MAIS is H17, the extra national costs of a strategy per tonne of avoided CO2. To simulate the effects of a lower participation rate on H17 using Vesta MAIS outputs, it needs to be known how H17 is built up and how the participation rate affects the components of H17. Equations 2 to 5 describes how H17 is built up (Hoogervorst et al., 2020).

$$(\text{eq. }2)\ \text{H17} = \text{H16} / \text{CO}_2\text{avoided}$$

$$(\text{eq. }3)\ \text{H16} = \text{K10} + \text{K18} = \sum \text{K1} - \text{K9}\ (\text{capital costs}) + \sum \text{K11} - \text{K17}(\text{variable costs})$$

It is assumed that the amount of CO2 avoided scales linearly with the participation rate, as can be seen in equation 4.

$$(\text{eq. }4)\ \text{CO}_{2,\text{new}} = \text{CO}_{2,\text{old}} * \text{Participation rate}$$

Table 4 describes components K1 – K18 and indicates whether or not it is assumed that these costs are affected by the participation rate. For the components that are assumed to be influenced by the participation rate, it is assumed that these scale in a linear way with the participation rate. This is described in equation 5.

$$(\text{eq. }5)\ \text{Kn}_{\text{new}} = \text{Kn}_{\text{old}} * \text{Participation rate}$$

Table 4: Cost components of the Vesta MAIS results and whether they are affected by participation rate

Component code	Description	Unit	Affected by participation rate?
K01	Costs for strengthening the electricity grid	€/year	No
K02	Costs for removing the gas grid	€/year	Yes
K03	Costs for adjusting the gas grid	€/year	No
K04	Costs for heat distribution neighbourhood	€/year	No
K05	Costs for heat distribution dwelling	€/year	Yes
K06	Costs for heat transport	€/year	No
K07	Costs for heat sources	€/year	No
K08	Costs for envelope measures	€/year	No
K09	Costs for installations	€/year	Yes
K10	Sum of capital costs	€/year	-
K11	Heat costs	€/year	Yes
K12	Gas costs	€/year	Yes
K13	Electricity costs	€/year	Yes
K14	O&M buildings	€/year	Yes
K15	O&M DH network	€/year	No
K16	O&M gas and electricity grid	€/year	No
K17	Total variable costs	€/year	-
K18	Total extra variable costs	€/year	-

K18 is calculated by subtracting the variable costs when doing nothing from the variable costs of the strategy, because in the situation with a lower participation rate, a part equal to (1-participation rate) does nothing. Therefore, the variable costs of this part of the neighbourhood not participating in the DH network need to be accounted for and are added to the variable costs of the strategy to gain an as accurate K18 as possible. Next, H17 is recalculated using the updated values for the Kn components that were affected by a lower participation rate and the new amount of avoided CO2. This way the effects of a lower participation rate on the extra national costs of the scenarios can be evaluated.

Shell improvement lowers the energy demand per connection, as is depicted in figure 3. In the Template Business Case DH networks, the effects of shell improvement can be simulated in several ways. In the template, there is a parameter 'autonomous heat demand reduction' which represents the lowering in heat demand over time to correct for a warmer climate and factors like change in behaviour or insulation. This is defaulted at 0.35% per year (PBL, 2021), but can be increased to represent more building owners insulating their buildings. Another way to simulate the effect of shell improvement is by using heat demand numbers from either S2a or S3 of the 'Startanalyse'. The current heat demand numbers per neighbourhood are taken from S2d in the 'Startanalyse', where it is assumed all buildings insulate to label D or better. In S2a and S3, it is assumed that all buildings insulate to label B or better. Using the demand numbers from S2a or S3 would therefore reflect the effect of all buildings insulating from label D to B has on the business case of the new MT DH system. The last way the effects of shell improvement can be simulated is by lowering the current energy demand numbers by a certain percentage. For this thesis, the effects of higher insulation (label B instead of D) are taken for the scenario analysis, as this reflects a plausible, real scenario. The energy demand figures are taken from Vesta MAIS, by evaluating the MT DH demand output (H12) from strategy S2a, where all houses are insulated to label B.

In Vesta MAIS, the effects of better insulation can be evaluated by running the model using strategy S2a instead of S2d, while keeping all other input parameters, as defined in sub-question 1, the same.

The resulting scenarios are given in Chapter 5. Here, it is also explained how the values for participation rate and heat demand were determined.

3.2.3 Sub-Question 3: Calculating the new scenarios and uncertainty + sensitivity analysis

5. Calculate the new business case under these scenarios using Vesta MAIS and the Business case template (S.Q.3)

The next step was to recalculate the business case for DH systems in the subject neighbourhood for each scenario. This was done in the same way scenario 0 was calculated, using Vesta MAIS and the Template Business case as described in section 3.3. The Vesta MAIS results are used to evaluate whether, in a new scenario, a DH system is still the option with the lowest national costs. When that is not the case, the chances are high that there will not come a DH system in that neighbourhood. The business case template results are used to evaluate the business case in the different scenarios. The results from the scenarios are then compared to the reference scenario to draw conclusions.

6. Perform Monte Carlo analysis on uncertain parameters

After all scenarios were calculated, a Monte Carlo uncertainty analysis was conducted using uncertain parameters and variables. The following input parameters are defined as uncertainties and therefore require further investigation using the Monte Carlo analysis:

- Heat purchase price
- Heat sale price
- Infrastructure cost of main distribution network, primary pipes and secondary pipes

  - Length
  - Costs per meter
- Costs for sub-stations
  - Amount of substations
  - Costs per substation

Section 7.1 elaborates on why these parameters are deemed uncertain. Table 28 in section 7.2 summarises the PDF settings used for the uncertain parameters. This includes the type of distribution, the assumed confidence intervals and the settings regarding mean, std deviation, maximum, minimum and most likely value.

7. Conduct sensitivity analysis on important parameters

The tornado and spider diagram outputs of the Monte Carlo analysis show the magnitude of influence uncertain parameters have on the resulting NPV. For the parameters deemed as influential by the outcomes of the Monte Carlo analysis, a separate sensitivity analysis is conducted. With a sensitivity analysis, the influence of a variable on the result is analysed by imposing a (percentile) change on that variable, while all other parameters remain the same (Saltelli, 2002). For this thesis, a percentile change of -20% to +20% is evaluated.

Another correlation that is researched is the correlation between the heat revenue per unit of heat (heat sale price – heat purchase price) and the heat demand for different IRR values. This results in a figure where for different IRR values, it can be observed what the minimum combination of heat demand and revenue is.

3.3 Calculating the Business Case

This section describes the mathematical equations used to calculate the total costs and benefits for the business case of DH systems, using the components as described in sections 2.1.5.

The yearly costs are a sum of the heat costs, the depreciation costs and the operation and maintenance costs. Equation 6 describes the total costs. Equations 7 to 9 describes the individual components of the total costs.

$$(eq. 6)\ C_{total} = C_{heat} + C_{depreciation} + C_{O\&M}$$

The heat costs are the sum of the demands of all the connections multiplied by the purchase price of heat, plus the costs of the heat transportation from the source to the DH network.

$$(eq. 7)\ C_{heat} = \sum_{i=1}^{n} D_{heat,i} * P_{heat,purchase} + C_{transportation}$$

The depreciation costs are the sum of all made (infrastructure) investments, so the different types of pipes and substations, and all complementary equipment like delivery sets and measure equipment.

$$(eq. 8)\ C_{depreciation} = \sum_{i=1}^{n} \frac{I_i}{Lifetime_i}$$

The O&M costs are the sum of all the O&M costs, which are expressed as a percentage of the investments in the different parts of the DH system. These are things like pipes, heat transfer stations and installations.

$$(eq. 9)\ C_{O\&M} = \sum_{i=1}^{n} I_i * C_{O\&M,i}$$

The benefits of a DH system for a DH company consist of the income from selling heat to end-users, plus a one-off contribution for connecting to the DH network, described by equation 10. Equations 11 and 12 describe the individual parts of equation 10.

$$(eq. 10)\ B_{total} = B_{heat} + B_{one-off\ contributions}$$

The benefits of selling heat consist of a fixed and variable component. The variable component is dependent on the amount of heat sold per connection. The fixed component consists of a fixed rate plus the income from the rental of delivery sets and measuring equipment. The one-off contributions are contributions made by building owners for connecting to the DH network. These contributions often differ for ground-bound dwellings, stacked dwellings, collective connections and utility connections.

$$(eq. 11)\ B_{heat} = \sum_{i=1}^{n} (D_{heat,i} * P_{heat,sold} + P_{fixed})$$

$$\begin{aligned}(eq. 12)\ B_{one-off\ contributions} &= n_{g.b.} * Contr_{g.b.} + n_{stacked} * Contr_{stacked} + n_{collective} * Contr_{collective} \\ &+ n_{utility} * Contr_{utility} +\end{aligned}$$

Other factors also influence the business case. For instance, it is possible to fill in vacancy rates to better replicate the true situation. The heat demand declines with the vacancy rate. Heat losses are calculated as extra heat purchased for the DH company, resulting in extra costs.

3.4 Time scope, data collection and ethical concerns

This section elaborates on the time scope of this thesis, the type of data used for this thesis and what ethical concerns are present. This thesis researches a potential future MT DH system. For this thesis, it is assumed that the development of the DH system starts in 2023 and that the exploitation length is 30 years. This results in a time scope of 2023 – 2053. During this research, different types of data are used. Through literature research, scientific literature about heat strategies, business models of DH networks and other heat strategies that might influence DH networks will be obtained, mostly through Google Scholar. To get a good view of the business case and relevant indicators for the business case, a semi-structured interview with a DH company was conducted. Note that this interview was used to gain a quick image of how DH companies operate and make investment decisions. The (Dutch) transcript of the interview is given in Appendix D. Reports from governmental agencies or advisory bodies about heat strategy and potentials were gathered to specify parameters and input for the models and scenarios. To select neighbourhoods to analyse, the 'Startanalyse' from PBL was used. Furthermore, newspaper articles and parliament letters about the heat law and -transition were used to get more background information about the subject. This way, all relevant aspects of the DH networks and the heat market are taken into account. For the models used to calculate the business case, data and parameters from the database of PBL were used, combined with outcomes from literature research and publicly available papers.

Most data that was used is openly available and thus does not require specific handling. Vesta MAIS and the Template Business case both contain large data sets and key figures which are publicly available. The semi-structured interviews were not used to gather sensitive company information, but in advance of the interview, permission was asked to record the interview and to use the company's name. It is not expected that confidentiality or other ethical issues will arise.

4. S.Q. 1 – Research area and Reference Scenario

'What is the business case of new DH systems in a neighbourhood in the Netherlands where a DH system is likely to be developed without considering the impact of other competing strategies or shell improvements on heat demand?'

4.1 Research case areas selection

This section elaborates on the selection of neighbourhoods for the analysis as described in the method section.

4.1.1 Selected neighbourhood

The first result of this sub-question is the selected neighbourhood. Figure 7 gives the difference between strategy 2 and the second-best option for neighbourhoods where strategy 2 was the cheapest option. This is analysed both in an absolute (€/tCO_2 avoided) as a relative cost difference, with the absolute difference compared to the second-best option on the X-axis and the relative amount the DH strategy is cheaper than the second-best option on the Y-axis.

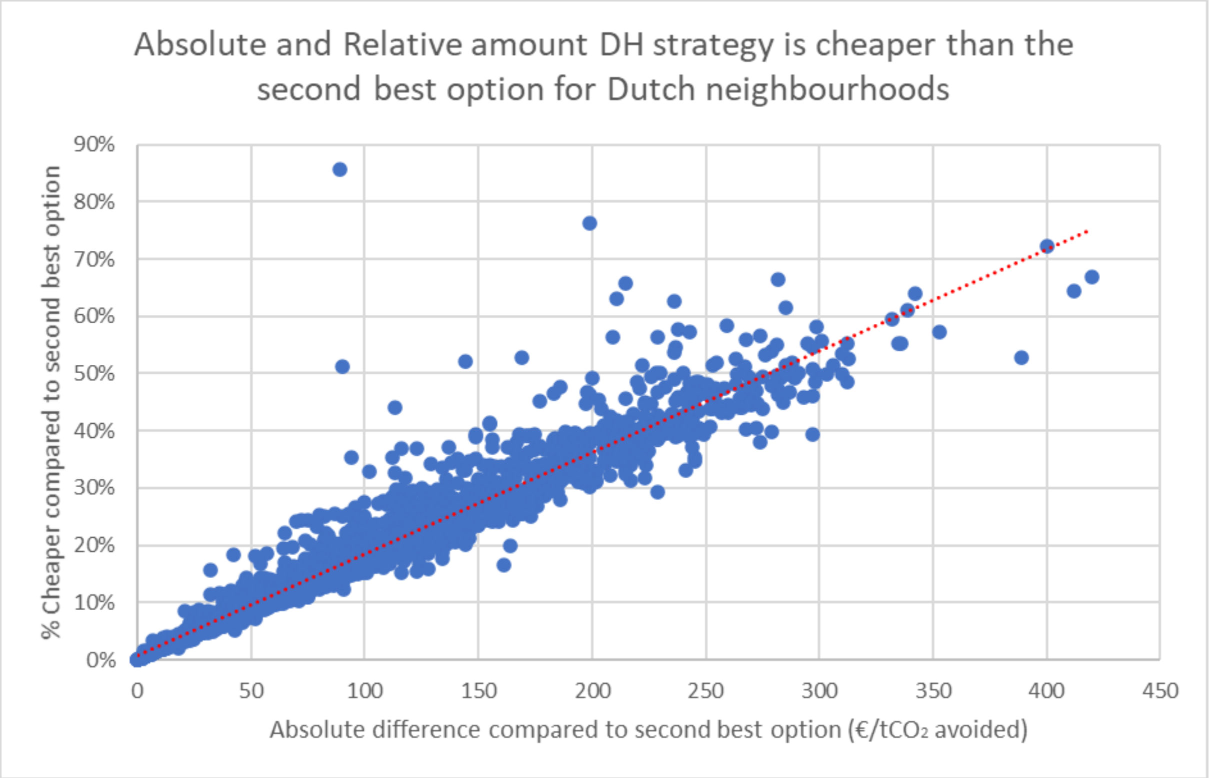

Figure 7: Relative and absolute differences between S2 and the cheapest alternative for neighbhourhoods in the Netherlands with S2 as the strategy with the lowest nation costs

In Figure 7, the neighbourhoods that are most to the top and the right are assumed to likely be subject for the development of a MT DH system in the future. This is because these neighbourhoods have the largest absolute and/or relative difference in extra national costs compared to the second-best strategy. When all neighbourhoods that are located in the top two rows (>70% cheaper than the alternative) and the most right two columns (>350 €/tCO_2 cheaper than the alternative) are considered, seven neighbourhoods are left to choose from. This is shown in figure 8. Table 5 summarises these neighbourhoods.

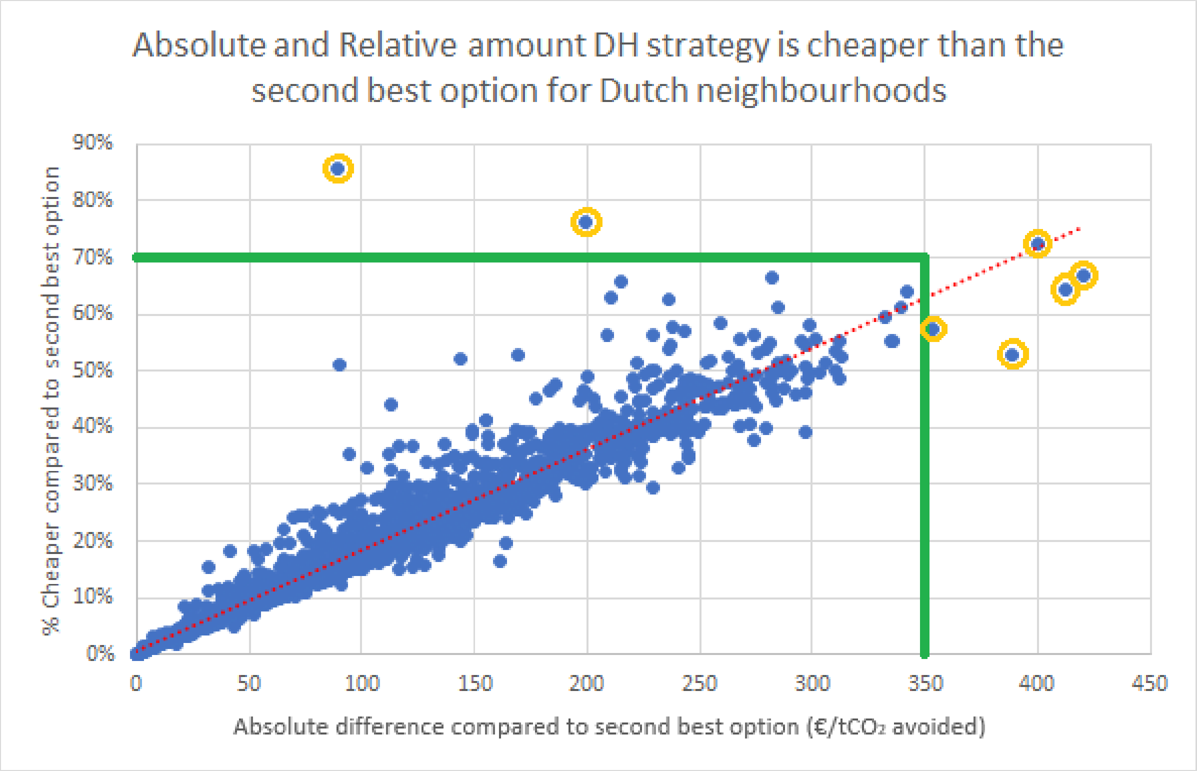

Figure 8: Relative and absolute differences between S2 and the cheapest alternative for neighbhourhoods in the Netherlands with S2 as the strategy with the lowest nation costs. Showcasing the most extreme points

Table 5: Names and data of the most extreme points from Figure 8

Neighbourhood Code	City	District	€/tCO₂ avoided			
			S2	Next best	Δ Abs	Δ Rel
BU05032505	Delft	Wijk 25 Buitenhof	209	639	420	67%
BU05032506	Delft	Wijk 25 Buitenhof	227	616	412	64%
BU03633303	Amsterdam	Oostelijk Havengebied	153	553	400	72%
BU06420509	Zwijndrecht	Wijk 05 Kort Ambacht	348	737	389	53%
BU05032503	Delft	Wijk 25 Buitenhof	263	595	353	57%
BU04390502	Purmerend	Wijk 05 Purmer-Noord	62	261	199	76%
BU17110528	Echt-Susteren	Wijk 05 Echt	15	104	89	86%

As can be seen in Table 5, three of the seven best neighbourhoods are in the city of Delft and all those neighbourhoods are in the same district of the city. Table 6 gives the ‘Startanalyse’ outcomes for all neighbourhoods in the district ’Wijk 25 Buitenhof’. Of the eleven neighbourhoods in the district, six neighbourhoods have a MT DH system as the sustainable heat alternative with the lowest extra national cost. The size of the neighbourhood is expressed in housing equivalents. Each dwelling in a neighbourhood equals one housing equivalent and every 130 m^2 of utility area in a neighbourhood counts as one housing equivalent (Hoogervorst et al., 2020)

Table 6: 'Startanalyse' Outcomes for all neighbourhoods in District 25 'Buitenhof' in Delft

Code	Name	Housing eq.	Strategy	S2 vs Next strategy	
				Abs ↓	Rel
BU05032505	Het rode dorp	522	S2d	420	67%
BU05032506	Pijperring	360	S2d	412	64%
BU05032503	Gillisbuurt	665	S2e	353	57%
BU05032501	Buitenhof-Noord	1940	S2d	306	51%
BU05032504	Fledderusbuurt	545	S2d	285	61%
BU05032502	Juniusbuurt	573	S2d	235	42%
BU05032508	Vrijheidsbuurt	761	S4d	-123	-37%
BU05032507	Verzetsstrijdersbuurt	1191	S4d	-227	-77%
BU05032509	Buitenhof-Zuid	311	S3a	-20	-4%
BU05032500	Reinier de Graafbuurt	910	S3h	-61	-24%
BU05032510	Kerkpolder	81	S1a	-159	-15%

The area to analyse will consist of the six neighbourhoods in Delft where a MT DH system is the strategy with the lowest extra national costs. Reasons why these neighbourhoods have relatively low extra national costs can be because of favourable heat sources or existing DH systems in the vicinity and because of a high building density and many stacked buildings (*Beschrijving Buitenhof | Gemeente Delft*, n.d.). The area these neighbourhoods cover in Delft is shown in figure 9. Table 7 summarizes the used neighbourhoods with some characteristics and gives some properties of the combined area.

Table 7: Neighbourhoods in 'Buitenhof' with S2 as the strategy with the lowest extra national costs

Code ↓	Name	Housing eq.	Area (ha)	Heat demand S2d (GJ/Heq)	Total heat demand (GJ)
BU05032501	Buitenhof-Noord	1,940	32	27	52,380
BU05032502	Juniusbuurt	573	16	23	13,179
BU05032503	Gillisbuurt	665	11	28	18,620
BU05032504	Fledderusbuurt	545	17	27	14,715
BU05032505	Het rode dorp	522	11	24	12,528
BU05032506	Pijperring	360	10	26	9360
Total	**Buitenhof**	**4,605**	**97**	**26.23**	**120,782**

Figure 9: Neighbourhoods in Delft. The green outlined neighbourhoods are the subject neighbourhoods

When analysing the heat plan of the municipality Delft, it can also be concluded that the chosen neighbourhoods are likely to be subject for a DH system and have a high priority. This can be seen in Figure 10. All these points lead to the conclusion that a MT DH system will likely be developed in these neighbourhoods in the future. This makes it a suitable area to analyse to answer the research question.

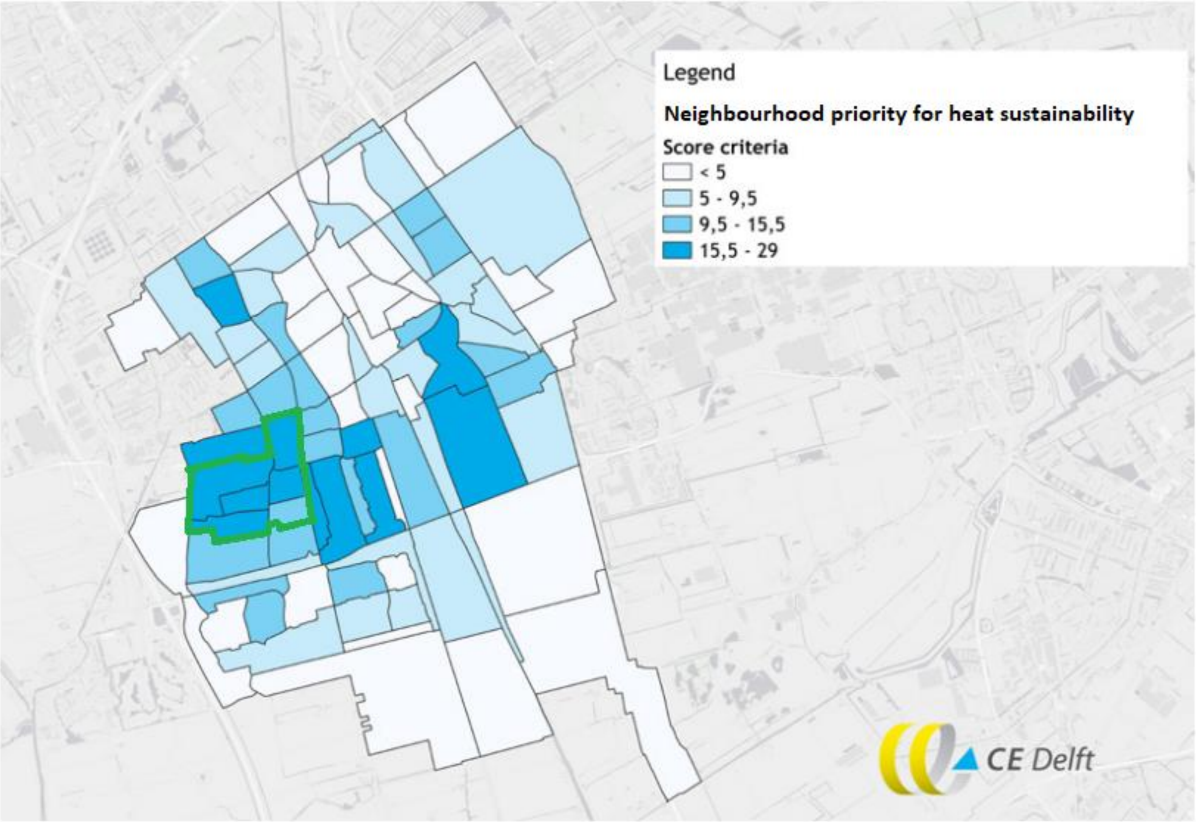

Figure 10: Priority for heat sustainability in Delft. Source: heat transition vision Delft

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4.1.2 heat sources and grids for selected case areas

This section elaborates on the existing DH systems in the vicinity of the chosen area, as well as potential heat sources. It also describes the design of the potential DH system in the neighbourhoods.

There currently already exist DH networks in and around Delft. Figure 11 shows the DH systems that are already present in Delft (purple colour), and the newly to be developed DH system (red lines). It can be seen that it lies next to an existing one, with the Julniusbuurt already having a DH network, on which 37% of the dwellings are connected (Hoogervorst et al., 2020), making it possible to connect the DH systems.

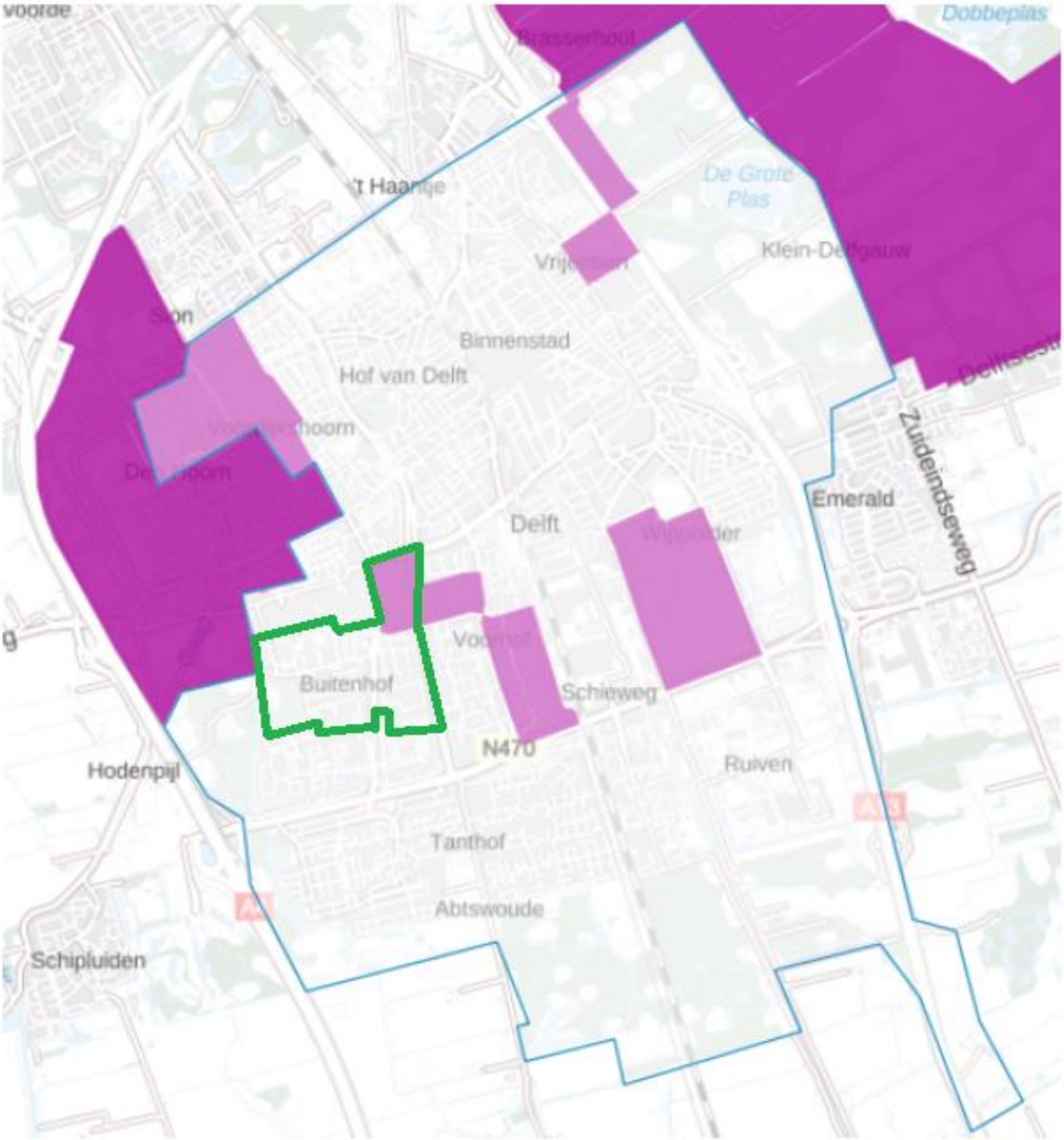

Figure 31: Existing DH systems in and around Delft

The heat source for the existing DH systems is a large chemical company North of Delft, DSM, with 11.25 MW of residual heat capacity (van der Molen et al., 2021) and is large enough to connect the new neighbourhoods on. However, there are plans to create the so-called 'Warmterotonde' (heat roundabout), a transport network for residual heat from the port of Rotterdam to multiple locations in South-Holland, including Delft. This heat network will cross through Delft, as can be seen in Figures 12 and 13**.** The capacity of WarmtelinQ is going to be 248 MW, meaning that this heat source is suitable to supply the heat for the given area in Delft which is going to be analysed (Gasunie, 2021).

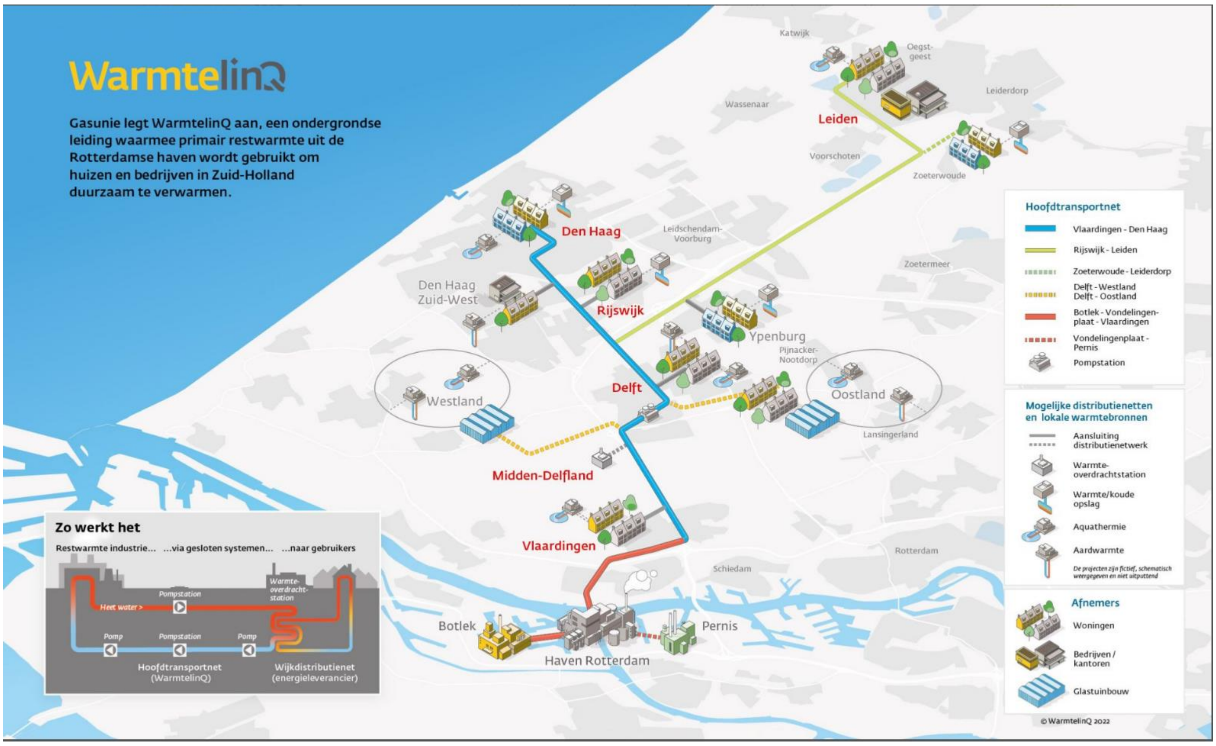

Figure 12: WarmtelinQ heat transportation network through South-Holland (Gasunie, 2021)

Figure 13: View of how the WarmtelinQ heat transportation pipe crosses Delft

For the analysis of the selected neighbourhoods in District 25 'Buitenhof' in Delft, it is therefore assumed that the whole DH network that is going to be analysed will be connected to the WarmtelinQ heat transportation network. *The consequence of this assumption is that there is no need for the development of a new heat source for the DH system. There will be heat purchase costs and extra transportation costs for transporting the heat from the port of Rotterdam to the neighbourhood in Delft.*

The design of the DH system, consisting of the distribution of pipes and heat transfer station and substations as a result of the guidelines given in the research approach section, is given in Figure 14. Note that this is not a professionally made blueprint for the DH network and therefore might not fully represent the reality.

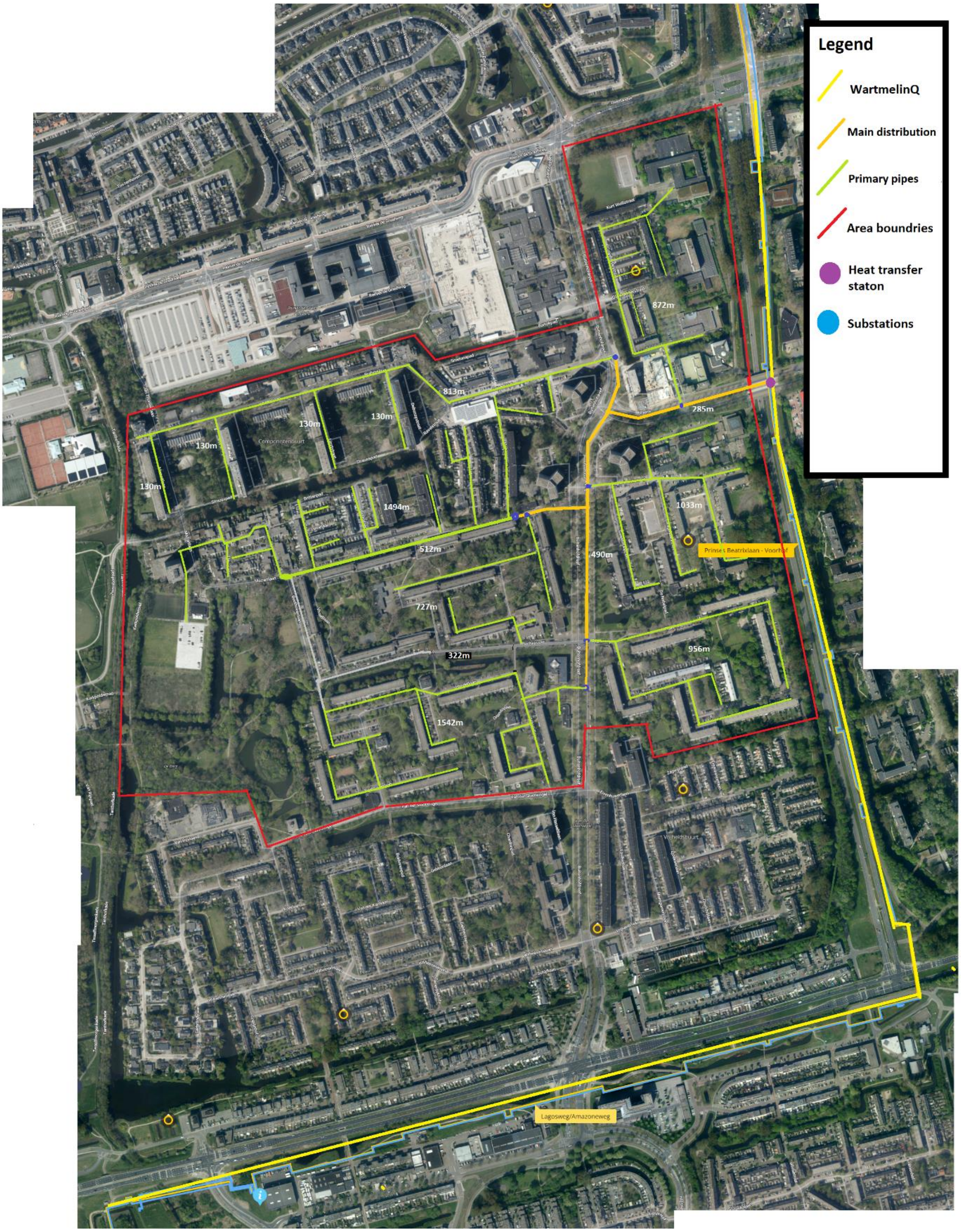

Figure 14: Designed DH system in the selected neighbourhoods in Delft (own work)

4.2 Data inputs for/alterations to Vesta MAIS

The following alterations were made to Vesta MAIS before conducting the analysis in order to get the most accurate results.

- Added WarmtelinQ as a heat source in Vesta MAIS
    - Capacity: 10MW (so that its high enough for our heat area to connect)
    - X: 84050
    - Y: 446200
    - SourceTemp: 80
- Adjusted the amount of available green gas, scaling with the size of the neighbourhoods to be analysed. The scaling was done using the following equation, where the assumption is that for the whole Netherlands, 1.5 billion cubic metres (bcm) of green gas would be available. The data used was the 2021 data and retrieved from allecijfers.nl.

  $$GG_{Heat\ area} = 1.5bcm * \frac{population_{Heat\ area}}{population_{Netherlands}}$$

  This resulted in an availability of 728,309 m^3 of green gas.

- Adjusted study area to only the selected neighbourhoods instead of the whole municipality. Figure 15 shows the study area, as well as the heat sources in that area. WarmtelinQ is the heat source closest to the heat area.

Figure 15 Shows the heat area in Vesta MAIS with the heat source.

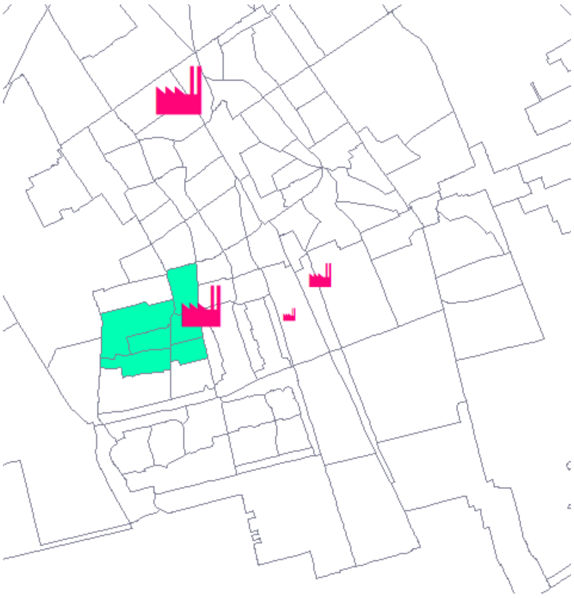

Figure 15: Study area and heat source (Vesta MAIS)

4.3 Techno-economic data inputs for the business case evaluation

This section gives the most important data inputs for the template business case from ECW. Table 8 gives the inputs for the sheet ‘assumptions’, while Table 8 gives the inputs for the sheet ‘numbers and phasing’. Appendix B gives a more elaborate description of how certain parameters are calculated and inserted into the model and how certain assumptions were made. For instance, in Appendix B it is explained that the heat sale and purchase price are based on two different gas prices. The sale price is based on the small consumer gas price in combination with the principle that a DH user cannot pay more than someone who heats their house using natural gas. The heat purchase price is based on the large consumer gas price in combination with information provided by Gasunie. These gas prices differ due to different taxing structures based on the amount of gas usage (Rijksoverheid, 2022c). How the neighbourhoods and connections were inserted into the model, is also described in Appendix B.

4.3.1 Sheet: ‘Assumptions’

Table 8: Input parameter values for the sheet 'Assumptions'

Parameter	Value	Source
Vacancy rate – individual and collective connections	1.70%	CBS, 2021
Vacancy rate – utility	6.5%	CBS, 2021
EIA subsidy – Yes/No	Yes	RVO, 2022
EIA subsidy – amount	20,526,800	Template calculations
Length of pipes – head distribution	1.29 km	Google maps
Length of pipes – primary distribution	8.28 km	Google maps
Length of pipes – secondary distribution	22.93 km	Koster et al., 2022
Heat losses	28%	Koster et al., 2022
Autonomous heat demand reduction	0.35%	PBL, 2021
Discount rate / profit margin	6.80%	Koster et al., 2022
Rates and one-off contributions - individual	Eneco Averages / ACM max	Eneco, 2022 ACM, 2022
Heat sale price (excl. VAT)	26.60 €/GJ	PBL, 2021
Rates and one-off contributions – collective and utility	Eneco Averages / ACM max	Eneco, 2022 ACM, 2022
Costs of pipes – head distribution	1,480,000 €/km	Interpolation using the Template and Koster et al., 2022
Costs of pipes – primary distribution	711,000 €/km	Interpolation using the Template and Koster et al., 2022
Costs of pipes – secondary distribution	414,000 €/km	Interpolation using the Template and Koster et al., 2022
Heat transfer station – costs	€ 910,000	Koster et al., 2022
Primary substations – costs	€ 825,000	Koster et al., 2022
Secondary substations – costs	€ 62,500	Koster et al., 2022
Connections costs – small consumer	€ 4,544	Koster et al., 2022

		Vesta MAIS
Connections costs – stacked connection	€3,302	Koster et al., 2022 Vesta MAIS
Connections costs – collective / utility	€ 22,597	Koster et al., 2022 Vesta MAIS
Heat exchanger – small / stacked connection	€ 1,300	Koster et al., 2022 Vesta MAIS
Heat exchanger – collective / utility	€ 6,844	Koster et al., 2022 Vesta MAIS
Heat meter – small / stacked connection	€ 917	Koster et al., 2022 Vesta MAIS
Heat meter – Collective / utility	€ 1,588	Koster et al., 2022 Vesta MAIS
O&M percentage – head Pipes	1.80%	Koster et al., 2022
O&M percentage – head installations	1.00%	Koster et al., 2022
O&M percentage – heat transfer station	2.70%	Koster et al., 2022
O&M percentage – primary pipes	1.80%	Koster et al., 2022
O&M percentage – primary installations	1.00%	Koster et al., 2022
O&M percentage – primary substations	2.70%	Koster et al., 2022
O&M percentage – secondary pipes	1.90%	Koster et al., 2022
O&M percentage – secondary installations	1.00%	Koster et al., 2022
O&M percentage – secondary substations	2.70%	Koster et al., 2022
O&M percentage – connections	2.00%	Koster et al., 2022
O&M percentage – heat delivery sets and heat meters	2.30%	Koster et al., 2022
Administrative costs	70 €/year/connection	Koster et al., 2022
Purchase price heat	5.60 €/GJ	PBL, 2021
Connection capacities – ground-bound connection	4.18 kW	Template Business Case Vesta MAIS
Connection capacities – stacked connection	2.70 kW	Template Business Case Vesta MAIS
Indexing	2.00%	Template Business Case

4.3.2 Sheet: 'Numbers and Phasing'

Table 9: Input parameter values for the sheet 'Numbers and Phasing'

Parameter	Value	Source
Start year	2023	-
Exploitation length	30 years	Template Business Case
Connection speed	Calculated	-
Heat demand – Buitenhof Noord	27 GJ/Housing equivalent/year	Vesta MAIS calculation
Heat demand – Juniusbuurt	23 GJ/Housing equivalent/year	Vesta MAIS calculation

Heat demand – Gillisbuurt	28 GJ/Housing equivalent/year	Vesta MAIS calculation
Heat demand – Fledderusbuurt	27 GJ/Housing equivalent/year	Vesta MAIS calculation
Heat demand – het Rode dorp	24 GJ/Housing equivalent/year	Vesta MAIS calculation
Heat demand – Pijperring	26 GJ/Housing equivalent/year	Vesta MAIS calculation
Lifetime – Head pipes	30 years	Koster et al., 2022
Lifetime – Primary pipes	30 years	Koster et al., 2022
Lifetime – Secondary pipes	30 years	Koster et al., 2022
Lifetime – CAPEX remaining	20 years	Koster et al., 2022
Lifetime – Connections	30 years	Koster et al., 2022
Lifetime – Heat exchanger + delivery sets	15 years	Koster et al., 2022
Lifetime – heat meters	15 years	Koster et al., 2022

4.4 Results

In this section, the results for the reference scenario are given. First, the Vesta MAIS results are given in Table 10. Then, the business case results are provided in Figures 14 to 17 and Table 11.

4.4.1 Vesta MAIS Results

This section elaborates on the results for scenario 0 in Vesta MAIS. Table 10 gives the Vesta MAIS results of the reference scenario, altered as described in section 4.2. All neighbourhoods are emission-free, due to the heat provided being from residual sources. In the calculations of Vesta MAIS, not all energy demand was supplied by the DH system, as for peak demand, still, some green gas is being used and electricity is used for cooking and appliances. The demand is also higher because of heat losses while transporting the heat towards the dwellings. The average extra national cost per tonne of avoided CO2, taking neighbourhood sizes into account, is 239.38 € / t CO2 avoided.

Table 10: Vesta MAIS results for the reference scenario

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	Extra national costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	37	27	0.903	282
Juniusbuurt	41	23	0.198	238
Gillisbuurt	35	28	0.239	217
Fledderusbuurt	38	27	0.155	171
Het rode dorp	33	24	0.145	191
Pijperring	34	26	0.121	218
Total	**-**	**-**	**1.762**	**239.38**

4.4.2 Template Business Case DH networks Results

In this section, first, general scenario-unspecific results of the business case are presented, followed by the financial, reference scenario-specific results. As can be seen in Figure 16, around 4,200 connections are realised in this project, most of which are stacked dwellings. Ground-bound connections and collective connections also make up a significant part of the connections, while utility connections only make up a small part of the total amount of connections.

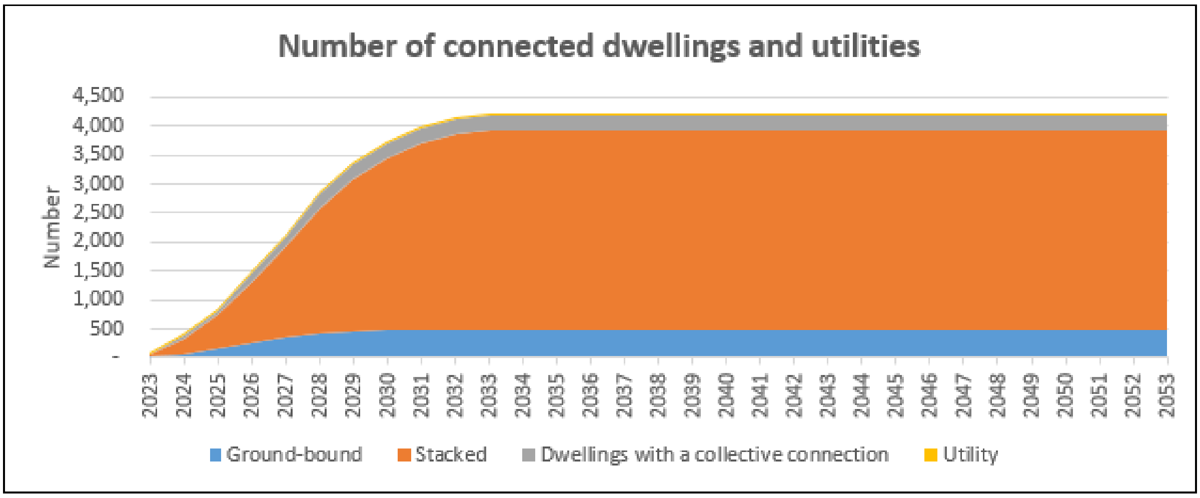

Figure 16: Connection types and speed for the designed DH system

Figure 17 shows the CAPEX investments made over the years and the cost recovery contributions (CRC) and connection contributions (CC) made. As can be seen, the investments are the largest in the first four years of the project, as the DH system is still being developed then and neighbourhoods are still being connected. The green positive bars represent the connection contribution building owners pay the DH company. As these are paid to the DH company, this results in incomes and therefore positive bars. After the initial investments, a couple of years follow in which no investments are necessary. Starting from 2039, re-investments are needed to replace the heat exchangers and metering equipment in dwellings, as they only have a lifetime of 15 years.

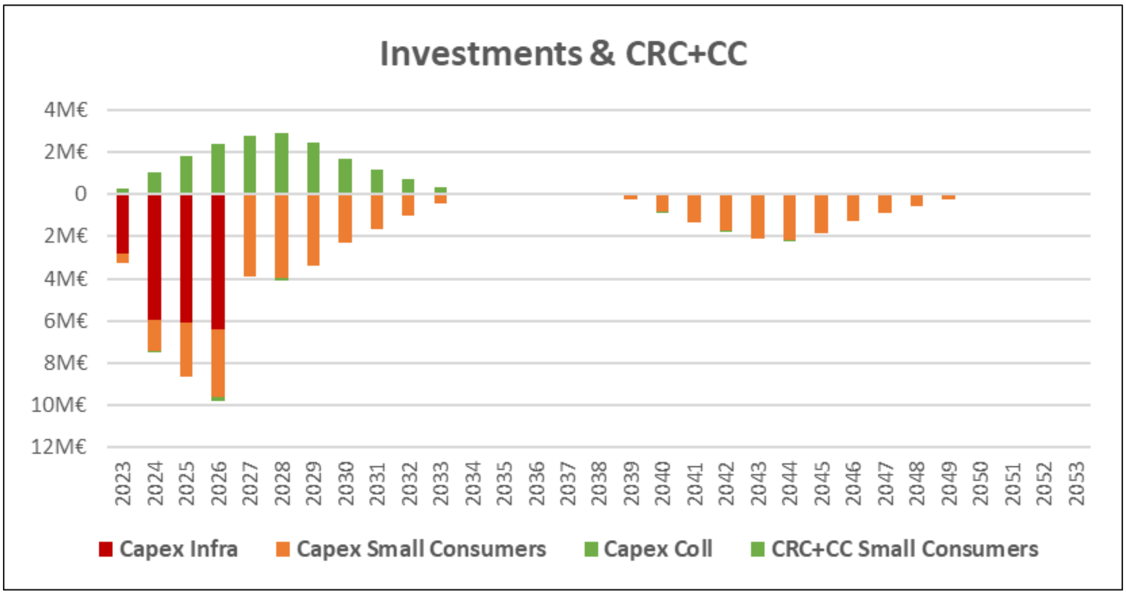

Figure 17: CAPEX investments and cost recovery contributions + connection contributions over the lifetime of the project

The yearly (variable) benefits and costs for the project are given in Figure 18. As can be seen, both the yearly benefits and the yearly costs grow each year. This grow in costs and benefits is mainly attributed to the rising of heat purchase and sale price, and the rising of operation and maintenance costs.

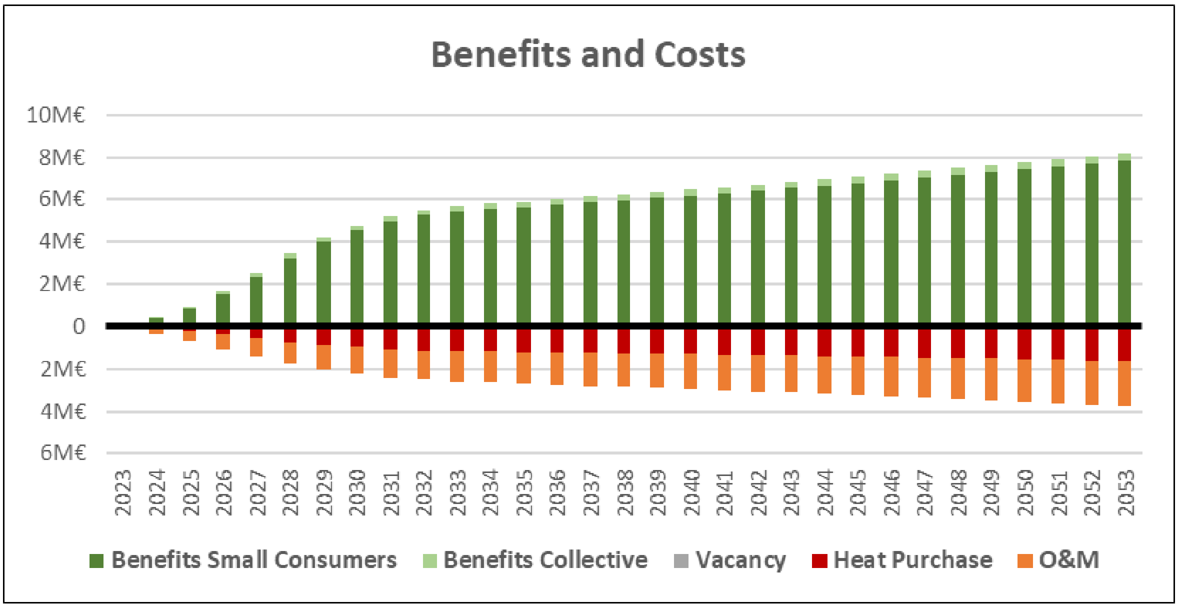

Figure 18: Yearly benefits and Costs over the lifetime of the project

Figure 19 presents the cash flow overview during the lifetime of the project. It shows in the first five years strong negative cashflows, as the DH network is still being developed then. After 14 years, the investments are paid back and the cumulative cash flow is positive.

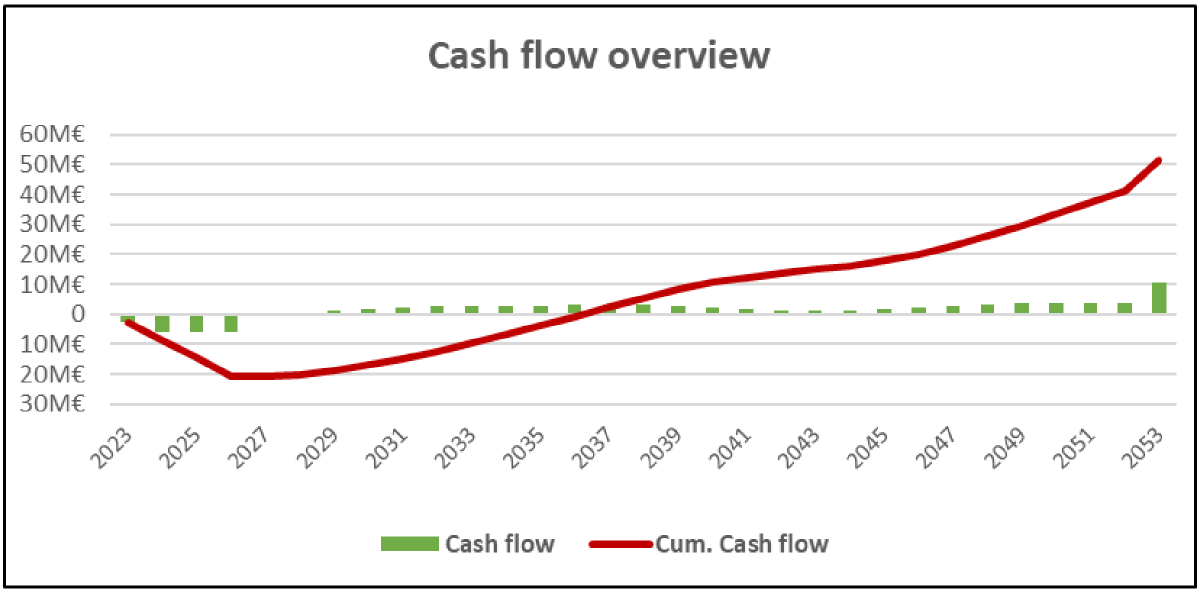

Figure 19: Cash flow overview for the reference scenario

When the DH system is inserted in the template as described in section 4.1 and 4.2, the business case is positive. To acquire a project return which is equal to the required project return (6.80%), there is a negative cost recovery contribution of -5.11 M€. This means that users of the DH system can *theoretically* gain a collective discount of € 5.11 million in total or around € 1,293 per connection, and the business case would still be positive.

Table 11 gives the most important indicators for the calculated business case. It presents investment numbers like the gross investment that is necessary to develop the DH system, the cost recovery contribution to make the IRR the same as the required rate of return, the connection contributions paid by building owners and the net investment that the DH company needs to make. It also presents financial indicators like the IRR, NPV and PBP. From this table, it can be seen that when the DH company does not give a discount on costs in the form of a negative cost recovery contribution, the project rate of return is 8.24% and the NPV is 3,7 M€. This indicates a positive business case.

Table 11: Most important indicators of the business case in the reference scenario

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 43.9	M€ 43.9
Cost recovery contribution	M€ -5.1	€ 0
Connection contributions	M€ 16.3	M€ 16.3
Net investment	M€ 32.8	M€ 27.6
IRR	6.80 %	8.23 %
NPV	€ 0	M€ 3.7
PBP	15 years	14 years

4.4.3 Summary SQ1

In this chapter, the first sub-question: “*What is the business case of new DH systems in a neighbourhood in the Netherlands where a DH system is likely to be developed without considering the impact of other competing strategies or shell improvements on heat demand?*” was answered. To answer the sub-question, first, six neighbourhoods from the district ‘Buitenhof’ in Delft were chosen to do the analysis on. Next, the extra national costs for implementing a MT DH system in these neighbourhoods were determined. This resulted in the average extra national costs of 239.38 €/tonne of avoided CO2. Using the business case template, it was determined that in this reference scenario, the business case is **positive**, with an NPV of 3.7 M€ and an IRR of 8.23%.

5. S.Q. 2 – Competing heat strategies and Scenario creation

'What are the potential changes in heat demand due to the implementation of other heat strategies?'

5.1 Input assumptions for the scenarios

For assuming realistic participation rates, Dutch policies are investigated. The Dutch government stimulates the deployment of hybrid heat pumps in a way that by 2030, around 1 million hybrid heat pumps should have been deployed to houses and buildings (Techniek Nederland, 2022). As there currently are around 8 million households in the Netherlands, this will be around 12% (CBS, 2022)). To make this into a scenario, a decline in participation rate of 15% is assumed. DH companies usually consider a 70% participation rate as the lowest possible rate for a DH project to be efficient (Gemeente Utrecht, 2021). Therefore, a 70% participation rate is also taken as an assumption for a scenario. This results in three variants for participation rate: 100% (default), 85% and 70%.

As described in the method section, for the insulation levels there are two variants assumed. These are label D energy demands and label B energy demands. Using Vesta MAIS, the demand figures were calculated. These are given in Table 12. As can be seen, in some neighbourhoods the heat demand drops by around 20%, while for other neighbourhoods the demand only drops slightly. This is probably because these neighbourhoods already have a relatively high amount of insulated buildings, or have less ground-bound connections. In total, the heat demand for the scenarios drops from an average of 26.23 GJ / housing eq. to 22.31 GJ / housing eq., a drop of 14.9%.

Table 12: Label D and label B heat demands per neighbourhood. Data taken from Vesta MAIS calculations

Code	**Name**	**Housing eq**	**Label D demand (GJ / Housing eq)**	**Label B demand (GJ / Housing eq)**
BU05032501	Buitenhof-Noord	1,940	27	23
BU05032502	Juniusbuurt	573	23	22
BU05032503	Gillisbuurt	665	28	22
BU05032504	Fledderusbuurt	545	27	23
BU05032505	Het rode dorp	522	24	20
BU05032506	Pijperring	360	26	22
Total	**Buitenhof**	**4,605**	**26.23**	**22.31**

5.2 Resulting scenarios

This sub-question aimed to answer the question "*What are the potential changes in heat demand due to the implementation of other heat strategies?*". By investigating other sustainable heating strategies, scenarios were created to reflect these potential changes in heat demand. Table 13 provides an overview of the scenarios, which answers the sub-question. There are three variants in participation rate and two variants in heat demand, resulting in, including scenario 0, six total scenarios.

Table 13: Overview of the created scenarios

Scenario	**Participation rate**	**Heat demand**
0	Default (100%)	Default (label D demand)
1	85%	Default (label D demand)
2	70%	Default (label D demand)
3	Default (100%)	Label B demand
4	85%	Label B demand
5	70%	Label B demand

6. S.Q. 3 – Scenario analysis

'How and to what extent is the business case of the DH system in the subject neighbourhood influenced by the change in heat load?'

6.1 Results per scenario

In this section, the results per scenario are presented. First, the results of the analysis using Vesta MAIS are presented, followed by the results of the analysis using the Template Business Case DH systems. In section 6.2, the results are compared to Scenario 0 and the sub-question is answered.

6.1.1 Vesta MAIS scenario results

6.1.1.1 Scenario 1

When the participation rate for the DH system drops to 85%, the avoided CO2 emissions drop as well, resulting in net CO2 emissions. Next to CO2 emissions, having a lower participation rate also results in higher extra national costs. Although the capital costs for the DH system are lower for society due to lower in-building costs, the extra variable costs, and resulting total extra national costs, are higher. This has to do with the way the extra variable societal costs are calculated, as this is the difference between the variable costs when implementing a strategy and the variable costs when doing nothing. Because the variable costs when doing nothing are higher than the variable costs when a DH system is deployed, and because when the participation rate for the DH system drops it is assumed that these non-participating buildings do nothing, the extra variable costs rise when the participation rate drops.

This lower CO2 reduction in combination with higher extra national costs results in a higher extra national cost per tonne of avoided CO2. In this scenario, the weighted average of the extra national costs per tonne of avoided CO2 for implementing a DH system is 292.02 € / t CO2 avoided. The results per neighbourhood are given in Table 14.

Table 4: Vesta MAIS results for Scenario 1

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	CO2 emission (Mg/Year)	National costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	37	27	480.24	0.927	341
Juniusbuurt	41	23	124.24	0.208	294
Gillisbuurt	35	28	165.61	0.248	265
Fledderusbuurt	38	27	136.50	0.165	214
Het rode dorp	33	24	114.09	0.152	235
Pijperring	34	26	83.73	0.127	268
Total	**-**	**-**	**1,104.24**	**1.827**	**292.02**

6.1.1.2 Scenario 2

When the participation rate drops further, to 70%, the CO2 emissions increase. For the same reason as with Scenario 1, the extra national costs also increase. Due to less CO2 avoided and higher costs, the extra national costs per tonne of avoided CO2 for the whole DH system increases to 367.25 € / t CO2 avoided. Table 15 provides the results per neighbourhood.

Table 5: Vesta MAIS results for Scenario 2

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	CO2 emission (Mg/Year)	National costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	37	27	960.48	0.952	425
Juniusbuurt	41	23	249.22	0.218	375
Gillisbuurt	35	28	330.15	0.257	333
Fledderusbuurt	38	27	273.00	0.175	275
Het rode dorp	33	24	228.18	0.159	298
Pijperring	34	26	167.46	0.133	339
Total	**-**	**-**	**2,208.48**	**1.892**	**367.25**

6.1.1.3 Scenario 3

In Scenario 3 the participation rate is the most optimal (100%), but houses are insulated to label B instead of label D. In this situation, there are zero CO2 emissions as in the reference scenario, but for each of the neighbourhoods the extra national costs are higher due to extra insulation costs. These higher costs lead to higher extra costs per tonne of avoided CO2. Table 16 shows the most important results per neighbourhood and for the heat area in total. The average extra national cost per tonne of avoided CO2 is 454.66 € / t CO2 avoided.

Table 6: Vesta MAIS results for Scenario 3

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	CO2 emission (Mg/Year)	National costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	33	23	0	1.678	524
Juniusbuurt	40	22	0	0.295	355
Gillisbuurt	29	22	0	0.495	450
Fledderusbuurt	34	23	0	0.324	356
Het rode dorp	29	20	0	0.310	408
Pijperring	30	22	0	0.252	452
Total	**-**	**-**	**0**	**3.354**	**455.66**

6.1.1.4 Scenario 4

When next to insulating to label B, the participation rate drops to 85%, the extra national costs increase further, following the same reasoning as in Scenarios 1 and 2. The CO2 emissions increases with the same magnitude as in Scenario 1. The overall extra national cost per tonne of avoided CO2 in this scenario is 548.94 € / t CO2 avoided. The results per neighbourhood are presented in Table 17.

Table 7: Vesta MAIS results for Scenario 4

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	CO2 emission (Mg/Year)	National costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	33	23	480.24	1.708	628
Juniusbuurt	40	22	124.24	0.306	433
Gillisbuurt	29	22	165.61	0.508	543
Fledderusbuurt	34	23	136.50	0.336	434
Het rode dorp	29	20	114.09	0.319	493
Pijperring	30	22	83.73	0.259	546
Total	**-**	**-**	**1,104.24**	**3.435**	**548.94**

6.1.1.5 Scenario 5

In the scenario where the participation rate drops to 70% and the insulation is label B, the national costs increase the most compared to the reference scenario. The CO2 emissions are the same as in Scenario 2 due to the same participation rate. The extra national costs per tonne of avoided CO2 is the highest in this Scenario, with a cost of 682.20 € / t CO2 avoided. Table 18 summarises the most important results of this scenario per neighbourhood.

Table 8: Vesta MAIS results for Scenario 5

Name	Energy demand (GJ/House*Year)	Input MT DH (GJ/House*Year)	CO2 emission (Mg/Year)	National costs (M€)	National costs (€ / t CO2 avoided)
Buitenhof-Noord	33	23	960.48	1.739	776
Juniusbuurt	40	22	249.22	0.316	544
Gillisbuurt	29	22	330.15	0.520	675
Fledderusbuurt	34	23	273.00	0.347	545
Het rode dorp	29	20	228.18	0.328	615
Pijperring	30	22	167.46	0.266	680
Total	**-**	**-**	**2,208.48**	**3.515**	**682.20**

6.1.2 Template Business Case scenario results

6.1.2.1 Scenario 1

When the DH system is inserted in the template in the same way as described for scenario 0, except that the participation rate is changed from 100% per neighbourhood to 85% per neighbourhood, the business case is positive, as the IRR is higher than the required project return. In figure 20, the cash flows and cumulative cash flows of this scenario are presented. It can be observed that when no cost recovery contribution is asked from building owners, the investment is paid back in 15 years. In this case, the IRR of the project is 7.07%, which is higher than the required 6.80%.

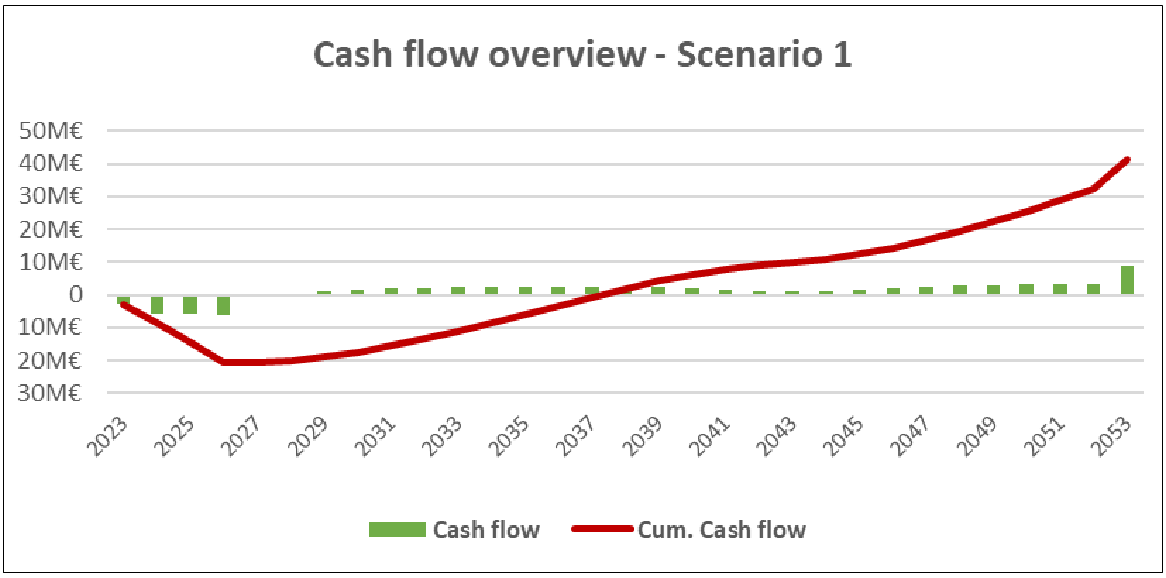

Figure 4: Cash flow overview for the business case in Scenario 1

When no cost recovery contribution is asked, the project has an NPV of 0.672 M€. To make the NPV zero, the DH company could give a discount of 0.92 M€ in total or € 272 per connection to make the IRR the required 6.80%. If this would be done, the investment would still be paid back in 15 years. Table 19 summarises the most important financial indicators of Scenario 1.

Table 9: Business case indicators for Scenario 1

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 40.6	M€ 40.6
Cost recovery contribution	M€ -0.923	€ 0
Connection contributions	M€ 13.9	M€ 13.9
Net investment	M€ 27.6	M€ 26.7
IRR	6.80%	7.07%
NPV	€ 0	M€ 0.672
PBP	15 years	15 years

6.1.2.2 Scenario 2

When the participation rate is lowered to 70% for Scenario 2, the business case becomes negative. This shows that for the participation rate alone, the minimum to gain a positive business case is somewhere between 70% and 85% when everything is as described in sections 4.1 and 4.3. In this scenario, the IRR is 5.75%, which leads to the investments being paid back in 16 years, which is still before the end of the lifetime of the project. Figure 21 shows the cashflows and cumulative cash flow in this scenario.

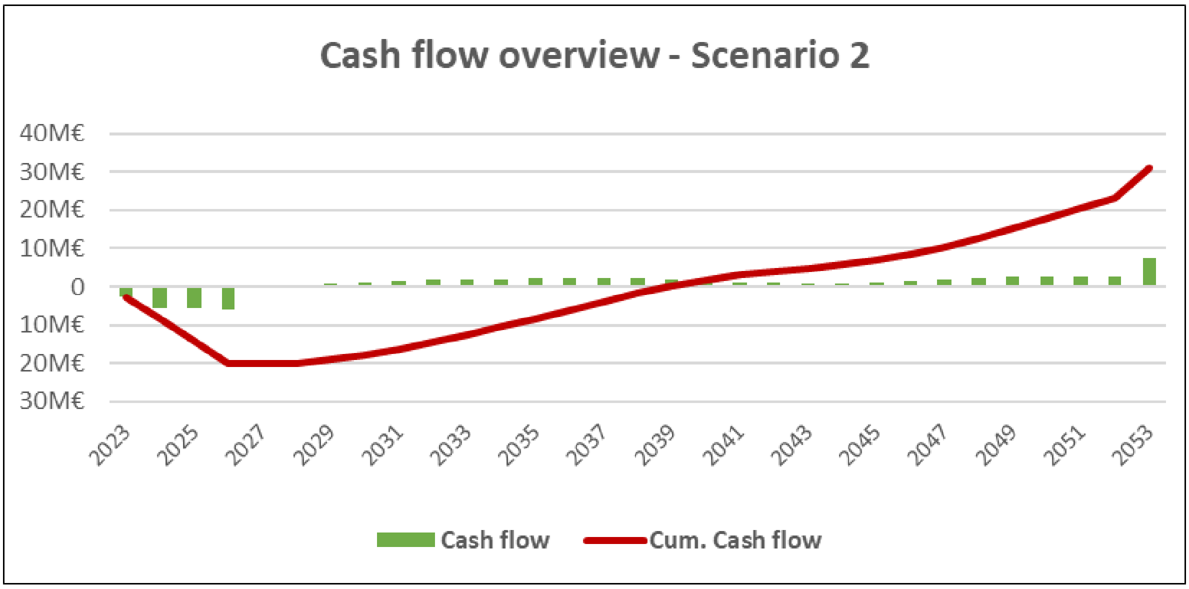

Figure 5: Cash flow overview for the business case in Scenario 2

The NPV in this scenario without a cost recovery contribution is -2.43 M€, meaning the DH company makes almost 2.5 million less profit than needed to achieve the required IRR. If the DH company wants to make the IRR the same as the required project return, a cost recovery contribution of 3.31 M€ in total or around €1,200 per connection would be necessary. Table 20, summarises the most important financial results of Scenario 2.

Table 10: Business case indicators for Scenario 2

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 37.2	M€ 37.2
Cost recovery contribution	M€ 3.31	€ 0
Connection contributions	M€ 11.4	M€ 11.4
Net investment	M€ 33.5	M€ 25.8
IRR	6.80%	5.75%
NPV	€ 0	M€ -2.44
PBP	15 years	16 years

6.1.2.3 Scenario 3

If the assumed heat demand per neighbourhood changes from the label D assumption value to the label B assumption value, the business case is positive. It is slightly less positive compared to Scenario 1, with an IRR of 7.00% and a payback period of 15 years. Figure 22 shows the cashflows and cumulative cash flow of this scenario.

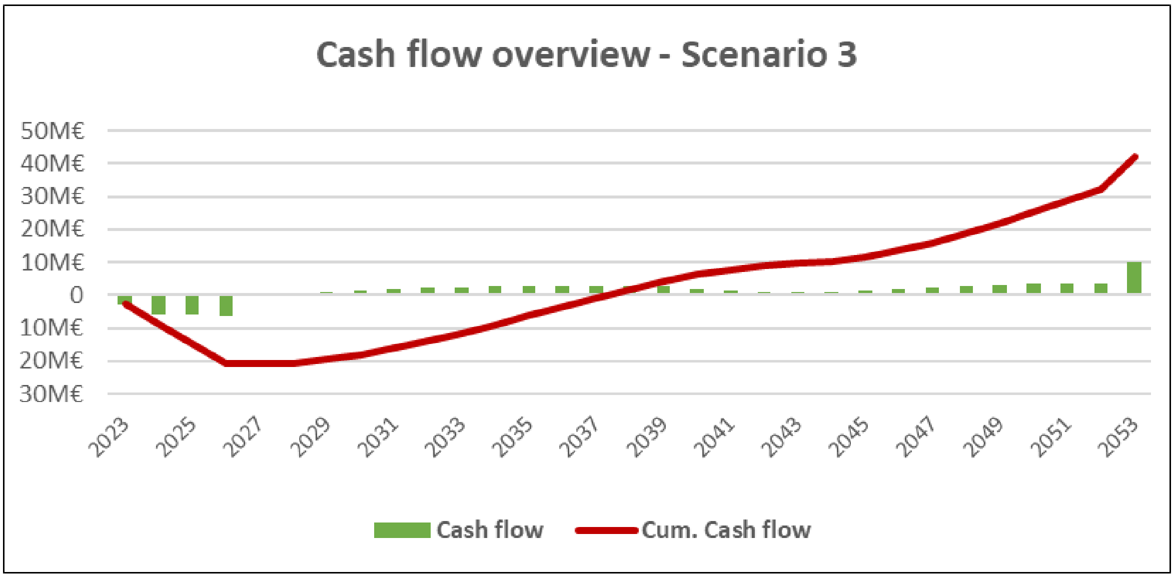

Figure 6: Cash flow overview for the business case in Scenario 3

Without a cost recovery contribution, the NPV of the project under the assumptions of Scenario 3 becomes 0.502 M€. If the NPV would become zero, and therefore also an IRR equal to the required project return, a cost recovery contribution of € -0.685 M€ in total or € -173 per connection would be necessary. This means that in this scenario, the DH company could give building owners a discount on their connection contribution. The most important financial results are summarised in Table 21.

Table 11: Business case indicators for Scenario 3

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 43.9	M€ 43,9
Cost recovery contribution	M€ -0.685	€ 0
Connection contributions	M€ 16.2	M€ 16.2
Net investment	M€ 28.4	M€ 27.7
IRR	6.80%	7.00%
NPV	€ 0	M€ 0.502
PBP	15 years	15 years

6.1.2.4 Scenario 4

When next to the lowered heat demand assumption, also a lower participation rate of -15% is assumed, the business case is negative, but the initial investment will still be paid back in 16 years. In this scenario, the project has an IRR of 5.90% and an NPV of -2.15 M€. The cashflows and cumulative cash flow for this scenario are given in Figure 23.

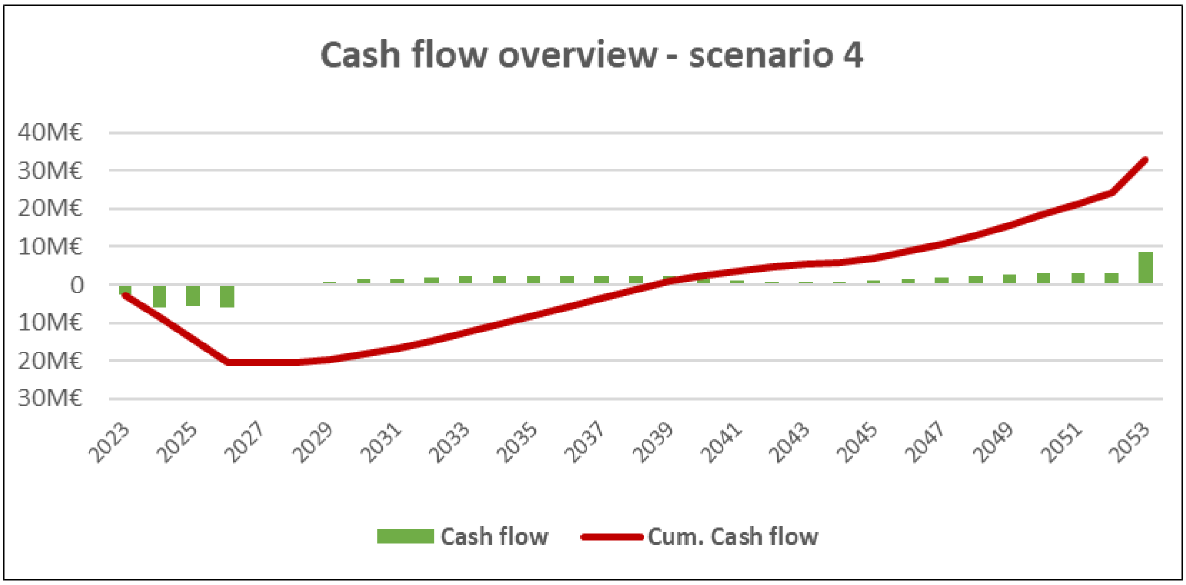

Figure 7: Cash flow overview for the business case in Scenario 4

To make the NPV zero and the IRR the same as the required project return, a cost recovery contribution of 2.93 M€ in total or € 870 per connection is necessary. If this would be done, the investment would be paid back after 15 years. The most important indicators of Scenario 4 are given in Table 22.

Table 12: Business case indicators for Scenario 4

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 40.6	M€ 40.6
Cost recovery contribution	M€ 2.93	€ 0
Connection contributions	M€ 13.8	M€ 13.8
Net investment	M€ 23.8	M€ 26.7
IRR	6.80%	5.90%
NPV	€ 0	M€ -2.15
PBP	15 years	16 years

6.1.2.5 Scenario 5

If both the most negative assumption about participation rate (70%) and the assumption of label B heat demand are active, the business case would be the most negative of all the scenarios. In this scenario, the IRR is 4.65% if no cost recovery contribution is asked by the DH company. This positive IRR still leads to the investment being paid back before the end of the project lifetime, namely after 19 years. Figure 24 shows the cashflows in this scenario.

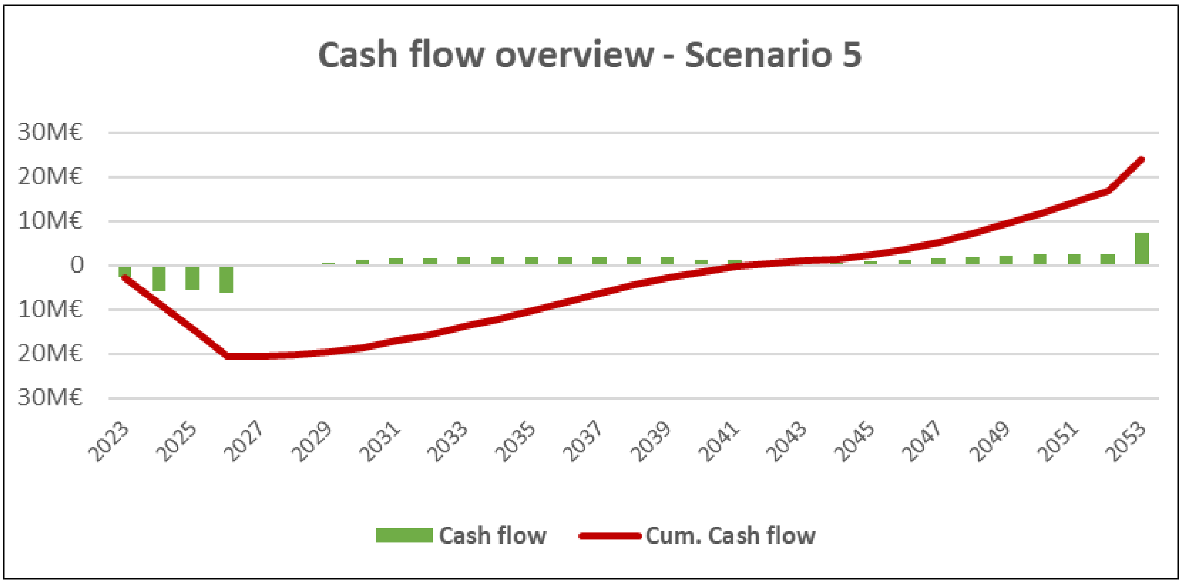

Figure 8: Cash flow overview for the business case in Scenario 5

With a cost recovery contribution of 6.57 M€ in total or € 2,367 per connection, the business case would be made positive for the DH company, as then the IRR equals the required project return. Although the DH company in this scenario still makes a profit on the project, it is not as high as it needs to be to meet the required return. Therefore it has an NPV of -4.82 M€. Table 23 summarises the most important results of Scenario 5.

Table 13: Business case indicators for Scenario 5

Indicator	Result – Cost recovery	Result – No cost recovery
Gross investment	M€ 37.2	M€ 37.2
Cost recovery contribution	M€ 6.57	€ 0
Connection contributions	M€ 11.4	M€ 11.4
Net investment	M€ 19.2	M€ 25.8
IRR	6.80%	4.65%
NPV	€ 0	M€ -4.82
PBP	15 ears	19 years

6.2 Result Summary and Comparison with Reference Scenario

This section aimed to answer the sub-question: “*How and to what extent is the business case of the DH system in the subject neighbourhood influenced by the change in heat load?”.* In this section, the results from all scenarios, including the reference scenario, are summarised and reflected on. First, the Vesta MAIS results are summarised and compared, followed by the template business case results.

6.2.1 Vesta MAIS result comparison

Table 24 summarises the most important Vesta MAIS results from the scenarios. These are the CO2 emissions, the extra national costs (H16) and the extra national costs per tonne of avoided CO2 (H17). The costs per tonne of avoided CO2 rises strongly for most of the scenarios, with Scenario 5 being almost three times as expensive per tonne of avoided CO2 compared to the reference scenario.

Table 14: Summary of most important Vesta MAIS scenario results

Indicator	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
CO2 emis (ktonnes)	0	1.10	2.21	0	1.10	2.21
H16 (M€)	1.76	1.83	1.89	3.35	3.43	3.52
H17 (€/t)	239.38	292.02	367.25	455.66	548.94	682.20

To fully understand the Vesta MAIS results and put them in perspective, they must be compared with other sustainable heating strategies. Tables 25 and 26 give the comparison per neighbourhood and in total with the cheapest alternative strategy when green gas is taken into account and when green gas is not taken into account. If a number is green, the extra costs per tonne of avoided CO2 is lower than the cheapest alternative, if red, it is more expensive.

Table 15: Comparison of Vesta MAIS results with cheapest alternative (excl. GG)

Scenario	0	1	2	3	4	5	Cheapest second	H17 score
Buitenhof-Noord	282	341	425	524	628	776	S3h	594
Juniusbuurt	238	294	375	355	433	544	S1a	565
Gillisbuurt	217	265	333	450	543	675	S1a	616
Fledderusbuurt	171	214	275	356	434	545	S3h	464
Het rode dorp	191	235	298	408	493	615	S3f	629
Pijperring	218	268	339	452	546	680	S3h	639
Total	239.38	292.02	367.25	455.66	548.94	682.2	-	585.67

As Table 25 shows, when green gas is not considered a robust option, only in Scenario 5 is the MT DH system not the strategy with the lowest national cost overall. Neighbourhood 1 is the only neighbourhood where also in Scenario 4 the MT DH system is not the option with the lowest national cost. When green gas is considered a robust option in 2030, then only Scenario 1 and the reference scenario are cheaper, as can be seen in Table 26.

Table 16: Comparison of Vesta MAIS results with cheapest alternative (incl. GG)

Scenario	0	1	2	3	4	5	Cheapest second	H17 score
Buitenhof-Noord	282	341	425	524	628	776	S4d	304
Juniusbuurt	238	294	375	355	433	544	S4d	354
Gillisbuurt	217	265	333	450	543	675	S4d	292
Fledderusbuurt	171	214	275	356	434	545	S4d	241
Het rode dorp	191	235	298	408	493	615	S4d	270
Pijperring	218	268	339	452	546	680	S4d	258
Total	239.38	292.02	367.25	455.66	548.94	682.2	-	293.58

Figure 25 visually represents these results. Here the bars are the average extra national costs per avoided tonne of CO2 per scenario and the lines represent the average extra national costs per tonne of avoided CO2 for when the cheapest alternative sustainable heating strategy would be chosen. The red line is for when green gas is excluded as a robust strategy, the green line is when green gas is included. As can be seen, when green gas is excluded, only Scenario 5 is more expensive. When green gas is included, Scenarios 2, 3, 4 and 5 have higher national costs for a MT DH system than the cheapest alternative.

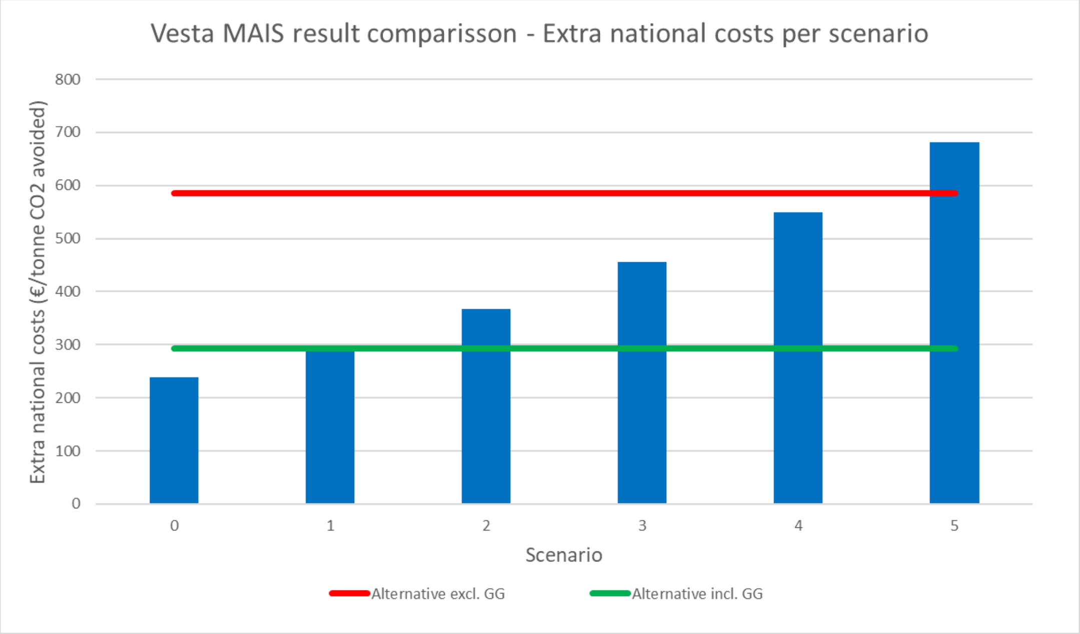

Figure 9: Visual representation of Vesta MAIS scenario result and comparisson with other strategies. Green line is including GG, red line excluding GG

6.2.2 Template Business Case result comparison

Table 27 summarises the most important template results from the Scenarios. Note that the results from the column without the cost recovery contribution are taken, except for the indicator with the amount of cost recovery contribution needed to make the IRR the same as the required project return.

Table 17: Most important business case results for the scenarios

Indicator	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
IRR	8.23%	7.07%	5.75%	7.00%	5.90%	4.65%
PBP	14 years	15 years	16 years	15 years	16 years	19 years
NPV (M€)	3,748	0.672	-2.43	0.502	-2.15	-4.82
CRC (M€)	-5,11	-0.916	3.31	-0.685	2.93	6.57

Figure 26 shows the PBP and IRR per scenario in a bar chart. This figure clearly shows that the business case is **negatively influenced** by the changing assumptions resulting from competing heat strategies. The reference scenario scores the best, which is expected as in this scenario, the assumed heat demand is the highest. The figure also shows that for the reference scenario, scenario 1 and scenario 3, the business case is positive, as the IRR is above the red line (≥ 6.80%) and the PBP is beneath the red line (≤ 15 years). The other scenarios (2, 4 and 5) have a lower IRR and a higher PBP.

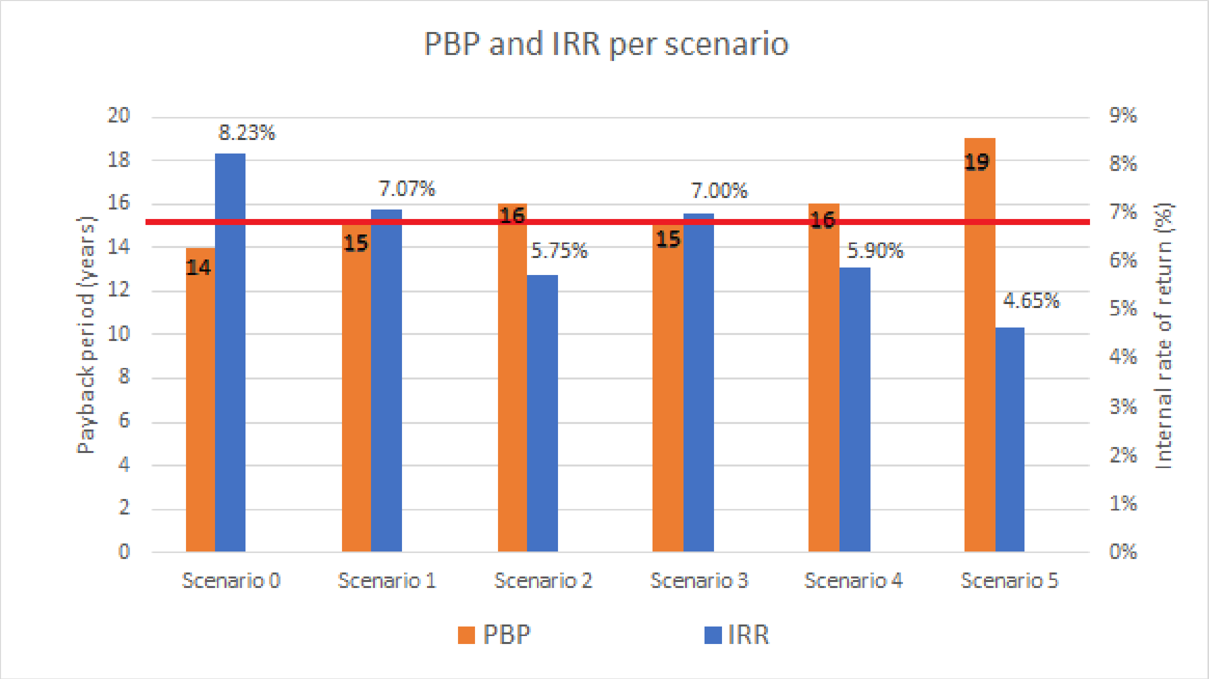

Figure 10: PBP and IRR per scenario. Red line indicates minimum (IRR) and maximum (PBP) values for which the business case is positive

7. Monte Carlo uncertainty analysis

This section elaborates on the Monte Carlo uncertainty analysis. First, the uncertain parameters which are subject to this analysis are described and it is explained why these parameters are uncertain. Next, the settings for the PDFs are described. Following this, the results of the Monte Carlo analysis are presented.

7.1 Parameters for uncertainty analysis

The following input parameters are defined as uncertainties and therefore require further investigation using the Monte Carlo analysis:

- Heat purchase price from WarmtelinQ

The heat purchase price has been deducted using large consumer gas prices in combination with email contact with Gasunie, the exploiter of WarmtelinQ. However, because WarmtelinQ is not yet finished, it is still uncertain what the exact price of heat from WarmtelinQ is going to be. Therefore, it is a very uncertain parameter, suitable for the Monte Carlo analysis. In the integral design document the lowest scenario price was €4.50/GJ, this is set as the lowest boundary for the probability distribution (Gasunie, 2021). Because due to world events the price for heat could take extreme forms, a lognormal distribution is chosen.

- Heat sale price

The current heat sale price is based on the average of the projections of 2025 – 2050 from the climate and energy outlook 2021. However, these projections are very uncertain, making this parameter suitable for the uncertainty analysis. Because little is known about the uncertainty of this parameter, a normal distribution is assumed, with the assumed value as the mean and 10% of the mean as the standard deviation.

- Infrastructure cost of main distribution network, primary pipes and secondary pipes
    - Length

The length of the main distribution pipes, the primary pipes and the secondary pipes were estimated by designing a DH system and then measuring the length of the different types of pipes. Whether or not the real DH system will have the same design as how it is designed in this thesis is uncertain. Because the uncertainty is symmetric, the normal distribution suits these parameters best. A standard deviation of 10% of the mean has been chosen.

    - Costs per meter

The costs per meter of the different pipes is also uncertain. By estimating the necessary pipe capacities and using interpolation, the prices of pipes were deducted. This was an uncertain process, making the cost per meter variables suitable for the Monte Carlo analysis. For these parameters, a normal distribution with a standard deviation of 10% of the mean has been chosen.

- Costs for sub-stations
    - Amount of substations

The amount of substations is based on the assumptions regarding pipe capacity. This assumption might not be correct and therefore this amount of substations is subject for the Monte Carlo analysis. Because it is deemed unlikely that the real amount of substations is five substations more or less than the amount assumed, the minimum is set on 23 substations, with 28 as the most likely value and 33 as the maximum.

- Costs per substation

The cost per substation is deducted using estimated capacities and Koster et al. (2022). As these estimated capacities are uncertain, and also because the values from Koster et al. are indications of costs, this parameter is also suitable for the Monte Carlo analysis. Because not much is known about the uncertainty, a normal distribution is assumed, using a standard deviation of 10% of the assumed value.

7.2 PDF settings

Table 28 summarises the PDF settings for the uncertain parameters. It is described what type of distribution is assumed, including the confidence interval. The PDF settings are also given per uncertain parameter.

Table 18: Summary of PDF settings for the Monte Carlo analysis

Parameter	Type of PDF / Confidence interval	PDF Settings
Heat purchase price (€/GJ)	Lognormal / 90%	• μ: 0.4674 • σ: 0.61 • Minimum: 4.50 • Mode: 5.60 • Maximum: +∞
Heat sale price (€/GJ)	Normal / 90%	• μ: 26.60 • σ: 2.66
Length - main distribution pipes (m)	Normal / 90%	• μ: 1,290 • σ: 129
Cost per meter – main distribution pipes (€/m)	Normal / 90%	• μ: 1,480 • σ: 148
Length - primary pipes (m)	Normal / 90%	• μ: 8,280 • σ: 828
Cost per meter - primary pipes (€/m)	Normal / 90%	• μ: 711 • σ: 71.1
Length - secondary pipes (m)	Normal / 90%	• μ: 22,930 • σ: 2,293
Cost per meter - secondary pipes (€/m)	Normal / 90%	• μ: 414 • σ: 41.4

Number of substations (n)	Triangular / 100%	Minimum: 23 Most likely: 28 Maximum: 33
Cost per substation (€)	Normal / 90%	µ: 62,500 σ: 6,250

7.3 Results

Here, the results of the Monte Carlo analysis are presented per scenario. For all scenarios, 10.000 iterations were used to produce a robust result. For each scenario, the outcome probability distribution figure is given. Because the tornado and spider diagram showed similar trends between all scenarios, these are only shown for Scenario 0. For Scenario 1 – 5, the tornado and spider diagrams can be found in Appendix C.

7.3.0 Scenario 0

When all uncertain parameters are defined with PDFs as described in Table 28, the outcome probability distribution is as in Figure 27. As can be seen, the outcomes have a normal, slightly negative skewed, distribution. The mean NPV outcome value is 2.55 M€ and the mode is 3.19 M€. In 76.4% of the 10,000 iterations, the NPV comes out as a positive number, meaning that in those cases the IRR is higher than the required project return.

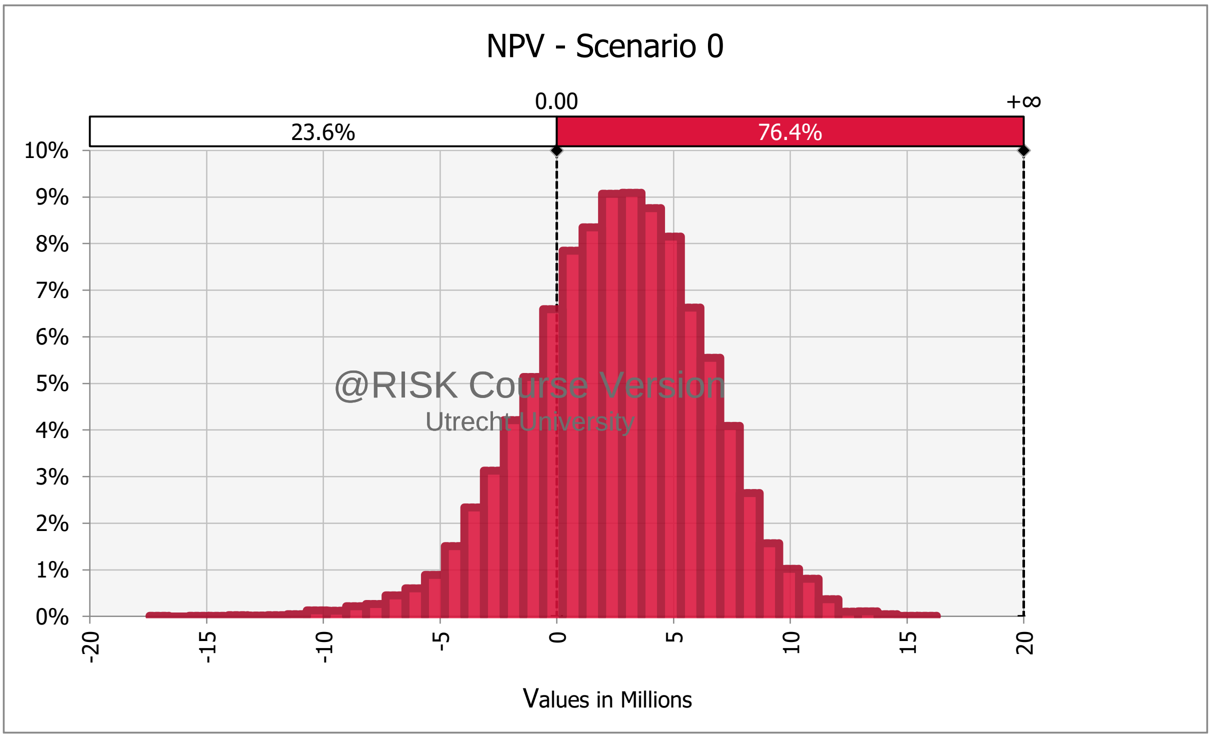

Figure 11: NPV probability distribution for Scenario 0

Figure 28 provides the tornado diagram associated with the Monte Carlo analysis for Scenario 0. It shows how much influence different uncertain parameters have on the result and ranks them from most influential to least influential. As figure 28 shows, the heat purchase price from WarmtelinQ has the highest influence on the results, followed by the price for which heat is sold to the end-user.

Uncertain parameters regarding the primary and secondary pipes also have a notable effect on the results, while the other uncertain parameters have little effect on the outcome NPV.

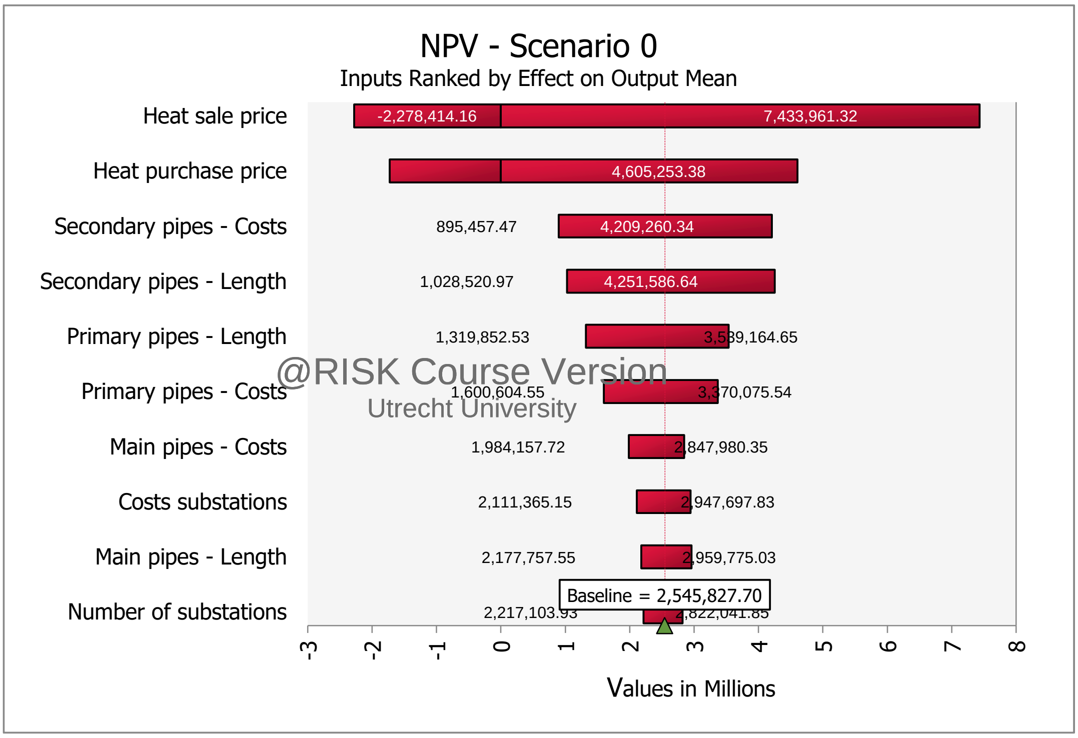

Figure 12: Tornado diagram output for Scenario 0

Figure 29 shows the spider diagram of the Monte Carlo analysis for Scenario 0. Here, the parameters with the steepest lines have the most influence on the NPV. Using this figure, it can also be observed that the heat purchase price from WarmtelinQ (red line) and the price for which heat is sold to end-users (blue line) are the most influential uncertain parameters.

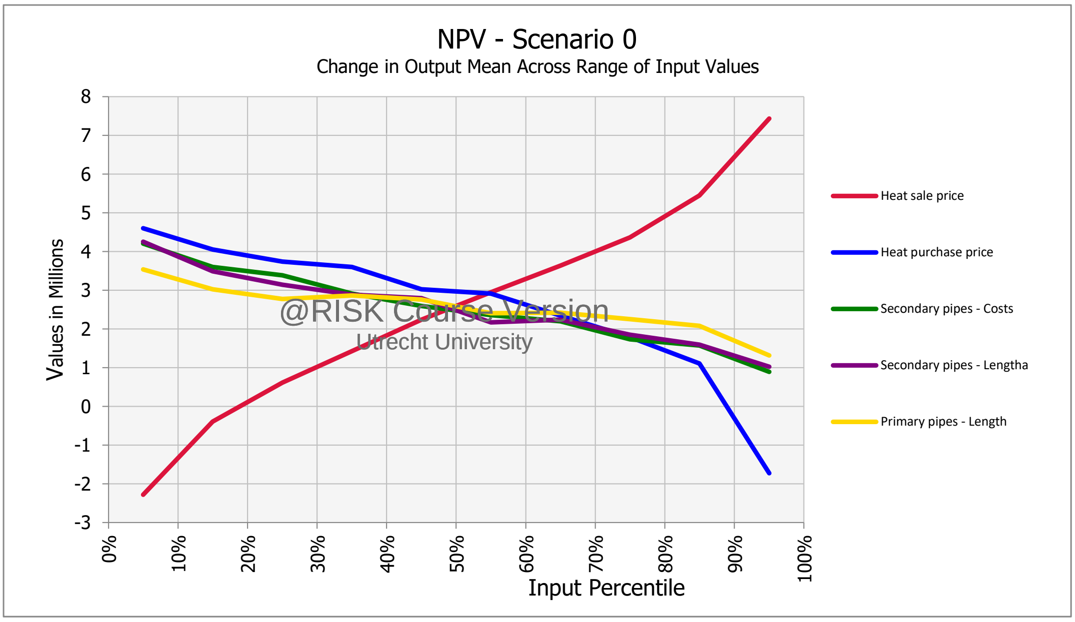

Figure 13: Spider diagram output for Scenario 0. Steeper lines indicate a stronger correlation between the uncertain parameter and the NPV

7.3.1 Scenario 1

As can be seen in Figure 30, when a lower participation rate is assumed and the uncertain parameter PDFs are defined as in Table 29, the NPV is positive in 46.1% of the iterations. In this scenario, the average output NPV is -0.37 M€ and the most occurring value is -0.99 M€.

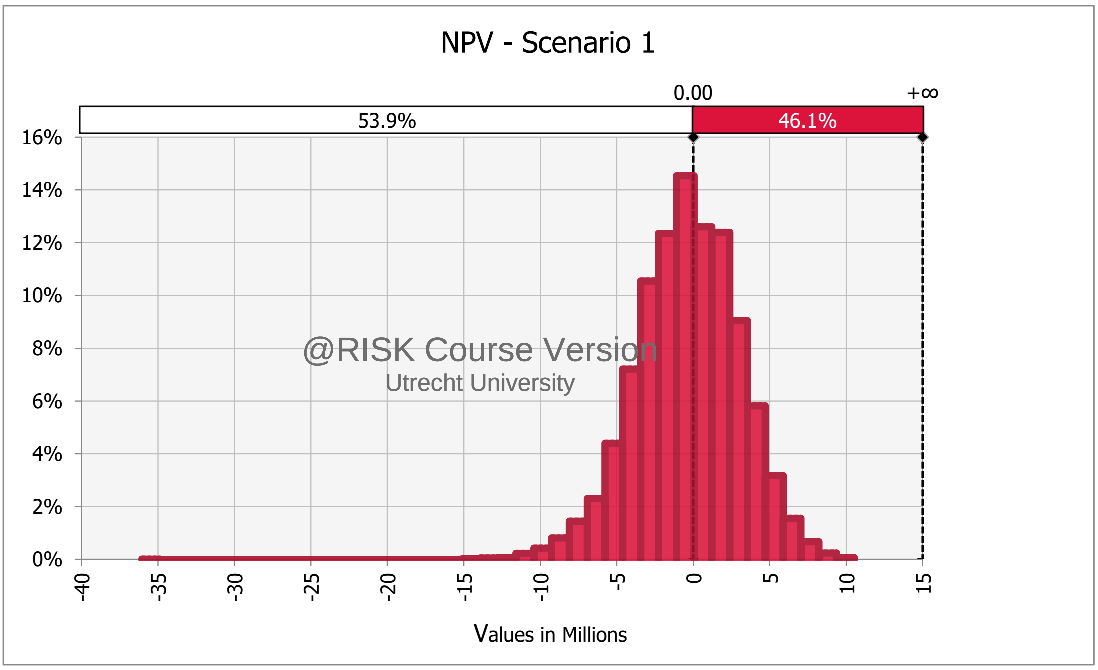

Figure 14: NPV probability distribution for Scenario 1

7.3.2 Scenario 2

Using the Scenario 2 assumptions and uncertain parameter PDFs as described in Table 28, the chance of a positive NPV outcome and an IRR higher than the required project return is 12.7%. The average outcome for this scenario is -3.31 M€, while the mode lies at -3.81 M€. The probability distribution is given in Figure 31

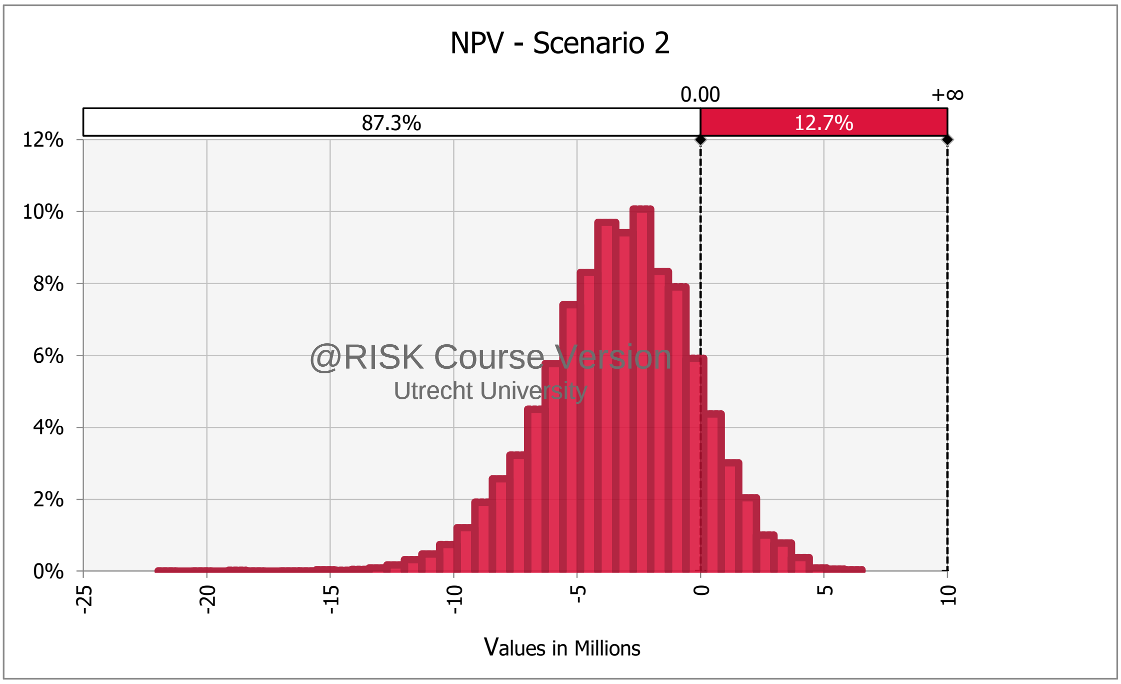

Figure 15: NPV probability distribution for Scenario 2

7.3.3 Scenario 3

With label D energy demand instead of Label B and participation rates of 100%, the chance of a positive NPV is 45.0% when the uncertain parameter PDFs are as defined in Table 28. This is shown in Figure 32. The average NPV under these circumstances is -0.49 M€ and the most occurring value is -1.65 M€.

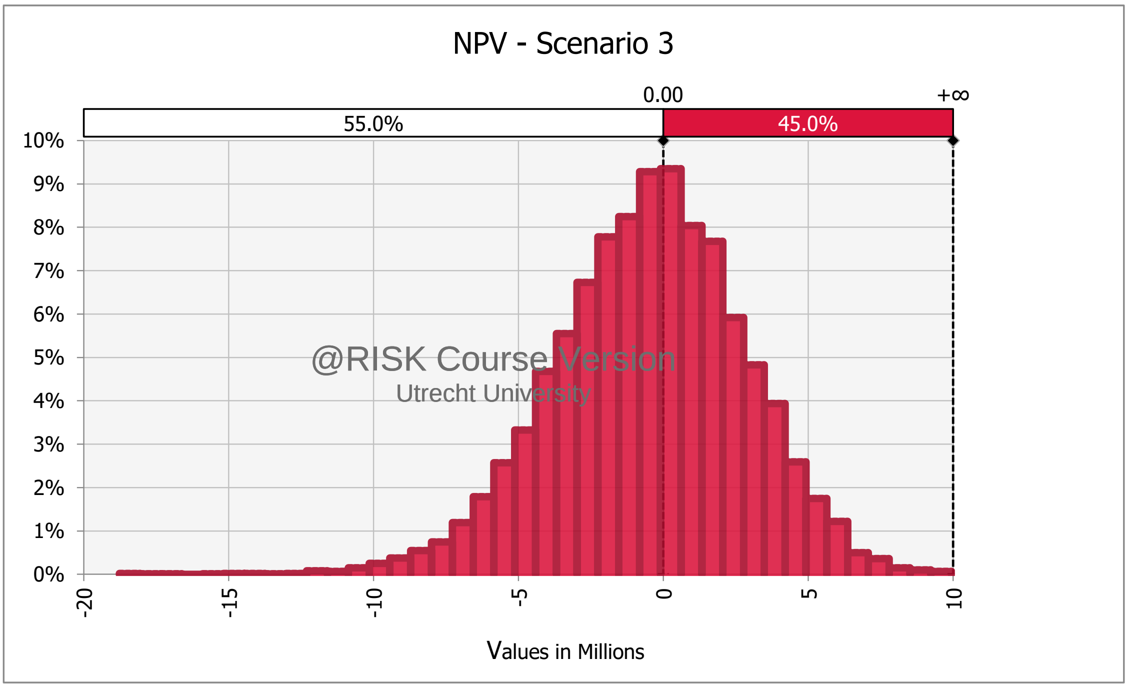

Figure 16: NPV probability distribution for Scenario 3

7.3.4 Scenario 4

For Scenario 4, the chances of an IRR above 6.8% and an accompanying positive NPV are 15.1% when the uncertain parameter PDFs are as described in Table 28. For this scenario, the mean outcome for the NPV is -3.01 M€ and the mode is -3.94 M€. The probability distribution is given in Figure 33.

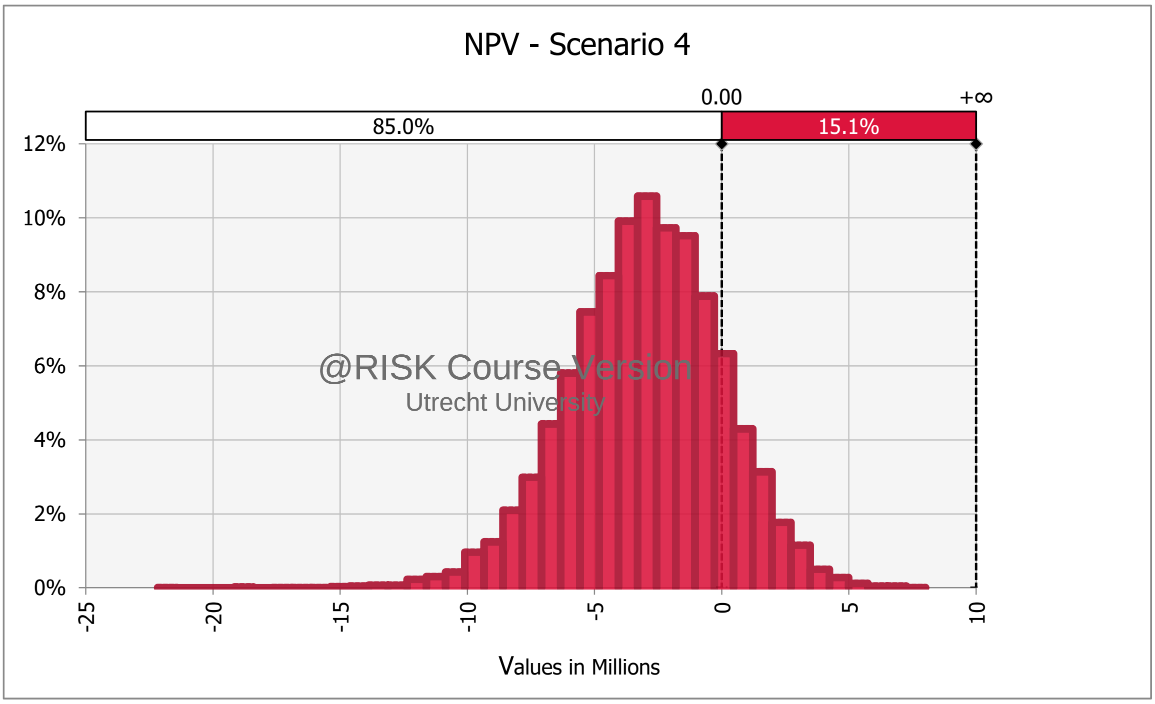

Figure 17: NPV probability distribution for Scenario 4

7.3.5 Scenario 5

In the scenario with the least positive assumptions, the NPV is only positive in 1.7% of the iterations, as can be seen in figure 34. For this scenario, the average NPV is -5.56 M€ and the mode -5.79 M€.

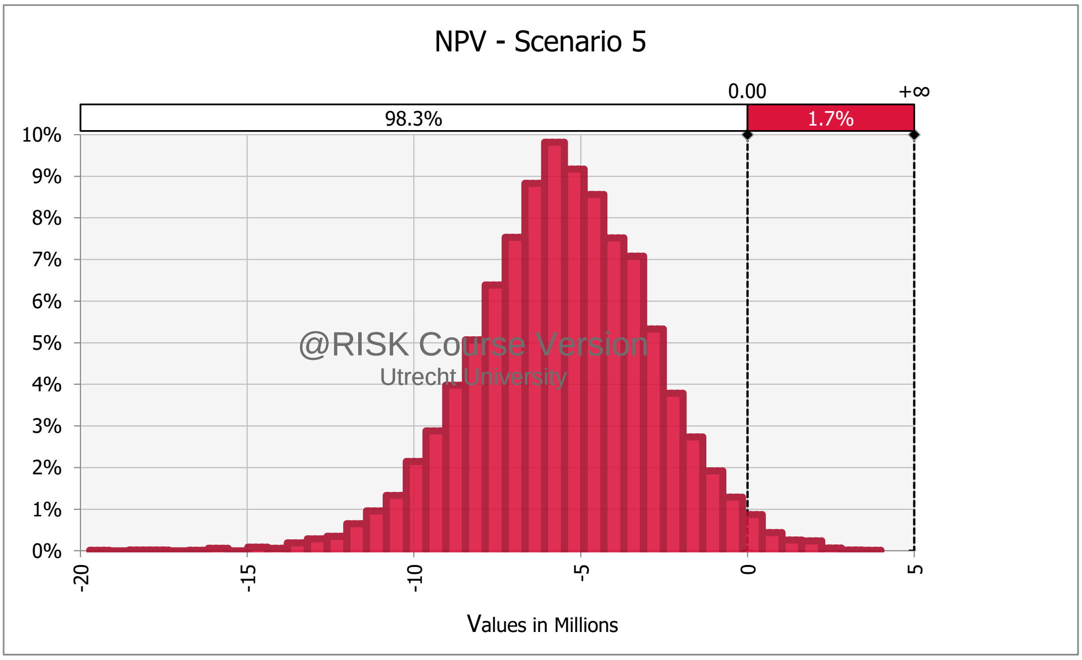

Figure 18: NPV probability distribution for Scenario 5

7.3.6 Result summary

Table 29 summarises the most important outputs of the Monte Carlo analysis per scenario. As can be seen, in all scenarios, under the current assumptions and PDFs as defined in Table 28, there is a chance that the NPV will be positive. In Scenarios 2, 4 and 5 this chance is very slim, however. Only in the reference scenario there is a chance higher than 50% that the NPV will turn out to be positive. The steep drop in positive NPV probability indicate that when the participation rate drops or insulation levels rise, extra risks should be taken into account. Also, the results showed that uncertainties can strongly affect the business case, with widely spread NPV values in all Monte Carlo analyses.

Table 19: Result summary of the Monte Carlo uncertainty analysis

Scenario	Reference	1	2	3	4	5
% Positive NPV	76.4%	46.1%	12.7	45.0	15.1%	1.7%
NPV mean (M€)	2.55	-0.37	-3.31	-0.49	-3.01	-5.56
NPV mode (M€)	3.19	-0.99	-3.81	-1.65	-3.94	-5.79

7.4 Sensitivity analysis

To evaluate the influence of the most uncertain parameters, a sensitivity analysis is conducted. The parameters subject for this analysis are deduced from the tornado and spider diagrams provided by the Monte Carlo analyses. These are the price for which heat is bought from WarmtelinQ and the price for which heat is sold to end-users.

To analyse the effect a change in either of these variables has on the results of the scenarios, it is evaluated how the NPV changes when one of these variables undergoes a percentile change while all other parameters and assumptions remain the same. The percentile change goes from -20% to +20%. Figure 35 gives the sensitivity analysis for the heat purchase price from WarmtelinQ and Figure 36 gives the sensitivity analysis for the price for which heat is sold to end-users. The heat sale price has a positive correlation with the NPV, while the heat purchase price has a negative correlation.

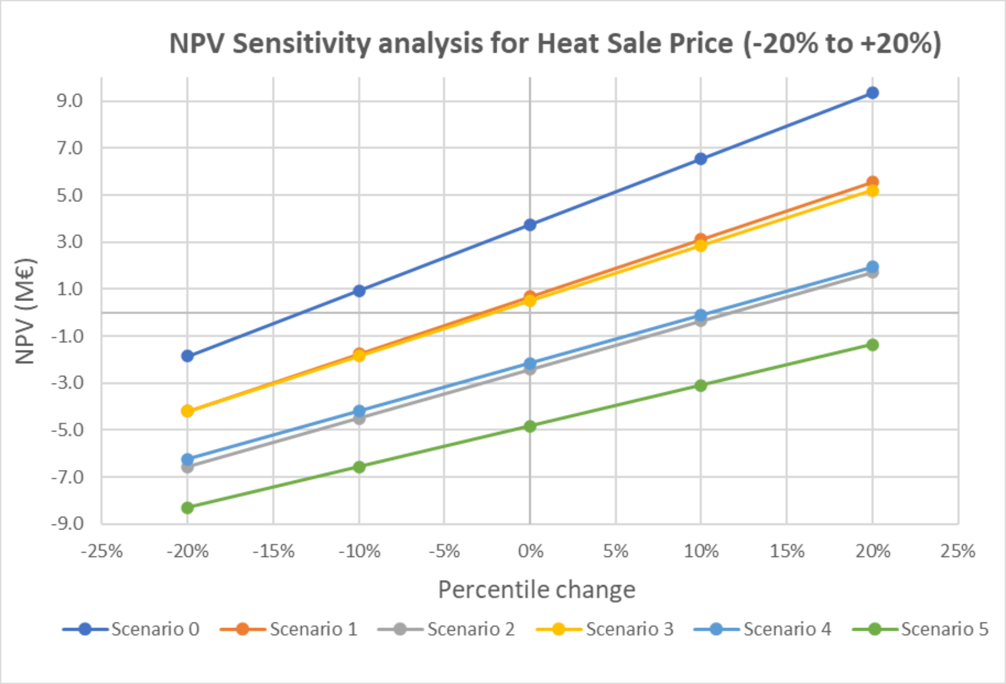

Figure 19: Sensitivity analysis of the heat sale price on the NPV for all scenarios. Heat sale price varied from -20% to +20%

As already shown in Figure 28, the price for which heat is sold has a greater influence on the NPV when a percentile change is imposed on the parameter than the price for which heat is purchased. This is expected because the net change in parameter value is higher for the heat sale price than for the heat purchase price. After all, the heat sale price has a higher base value. Figure 35 shows that a percentile change of -20% and 20% for the heat sale price results in NPV changes, varying from around ± 5.61 M€ for the reference scenario to ± 3.45 M€ for Scenario 5. The NPV in Scenario 5 is always negative with the chosen heat sale prices, while for all other scenarios, the break-even point lies somewhere between the -20% change and the +20% change in heat sale price.

A percentile change in the heat purchase price has less impact on the NPV. Changing the heat purchase price by ±20% imposes the biggest change in NPV of ±1.64 M€ in the reference scenario and the slimmest change in Scenario 5, with a change of ± 1.01 M€. This can also be seen in Figure 36. The effect of a 20% change in variables is the highest in the reference scenario for both variables because, in the reference scenario, the heat demand is the highest. The reference scenario is always positive with the chosen variations in the heat purchase price, while Scenarios 1 and 3 cross the zero mark somewhere around the +10% change. Scenarios 2, 4 and 5 are always negative for the chosen percentile changes in the heat purchase price.

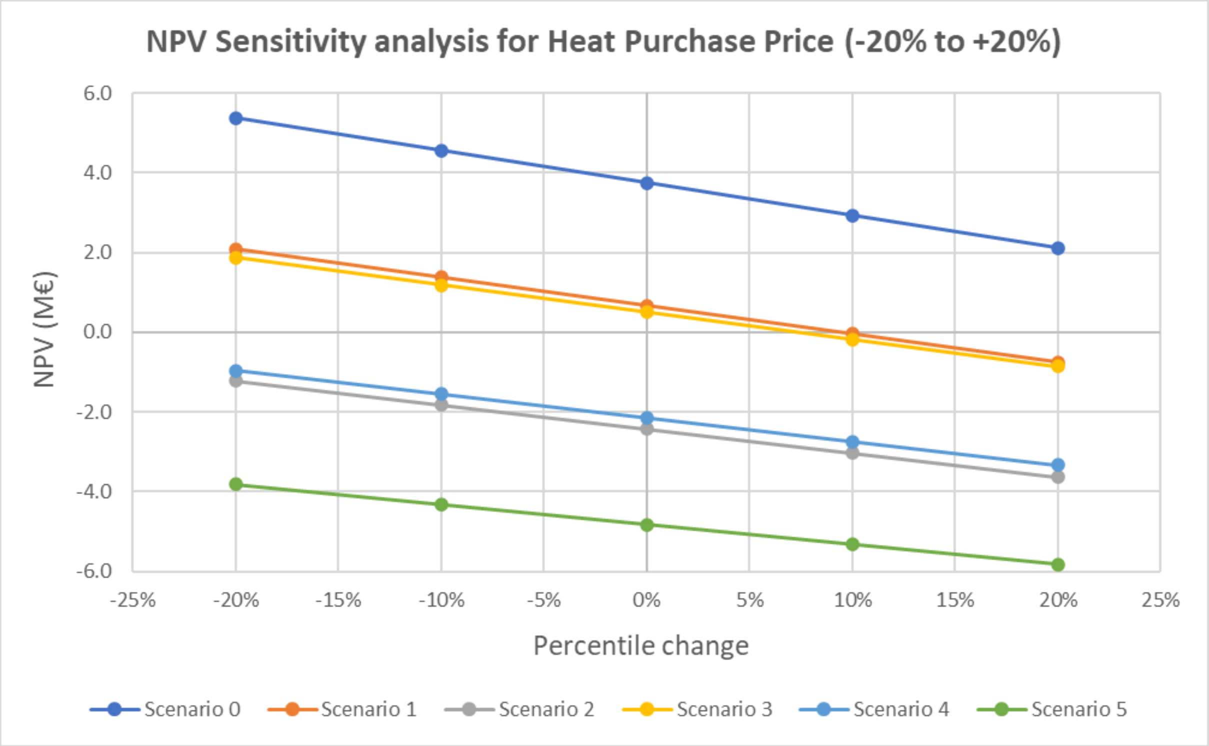

Figure 20: Sensitivity analysis of the heat purchase price on the NPV for all scenarios. Heat sale price varied from -20% to +20%

To better illustrate the effect a lower heat load has on the business case, an analysis of the influence of heat demand on the NPV has been conducted, shown in Figure 37. For this analysis, it was assumed the Δ heat price (heat revenue per unit of heat, purchase – sale) stays the same, as well as the number of connections, but the total heat demand is changed. As can be seen, there is a linear relationship between the heat demand and the NPV, with the NPV following roughly the line: $y = 0.00015x - 15$. Where Y is the NPV and x is the total heat demand. Under current assumptions, the heat demand needs to be at least around 100,000 GJ/year to result in a positive NPV.

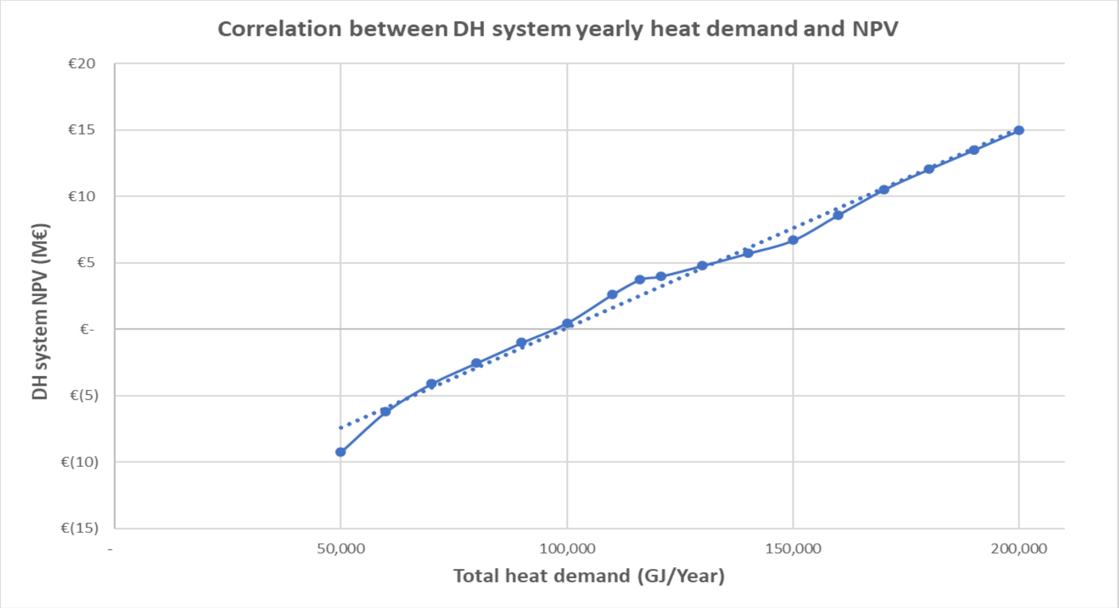

Figure 21: Correlation between heat demand for the DH system and the DH system NPV

Because the heat revenue per unit of heat (€/GJ) and the total heat demand are the two most important factors for the business case for the MT DH system, it provides insights to know the relation between the two for different required project returns. Figure 38 shows this relation, where the different lines represent different IRR outcome values. Each point on a line represents a combination of a heat demand and a heat revenue per GJ which results in that IRR. When a combination of heat demand and Δ heat price lies above or to the right of a line, it means that it results in a higher IRR. This figure also shows that with a lower required project return, a lower heat demand or heat price would be necessary to achieve this project return. The IRR of 6% has been chosen because DH systems previously regarded 6% as the required project return (Koster et al., 2022). 4% is displayed because this is considered a good value for a social discount rate (European Commission, n.d.) .

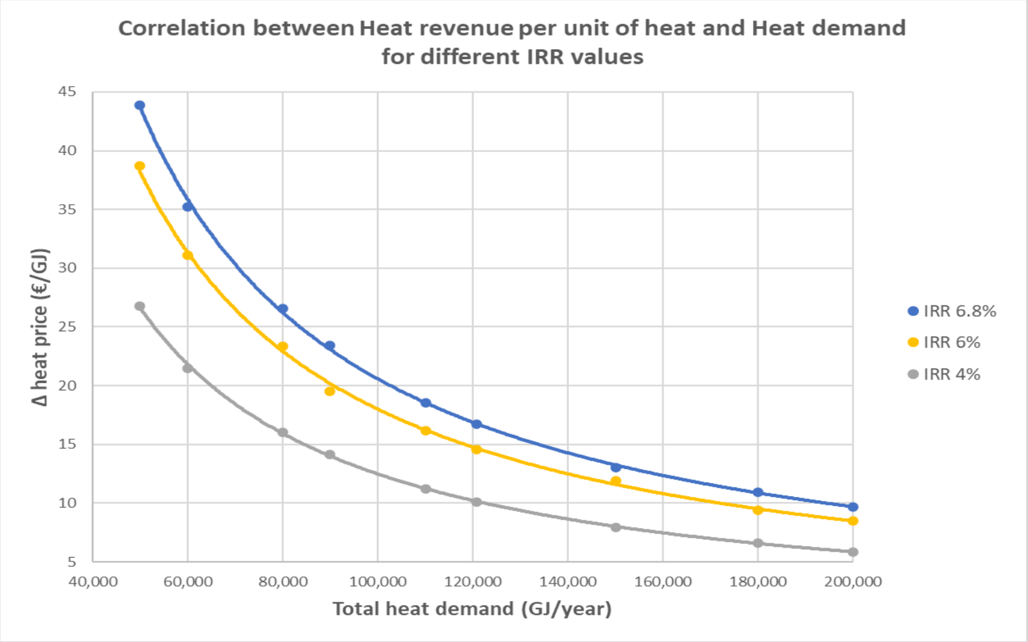

Figure 22: Correlation between the heat revenue per unit of heat (sale price - purchase price) and the total heat demand for the DH system for different IRR values

8. Discussion

In this section, first, the most important findings are discussed, followed by the limitations of this thesis project. Next, it is elaborated on what the theoretical implications were and suggestions for further research and improvements are mentioned. This section ends with the managerial implications and policy suggestions.

8.1 Important findings

The most important results from this research are summarised in Table 30. An important finding was that under certain circumstances, it is possible for a DH system to be the option with the lowest extra national costs, while not having a positive business case for the DH company. This is the case in scenarios 2 and 4. From a national perspective, the costs per avoided tonne of CO2 almost triples for Scenario 5 compared to the reference scenario, indicating a strong influence. Another interesting finding is that while Scenario 2 has a lower extra national cost compared to Scenario 3, it does have a worse business case. This is because insulating is relatively expensive for society, while the project return for the DH company only lowers from 8.23% in the reference scenario to 7.00% in Scenario 3. From the Monte-Carlo analysis, it can be concluded that the chances of the business case turning out positive quickly diminishes when the circumstances are less favourable, with a chance of 76.4% in the reference scenario and only 1.7% in Scenario 5, also indicating a strong potential effect of competing strategies on the business case. In the sensitivity analysis, it was observed that under the circumstances as assumed in this thesis, the NPV is dependent on the heat demand with roughly 150 € per GJ of total yearly heat demand. It was also observed that for every heat demand, there is a minimum revenue per unit of heat sold necessary to recuperate the investments and make the business case positive. When heat demand is higher, the DH company can accept lower revenues per unit of heat and still have a positive business case.

Table 20: Summary of the most important results of this thesis

	Scenario	**0**	**1**	**2**	**3**	**4**	**5**
Vesta MAIS	**Extra national costs (€/tonne CO2)**	239.38	292.02	367.25	455.66	548.94	682.2
	Cheapest option excl. GG	Yes	Yes	Yes	Yes	Yes	No
	Cheapest option incl. GG	Yes	Yes	No	No	No	No
Template	**IRR**	8.23%	7.07%	5.75%	7.00%	5.90%	4.65%
	Positve business case	Yes	Yes	No	Yes	No	No
	Probability positive business case	76.4%	46.1%	12.7%	45.0%	15.1%	1.7%

8.2 Limitations

Due to time limitations during this thesis project, it was only possible to evaluate the effects of alternative sustainable heating policies on the business case of one potential DH system. Although the results give a good view of the business case and the effects a lower participation rate or higher insulation has on the business case, the results are not generalisable for the whole of the Netherlands. Also, the neighbourhoods chosen for the DH system were chosen because according to the 'Startanalyse' a DH system in these neighbourhoods is the option with the lowest extra national costs. The result of this choice is on one side a neighbourhood for which it is likely to be subject to a DH system but on the other side a neighbourhood where a DH system probably has a good business case due to geographical and demographical properties. It is possible that for other DH systems with less favourable conditions, the results are more negative. It is expected, however, that the correlations and uncertainties remain the same.

Another limitation to the research is that the DH system as implemented in the business case template is not designed by professionals. The DH system was created by the researcher and might not be the exact DH system as it would be if it would be designed by a DH company. To counter the uncertainty which follows from this, parts of the infrastructure costs were subject to the Monte Carlo analysis to evaluate the risks created by these uncertainties. Also, the template business case is a static modelling tool where no dynamic prices or markets could be identified. This has the consequence that one assumption for a heat price must be chosen for 30 years, which is an unrealistic assumption.

During this research, a lot of assumptions were made that potentially influence the results. For instance, to determine costs for pipes and substations that did not have a cost key figure available, data for other pipes were used and interpolated to gain the costs of the needed pipes. Also, DH companies indicate that there are often uncertainties regarding what is found in the ground when pipes are being deployed. It is unclear whether the key figures used in this thesis already accounted for some of these uncertainties. However, these key figures are deemed accurate because they were verified in a DH system key figures review session organised by CE Delft and DH companies. The greatest uncertainty of this thesis is regarding the energy prices, which were very volatile during the period of this thesis. These were determined by using projections about the average heat purchase and sale price for the coming 30 years. These projections are very uncertain and therefore result in risks for the investor. Using the Monte Carlo analysis, it was possible to give a probability of positive NPV outcomes using a PDF for these uncertain parameters, resulting in more robust results and a better risk assessment.

Another limitation regarding the energy prices is the assumption that for heat purchased from WarmtelinQ, the rate is always the same. In reality, peak load demand is more expensive, resulting in a worsened business case. Also, due to lack of information, it was assumed that the WarmtelinQ price only has a variable component. In reality, it probably will have a fixed component, also negatively influencing the business case. Since WarmtelinQ is not yet developed, it is still uncertain whether projected capacity and prices will be met. If this is not the case, this can strongly influence the business case and might lead to the DH company having to make their own heat source or look at other sources of residual heat.

For the Vesta MAIS analysis, it was not possible to lower the participation rate for scenarios 1, 2, 4 and 5. To solve this problem, a workaround was created in which average cost numbers from different strategies were taken to replicate what would have happened in these scenarios. Although this method should create comparable results to the results Vesta MAIS would have given, it is more sensitive to errors and a less reliable way to calculate the results. Also, now it was assumed that the people not participating in the DH system would ‘do nothing, while in reality, these people might install an alternative sustainable heating solution, resulting in different extra national cost numbers.

The last limitation of this thesis is in the sensitivity analysis. All correlations resulting from this analysis were linear. In reality, however, this is unlikely. When the heat sale price for instance rises, end-users may change their behaviour and heat demand. It is also possible that with higher prices, fewer people want to connect to the DH system, also resulting in diminishing returns. Would the heat price decrease, the opposite effect is expected. It could also be argued that when the participation rate drops, first the dwellings with a relatively low heat demand from the DH system would opt-out, as these dwellings have relatively high fixed costs and low variable costs. Also, it is expected that badly insulated buildings insulate first, meaning that decreasing heat demand due to shell-improvement also does not occur linearly. These effects are not represented in the results because for this thesis, average heat demands per neighbourhood were assumed. To incorporate these effects, more detailed data about individual buildings in neighbourhoods can be used.

8.3 Theoretical implications and Further research

Previous studies regarding DH systems mostly focussed on the potential of DH systems in the future energy system or on new DH technologies. Although there is literature available regarding different DH business models and pricing mechanisms, there were not yet studies executed evaluating the business case for the DH companies. This thesis shows the impact of different heat loads as a result of competing sustainable heat strategies on the business case of DH systems for DH companies. It shows that with different heat loads the initial investment and costs are recuperated, but that only under favourable circumstances the required project returns are met. It also shows that the price for which heat is bought or generated and the price for which the heat is sold are the two most important parameters that decide the business case, which is in line with existing literature about DH business models (Chinese, 2008). As these prices are very uncertain and often changing, it is therefore important to keep evaluating these prices and re-evaluate the business case under these new prices.

Another important theoretical implication of this thesis is that although a DH system can be the cheapest option from a national point of view to go to a carbon-free heat system, it is not always a good business case for the DH company. This was the case in some investigated scenarios. This can lead to an asynergy in policy plans when a municipality wants a DH system to be developed in a certain area, but no DH company or investor want to invest in it, as the business case is not rewarding enough. This research also showed that in every scenario, under the right circumstances, the business case could be positive. However, uncertainties associated with competing heat strategies or sustainable behaviour could strongly influence the chance the business case turns out positive. This research has led to the following suggestions for further research:

- The results would be made more robust if more potential DH systems in the Netherlands would be evaluated. Now the neighbourhoods for which the DH option was the best compared to the second-best sustainable heating option were evaluated. It would also give useful information if neighbourhoods were chosen for which DH systems were only less costly than the second-best sustainable heating alternative. Also, investigating more potential DH systems would make the results more generalisable.
- Investigating the effect of competing sustainable heating strategies or behaviour on the business case from the end perspective of other stakeholders, like municipalities or end-users. Rising uncertainties about heat load can result in DH companies rising the heat prices, connection fees or other cost components for end-users. This way the investment may become less risky for the DH company, but this can negatively influence the business case from the end user's perspective. Investigating this tension between the business case for the DH company and the business case for the end-user may lead to useful scientific and managerial insights.
- The effects of the new heat law should also be investigated. Most important from the new heat law is the changed cost structure. It should be investigated how this will work and what the consequences of this change are for the business case of new MT DH systems.
- Conducting a study that evaluates if and to what extent it is possible for the government to subsidise DH systems to make the business case positive in more situations. In scenarios where a MT DH system is the option with the lowest extra national costs, but the business case is not positive, it would provide useful insights to investigate if a MT DH system is still the option

with the lowest national costs if the CRC would be subsidised by the government. For neighbourhoods where this is the case, this would provide a backbone for subsidising the missing profits for a DH company to invest in a new DH system, resulting in faster development of DH systems.

- The same study could be conducted, but now analysing the effects for a LT DH system. This would provide scientific value as lower-temperature DH systems are considered more sustainable. Also, it adds value if the relation between heat load and the business case would also be determined for these LT DH systems.

8.4 Managerial implications

From a policy maker's point of view, it is important to take into account that for a lower heat load due to competing heat strategies, a DH system can still be the cheapest option for a carbon-free built environment. However, the financial incentives might be lacking for a private DH company to invest in. When the required project return lowers, all scenarios can result in a positive business case, as the investments and costs are recuperated. This leads to the suggestion that in neighbourhoods with lower heat demand or participation rates, it might be better to let the DH system be exploited by public DH companies who require fewer returns. For either public or private DH companies, however, it is important to be careful when deciding the business case and keep in mind uncertainties, especially regarding pricing. The government could also implement policies where the cost recovery contribution is subsidised to incentivise private DH companies to invest in more DH systems. This can be more beneficial than creating public DH companies, as in general private companies have more knowledge and expertise in running an economically healthy DH system. The height of these subsidies could be the same as the CRC needed to make the business case positive, meaning a subsidy of around 6.5 M€ for Scenario 5. Whether this is cost-efficient, however, first should be researched.

For DH companies, it is important to realise that governmental policies stimulating alternative sustainable heat solutions or behaviour can negatively influence the business case for MT DH systems. Using policy assessments regarding competing heat strategies, it should be possible for DH companies to make educated guesses about the impact of competing heat strategies on the demand for heat from DH systems. When this is executed, the DH company can internalise the risk associated with these competing heat strategies. A possibility to internalise risks for a DH company is by changing their fixed and variable rates, which in this thesis were assumed to be constant and independent of the projected NPV. In reality, however, DH companies can calibrate the fixed and variable components of the heat prices, or adjust connection costs to compensate for uncertainties. By raising the fixed components, risks from lower heat demand might be reduced because higher heat usage becomes relatively cheaper for end-users. However, it might lead to fewer people with lower heat demand participating in the DH system. This could also be investigated in further research.

9. Conclusion

The research question of this thesis was: ‘How does a change in heat demand for DH systems due to competing heat strategies influence the business case of new MT DH systems for DH companies in the Netherlands?’. To answer this question, first, it was evaluated what the business case of a DH system is. Then the business case was calculated under the current/most positive assumptions for a neighbourhood in the Netherlands where it is likely that a DH system is to be developed in the future (SQ1). This resulted in a **positive** business case. Next, based on alternative sustainable heating strategies and sustainable behaviour, scenarios were developed to evaluate the effects these strategies have on the business case (SQ2). This resulted in five extra scenarios with changing participation rates (100%, 85%, 70%) and heat demands (label D and label B). These scenarios were evaluated in two ways. First, in Vesta MAIS to see whether or not a DH system was still the strategy with the lowest national costs under the new assumptions. Second, the DH system business case template from ECW was used to evaluate whether investing in the DH system has a positive business case under the new assumptions (SQ3).

When analysing the results of the scenario analysis, it becomes clear that a lower heat load has **negative consequences for the business case** of new MT DH systems in the Netherlands. In this study, a DH system was designed in a location with favourable geographic and demographic conditions. This resulted in three out of six scenarios (including the reference scenario) having a positive business case. The business case is still positive when the participation rate drops a bit (Scenario 1) or when building owners decide to insulate their buildings (Scenario 3). In these scenarios, however, according to the Monte Carlo analysis, the probability of a positive business case is slightly lower than 50% (46.1% and 45.1%). When the participation rate drops further (Scenario 2), or is combined with higher insulation levels (Scenario 4 and 5), the business case is not positive anymore for the DH company. Although the NPV was negative in half of the scenarios, the project made a profit and recuperated the investment costs in all scenarios. This suggests that if DH companies would accept lower profits, the business case is positive in more scenarios under less favourable conditions. With a required project return of only 4.5% for instance, all scenarios turn out positive. To make the business case in Scenario 5 positive, a CRC of around 6.5 M€ would be necessary. This corresponds to 2.35 k€ per connection, which is twice the average energy bill of an average Dutch household in 2021 (Milieu Centraal, 2022).

When analysing the Vesta MAIS results it becomes clear that in the selected neighbourhoods, a MT DH system can under less favourable conditions still be the option with the lowest national costs. However, there were scenarios where the DH system would come out as the option with the lowest national cost, but where the business case was not positive. This would result in a situation where a municipality would decide for an area that there is going to be a DH system, but no DH company who wants to develop and exploit it. This problem could be solved if DH companies would accept lower rates of return or when the missing profits would be paid by governments through subsidies. Whether or not the latter option is efficient must come out of further research. Another conclusion from the Vesta MAIS results is that insulating buildings strongly influences the national costs, while it does not worsen the business case for the DH system much. However, in less favourable locations it is possible that this insulation effect results in a negative business case.

Concluding this thesis, it has become clear that the uncertainties regarding heat load as a consequence of alternative sustainable heating strategies or sustainable behaviour **imposes great risks on the business case of new MT DH systems in the Netherlands**. From a national perspective, the extra costs per avoided tonne of CO2 almost triples when the circumstances worsen in Scenario 5, decreasing the chance that DH systems get priority for sustainable heating. From the DH company's perspective, the business case is also strongly affected by the participation rate and heat demand. For every total heat demand, there is a minimum revenue per unit of heat needed to recuperate the investments associated with delivering that heat. When the heat demand is higher, a DH company can afford to make less revenue per unit of heat sold. Due to the selected neighbourhoods having favourable geographic and demographic characteristics, the business case was positive under slightly negative assumptions (Scenario 1 and 3) and negative in the other scenarios. It is possible that when the business case for less ideal neighbourhoods would be investigated, also these scenarios would result in a negative business case. This stresses the importance of quality risk and uncertainties assessments when evaluating a business case for a new MT DH system in the Netherlands.

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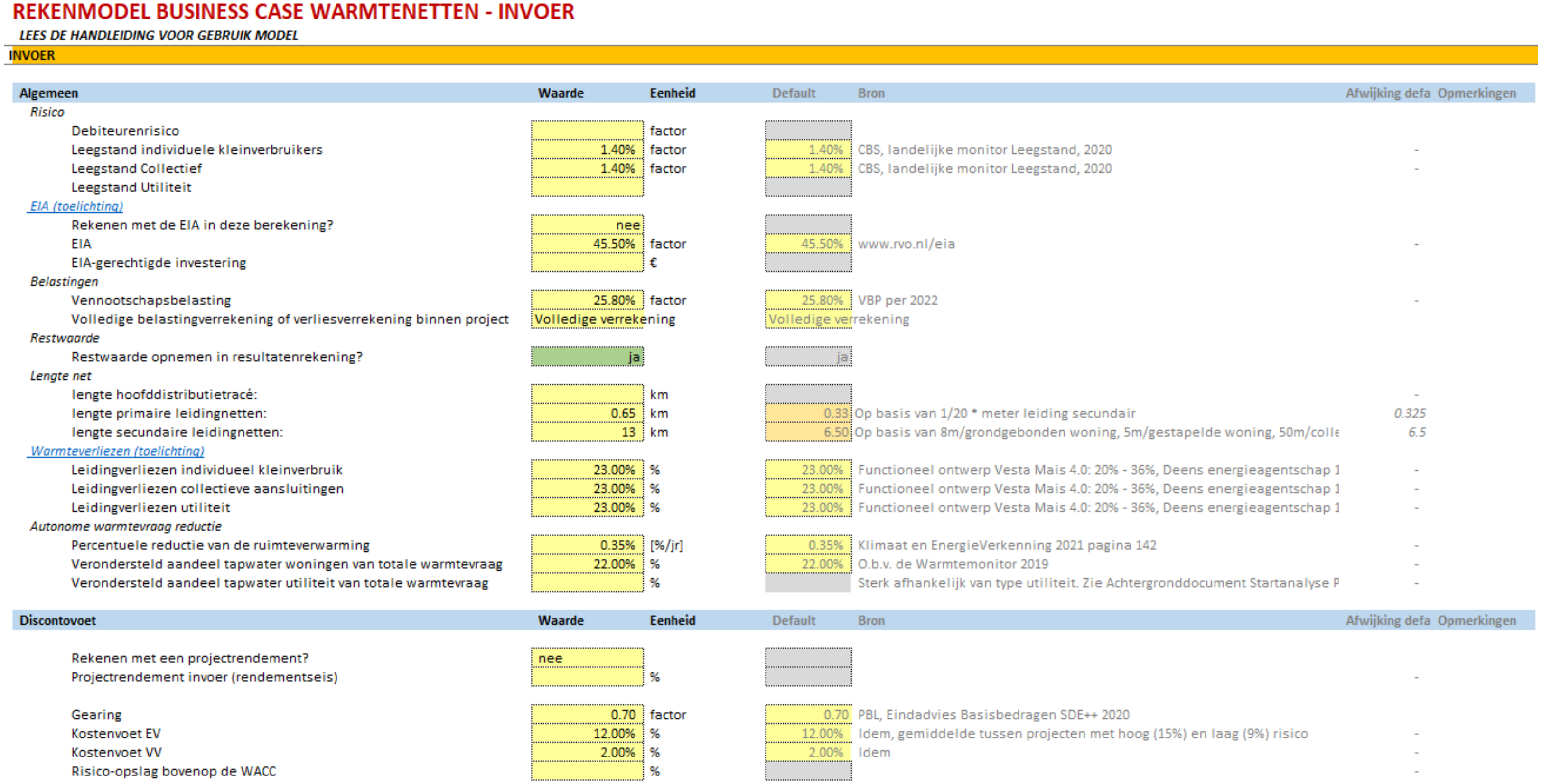
Appendix A – Template Business Case Sheets

This appendix presents the sheets from Template Business Case from ECW that need to be filled in. It is presented in the way it is downloaded from the ECW website, meaning that most values are not filled in, except for the default values.

Sheet ‘Uitgangspunten’ (Assumptions)

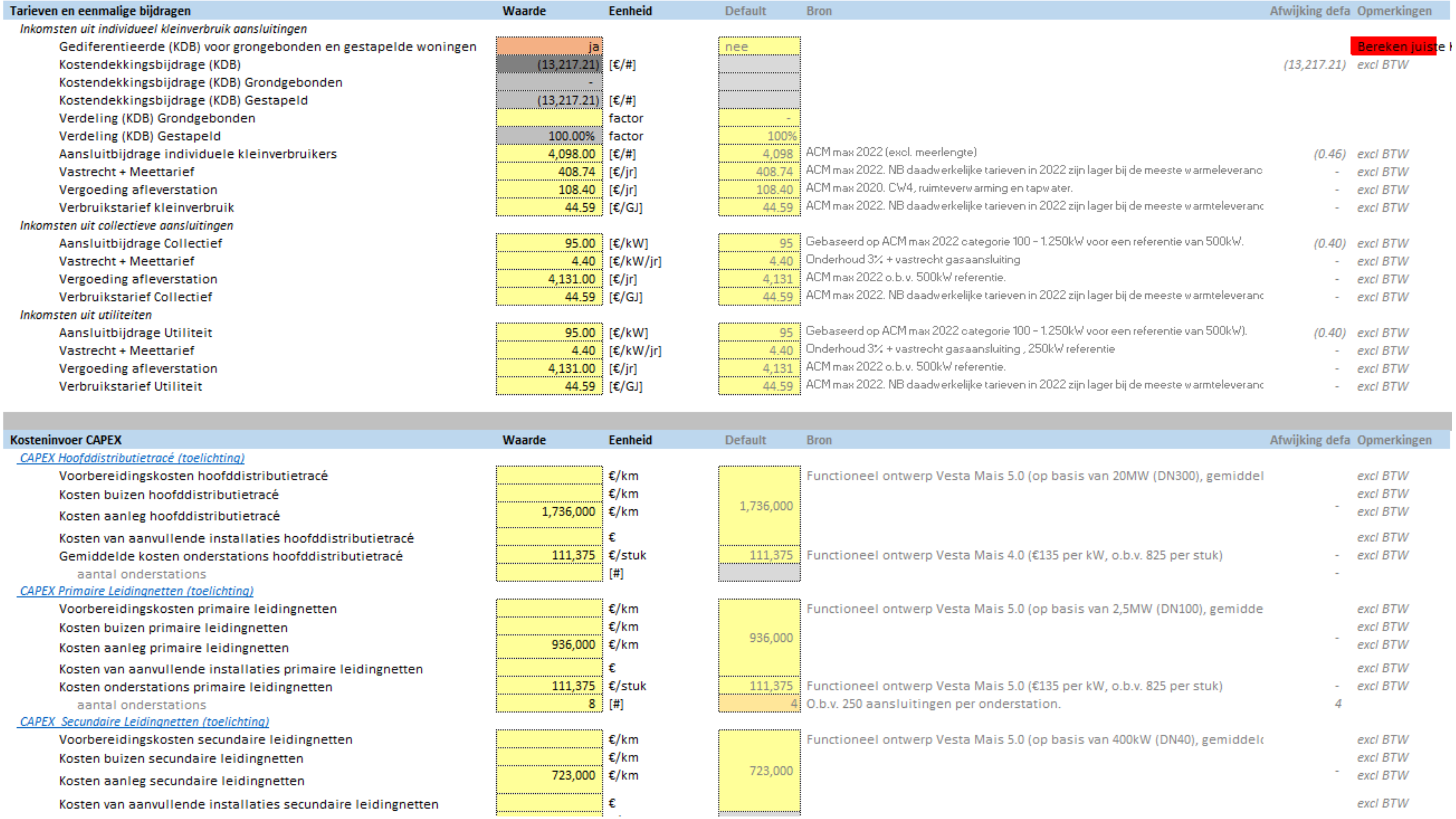


REKENMODEL BUSINESS CASE WARMTENETTEN - INVOER

LEES DE HANDLEIDING VOOR GEBRUIK MODEL

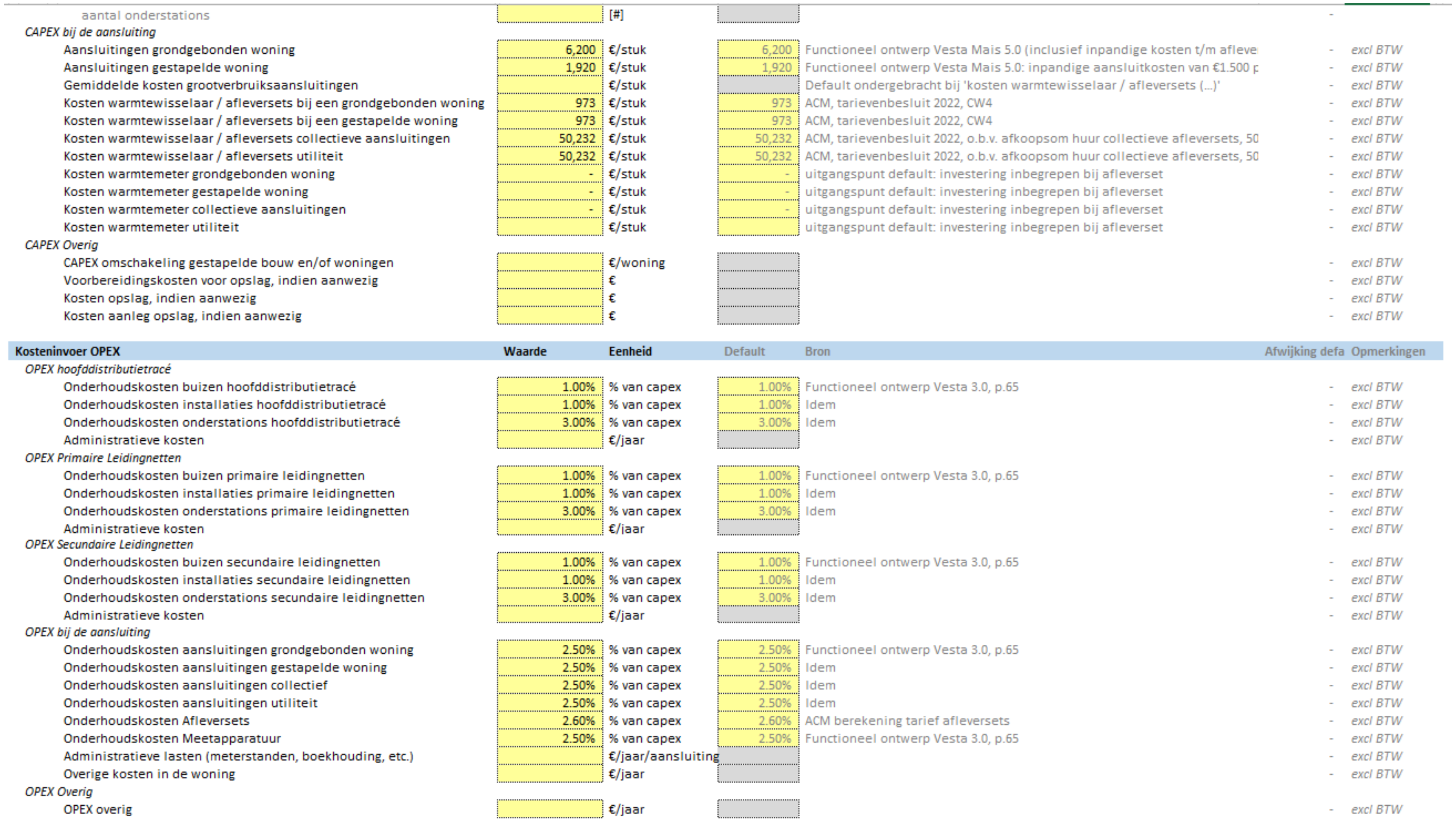
INVOER

Algemeen	**Waarde**	**Eenheid**	Default	Bron	Afwijking defa	Opmerkingen
Risico						
Debiteurenrisico		factor				
Leegstand individuele kleinverbruikers	1.40%	factor	1.40%	CBS, landelijke monitor Leegstand, 2020	-	
Leegstand Collectief	1.40%	factor	1.40%	CBS, landelijke monitor Leegstand, 2020	-	
Leegstand Utiliteit						
EIA (toelichting)						
Rekenen met de EIA in deze berekening?	nee					
EIA	45.50%	factor	45.50%	www.rvo.nl/eia	-	
EIA-gerechtigde investering		€				
Belastingen						
Vennootschapsbelasting	25.80%	factor	25.80%	VBP per 2022	-	
Volledige belastingverrekening of verliesverrekening binnen project	Volledige verrekening		Volledige verrekening			
Restwaarde						
Restwaarde opnemen in resultatenrekening?	ja		ja			
Lengte net						
lengte hoofddistributietracé:		km			-	
lengte primaire leidingnetten:	0.65	km	0.33	Op basis van 1/20 * meter leiding secundair	0.325	
lengte secundaire leidingnetten:	13	km	6.50	Op basis van 8m/grondgebonden woning, 5m/gestapelde woning, 50m/colle	6.5	
Warmteverliezen (toelichting)						
Leidingverliezen individueel kleinverbruik	23.00%	%	23.00%	Functioneel ontwerp Vesta Mais 4.0: 20% - 36%, Deens energieagentschap 1	-	
Leidingverliezen collectieve aansluitingen	23.00%	%	23.00%	Functioneel ontwerp Vesta Mais 4.0: 20% - 36%, Deens energieagentschap 1	-	
Leidingverliezen utiliteit	23.00%	%	23.00%	Functioneel ontwerp Vesta Mais 4.0: 20% - 36%, Deens energieagentschap 1	-	
Autonome warmtevraag reductie						
Percentuele reductie van de ruimteverwarming	0.35%	[%/jr]	0.35%	Klimaat en EnergieVerkenning 2021 pagina 142	-	
Verondersteld aandeel tapwater woningen van totale warmtevraag	22.00%	%	22.00%	O.b.v. de Warmtemonitor 2019	-	
Verondersteld aandeel tapwater utiliteit van totale warmtevraag		%		Sterk afhankelijk van type utiliteit. Zie Achtergronddocument Startanalyse P	-	
Discontovoet	**Waarde**	**Eenheid**	Default	Bron	Afwijking defa	Opmerkingen
Rekenen met een projectrendement?	nee					
Projectrendement invoer (rendementseis)		%			-	
Gearing	0.70	factor	0.70	PBL, Eindadvies Basisbedragen SDE++ 2020		
Kostenvoet EV	12.00%	%	12.00%	Idem, gemiddelde tussen projecten met hoog (15%) en laag (9%) risico	-	
Kostenvoet VV	2.00%	%	2.00%	Idem	-	
Risico-opslag bovenop de WACC		%			-	

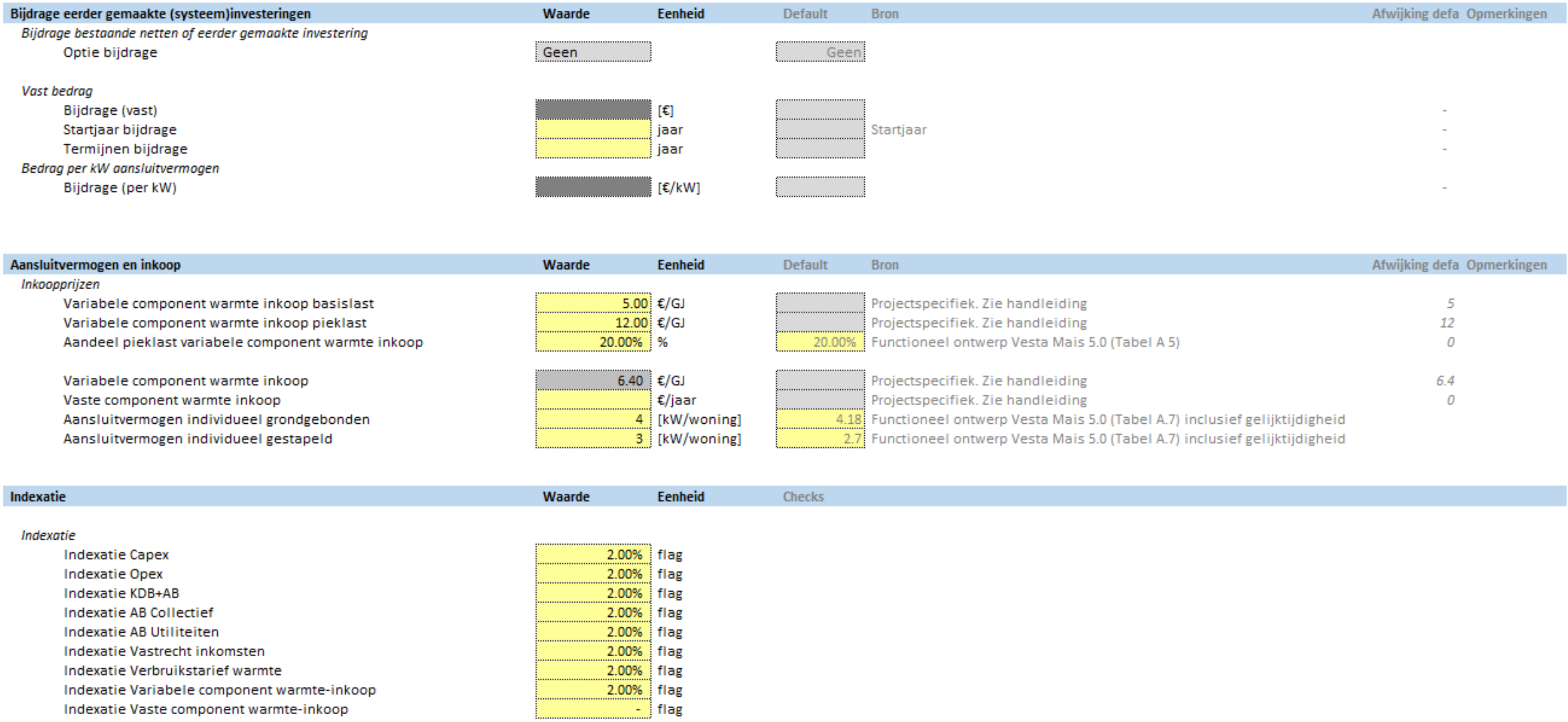


Tarieven en eenmalige bijdragen	**Waarde**	**Eenheid**	Default	Bron	Afwijking defa	Opmerkingen
Inkomsten uit individueel kleinverbruik aansluitingen						
Gediferentieerde (KDB) voor grongebonden en gestapelde woningen	ja		nee			Bereken juiste I
Kostendekkingsbijdrage (KDB)	(13,217.21)	[€/#]			(13,217.21)	excl BTW
Kostendekkingsbijdrage (KDB) Grondgebonden	-					
Kostendekkingsbijdrage (KDB) Gestapeld	(13,217.21)	[€/#]				
Verdeling (KDB) Grondgebonden		factor	-			
Verdeling (KDB) Gestapeld	100.00%	factor	100%			
Aansluitbijdrage individuele kleinverbruikers	4,098.00	[€/#]	4,098	ACM max 2022 (excl. meerlengte)	(0.46)	excl BTW
Vastrecht + Meettarief	408.74	[€/jr]	408.74	ACM max 2022. NB daadwerkelijke tarieven in 2022 zijn lager bij de meeste warmeleveranc	-	excl BTW
Vergoeding afleverstation	108.40	[€/jr]	108.40	ACM max 2020. CW4, ruimteverwarming en tapwater.	-	excl BTW
Verbruikstarief kleinverbruik	44.59	[€/GJ]	44.59	ACM max 2022. NB daadwerkelijke tarieven in 2022 zijn lager bij de meeste warmteleveranc	-	excl BTW
Inkomsten uit collectieve aansluitingen						
Aansluitbijdrage Collectief	95.00	[€/kW]	95	Gebaseerd op ACM max 2022 categorie 100 - 1.250kW voor een referentie van 500kW.	(0.40)	excl BTW
Vastrecht + Meettarief	4.40	[€/kW/jr]	4.40	Onderhoud 3% + vastrecht gasaansluiting	-	excl BTW
Vergoeding afleverstation	4,131.00	[€/jr]	4,131	ACM max 2022 o.b.v. 500kW referentie.	-	excl BTW
Verbruikstarief Collectief	44.59	[€/GJ]	44.59	ACM max 2022. NB daadwerkelijke tarieven in 2022 zijn lager bij de meeste warmteleveranc	-	excl BTW
Inkomsten uit utiliteiten						
Aansluitbijdrage Utiliteit	95.00	[€/kW]	95	Gebaseerd op ACM max 2022 categorie 100 - 1.250kW voor een referentie van 500kW).	(0.40)	excl BTW
Vastrecht + Meettarief	4.40	[€/kW/jr]	4.40	Onderhoud 3% + vastrecht gasaansluiting , 250kW referentie	-	excl BTW
Vergoeding afleverstation	4,131.00	[€/jr]	4,131	ACM max 2022 o.b.v. 500kW referentie.	-	excl BTW
Verbruikstarief Utiliteit	44.59	[€/GJ]	44.59	ACM max 2022. NB daadwerkelijke tarieven in 2022 zijn lager bij de meeste warmteleveranc	-	excl BTW

Kosteninvoer CAPEX	**Waarde**	**Eenheid**	Default	Bron	Afwijking defa	Opmerkingen
CAPEX Hoofddistributietracé (toelichting)						
Voorbereidingskosten hoofddistributietracé		€/km	1,736,000	Functioneel ontwerp Vesta Mais 5.0 (op basis van 20MW (DN300), gemiddel		excl BTW
Kosten buizen hoofddistributietracé		€/km				excl BTW
Kosten aanleg hoofddistributietracé	1,736,000	€/km			-	excl BTW
Kosten van aanvullende installaties hoofddistributietracé		€				excl BTW
Gemiddelde kosten onderstations hoofddistributietracé	111,375	€/stuk	111,375	Functioneel ontwerp Vesta Mais 4.0 (€135 per kW, o.b.v. 825 per stuk)	-	excl BTW
aantal onderstations		[#]			-	
CAPEX Primaire Leidingnetten (toelichting)						
Voorbereidingskosten primaire leidingnetten		€/km	936,000	Functioneel ontwerp Vesta Mais 5.0 (op basis van 2,5MW (DN100), gemidde		excl BTW
Kosten buizen primaire leidingnetten		€/km				excl BTW
Kosten aanleg primaire leidingnetten	936,000	€/km			-	excl BTW
Kosten van aanvullende installaties primaire leidingnetten		€				excl BTW
Kosten onderstations primaire leidingnetten	111,375	€/stuk	111,375	Functioneel ontwerp Vesta Mais 5.0 (€135 per kW, o.b.v. 825 per stuk)	-	excl BTW
aantal onderstations	8	[#]	4	O.b.v. 250 aansluitingen per onderstation.	4	
CAPEX Secundaire Leidingnetten (toelichting)						
Voorbereidingskosten secundaire leidingnetten		€/km	723,000	Functioneel ontwerp Vesta Mais 5.0 (op basis van 400kW (DN40), gemiddelc		excl BTW
Kosten buizen secundaire leidingnetten		€/km				excl BTW
Kosten aanleg secundaire leidingnetten	723,000	€/km			-	excl BTW
Kosten van aanvullende installaties secundaire leidingnetten		€				excl BTW



aantal onderstations		[#]			-	
CAPEX bij de aansluiting						
Aansluitingen grondgebonden woning	6,200	€/stuk	6,200	Functioneel ontwerp Vesta Mais 5.0 (inclusief inpandige kosten t/m afleve	-	*excl BTW*
Aansluitingen gestapelde woning	1,920	€/stuk	1,920	Functioneel ontwerp Vesta Mais 5.0: inpandige aansluitkosten van €1.500 p	-	*excl BTW*
Gemiddelde kosten grootverbruiksaansluitingen		€/stuk		Default ondergebracht bij 'kosten warmtewisselaar / afleversets (...)'	-	*excl BTW*
Kosten warmtewisselaar / afleversets bij een grondgebonden woning	973	€/stuk	973	ACM, tarievenbesluit 2022, CW4	-	*excl BTW*
Kosten warmtewisselaar / afleversets bij een gestapelde woning	973	€/stuk	973	ACM, tarievenbesluit 2022, CW4	-	*excl BTW*
Kosten warmtewisselaar / afleversets collectieve aansluitingen	50,232	€/stuk	50,232	ACM, tarievenbesluit 2022, o.b.v. afkoopsom huur collectieve afleversets, 50	-	*excl BTW*
Kosten warmtewisselaar / afleversets utiliteit	50,232	€/stuk	50,232	ACM, tarievenbesluit 2022, o.b.v. afkoopsom huur collectieve afleversets, 50	-	*excl BTW*
Kosten warmtemeter grondgebonden woning	-	€/stuk	-	uitgangspunt default: investering inbegrepen bij afleverset	-	*excl BTW*
Kosten warmtemeter gestapelde woning	-	€/stuk	-	uitgangspunt default: investering inbegrepen bij afleverset	-	*excl BTW*
Kosten warmtemeter collectieve aansluitingen	-	€/stuk	-	uitgangspunt default: investering inbegrepen bij afleverset	-	*excl BTW*
Kosten warmtemeter utiliteit		€/stuk		uitgangspunt default: investering inbegrepen bij afleverset	-	*excl BTW*
CAPEX Overig						
CAPEX omschakeling gestapelde bouw en/of woningen		€/woning			-	*excl BTW*
Voorbereidingskosten voor opslag, indien aanwezig		€			-	*excl BTW*
Kosten opslag, indien aanwezig		€			-	*excl BTW*
Kosten aanleg opslag, indien aanwezig		€			-	*excl BTW*
Kosteninvoer OPEX	**Waarde**	**Eenheid**	Default	Bron	Afwijking defa	Opmerkingen
OPEX hoofddistributietracé						
Onderhoudskosten buizen hoofddistributietracé	1.00%	% van capex	1.00%	Functioneel ontwerp Vesta 3.0, p.65	-	*excl BTW*
Onderhoudskosten installaties hoofddistributietracé	1.00%	% van capex	1.00%	Idem	-	*excl BTW*
Onderhoudskosten onderstations hoofddistributietracé	3.00%	% van capex	3.00%	Idem	-	*excl BTW*
Administratieve kosten		€/jaar			-	*excl BTW*
OPEX Primaire Leidingnetten						
Onderhoudskosten buizen primaire leidingnetten	1.00%	% van capex	1.00%	Functioneel ontwerp Vesta 3.0, p.65	-	*excl BTW*
Onderhoudskosten installaties primaire leidingnetten	1.00%	% van capex	1.00%	Idem	-	*excl BTW*
Onderhoudskosten onderstations primaire leidingnetten	3.00%	% van capex	3.00%	Idem	-	*excl BTW*
Administratieve kosten		€/jaar			-	*excl BTW*
OPEX Secundaire Leidingnetten						
Onderhoudskosten buizen secundaire leidingnetten	1.00%	% van capex	1.00%	Functioneel ontwerp Vesta 3.0, p.65	-	*excl BTW*
Onderhoudskosten installaties secundaire leidingnetten	1.00%	% van capex	1.00%	Idem	-	*excl BTW*
Onderhoudskosten onderstations secundaire leidingnetten	3.00%	% van capex	3.00%	Idem	-	*excl BTW*
Administratieve kosten		€/jaar			-	*excl BTW*
OPEX bij de aansluiting						
Onderhoudskosten aansluitingen grondgebonden woning	2.50%	% van capex	2.50%	Functioneel ontwerp Vesta 3.0, p.65	-	*excl BTW*
Onderhoudskosten aansluitingen gestapelde woning	2.50%	% van capex	2.50%	Idem	-	*excl BTW*
Onderhoudskosten aansluitingen collectief	2.50%	% van capex	2.50%	Idem	-	*excl BTW*
Onderhoudskosten aansluitingen utiliteit	2.50%	% van capex	2.50%	Idem	-	*excl BTW*
Onderhoudskosten Afleversets	2.60%	% van capex	2.60%	ACM berekening tarief afleversets	-	*excl BTW*
Onderhoudskosten Meetapparatuur	2.50%	% van capex	2.50%	Functioneel ontwerp Vesta 3.0, p.65	-	*excl BTW*
Administratieve lasten (meterstanden, boekhouding, etc.)		€/jaar/aansluiting			-	*excl BTW*
Overige kosten in de woning		€/jaar			-	*excl BTW*
OPEX Overig						
OPEX overig		€/jaar			-	*excl BTW*

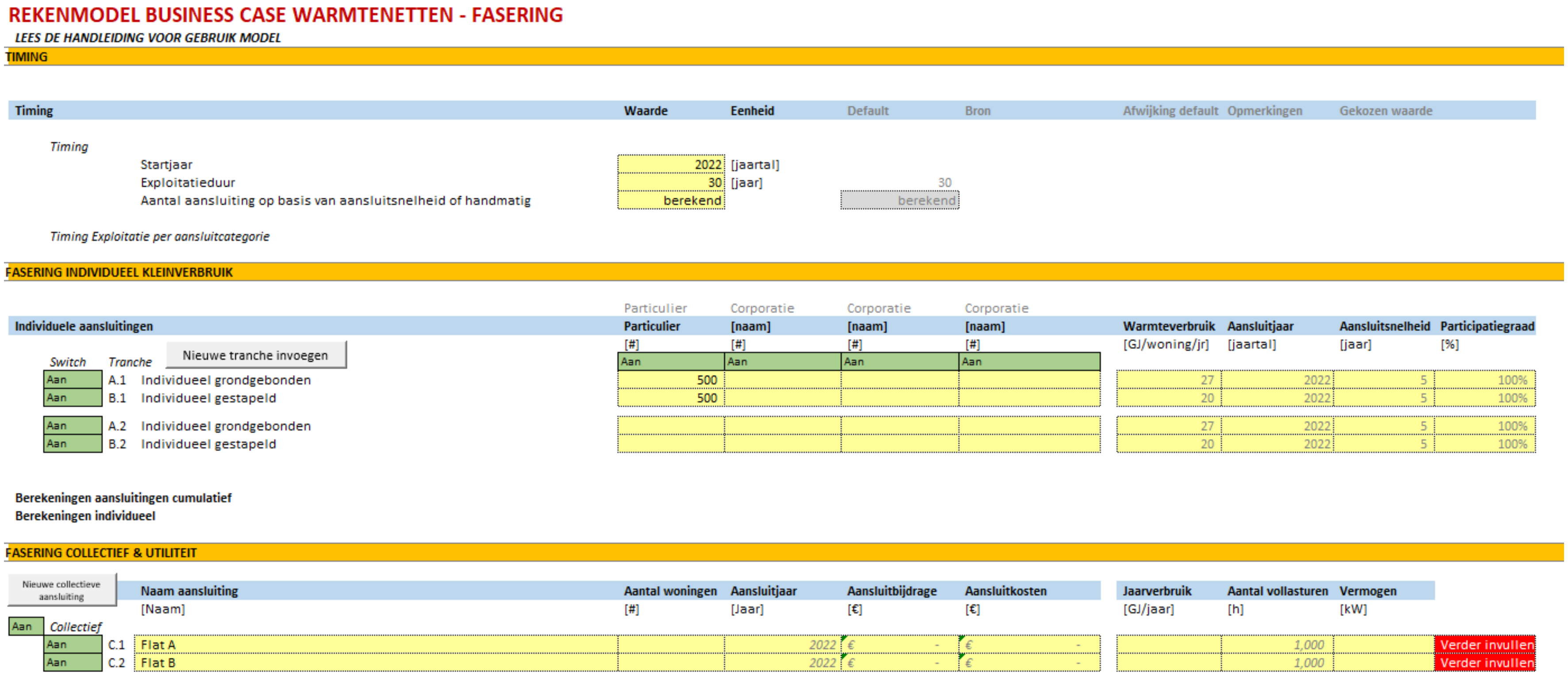


Bijdrage eerder gemaakte (systeem)investeringen	Waarde	Eenheid	Default	Bron	Afwijking defa	Opmerkingen
Bijdrage bestaande netten of eerder gemaakte investering						
Optie bijdrage	Geen		Geen			
Vast bedrag						
Bijdrage (vast)		[€]			-	
Startjaar bijdrage		jaar		Startjaar	-	
Termijnen bijdrage		jaar			-	
Bedrag per kW aansluitvermogen						
Bijdrage (per kW)		[€/kW]			-	

Aansluitvermogen en inkoop	Waarde	Eenheid	Default	Bron	Afwijking defa	Opmerkingen
Inkoopprijzen						
Variabele component warmte inkoop basislast	5.00	€/GJ		Projectspecifiek. Zie handleiding	5	
Variabele component warmte inkoop pieklast	12.00	€/GJ		Projectspecifiek. Zie handleiding	12	
Aandeel pieklast variabele component warmte inkoop	20.00%	%	20.00%	Functioneel ontwerp Vesta Mais 5.0 (Tabel A 5)	0	
Variabele component warmte inkoop	6.40	€/GJ		Projectspecifiek. Zie handleiding	6.4	
Vaste component warmte inkoop		€/jaar		Projectspecifiek. Zie handleiding	0	
Aansluitvermogen individueel grondgebonden	4	[kW/woning]	4.18	Functioneel ontwerp Vesta Mais 5.0 (Tabel A.7) inclusief gelijktijdigheid		
Aansluitvermogen individueel gestapeld	3	[kW/woning]	2.7	Functioneel ontwerp Vesta Mais 5.0 (Tabel A.7) inclusief gelijktijdigheid		

Indexatie	Waarde	Eenheid	Checks
Indexatie			
Indexatie Capex	2.00%	flag	
Indexatie Opex	2.00%	flag	
Indexatie KDB+AB	2.00%	flag	
Indexatie AB Collectief	2.00%	flag	
Indexatie AB Utiliteiten	2.00%	flag	
Indexatie Vastrecht inkomsten	2.00%	flag	
Indexatie Verbruikstarief warmte	2.00%	flag	
Indexatie Variabele component warmte-inkoop	2.00%	flag	
Indexatie Vaste component warmte-inkoop	-	flag	

Sheet ‘Aantallen & Fasering’ (Numbers & Phasing)



REKENMODEL BUSINESS CASE WARMTENETTEN - FASERING

LEES DE HANDLEIDING VOOR GEBRUIK MODEL

TIMING

Timing	Waarde	Eenheid	Default	Bron	Afwijking default	Opmerkingen	Gekozen waarde
Timing							
Startjaar	2022	[jaartal]					
Exploitatieduur	30	[jaar]	30				
Aantal aansluiting op basis van aansluitsnelheid of handmatig	berekend		berekend				

Timing Exploitatie per aansluitcategorie

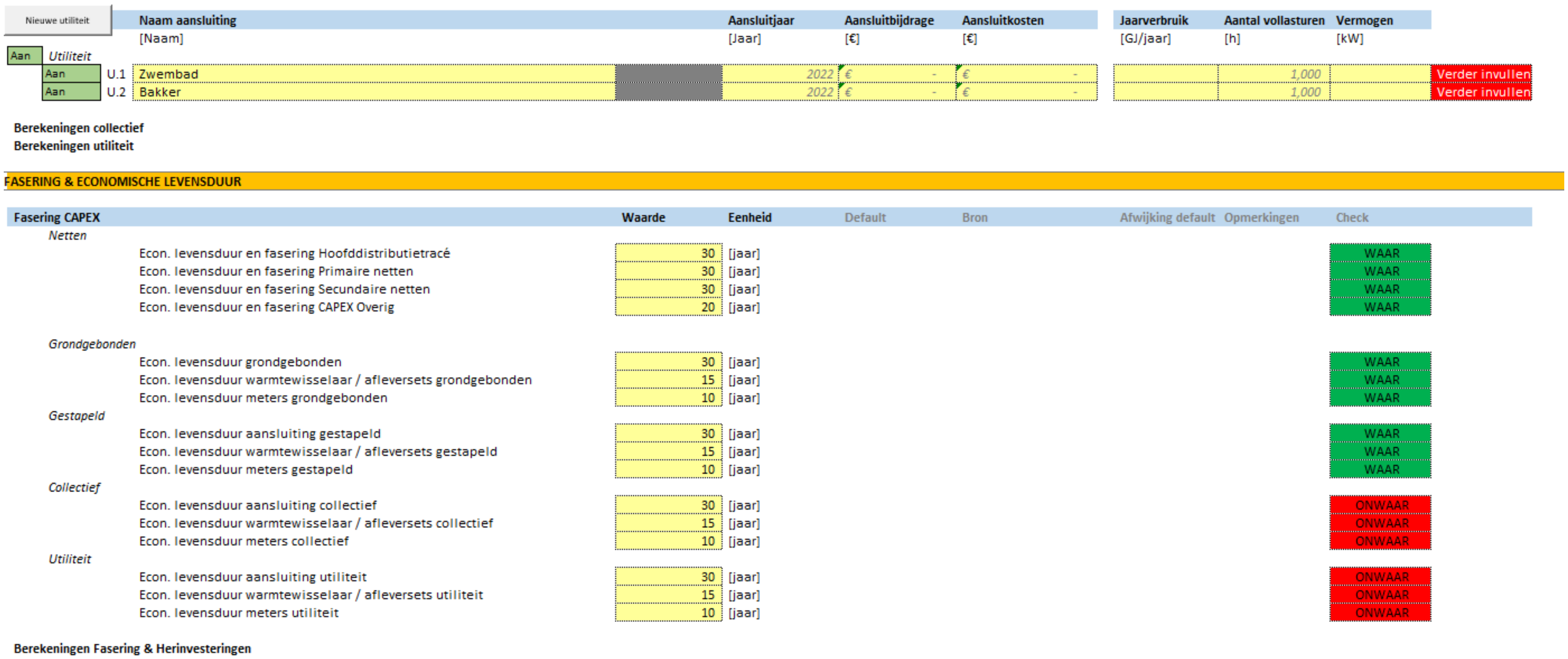
FASERING INDIVIDUEEL KLEINVERBRUIK

Switch	Tranche	Individuele aansluitingen	Particulier Particulier [#]	Corporatie [naam] [#]	Corporatie [naam] [#]	Corporatie [naam] [#]	Warmteverbruik [GJ/woning/jr]	Aansluitjaar [jaartal]	Aansluitsnelheid [jaar]	Participatiegraad [%]
		Nieuwe tranche invoegen	Aan	Aan	Aan	Aan				
Aan	A.1	Individueel grondgebonden	500				27	2022	5	100%
Aan	B.1	Individueel gestapeld	500				20	2022	5	100%
Aan	A.2	Individueel grondgebonden					27	2022	5	100%
Aan	B.2	Individueel gestapeld					20	2022	5	100%

Berekeningen aansluitingen cumulatief
Berekeningen individueel

FASERING COLLECTIEF & UTILITEIT

Nieuwe collectieve aansluiting		Naam aansluiting [Naam]	Aantal woningen [#]	Aansluitjaar [Jaar]	Aansluitbijdrage [€]	Aansluitkosten [€]	Jaarverbruik [GJ/jaar]	Aantal vollasturen [h]	Vermogen [kW]	
Aan	*Collectief*									
Aan	C.1	Flat A		2022	€ -	€ -		1,000		Verder invullen
Aan	C.2	Flat B		2022	€ -	€ -		1,000		Verder invullen



Nieuwe utiliteit			Naam aansluiting		Aansluitjaar	Aansluitbijdrage	Aansluitkosten	Jaarverbruik	Aantal vollasturen	Vermogen	
			[Naam]		[Jaar]	[€]	[€]	[GJ/jaar]	[h]	[kW]	
Aan	*Utiliteit*										
	Aan	U.1	Zwembad		2022	€ -	€ -		1,000		Verder invullen
	Aan	U.2	Bakker		2022	€ -	€ -		1,000		Verder invullen

Berekeningen collectief

Berekeningen utiliteit

FASERING & ECONOMISCHE LEVENSDUUR

Fasering CAPEX		**Waarde**	**Eenheid**	Default	Bron	Afwijking default	Opmerkingen	Check
Netten								
	Econ. levensduur en fasering Hoofddistributietracé	30	[jaar]					WAAR
	Econ. levensduur en fasering Primaire netten	30	[jaar]					WAAR
	Econ. levensduur en fasering Secundaire netten	30	[jaar]					WAAR
	Econ. levensduur en fasering CAPEX Overig	20	[jaar]					WAAR
Grondgebonden								
	Econ. levensduur grondgebonden	30	[jaar]					WAAR
	Econ. levensduur warmtewisselaar / afleversets grondgebonden	15	[jaar]					WAAR
	Econ. levensduur meters grondgebonden	10	[jaar]					WAAR
Gestapeld								
	Econ. levensduur aansluiting gestapeld	30	[jaar]					WAAR
	Econ. levensduur warmtewisselaar / afleversets gestapeld	15	[jaar]					WAAR
	Econ. levensduur meters gestapeld	10	[jaar]					WAAR
Collectief								
	Econ. levensduur aansluiting collectief	30	[jaar]					ONWAAR
	Econ. levensduur warmtewisselaar / afleversets collectief	15	[jaar]					ONWAAR
	Econ. levensduur meters collectief	10	[jaar]					ONWAAR
Utiliteit								
	Econ. levensduur aansluiting utiliteit	30	[jaar]					ONWAAR
	Econ. levensduur warmtewisselaar / afleversets utiliteit	15	[jaar]					ONWAAR
	Econ. levensduur meters utiliteit	10	[jaar]					ONWAAR

Berekeningen Fasering & Herinvesteringen

Appendix B – Data inputs and assumptions for the template business case from ECW

This appendix describes the input of data as inserted in the Business case Template from the ECW. It explains what assumptions were made and how this might affect the results, as well as elaborates on certain calculation methods and choices made during the data insertion. Beneath, all the choices made when filling in the Template, which data was inserted and how this data was acquired are summarised per sheet and subsection of the template. The instructions provided by the ECW are followed as much as possible.

A.B.1 Sheet 'Uitgangspunten'

General input

- For the vacancy share in the neighbourhoods, the standard value of 1.40% for individual and collective connections was changed to 1.70%, based on data for the neighbourhoods in Delft from the vacancy monitor from CBS. The vacancy rate for utility was set at 6.5%, based on CBS data of Delft which stated that there is a 7% vacancy rate for offices and 6% for retail (CBS, 2021).
- The EIA subsidy is applicable to the business case, as for the assumed DH system, more than 70% of the supplied heat is residual heat (RVO, 2022b). This subsidy allows for 45.5% of the infrastructure investment to be subtracted from the profits (RVO, 2022a). For this thesis, it is assumed that the investments that can be subsidised are the investments associated with the main, primary and secondary distribution pipes, which adds up to € 20,526,800.
- The taxes section remains unchanged, as taxes have not been changed since the last update of the model.
- The length of the DH network was set the following way (Koster et al., 2022):
    - Head distribution (primary pipes): 1.29 km
    - Primary distribution (secondary pipes): 8.28 km
    - Secondary distribution (pipes towards dwellings) 22.93 km (based upon the assumption of 8m per individual land-bound connections, 5m per stacked connection and 50m for collective connection.
- Heat losses were changed from 23% to 28% (Koster et al., 2022).
- The autonomous heat demand reduction was kept the same (0.35%) since the reports this is based upon did not have an update.

Discount rate

- The discount rate was set at 6.80%, based on the recommendations provided by CE Delft about discount rates for heat companies (Koster et al., 2022).

Rates and one-off contributions

- The rates and one-off contributions for individual connections are updated to the rates and prices Eneco maintains for their heat and equipment when no other information was available. This choice was made because Eneco currently exploits the DH systems in Delft. When certain rates were not provided by Eneco, the maximum as established by the ACM was maintained (Eneco, 2022)(ACM, 2022).
- Because the heat price is currently very high and is expected to normalise around 2025 (van Lier, 2021), taking the current Eneco heat price will result in a too high estimation of the incomes over the lifetime of the project. To estimate a realistic heat price, the gas prices from

the climate and energy outlook 2021 from PBL are used, in combination with the no more than otherwise principle stated by the ACM. This principle states that the price for heat may not exceed the price a consumer would pay if he had a HR boiler. For this assumption, the small consumer price is used, which differs from the large consumer price. This different price is partly due to different taxes which are relevant for small and large consumers. The climate and energy outlook has real data and projections for 2030. This data is then extrapolated to 2050 and the average over the years 2025-2050 is taken for the whole project lifetime. The data used is given in Table 31, the bold numbers are data from the climate and energy outlook 2021. These numbers are including VAT. This results in an average price of 26.60 €/GJ (excluding VAT) (PBL, 2021).

Table 21: Small consumer gas price projections and interpolations to 2050

Year	Gas price (€/GJ) incl. VAT
2018	**19.6105**
2019	**21.6747**
2020	**22.0188**
2021	**23.0509**
2022	23.5861
2023	24.1213
2024	24.6564
2025	25.1916
2026	25.7268
2027	26.2620
2028	26.7971
2029	27.3323
2030	**27.8675**
2031	28.5406
2032	29.1032
2033	29.6658
2034	30.2284
2035	30.7910
2036	31.3536
2037	31.9162
2038	32.4788
2039	33.0414
2040	33.6040
2041	34.1666
2042	34.7292
2043	35.2918
2044	35.8544
2045	36.4170
2046	36.9796
2047	37.5422
2048	38.1048
2049	38.6674
2050	39.2300
Average 2025-2050	**32.1878**

- The heat rates and one-off contributions for collective and utility connections are based on the maximum rates from the ACM, in combination with some assumptions based on the rates for individual connections from Eneco:
    - The fixed costs and metering rate from Eneco for collective and utility connections are expressed in € per kW. Since the kWs are unknown, the choice is made to base it on the same ratio between ACM max rate and Eneco rate for small consumers, namely 87% of the ACM max rate.
    - The costs for a collective heat delivery set is given by Eneco per dwelling. Since this is unknown, the average of Eneco is taken, which is (min: €17.98, max: €103.72) €60.85 per dwelling. The template however needs it in € per year and not per dwelling. The maximum price provided by the ACM is €4131 per year (ACM, 2022) and it is assumed that the Eneco maximum price is close to the ACM maximum price. This leads to the assumption that the €4131 ACM price is for (4131/103.72 =) 40 dwellings. Then the price for a collective delivery set inserted in the model becomes 40*60.85 = €2434.
    - Often larger consumers pay a reduced price. For simplicity however, the heat rates for utility and collective connections are assumed to be the same as for individual connections.

CAPEX input

- For the CAPEX costs of deploying the DH network, assumptions were made about the capacity of the network and the pipes.
    - From the integral design document of heat transport in Zuid-Holland, it is deduced that per 1000 housing equivalents in the DH system, roughly 1.48 MW of capacity is necessary (Gasunie, 2021). This leads to the head distribution pipe in the designed heat network needing 6.8 MW of capacity. It is assumed that at each of the seven substations, roughly 1MW of capacity is transferred to the primary distribution pipes.
    - To determine which pipes and corresponding costs are needed for these capacities, data provided in the Template Business Case in combination with data from a DH key

figures document was used to interpolate the capacities of different DN measures of pipes (Koster et al., 2022). From the Template, it was known that the DN300 pipe has a capacity of 20MW, the DN100 pipe a capacity of 2.50MW and the DN40 pipe a capacity of 400 kW (orange dots). Plotting a line between the points, allowed to make assumptions about the capacities of other pipe DN measures, as can be seen in Figure 38.

DN	MW	Average costs/m (Koster et al., 2022)
300	**20.00**	€ 2,129
250	13.98	€ 1,743
200	9.15	€ 1,480
150	5.31	€ 1,157
100	**2.50**	€ 811
80	1.62	€ 711
50	0.64	€ 627
40	**0.40**	€ 414
32	0.23	€ 406
25	0.10	€ 393
20	0.02	€ 375

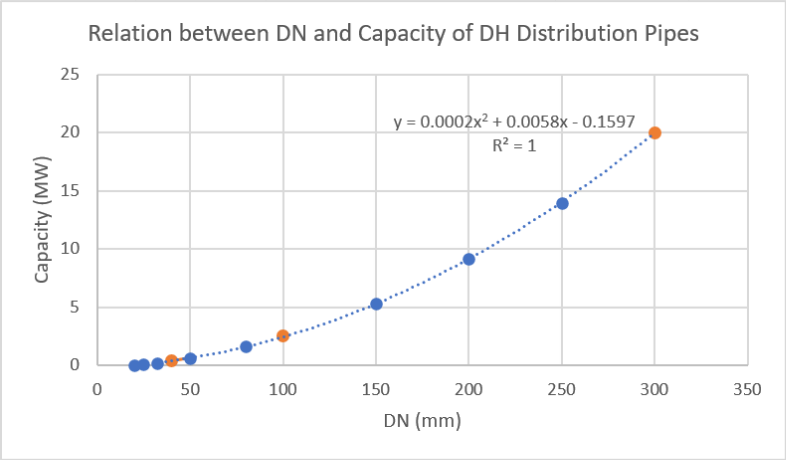


Figure 23: Interpolation of pipe thickness and prices for determining the prices of pipes

  - Using this interpolation, the choice was made to let the main distribution pipe be of DN200 Measure (€1,480/m), the primary pipes of DN80 measure (€711/m) and to keep the secondary pipes at the standard of DN40 (€414/m).
- The cost for the heat transfer station is assumed to be 135 €/kW. For 6800 kW is this €910,000 (Koster et al., 2022).
- For the substations, the costs strongly vary for different capacities. The substations that split from the main distribution pipe have an assumed capacity of 1MW, with a corresponding cost of €82,50/kW, resulting in a cost of €825,000 per substation. It is also assumed that per 250kW of total capacity, another, smaller, substation is needed. This results in 28 more substations of 250kW, which are €250/kW, resulting in €62,500 per substation (Koster et al., 2022).
- The connection costs per type of connection were taken from Koster et al. (2022) and VESTA MAIS. If a range for costs was given, the average was taken. The costs of connection consist of multiple components; connection costs, management costs, inconvenience compensation, and heat meter. The costs for the delivery system were inserted separately and also taken from Koster et al. (2022).

OPEX input

- The OPEX is a percentage of the CAPEX in the template. The numbers were updated according to VESTA MAIS and Koster et al. (2022). This meant an increase in maintenance for pipes and connection costs maintenance and a decrease in maintenance costs for substations and delivery sets.

Contribution earlier made costs

- In this section, costs made to develop WarmtelinQ could be inserted. However, contributions to costs regarding WarmtelinQ are already incorporated into the WarmtelinQ rate, so no contribution to earlier made costs are taken into account.

Connection capacity and purchase

- To determine the variable component of the heat costs for the DH system, the heat purchase price of heat supplied by WarmtelinQ must be known. In the integral design document of WarmtelinQ, two price scenarios were discussed; €4.50/GJ and €7.50/GJ (Gasunie, 2021).
- To determine a realistic long-term energy price, data from the climate and energy outlook 2021 from PBL is used, in combination with information provided by Gasunie. For this determination, the large consumer gas prices are used, since the DH system is a large consumer which consumes over 1 Mm^3 per year (van der Molen et al., 2021). Contact with Gasunie resulted in the information that Gasunie aims to let the price for heat from WarmtelinQ not exceed 70% of the gas price (Groeneveld, 2022). To determine the gas price, climate and energy outlook 2021 data was used, which is given in Table 32. The bold data points are data projections from the climate and energy outlook, the other numbers are extrapolated based on the trend in the years 2022 – 2030. As the template only allows for the insertion of one static energy price, the average of the years 2025 – 2050 is taken as the gas price for the whole project lifetime. This results in an average gas price of 7.99 €/GJ (PBL, 2021). To transform the gas price into the heat purchase price from WartmelinQ, it is multiplied by 70%, resulting in a price of 5.60 €/GJ.
- For simplicity, it is assumed that the peak load price is the same as the base load price of 5.60 €/GJ.
- The fixed costs are assumed to be zero because there is no information from WarmtelinQ about this. These costs are assumed to be incorporated into the heat purchase price from WarmtelinQ.
- The connection capacities also remained their default value because no better information was present. These values are 4.18kW/dwelling for ground-bound dwellings and 2.70kW for stacked dwellings.

Table 22: Large consumer gas price projections and extrapolations to 2050

Year	Gas price (€/GJ)
2022	**4.8247**
2023	**4.4589**
2024	**4.7313**
2025	**5.0038**
2026	**5.2762**
2027	**5.5487**
2028	**5.8211**
2029	**6.0936**
2030	**6.3660**
2031	6.4987
2032	6.7290
2033	6.9593
2034	7.1896
2035	7.4200
2036	7.6503
2037	7.8806
2038	8.1109
2039	8.3412
2040	8.5715
2041	8.8018
2042	9.0321
2043	9.2624
2044	9.4927
2045	9.7231
2046	9.9534
2047	10.1837
2048	10.4140
2049	10.6443
2050	10.8746
Average 2025-2050	**7.9940**

Indexing

- All indexes are kept at 2.00%, as no new information arose. This holds for the following indexing parameters: CAPEX, OPEX, CRC+CC, CC collective + utility, heat sale price, heat purchase price.

A.B.2 Sheet 'Numbers and Phasing'

Timing

- Year to start set to 2023.

- Exploitation length is kept at 30 years.
- The amount of connections in each year is calculated by the model. This means that the model automatically calculates the amount of connections linearly based on the inserted years it takes to connect a neighbourhood. It is assumed a neighbourhood takes five years to completely connect to the DH system once it starts connecting.

Phasing individual connections

- For each substation, one tranche was inserted into the model. The model can differentiate between types of ownership but this information was not available, so for each tranche, the number of housing equivalents are inserted.
- Data from the 'Startanalyse' was used to determine how much housing equivalent was ground-bound and how much stacked.
- The energy demand per housing equivalent was determined using Vesta MAIS. Vesta MAIS calculates the average energy demand per household when everything is insulated to label D in strategy S2d. The outcomes are given in Table 33.

Code ↓	Name	Housing eq (Heq)	Heat Demand (GJ/Heq)	Total heat demand (GJ)
BU05032501	Buitenhof-Noord	1,940	27	52,380
BU05032502	Juniusbuurt	573	23	13,179
BU05032503	Gillisbuurt	665	28	18,620
BU05032504	Fledderusbuurt	545	27	14,715
BU05032505	Het rode dorp	522	24	12,528
BU05032506	Pijperring	360	26	9,360
Total	**Buitenhof**	**4,605**	**26.23**	**120,782**

Table 23: Heat demand numbers per neighbourhood in de research area

- It is assumed that the connection to the DH system goes substation by substation and that it takes one year for each neighbourhood to connect. The first neighbourhood connects in 2023 and the last in 2029.

Phasing collective and utility

- For collective connections, it is assumed that existing buildings with block heating will get a collective connection. CBS Statline data provided the insight that in three of the six neighbourhoods, block heating is present. Buitenhof-Noord, the Gillisbuurt and Het rode dorp each have 67, 100 and 94 dwellings connected to block heating respectively.
- It is assumed that around 25-30 apartments are connected to a block heating system, resulting in two collective connections in Buitenhof-Noord and four collective connections in the Gillisbuurt and Het rode dorp (Agentschap NL, 2012).
- The heat demand per collective connection is determined by multiplying the number of dwellings in that connection by the average heat demand for the corresponding neighbourhood.
- For utility connections, first, it was determined per neighbourhood how much utility there is by subtracting the total housing equivalent of Table 33 with the amount of individual and collective dwelling connections. Then, the amount of housing equivalent in utility is multiplied with 130m2 / housing equivalent to get the amount of m2 in utility per neighbourhood (van Polen et al., 2020).

- Using the BAG-viewer of kadaster in combination with Google maps, the utility buildings in each neighbourhood were identified and separately inserted into the template. In each neighbourhood, there also is a 'remaining' utility building, representing the square meters of utility which could not be identified.
- The energy demand per utility building was determined by multiplying the amount of housing equivalents of the building with the average energy demand per housing equivalent of the corresponding neighbourhood.

Phasing and economic lifetime

- Changed the lifetime of installations to 20 years and delivery sets to 15 years, as described in Koster et al. (2022).

Appendix C – Tornado and Spider diagrams for Scenario 1 – 5

This appendix gives the tornado and spider diagrams of Scenario 1 – 5 in Figure 40 to 49.

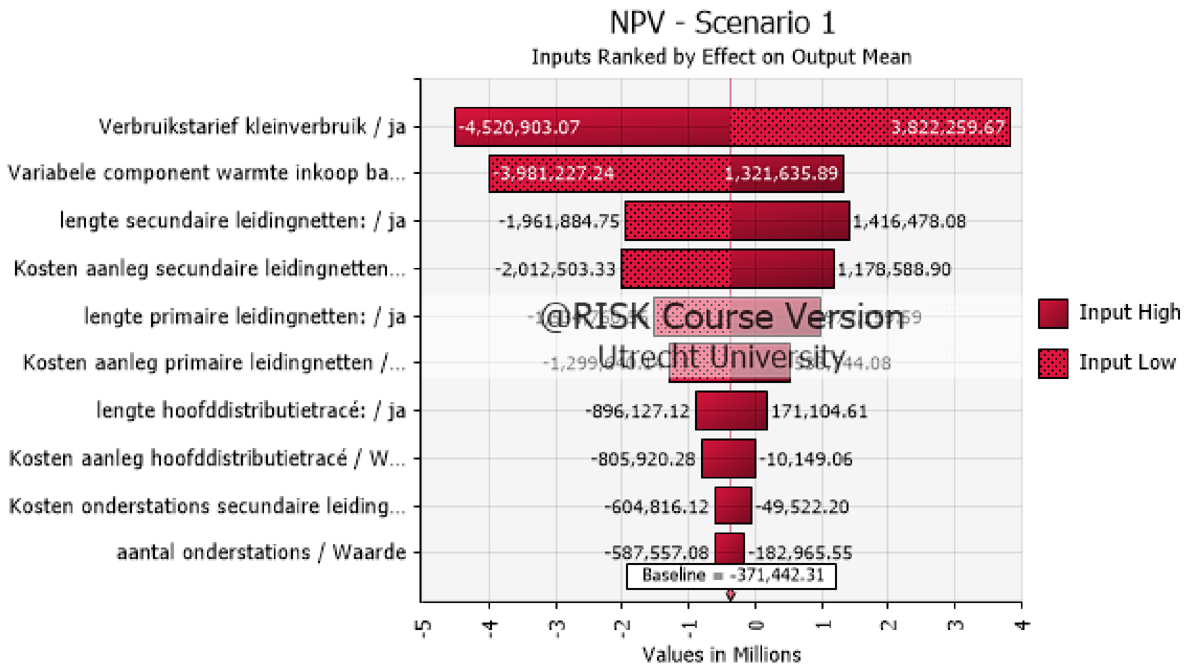


Figure 24: Tornado diagram output for scenario 1

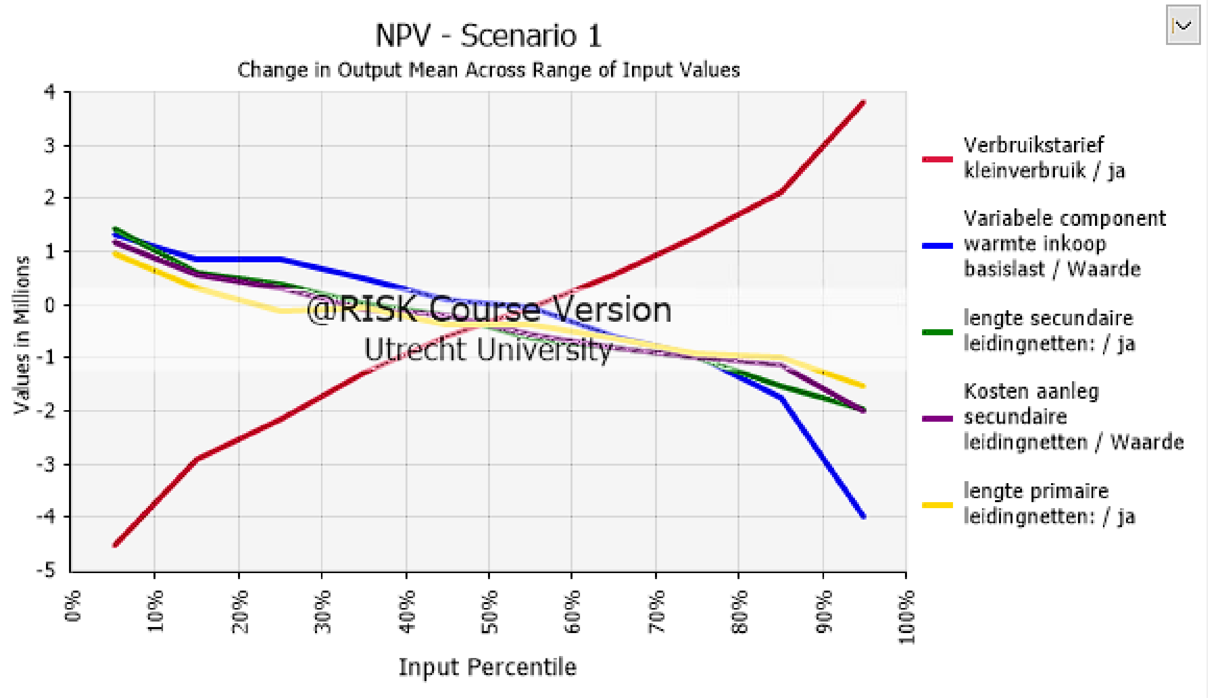


Figure 25: Spider diagram output for Scenario 1

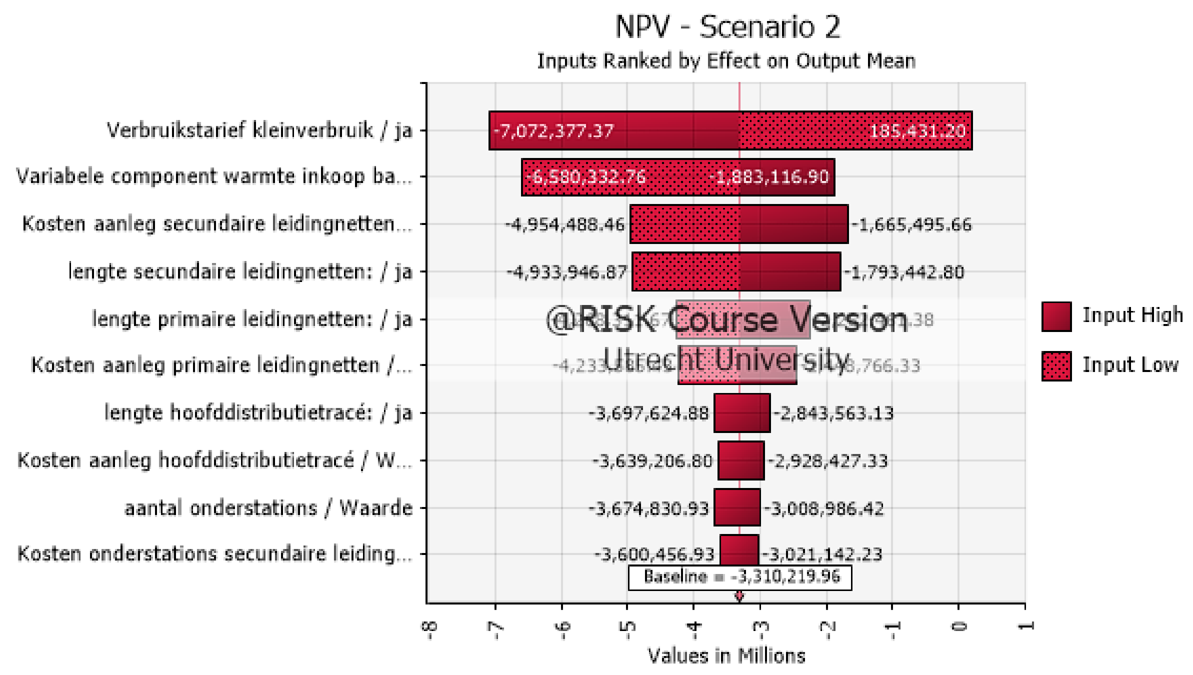


Figure 26: Tornado diagram output for Scenario 2

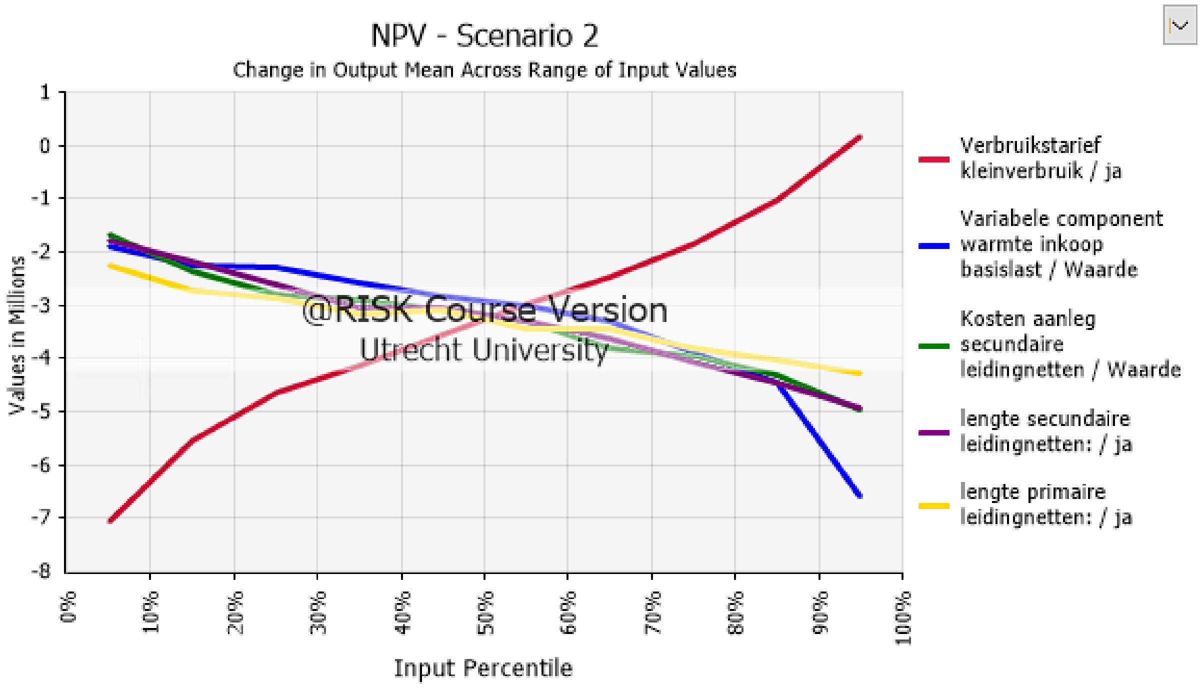


Figure 27: Spider diagram output for Scenario 2

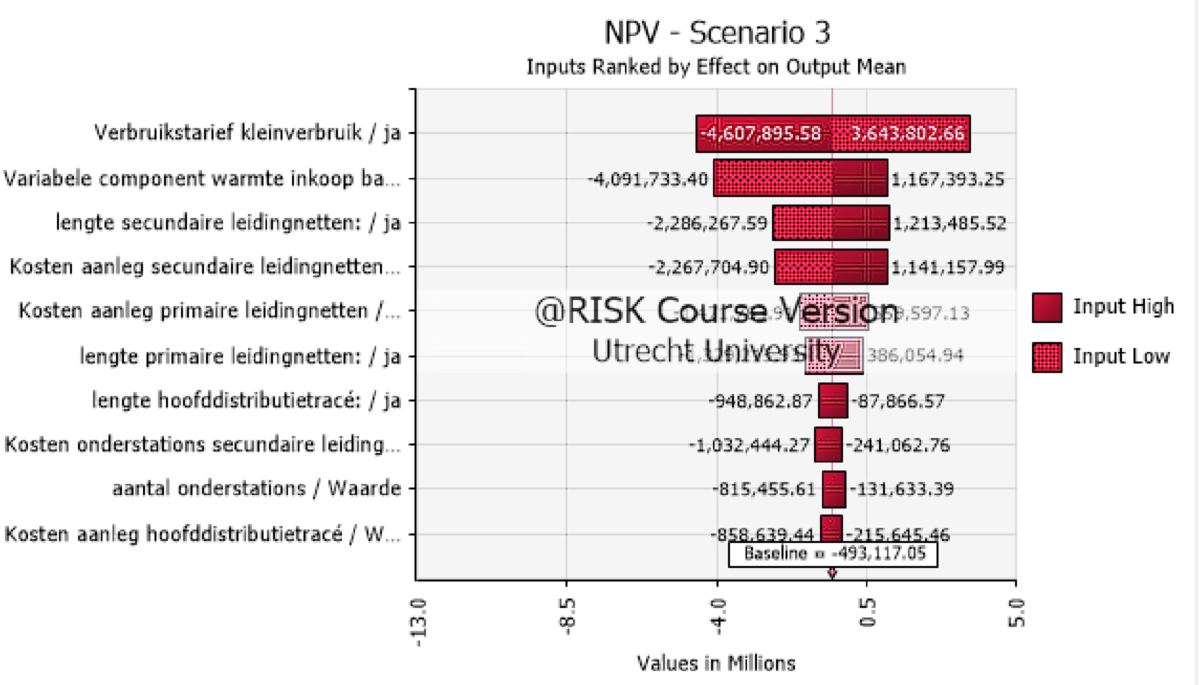


Figure 28: Tornado diagram output for Scenario 3

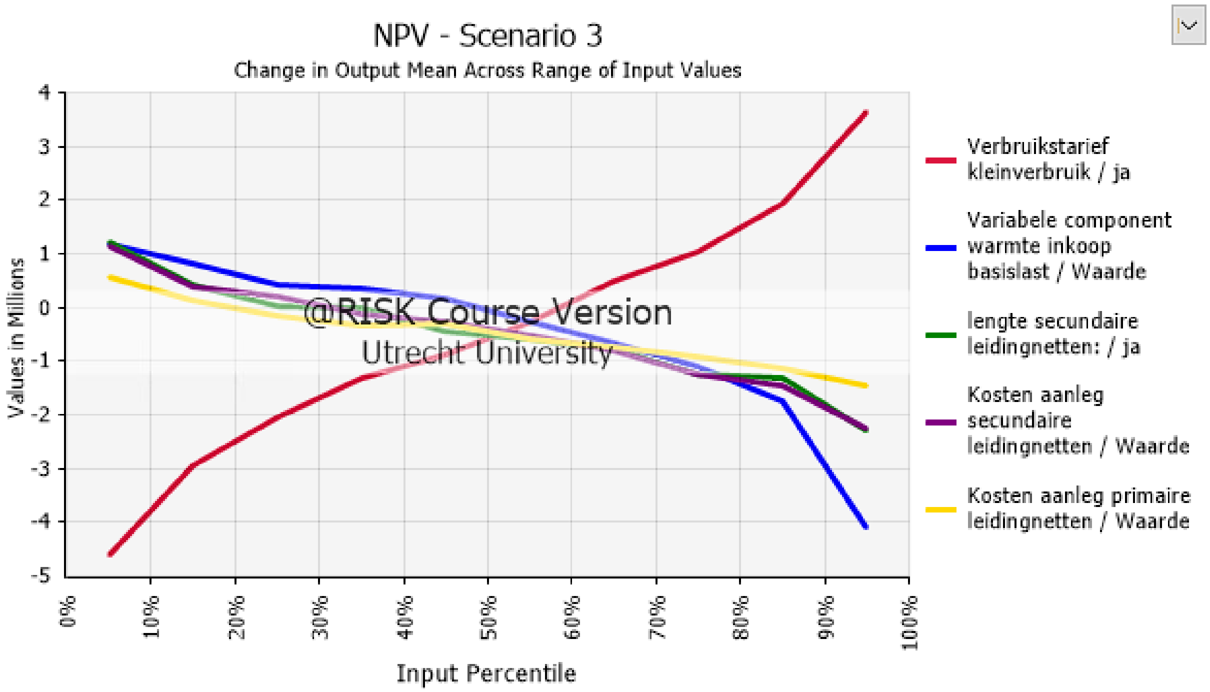


Figure 29: Spider diagram output for Scenario 3

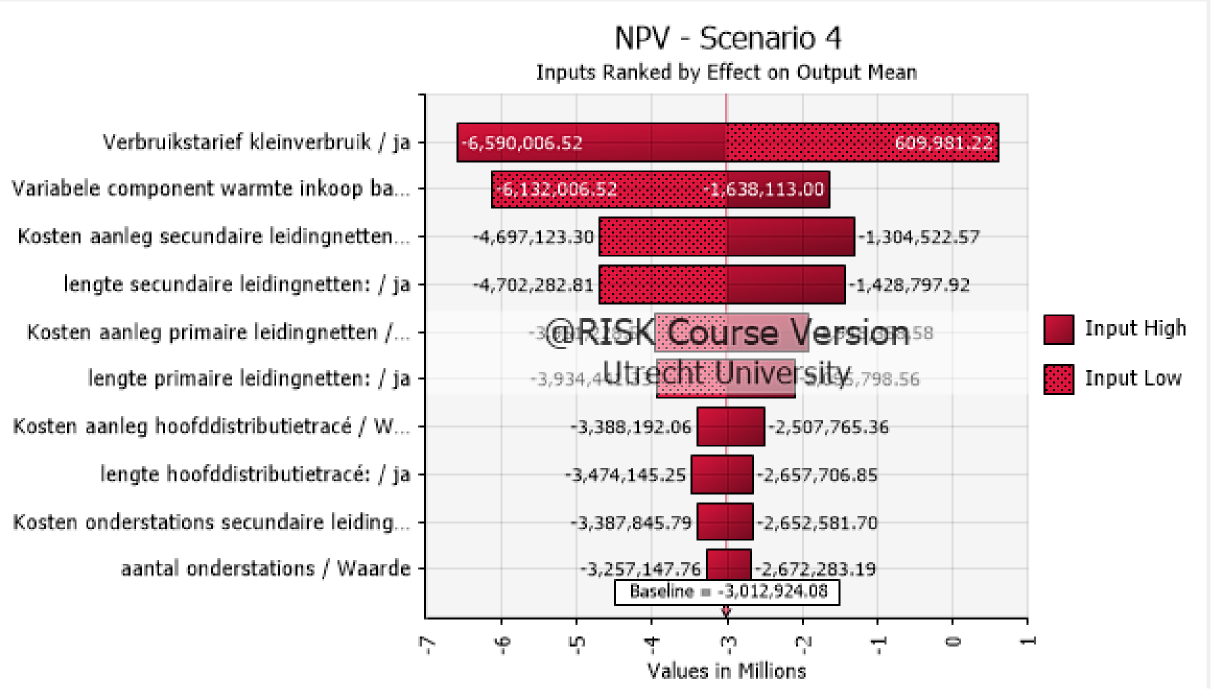


Figure 30: Tornado diagram output for Scenario 4

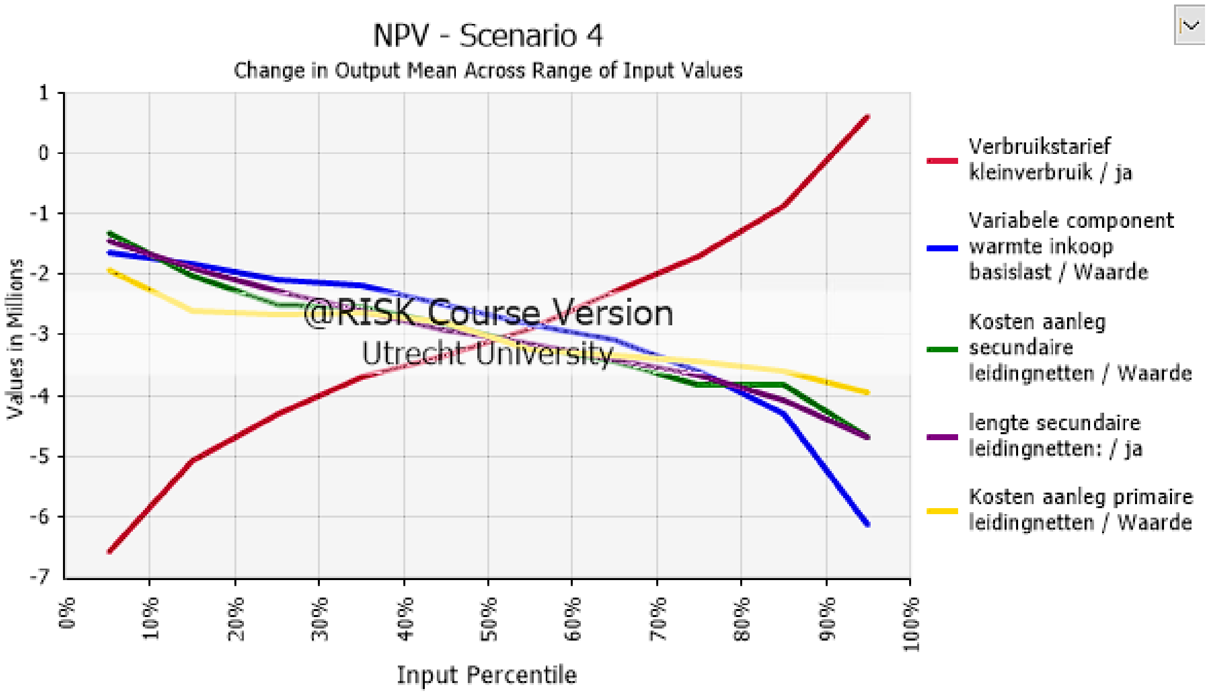


Figure 31: Spider diagram output for Scenario 4

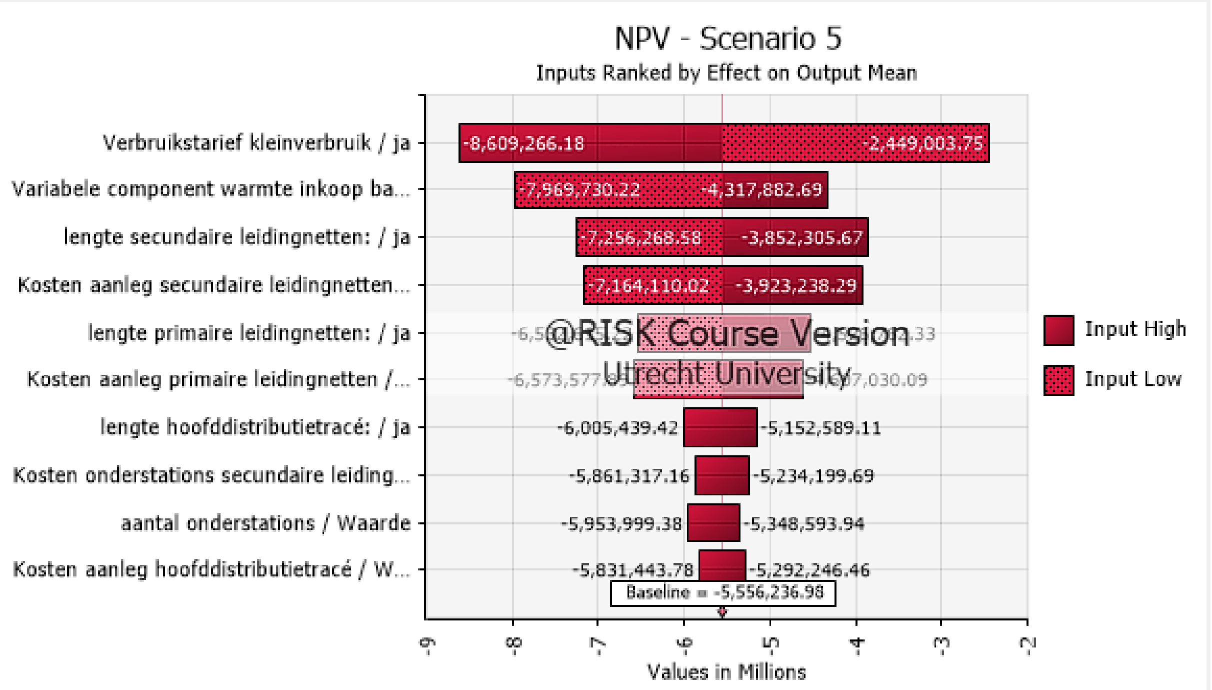


Figure 32: Tornado diagram output for Scenario 5

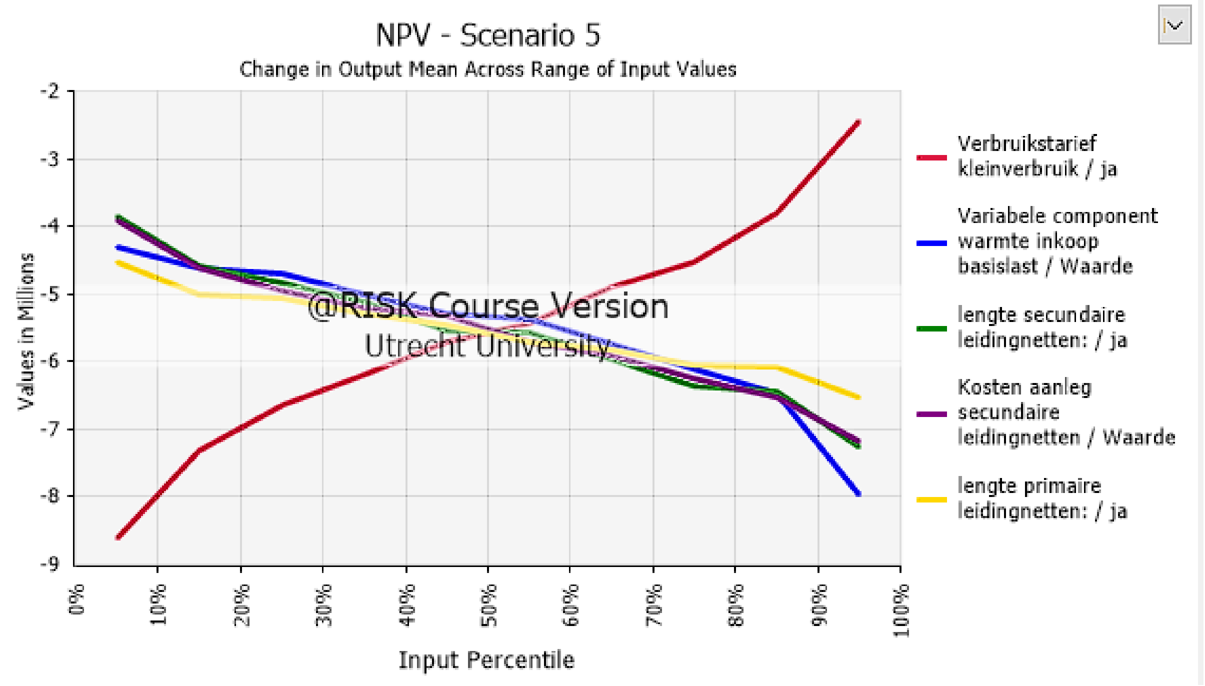


Figure 33: Spider diagram output for Scenario 5

Appendix D – Dutch transcript interview Ennatuurlijk

Eindhoven - 14-04-2022

Willem van Rossum: Als eerst heel erg bedankt dat je mee wil doen en dat ik hier kan interviewen. Ik heb volgens mij vorige keer al een beetje uitgelegd waar de vergadering nog maar even keer doen is voor hun masterscriptie ik studeer ergens science in Utrecht, ik doe nu voor het PBL onderzoek naar de robuustheid van de business case van warmtenet en dan ga ik met name onderzoek naar hoe andere strategieën dus of ja, wat er gebeurt als als mensen zelf ook al dingen gaan ondernemers, ons zelf gewoon aansluiten, aanschaffen of wordt gaan isoleren, wat voor effect heeft op de business case van warmtenet vooral omdat warmtenet en dat duurt een jaartje of want dat zijn team voordat ik daadwerkelijk ligt, dus dat kan er heel veel gebeuren. Ja, dat is eigenlijk ik ga doen. Nou, dan kun je als eerst uitleggen iets over en natuurlijk vertellen: wat doen jullie precies?

Geert de Lau: Ja, dus wij zijn überhaupt leverancier, met de nadruk op dus collectieve warmtelevering veelal door door middel van warmtenet de stadsverwarming zoals het ook wel eens genoemd wordt, hebben jullie wel bijvoorbeeld één op één objecten, dus dat je een week hoe systeem voor specifieke, een appartementencomplex of iets dergelijks hebt, maar de focus slechts wel met name op op op op die collectiviteit is. Of echt een warmtenet en daar ligt ook Nuon zn ons primaire doel om om de warmtenet die we hebben in de steden verder uit te breiden, natuurlijk te kijken naar zoals wij het dan een green 400 eigenlijk nieuwe gebieden, waar wij ook een een warmtenet kansrijk achtte, zie je wel dat dat met name dus de focus is besteden van je bepaalde gesticht tijd te gaan. Wij hebben nu ongeveer 80000 consument klanten en zo 1000 zakelijke aansluitingen landelijk actief is. Eigenlijk ja, vanuit, als je kijkt vanuit links, zitten we niet in de Randstad, daar zitten dus van oudsher Nuon en Vattenfall Eneco. We zitten bijvoorbeeld wel ja in Zeeland en een paar warmtenet een heel groot warmtenet in midden- en west Brabant, tussen Breda, Tilburg, dat is ongeveer 40000 aansluitingen dus eigenlijk het grootste. En dan verder in Brabant, naar rechts, naar Eindhoven, Helmond en eigenlijk, als je aan de oostkant kijkt, van onder naar boven dus van Maastricht, Sittard, Geleen een joint venture met met de gemeente, dus het groene werkdagen tot aan boven tot aan in Leeuwarden over die lijn, zeg maar van het proces nog het grootste warmtenet daar is in Enschede nog iets van zeven of 8000 aansluitingen ook een joint venture samen met Hengelo daar actief. Dat is eigenlijk niet bij wij zijn.

Willem van Rossum: Oké, en dat je, dr. Een warmte, leverancier zijn en hoe ziet hebben jullie? Hanteren je altijd dezelfde structuur van mn eigen, die domme zeg. Maar: is het warmte, net ook van jullie? Of is het warmtenet zijn? Zeg maar ook de netbeheerder.

Geert de Lau: Ja, in principe zijn wij vaak zijn we eigenaar van de hele keten, dus ook van productie. Oké, de productie, distributie en levering eigenlijk hè, of wat je ook wel zien en dat is bijvoorbeeld dus bij het warmtenet de medewerkers Brabant, maar ook in Enschede is dat niet geen eigenaar zijn van de productie, maar wel van de garage. Dus daar kopen de warmte in bij een ja bijvoorbeeld RWE of bij een bij afvalverbrander en verzorgen wij eigenlijk delen distributie en levering.

Willem van Rossum: Ja, oké, ehm, oké, goed om te horen. En wat is jouw rol precies binnen, en natuurlijk zijn dat kunnen beschermen.

Geert de Lau: Ja, ik ben een business analist, aan mijn primaire taak is eindelijk om business case is te maken en te beheren. En dan kunnen business case zijn voor uitbreiding van het bestaan. Dus dat kan heel klein zijn van naast ons bestaan te worden. Eén zakelijke aansluiting of tien, tien de consument aansluiting gerealiseerd, eh tot daar eigenlijk grotere uitbreidingen daarnaast zijn we ook verantwoordelijk dus voor business case is van wij wij aanpakken greenfield maar ook dus voor verduurzaming daar is eigenlijk tussen bewaken ook van ja, dat onze business case voldoen aan het financieel rendement.

Willem van Rossum: Oké, en je zei net al dat je dus vooral bezighoudt met het ontwikkelen van nieuwe warmte, en daar zou je kunnen beschrijven hoe het traject of het proces tijd ziet als als een bank met uitgebreid of een nieuwsnet aangelegd zou worden.

Geert de Lau: Ja, meestal meestal is dat eigenlijk met de klant. Vraag of een klant klantvraag dat kan dus zijn vanuit een, een projectontwikkelaar of een, bijvoorbeeld de zakelijke klant. Maar dat kan ook dus komen vanuit bijvoorbeeld een gemeente, woningcorporatie ik denk dat dat mijn naam is, waar je ook naar op zoek bent en dus daar begint het meestal mee. En dan wordt gekeken van een case achter wij, dat kansrijk is, dan meer. Nu de vraag van specifieke ons proces in of.

Willem van Rossum: Nou ja, ja, allebei een beetje, zeg, maar wat is je wordt heel veel dat vanuit de gemeente met tenders gaat en ja, daar reageerde jullie dan op. Ja, maar ik kan me voorstellen: bezig een warmte zaak dan als jullie al in een gebied zitten, dat er dan moeilijk een andere partij ook bij gaan komen.

Geert de Lau: Ja, dus dat kijk, wij hebben uiteindelijk, we hebben een keer komen mensen, een kou, managers, die houden zich dus bezig met acquisitie. Was de acquisitie niet goeiemorgen dus, dus zij zijn verantwoordelijk voor de commerciële stuk ehm. Echt de de grote trajecten met gemeente is van woningcorporaties dat dat zie je nu inderdaad steeds meer opkomen, dat dat door middel van aanbesteding fortuyn gaat. Bij de wat kleinere uitbreidingen naast onze eigen warmtenet is dat vaak wel een één op één relatie met met de klant of de desbetreffende projectontwikkelaar ET cetera dus daar komt die vraag vandaan. En wat we dan eigenlijk zelf doen, is dat wij aan de gang gaan. Daar ten eerste schetsontwerp op basis waarvan dus een eerste raming van de kosten wordt gemaakt en een business case opgesteld. Het is eigenlijk een soort haalbaarheidsonderzoek van: ja, is het mogelijk om die klanten aan te sluiten en wat voor zijn bijdrage zou daar onderaan de streep dan uitrollen dat is ja, dat kun je zeg maar met een bandbreedte zien van ongeveer 40 procent en op basis daarvan wordt dus ook met die met die partij het gesprek aan. Ja, wijk uit, willen we vervolg fase ingaan? Zo ja, dan ga je dus echt verder uit. Engineer en ook weer een update maken van de business case om zo tot uiteindelijk kunnen contracteren want die klanten komen nou voor een een kleine uitbreiding. Gaat dat dus relatief snel, zon wijkaanpak bijvoorbeeld? Ja, dat dat duurt gewoon een stuk langer. En ja, daar zijn we wel ook nog echt daar staan, ja, een soort frequin verkennende fase is, maar we hebben nog geen echt nu de afgelopen twee jaar een raamovereenkomst of iets dergelijks gesloten, waarbij we echt aan de komen zijn met deze mee te volgen. We hebben wel verkenningen lopen. Bijvoorbeeld hier in Hilversum zijn we heel actief met de gemeenten en woningcorporaties opgetrokken om daar de business case voor de hele wijk te maken, met ook socialisering pak en nou, dat lijkt me nu wel de goede kant op te gaan. Maar er zijn nog geen definitieve contract gesloten en er is nog geen schop in de grond gegaan. Dus daar zie je dat dat zeker de laatste jaren van de gemeente natuurlijk ook steeds meer naar die vraag naar voren komt. En ja, wij willen natuurlijk graag met aan het gesprek aangaan om om te kijken wat mogelijk is om op termijn wijk of buurt aan te sluiten, maar helaas zie je dat, ja daar ook doen dat dat nog niet zo zo hard gaat als als dat wij met zn allen wel.

Willem van Rossum: Ja.

Geert de Lau: Als je kijkt naar de verduurzaming opgave die we hebben, in hoe zou je eigenlijk nu al vol aan de bak moeten zijn? Maar ja, dat dat blijft lastig omdat je met heel veel stakeholders zit. Ja, uiteindelijk in die wijk wonen ook particulieren en die moet je ook uiteindelijk zien te overtuigen, want het zijn toch wel een ingrijpende maatregelen. Uiteindelijk zal er van bovenaf bepaald gaan worden wiens gasketel er uit gaat en wie aangesloten wordt op een warmtenet. We zijn wel met een aantal grote projecten bezig maar er zit nog geen schop in de grond.

Willem van Rossum: Oke, want als ik het goed begrijp dan hebben we het nu over gemeenten die willen verduurzamen en een TVW hebben opgesteld, dat de wijken waar ze een warmtenet willen dus nog geen aanbestedingen zijn gedaan? In hoe verre lopen die trajecten?

Geert de Lau: Er lopen wel wat aanbestedingen, maar die zijn nog niet afgerond. Bijvoorbeeld hier in Woensel, hier is geen aanbesteding geweest, maar zijn wij vanaf start in gesprek geweest met de gemeente en de woningcorporaties.

Willem van Rossum: Is dat omdat jullie hier ook de netten hebben?

Geert de Lau: Ja hier ligt al een warmtenet. We hebben ook een dergelijk project gedaan in tilburg en breda. Wat je nu ziet is dat er uiteindelijk een transparante businesscase uit komt. We hebben hem gevalideerd met een derde partij. Veel verschillende scenarios met verschillende woningen, volloopscenarios etc. Daar komt een bepaalkde BAK uit.

Willem van Rossum: Wat is een BAK?

Geert de Lau: Bijdrage aansluitkosten. Maar de vervolgstap moet nog gezet worden. Daar zie je dat dat ook gewoon lastig is omdat partijen een afwachtende houding aannemen. Een gemeente heeft nog geen instrument om te zeggen van deze wijk gaat dan van het gas af en hier komt een warmtenet. Je ziet nu wel dat de TVW zijn gepubliceerd, de meeste. De gemeenten zijn wel actief bezig met waar op termijn warmte en elektra komt, maar de vervolgstap moet nog gezet worden.

Willem van Rossum: Ik heb gelezen dat gemeenten een warmtekavel maken. Ik kan me voorstellen dat jullie dit zelf ook berekenen, wat gebeurt er wanneer er uit jullie berekening komt dat de kavel beter groter of kleiner kan?

Geert de Lau: Ja dat gebeurt zeker. Dat is in die zin ook een stukje gezond verstand. Als er zo een aanbesteding vanuit de gemeente komt gaan we inderdaad kijken hoe kunnen we dat indelen en hoe ziet de scope er dan uit. Dan krijg je dat gemeenten vaak willen werken met een gesocialiseerde bak. Het is een iteratief proces van he dit cluster is een stuk duurder omdat het vrijstaande huizen zijn en geen rijtjeshuizen. Dan is het wel het gesprek met de gemeente van hoe ga je om met de scope. Wat laat je er uit? Zie je inderdaad er naast nog een interessante wijk?

Willem van Rossum: Want per project is de BAK hetzelfde? Of verschilt het per woning?

Geert de Lau: Dat gaat in overleg met de gemeentes. Sommige gemeenten of woningcoorporaties willen 1 bedrag. In tilburg en breda maakten we de splitsing tussen hoog en laagbouw.

Willem van Rossum: Wat vinden de consumenten daarvan? Snappen zij dit als ze meer moeten betalen?

Geert de Lau: Dat weten we nog niet, we zijn nof niet zo ver gekomen. Ze zullen er ongetwijfeld iets van vinden, maar omdat we nog geen heel project gehad hebben waarbij we een hele wijk van het gas af halen weten we het nog niet. We sluiten nu al wel bestaande woningen aan maar dat is eigenlijk voor 95% wonincorporatiebezit dus dan heeft een huurder geen keuze. Zodra er 70% instemt moet iedereen meedoen. De huurder betaald ook niet de aansluitbijdrage.

Willem van Rossum: Ik heb gelezen dat het voor gemeenten een lastig punt is dat voor het aanwijzen van warmtekavels en het ontwikkelen van gebieden voor warmtenetten zij weinig transparantie ervaren bij de warmtebedrijven over wat voor kosten ze precies maken en hoe duur dingen worden. Hoe ervaren jullie dit?

Geert de Lau: Ik herken het wel. Er wordt wel eens wantrouwend naar ons gekeken van ze maken te veel rendement etc. Als ik kijk naar de trajecten waar we wel openheid van zaken hebben gegeven, dan zie je dat daar wel uitkomt dat het niet zo is. Wij maken rendement, maar dit is in verhouding met risico en rendement. Het wordt ook getoetst vanuit de ACM. Ik heb het beeld wel dat de projecten waar we openheid van zaken geven dat dat wel vertrouwen brengt.

Je noemde net risicos al, globaal gezien, wat voor risico analyses voeren jullie uit?

Geert de Lau: Enerzijds technisch. Dit zijn investeringsrisicos. Onze engeneering afdeling maakt een raming en maakt ook een risicoraming. Dit gaat echt over zaken als de stijging van materiaalkosten, mede door oorlog in Oekraine. Er zijn enorme staalprijzen, dit soort risicos worden meegenomen. Maar ook op bijvoorbeeld nie gesprongen explosieven, grondvervuiling of vertraging/stagnatie dat soort zaken. Dit zijn echt technische risicos die worden opgenomen in de risicoraming. Daarnaast hebben we ook businesscase risicos. Daarvan is een belangrijke het vollooprisico. Je neemt aan dat de woningen conform een bepaalde planning worden opgeleverd. Wat je ziet is dat wanneer dat naar achter schuift, wat vaker gebeurt dan dat het naar voren schuift, dat raakt de businesscase hard. Met name als je aan de voorkant grote investeringen moet doen voor de opwek of het primaire net en de cashflows uitblijven dan kost het wel op de businesscase. Dat is een belangrijk risico voor de busnesscase. Anderzijds heb je prijsindexeringen voor gas, elektra, warmte, of bepaalde afnames, onderhoudskosten etc. Dat soort risicos en gevoeligheden worden ook allemaal meegenomen in de uiteindelijke beslissing om wel of niet te investeren in een project. Wat je dus ziet met name ook nu met die gebiedsaanpak is dat je zit vaak zeker in de eerste gesprekken, daar zitten veel risicos in. Uiteindelijk wil je een uitvoeringsonterp met een vaste offerte van een aannemer. Dan zit je tussen de 5 en 10 % onzekerheid. Bij het schetsontwerp zit je op 30 – 40% onzekerheid. Daar zit dus een CAPEX risico in.

Willem van Rossum: We hadden het net al even over de bron, hoe bepalen jullie wat voor bron er wordt aangesloten op een warmtenet en hoe kijken jullie of de capaciteit genoeg is? Hoe gaan jullie er mee om als je een bron voor ogen hebt, maar dit van een derde partij is, zoals restwarmte?

Geert de Lau: De beschikbaarheid van een restwarmtebron of de beschikbaarheid van bronnen in het algemeen is redelijk beperkt en erg specigfiek. Wat ik hier eigenlijk mee bedoel is dat niet overal restwarmte zit, daar moeten wij als nederland naar kijken hoe zetten we die in. VESTA is daar een mooie tool voor. Wat ik bedoel met specifiek is dat bijvoorbeeld geothermie, een mooie duurzame oplossing, dat kan ook niet overal ontwikkeld worden. Als je begint met een project is het gewoon kijken wat voor opties je hebt. Biomassa is ook een optie maar dan moet je kijken hoe de gemeente daar tegenover staat. Dit is altijd een zoektocht. Hoe we omgaan met restwarmte van derde partijen, stel dat er een warmtenet ontwikkeld wordt bij een restwarmtebron, dan ga je in gesprek met de partij en sluit je een WLO, een warmteleveringsovereenkomst, af. Dat kan beginnen met een andere partij die aangeeft van he ik heb 10MW beschikbaar, dan ga je het gesprek aan. Soms is het eerst de head of terms vaststellen, globaal wat zijn de prijsafspraken, en wanneer je naar het closen van het project gaat, wordt het concreter. Dan kijken we naar wat Zijn de afspraken, wat gebeurt er als we meer of minder warmte afleveren. Als we zelf een bron ontwikkelen dan heb je dat in principe niet, maar dan heb je wel voor het ontwikkelen van de bron moet de engineer er naar kijken en heb je bij voorkeur bij de closing ook gewoon een offerte liggen.

Willem van Rossum: En hoe gaan jullie om met het risico dat een derde partij van wie jullie restwarmte kopen misschien ook verduurzamingsambities hebben? En hun eigen restwarmte willen gaan hergebruiken of maatregelen nemen waardoor ze ineens minder restwarmte gaan produceren?

Geert de Lau: Bij voorkeur heb je daar gewoon afspraken over gemaakt in je contract. In je businesscase wat we wel eens doen is dat we daar mee spelen. Op een gegeven moemnet weet je van we hebben zoveel MW restwarmte beschikbaar en uiteindelijk leidt dat tot een soort productieprofiel. Dus ik doe de baseload, bijvoorbeeld 80% kan ik opvangen met die restwarmtebron, en daar zit dan nog een peak- of back-up vermogen bij. Dat kan gas zijn maar dat kan ook een andere oplossing zijn, om de niet beschikbare uren of de piekmomenten op te vangen. Wat we in de businesscase doen is kijken wat er bijvoorbeeld gebeurt als dit niet 80/20 is maar bijvoorbeeld 60/40. Op die manier speel je dan met de gevoeligheid om te kijken wat er dan gebeurt met de businesscase en het rendement.

Willem van Rossum: Hoe duurzaam zijn jullie netten op dit moment ongeveer?

Geert de Lau: Dat staat op onze website bij de warmteetiketten. Daar staat per net hoe duurszaam het is. Er is richting vanuit de wartmewet, het verschilt we hebben een heel scala aan bronnen en warmtenetten. Sommige scoren al heel goed, sommige wat minder, we hebben ook nog gas gestookte netten, daar zit wel een verduurzamingsopgave.

Willem van Rossum: Want jullie ambiëren wel om alleen nog maar groene netten te ontwikkelen?

Geert de Lau: We hebben doelstellingen, die staan op de site. Deze gaan over CO2 reductie voor 2030, 2040, 2050. Dit is ook vastgelegd in de nieuwe warmtewet. Dit wordt elk jaar strenger en is een hele opgave. We zijn ons er van bewust en de verduurzamingsstrategie gaat uit van dat we het zelfs iets eerrder bewerkstelligen dan dat er vanuit de overheid verplicht is.

Willem van Rossum: Nog even terug naar onzekerheden en risico's, hoe gaan jullie om met onzekerheden met betrekking op gedrag van consumenten? Ik kan me voorstellen dat jullie uitgaan van bepaalde standaarden of aannames doen? Maar misschien heb je ineens een complex waarbij mensen niet bewust bezig zijn met hun verbruik en het afwijkt van wat jullie geraamd hebben?

Geert de Lau: Kijk in die zin heb je die fit en doen we een gevoeligheidsanalyse. Het risico zit het er natuurlijk in dat er te weinig wordt afgenomen, maar het kan ook dat er meer wordt afgenomen. We kijken wel wat er gebeurt als het gebeurt. Het is lastig er zo een getal aan te hangen maar we kijken wel wat als er 10% meer of minder verbruikt wordt.

Willem van Rossum: Hoe gaan jullie om met onzekerheden over wat er in de grond wordt aangetroffen?

Geert de Lau: Dat wordt meegenomen in de technische risicoanalyse/raming. Daar hebben we dus eigenlijk gewoon een begroting, waarbij we uitrekenen hoeveel meter pijp, graafwerk etc er nodig is. Dan wordt er gekeken van dit is een verdacht gebied voor bodemvervuiling, en doen we via anthea een bodemonderzoek waar uit kan komen of het schone grond is of dar er wel risico is. Op basis daarvan wordt een inschatting gemaakt met het risico op grondvervuiling en wat voor extra kosten er bij kunnen komen. Als het hoog risico is is de kans op extra kosten groter.

Willem van Rossum: Hanteren jullie per project een andere risicovoet?

Geert de Lau: De risicoraming is inderdaad projectspecifiek.

Willem van Rossum: Hoe bepalen jullie de uiteindelijke prijs van de warmte die jullie leveren?

Geert de Lau: We zijn deels gecapt door de warmtewet en de ACM. Ieder jaar kijken we waar we op uit komen en proberen we, zoals dit jaar waar wij ook last hebben van hogere gasprijzen net als veel contracten voor restwarmte die zijn ook gasgerelateerd, Net als sommige subsidies die zijn ook gasgerelateerd. We kijken jaar op jaar wat voor impact het heeft op de marge en daarin proberen we stabiel te blijven. Als we zien dat de kosten de pan uit reizen, kijken we welke kosten ons echt raken en wat zit er bijvoorbeeld in de gasprijs van de ACM die ons niet aan de inkoopkant raakt.

Willem van Rossum: Hanteren jullie de maximumprijs?

Geert de Lau: Nee. We zitten al een aantal jaren onder de maximumprijs. Je ziet wel dat we dit jaar relatief meer korting geven op het maximumtarief. We proberen onze marge constant te houden en dit jaar geven we een extra korting.

Willem van Rossum: Hoe gaan jullie om met een tegenvallend aantal aansluitingen op een project, of een lagere warmtevraag. Passen jullie dan de prijs van warmte aan of wordt dan bijvoorbeeld de aansluitbijdrage hoger? Hoe reageren jullie op zo een tegenvaller? Welk aspect van de kosten (aansluit, vast variabel) wordt daar op aangepast?

Geert de Lau: Wij sluiten contracten met een partij. De aansluitbijdrage ligt dan vast. Die wordt wel geindexeerd, dus stel dat de aansluiting over 5 jaar worden aangesloten, dan wordt die wel geindexeerd. Het is niet zo dat we die bijdrage aanpassen op basis van de ontwikkeling van het project. Dat is ons risico, dat geldt ook voor de warmtetarieven. We streven voor een standaard Ennatuurlijk tarief voor iedereen, niet per net verschillend. Dat kan eventueel veranderen in de nieuwe warmtewet. Nu hebben we 1 standaardtarief. Er zijn wel afwijkingen op bepaalde netten maar dat komt door afspraken in het verleden. Als we nu een businesscase maken voor de uitbreiding van een warmtenet gaan we in principe uit van onze stadnaardtafrief methodiek. Voor de accountmanager die het project zowel intern als extern moet verkopen is de draaiknop de aansluitbijdrage. Uiteindelijk rekenen wij uit wat voor aansluitbijdrage nodig is om het project rendabel te maken voor ons. Het risico op CAPEX overschrijvingen en vertraging of volloop ligt bij ons. Wat we daarin bijvoorbeeld wel doen is dat we afspraken doen voor een partij van dat alles wordt gerealiseerd in 2023 dan nemen we wel een clausule op die zegt dat eind 2024 gaan we wel aansluitbijdrage in rekekening brengen voor nog op te leveren woningen om zo het risico een beetje te dekken. We monitoren hoe het zich ontwikkeld, met name op CAPEX kosten, er wordt bedacht dat het bijvoorbeeld een miljoen moet kosten, en dan ziet een projectleider snel van daar of daar gaat het wat meer kosten. Echter, ligt na het contract de aansluitbijdrage vast. Dus het is ons risico of onze winst als het duurder wordt of wanneer het meevalt. Een vertaalslag naar jouw onderzoek; dit zijn dus wel projecten met een wat kleinere schaal. Dat varieert dus van 10-15 woningen tot een paar 100. Ik kan me wel voorstellen dat wanneer je over gaat op eene echte wijkaanpak, zoals hier in Woenssel waar het gaat over 11.000 woningen, dan moet je denk ik op het momoent dat je de contractfase ingaat heel goed kijken van hoe gaan we dat met elkaar doen. Je kan er wel bepaalde afspraken over maken vna dat je eens in de zoveel tijd wel de businesscase update en kijkt van hoe ziet het er uit tov wat we met elkaar bedacht hadden. Wat nu een beetje jammer is is dat we nog niet echt een hele keten hebben doorlopen qua wijkaanpak dus ik kan nog niet vertellen hoe het er precies aan toe gaat. De ene variant is dat alles voor rekening en risico is van Ennatuurlijk, zeker op trajecten waar we nu in zitten, je wilt niet iets van een schetsontwerp met een risico bandbreedte vban 40% zeggen van dit is de BAK., dat is een te groot risico. Je zou wel een soort verrekening met elkaar kunnen doen, dan houdt je een transparante businesscase aan de voorkant die je blijft ontwikkelen en zou je met een soort potje moeten werken waarmee bepaalde risicos opgevangen kunnen worden. Dit zou 2 kanten opp kunnen werken, dat het ook zo is dat als het goedkoper uitvalt de al aangesloten woningen een bedrag terug zouden krijgen. Ik denk dat daar heel Nederladn wel een beetje mee worstelt. Uiteindelijk kan een gemeente heel erg helpen met het inkaderen en inperken van bepaalde risicos. Als je met gemeentes bepaalde afspraken kan maken over bijvoorbeeld het openmaken van straten en herstelwerkzaamheden, eventueel op rekening van de gemeente, dan kan je daar risicos mee inperken. Dat zijn we nu heel erga aan het leren eigenlijk

Willem van Rossum: Hoe bepalen jullie de businesscase, hebben jullie een template, gebruiken jullie een tool. En eigenlijk al een vervolgvraag; ben je bekent met de template van het ECW? Zo ja, wat vind je ervan?

Geert de Lau: Hoe bepaal je dat? We brengen een wijk in beeld en kijken naar de vorm van bezit, is het wonincorporatie of particulier. Dan ga je het gesprek aan met elkaar en kijk je wat de scope is en hoe veel particulieren willen aansluiten. Vaak is dat uiteindelijk ook weer een resultant van de aanslutibijdrage. Wanneer het aangesloten kanw orden maar heel duur is is het minder realistisch dat iedereen zich aansluit dan wanneer het een stuk goedkoper kan (10k vs 2k genoemd). Wat we nu doen is scenarios indraaien, wat als 10% mee doet, wat als 50% wat als 100% mee doet. Hier in Eindhoven bijvoorbeeld zijn al die businesscases opgesteld met Greenvis, daar zit een dynamishc begrotingsmodel achter dat je echt ziet van als je minder particulieren aalsuit wordt je distributie kleiner of vallen bepaalde stukken af. Hij rekent dan ook opnieuw de investering uit. Vanuit dat model een brug maken met de Template, wij gebruiken die eigenlijk niet. Dit omdat het heel erg statisch is. Je kan soort van 1 scenario er in zetten en dat sluit niet aan bij de werkelijkheid waarbij jen met de gemeente opzoek gaat naar de ideale scope en aansluitbijdrage. Voor grote trajecten gebruiken we maatgemaakte modellen. Die worden bijvoorbeeld samen opgesteld met Greenvis, een externe partij, of hij wordt gevalideerd door een externe partij, zoals in Tilburg en Brede, om wel vertrouwen bij de gemeente te wekken.

Willem van Rossum: Op basis van welke primaire financiele indicatoren bepalen jullie uitiendelijk of het een go/no go wordt. Heb je het dan over de NCW of meot het project een bepaald rendement halen?

Geert de Lau: Wij kijken inderdaad naar de NCW en de IRR, als je investering precies voldoet aan het gewenste rendement, is je NCW 0. Daar kijken wij naar, wat we wel daarin doen is dat we zeker voor wat wij platforminvesteringen noemen, dus als we bijvoorbeeld met woningcorporaties in zee gaan, dan kunnen ze toezegging doen op een aantal aansluitingen en een afname. Daar willen we zeker van zijn dat er een rendement op komt, en hopelijk groeit dat door naar het gewenste rendement, als je dus een X percentage particulieren ook aan gaat sluiten. Dat is hoe wij de afweging nemen.

Willem van Rossum: Hoe doen jullie aannames over hoeveel particulieren er mee gaan doen?

Geert de Lau: Dat is nu nog heel erg op boeren verstand. Dus het gesprek aangaan met de corporaties en particulieren over hoe realistisch het is dat woningen zich aansluiten. En de combinatie met wat voor aansluitbijdrage er uit komt en hoe het er voor de klant uit gaat szien. Woningcorporaties willen dat het kostenneutraal is voor de bewoner.

Willem van Rossum: Voor een particulier is kostenneutraal niet goed genoeg vaak toch?

Geert de Lau: Dat klopt. Echter moet die ook op termijn een keer zn gasketel vervangen of wanneer het gasnet er uitgetrokken wordt moet die ook een alternatief hebben. Simpel gezegd is dat een warmtepomp of een warmtenet. Daar kijken we wel naar in combinatie met de aansluitbijdrage.

Willem van Rossum: Dan heb ik nog een laatste vraag, doen jullie ook aan cascadering in jullie netten?

Geert de Lau: Daar zijn we wel mee bezig. Ik weet niet of we het al hebben maar we zijn er wel naar aan het kijken. We nemen het wel mee in de optie voor de businesscase. Het is een technisch concept, maar het is een van de eerste stappen in het concept. Onze engineers kijken hier naar wat de mogelijkheden zijn. De duurzaamheid en innovatie afdeling hier mee bezig, ook met temperatuurverlaging en kijken hoe het net zo efficiënt mogelijk kan worden. Cascadering is daar 1 van.

Willem: Hartelijk dank voor je medewerking en het interview.