Analysing residential heating technology trade-offs to influence decision making of municipalities using a GIS-model

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TU Delft & University of Leiden, Master Thesis Industrial Ecology – July 2018

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Keywords: [Heating transition], [GIS], [Heating networks], [Heat pump]

Summary

The heating transition goals of the Netherlands are ambitious. To reach the goal of an 80% reduction of CO_2 emission by 2050, the total residential heat consumption would need to be drastically cut down. The Dutch government is leaning towards implementing large-scale heating networks and reusing waste heat from non-renewable industry. However, doubts exist whether or not that is the most viable solution. Other research lacks an overlapping approach to the modelling of a complex problem like the heating transition. The aim of this paper is to make a GIS-based framework to develop scenarios for the heating transition in cities and evaluate the implementation of different combinations of technologies to reach the Dutch climate goals. This analysis focusses on residential buildings because there is an ongoing discussion who is going to pay for the investment necessary to achieve the heating transition for this type of building. The case study of this paper focusses on the Merenwijk in the city of Leiden in the Netherlands

The technologies covered in this paper are heat pumps, low temperature heating networks and high temperature heating networks. These technologies are evaluated on their technical, financial and environmental aspects to determine their impact. Next to these impacts the trade-offs of implementing these technologies are evaluated and which impact these could have on the stakeholders involved. Three scenarios were made to cover a few combinations of these technologies: 1) a scenario based on the *warmtevisie* from Leiden utilizing heat pumps and low temperature heating networks; 2) a scenario utilizing only heat pumps; and 3) a scenario implementing low and high temperature heating networks for the whole neighbourhood.

All technologies have specific characteristics which should be considered before implementing on a large scale. Financial assistance from the municipality or the government is needed for the home owners in order to achieve the heating transition within 32 years. The energy sources used by the heating technologies will be crucial for reaching the climate goals. At some point the Dutch government has to choose between a quick wins solution by reusing waste heat from the harbour of Rotterdam, or to implement a long term sustainable energy transition with heat pumps and low temperature heating networks. This paper provides an overview of the three mentioned heating technologies to be implemented during the heating transition as an alternative to natural gas. Moreover, it will hopefully invoke some debate about the Dutch government's heating transition agenda.

1 Introduction

The Netherlands is facing a big challenge in its heating transition. All the buildings in the country have to be energy neutral before 2050 (Gemeente Leiden, 2017) while currently being predominantly reliant on natural gas (Rijksoverheid, 2017). The heating of a city is a huge energy drain and a huge financial investment, while the energy supply is dominated by fossil fuels. 43% of the heat supply in the EU is sourced by natural gas, and only 10% comes from renewable resources (Connolly et al., 2017). In the historical city of Leiden, where most buildings were built before 1900, 80% of the heating demand is satisfied with natural gas (Gemeente Leiden, 2017). Overall, the country of the Netherlands needs to reduce its CO_2 demand with a significant margin compared to its current consumption (Rijksoverheid, 2017). However, this is not the first heating transition the Dutch have faced. The primary heating method for residential buildings was changed from coal to gas during the 1960's. Heating buildings on coal had a lot of drawbacks which made the transition to natural gas attractive and therefore did not meet a lot of resistance (HIER, 2018a). The current transition away from natural gas to more alternative energy sources is different and much more complex, as there are multiple alternatives available and as it will require substantial investment by residents and home-owners (Rijksoverheid, 2017). Another important initiative in the Netherlands is the *warmterotonde*, in which the harbour of Rotterdam will supply waste heat from its refineries and coal-fired power plants. This waste heat is used in high temperature heating networks to supply residential homes.

The objective of this report is to contribute to the societal problem of the Dutch heating transition with regard to residential buildings. The Dutch government in 2017 set a goal in its energy agenda to be energy neutral by 2050. The term energy neutral is defined by the Dutch government as having 80-95% less CO_2 emission compared to 1990 (Rijksoverheid, 2017). While the energy transition in the Netherlands in general encompasses all different energy sources for all different uses, the heating transition focusses specifically on the heating of buildings. The heating transition is thus a part of the energy transition as a whole (Bosman & Rotmans, n.d.). In Sweden a heating transition towards more sustainable heating technologies has already taken place. Multiple low temperature district heating networks were developed over the course of 30 years which changed Sweden's main heating source from coal fired powered plants to biomass (Werner, 2018). The Netherlands is facing a different challenge in meeting its heating demand as it does not have a large quantity of biomass available to implement the use of biomass as the main source of heating. It is also one of the worst performing countries in Europe regarding the production of sustainable energy (Bosman & Rotmans, 2016). Its strong coal and oil industry can also lead to a lock-in for the use of fossil-fuels in the heating of buildings. The Dutch government is inclined to implement large-scale heating networks and reusing waste heat from non-renewable industry (Rijksoverheid, 2017). However, doubts exist whether or not that is the most viable solution.

This paper uses spatial data generated by the GIS file format in order to do a bottom-up analysis of the heating challenges faced by the municipality of Leiden, more specifically the neighbourhood of Merenwijk. Multiple large-scale frameworks to analyse urban heating challenges based on GIS data already exist: these include analysing energy saving potentials, urban heat storage or other urban problems like green infrastructure implementation (Nouvel et al., 2015) (Grimmond & Oke, 1999) (Meerow & Newell, 2017). The framework developed by Meerow & Newell proposes a Green Infrastructure Spatial Planning (GISP) model. The goal of this model is to analyse the impact of green infrastructure on the social and ecological resilience of a city. Nouvel has for example done a very thorough statistical analysis of the savings potential of residential buildings in Rotterdam. This statistical analysis focused on predicting the heat consumption of buildings with different statistical methods. The model by Grimmon & Oke looks at the energy balance of buildings in their structure and the impact on the surface temperature. Meerow & Newell on the other hand, have made a stakeholder-driven approach to maximize green infrastructure ecosystem services. The municipalities of South-Hollands have made in cooperation with the company Overmorgen a GIS-based map covering urban challenges like the heating transition (Overmorgen, 2017). Another example is the bottom-up model to assess space heating demand on a regional level (Froemelt & Hellweg, 2018) which is also available.

All of these research papers contribute individually to the understanding and solving of the problem of the heating transition. However, it is important to note that these frameworks only tackle specific elements of the heating transition, while the overall challenge of the heating transition is far more complex (Gemeente Leiden, 2017) (Bokhoven & D, 2018). In the paper by Wiese (2016), it is argued that socio-ecological elements also impact the heating transition. Therefore, technical, social and ecological aspects are also important to analyse for the heating transition (Wiese, 2016).

A city is a complex ecosystem with multiple flows and balances of money, goods, services and materials (Barthel, 2008). In order to assess the impact of a change, several of these aspects need to be addressed when researching the urban environment. It is unclear what effect some heating systems have on their surrounding and what the impact is on the stakeholders involved. Because of the disparity between the output by the different solutions proposed, it is hard to compare the results of these papers. This piece therefore aims at bridging the gap between the solutions proposed and making theses outputs comparable to implement bottom-up solutions on a district scale. These results can then be extrapolated to the scale of neighbourhoods and cities to assess the impact of the individual solutions and their effect on one another on that scale.

There are already potent technologies available to replace natural gas. These all have different characteristics and function therefore most efficiently within different settings. However, all of these technologies have different drawbacks: heating networks create a lock-in in which the home-owner cannot easily change his or her energy provider or technology while heat pumps can put a serious strain on the electricity network during winter seasons (Kieft, Harmsen, & Wagener, n.d.). This paper will discuss the different technologies and the trade-offs of their use.

The main research question of this paper is as follows:

"What are the trade-offs of different non-natural gas heating technologies in the current heating transition in the Netherlands and their influence on the involved stakeholders?"

Sub questions:

- *Which stakeholders are involved in the heating transition in the Netherlands and what are their priorities?*
- *How can a GIS method be adjusted for this heating analysis?*
- *Which indicators influence or support the plans of the municipality of Leiden?*
- *Which heating technologies are important to evaluate and how do they work from building to neighbourhood level?*
- *Which indicators can be linked to which GIS dataset?*
- *How can the chosen technologies be compared?*
- *What are the trade-offs between the different heating technologies for the stakeholders involved?*

The following chapter will develop the model scope and the description of the chosen technologies. In chapter two the methodology of this paper is summarized, following by the assumptions, stakeholders and the spatial data used in this analysis. The generation of the scenarios is explained in chapter three, after which the results are shown in chapter four. In chapter five the sensitivity analysis is laid out, with the example scenario covering the whole municipality of Leiden shown in chapter six. The results are concluded and discussed in chapter eight and nine with an advice on future research possibilities.

1.1 Model scope

The Dutch government has set the goal to be energy neutral by 2050, which means the Netherlands has a maximum of 32 years to complete its heating transition. The scenarios in this research are made to accommodate this time period and utilize the maximum amount of time available. The analysis in this paper focusses on residential buildings because there is an ongoing discussion who is going to pay for the investment necessary to achieve the heating transition for this type of building (Gemeente Leiden, 2017). Monuments will not be included in the analysis because these have different regulations regarding insulation and the implementation of new technologies. The neighbourhood Merenwijk in Leiden is used as the case study in this paper. The relatively low age of the buildings in this neighbourhood provide multiple technological possibilities for heating as an alternative to natural gas. The municipality of Leiden has made their own plans to achieve the heating transition for their municipality which are described in their *warmtevisie* (Gemeente Leiden, 2017). The changing prices of electricity and gas are not taken into account in the overall analysis. However, an extra scenario will be made to analyse the impact of changing gas prices on the payback times and investment in the results section.

The behaviour of residents is a factor that can significantly influence the heat consumption of a building. The amount of time people spend at home, the room temperature they find comfortable and the amount of people living in a building are all factors that influence heat consumption (Wei, Liu, Fan, & Wu, 2007). To limit the complexity of the model the behaviour of the residents is presumed uniform for each building. Only technologies that are currently available on the market are evaluated in their use an alternative for natural gas in this paper. The air-to-water heat pumps, low temperature heating networks and high temperature heating networks are evaluated, as these technologies possess the potential to replace natural gas on a large scale (Froemelt & Hellweg, 2018). Other technologies such as solar boilers, solar panels and pebble heaters are considered as supporting heating systems because they are not capable of heating large scale communities. Hybrid heat pumps are also not taken into account, as these do not solve the problem of using natural gas in the long run. The chosen technologies are evaluated on their energy efficiency and CO_2 performance in comparison to natural gas. Maintenance costs for the heat pump and the heat exchangers are not taken into account and their impact on the final costs will be discussed in chapter eight.

The infrastructure investment necessary to transfer the energy from the heat source to the residential buildings are taken into account. Besides this, the lifetime of the technologies, investment necessary to reach the insulation goals and technology investment of the residential buildings are analysed. The maintenance and the replacement costs of these infrastructures will not be taken into account, as coherent data hereof was difficult to retrieve. Energy storage is not taken into account in the model as the existing technologies are not mature enough to significantly influence the current implementation of energy technologies (Connolly et al., 2017). In the process of implementing the heating transition a variety of different stakeholders are involved.

Table 1: the model scopes:

Scope category	**Description**
Geographic	Residential buildings in the Merenwijk, Leiden, the Netherlands
Technologies	Heat pump, low and high temperature heating networks
Financial	Infrastructure, heat exchanger/heat pump, insulation and lifetime
Behaviour	Uniform across all houses
Time period	From 2018-2050

1.2 Technologies

The selected heating technologies all have specific characteristics that should be considered before implemented on a large scale. More than 90% of the Dutch houses are currently heated with a high temperature heating system (HTV) that has an operating temperature of 80-90 degrees Celcius (Rijksoverheid, 2018). This is the temperature of the water used to transfer the heat to the radiators and to heat up the whole building. Low temperature heating (LTV) is when the water's temperature is lower than 55 degrees Celsius. The LTV technology needs a strongly insulated house to be able to reach a comfortable temperature for the residents, as the overall heat release is lower than with HTV. The HTV technologies are less bound by these restrictions, but are overall less efficient due to the energy losses (Ecofys, 2018). Existing buildings that are using HTV have to be converted to LTV and need an adjusted heating system to lower the overall heat consumption. Floor heating or low temperature radiators have to be installed in order to adjust them to the different heating technology. LTV radiators have a higher surface area so they transfer the same amount of heat as a HTV but with a lower temperature in comparison to HTV (Ecofys, 2018). For the analysis in this report all the buildings will be converted to an LTV heating system.

1.2.1 All electric

All electric solutions are defined in this paper as the use of heat pumps as the main heating technology of a residential building. There are several heat pumps available, each having its own particular mechanism and capacity. Air-to-water and water-to-water technologies are the most commonly used. The water-to-water heat pump gets its heating and cooling capacity from a water source connected to it. This can be a source in the ground or a connection to a water network installed for heating (Milieu centraal, 2018). These are generally expensive although they are more efficient in comparison to air-to-water heat pumps. However, the user will be dependent on the water source it is connected to. Using surface water can solve some of these problems, but at the moment there are strong regulations regarding the use of surface water (Interview Joeri Oudshoorn). Reusing the heat in water which would normally be discharged to the sewer could also be a source of heat (Funamizu, 2001). The air-to-water heat pump gets its thermal capacity from the outside air. This technology has enough capacity to heat a home during most of the year and will require the lowest financial investment (Milieu centraal, 2018). This technology will however require an additional source of energy to reach the peak-winter heating demand, especially when a house is not properly insulated. Supporting heating solutions such as solar boilers, radiant heat and pellet heaters can provide the extra heat required during those periods but will also require extra investment.

The warm water demand of a residential building can be satisfied with this technology. Some heat pumps generate warm water for use in the house, while other solutions for the heating of tap water are also available with limited investment necessary (Milieu centraal, 2018). Heat pumps generate two times less CO_2 for the production of heat in comparison to natural gas, even in comparison to a non-renewable source of electricity (Milieu centraal, 2018). This technology has a potential to have no CO_2 emissions when renewable energy sources are used for its electricity production. An important aspect of this technology is the impact on the electricity network, it could overload the current existing infrastructure or require extra investment in the future. This can be compensated with storage solutions or solar panels to lower the impact. It is also possible to have one central high capacity heat pump that powers multiple homes (RVO, 2017). For resident associations & building corporations this could provide a solution with an even higher thermal efficiency. The heat can be extracted from the ground with a heat and cold thermal storage system. In Haarlem a building corporation implemented this in a building with multiple apartments to lower their energy impact (RVO, 2017). The electricity of the heat pump was partly supplied by solar panels while a cold and thermal storage was used as the heat source.

1.2.2 Low temperature heating networks

Low temperature heating networks utilize low operating temperatures ranging from 30-55 degrees Celsius and have lower transportation losses in comparison to high temperature heating networks. Sustainable heating sources tend to be low temperature and can be connected to these networks (TNO, 2017). Geothermal sources are an example of a sustainable source of heat available in the Netherlands (Haffner, 2018). In order to utilize the efficiency of this network, houses connected to this network need to be optimized for LTV (Haffner, 2018). A low temperature network can operate on a smaller scale than a high temperature heating network, and will need only a few hundred houses connected. It can also be part of a high temperature heating network by reusing the returning heat of that network as a low temperature heating source (Interview Nuon). This parameter is not used in the calculations but seen as a method to possibly improve the system's efficiency. In order to convert a house to a heating network, a heat exchanger needs to be installed to transfer the heat from the heating network to the network of the house. The heat supplied from a heating network is fixed as the heating sources provide a uniform capacity by nature. This could be a problem during the winter when there is a higher demand for heat (Interview Nuon).

When a house is connected to a heating network, a technological lock-in takes place in which the home-owner have difficulty to change their heat provider or a different technology. An open heat exchange on which stakeholders can buy and sell their heat transported through a heating network could provide an incentive to implement more low temperature heat production. In this way there is less technological lock-in, as consumers can still choose their heat source and provider. At the moment heating networks are not taxed in the Netherlands, which makes the comparison to other technologies which are being taxed at the moment not equal (Colofon, 2017). It is unsure if this will remain in the future when there are more large-scale heating networks implemented, and what its impact will be on the business case for this technology. Low temperature heating networks have the potential to deliver sustainable heat to homes, but it is still unclear if there are enough sustainable heat sources available to satisfy the demand (Haffner, 2018). Heating networks could also be used for cooling, and in the future the demand for cooling in homes and buildings could increase (Colmenar-Santos, Borge-Díez, & Asensio, 2017) (Colmenar-Santos, Borge-Díez, & Asensio, 2017). Old city centres like the one in Leiden have a great difficulty with implementing heating networks. The ground is filled with infrastructure and adding a heating network would shut down parts of the city for months due to the high density of buildings and roads.

1.2.3 High temperature heating networks

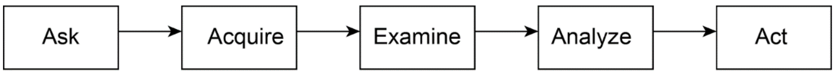
High temperature heating networks have been around for a while, almost all of them utilize non-sustainable heat with operating temperatures around 70-90 degrees Celsius. Waste heat from the industry is utilized for the heat of these heating networks, but it is not always clear if this source is more sustainable than natural gas (TNO, 2017). High temperature heating networks only work on a large scale of 1000-2000 residents or more to create a viable return on investment (Colmenar-Santos et al., 2017). Leiden already has a high temperature network and wants to add to this existing capacity. Just like the low temperature heating technologies, there is no tax on the heat supplied by these networks, which could change in the future. The harbour of Rotterdam will supply waste heat from its refineries and coal-fired power plants for the *warmterotonde*. However, the coal fired powered plants will have to be shut down after 2030 in order to reach the climate goals of the energy transition as a whole (Rijksoverheid, 2018). This will create a supply lock-in with polluting heat, while also requiring more investment for the *warmterotonde* to change its heating source after 2030 (Haffner, 2018). More sustainable heat sources are low temperature and will require energy investment lowering the overall efficiency to be compatible with high temperature heating networks.

2 Methodology

The modelling in this research is based on an indicator-based evaluation. Indicators are used in research for measuring, analysing, monitoring and the communication of the impact of the subject on a surrounding or area (Kabisch et al., 2016). The selection of these indicators is based on literature and stakeholder interviews (Binder, Mühlemeier, & Wyss, 2017). The composition of indicators covers multiple themes, focussed on the environmental, financial, social and technical aspects. A bottom-up approach is used to maintain as much detail as possible on the smallest spatial resolution. Therefore, the calculations are done on the building level, and then scaled back to district level scenarios. The term trade-offs is used to described the improvements and drawbacks of the implemented technologies in comparison to natural gas (Meerow & Newell, 2017).

The characteristics of the house covering the use of gas, usable area and building year were used to determine the required improvements. The GIS framework of this research was developed by looking at the heating vision of the municipality of Leiden (Gemeente Leiden, 2017), and existing models looking at the heating transition like Overmorgen (Overmorgen, 2017) and the GISP model (Meerow & Newell, 2017). The modelling and calculations were done in ArcGis, as it provides a good and versatile environment to develop the model. The modelbuilder tool was used to ensure that the results were automatically generated from the gathered datasets, and to lower the chance of human error. Multiple geo databases were used and one of them was implemented as the vector foundation into which the other data could be merged. For the modelling of the GIS-data the five steps of the geospatial approach were used. The five steps of the geographic approach are used for location-based analysis and decision making. It provides a research focused iterative process for examining diverse datasets and uncovering potential solutions.

Figure 1: The five steps of the geographical approach (Artz & Baumann, 2018).



The data was derived from multiple geo-databases from the central bureau of statistics (CBS) (NRG, n.d.), and other public data which is published by the Dutch national government. The BAG3D register is used as the template as it is the most detailed visualisation of the Dutch urban areas available for this research in GIS-data. This dataset also contains information about the building floor area, height and zip-code. From the national georegister the CBS dataset containing the energy use of buildings in the Netherlands was extracted (NRG, n.d.). The information from the datasets was merged with the BAG3D base layer on spatial location, and most of the data that is not use in the analyses was deleted to limit the file size. The BAG register was used to get information about the functional area of a building, and also merged with the BAG3D layer based on location. Eventually the neighbourhood map of the Netherlands was used to clip the data to the municipality of Leiden. This was done to significantly lower the time needed to calculate the model outputs in ArcGis.

Some Dutch municipalities have already made their own technology shortlist to replace natural gas (Overmorgen, 2017). For example: the municipality of Leiden has made a few documents regarding the heating transition, and a lot of stakeholders have already been involved in the signing of these documents (Gemeenteraad van Leiden, 2015). The technologies for this paper were identified based on their potential to replace natural gas and their scale on which they could be implemented. Only technologies which are available at the moment of this research are taken into account, as future technologies could have other requirements (CE Delft, 2018). Semi-structured interviews with stakeholders and documents regarding the energy transition from the Dutch government and municipalities created insight into which outputs determine their decision making. The model in this research is based on three main indicators derived from the interviews and documents. These indicators cover the use of natural gas per functional area of a building, investment costs, payback times, the costs as a percentage of the value of the house

(WOZ value in the Netherlands) and the CO_2 savings achieved. The investment and the savings by implementing these new technologies are calculated in comparison to the continued consumption of natural gas. The available data used in these datasets ranges from gas use per building, building size, height, building year and function. The technologies are analysed with regard to their performance, influence and their drawbacks. Combinations of these technologies are used in scenarios to assess the financial, environmental and social impact on the neighbourhood. The outputs of the model scenarios are evaluated with a sensitivity analysis and regarding possible future developments. Eventually the investment costs are evaluated per stakeholder, covering governmental interventions and how a CO2 tax could influence these investment.

2.1 Model assumptions

Changing the heating technology is on its own not enough to reach the Dutch climate goals; investment in more insulation for residential buildings are also required. To achieve these goals, all the technologies in the analysis are used in combination with enough insulation to bring all residential buildings to a Dutch energy standard 'label A'. This translates to roughly 80 kWh/m2 per year of energy used for heating. Next to the importance for the overall CO_2 reduction, more efficient heating by way of insulation is also needed to lower the impact of the winter season. During this time the heat demand will peak, and heat pumps and heating networks can struggle with meeting the high demand during that time (Interview Joeri Oudshoorn). For the analysis the following prices of energy were used: a kWh of electricity is set at € 0,23 and a m3 of natural gas € 0,65.

2.1.1 Technology characteristics

The chosen technologies have some improved characteristics in comparison to natural gas. For the analysis the CO_2 produced per kWh and the absolute energy use in kWh are evaluated. To keep track of replacement costs the lifespan of the products is also taken into account. The values implemented in the model are summarized in tables 2,3 & 4.

Table 2: key technology lifespans for the heat pump & heat exchangers for the heating networks.

Technology	Source	Lifetime (years)
All electric	(Schurink & Nollet, 2018)	15
Low temperature heating networks	(RVO, 2017)	15
High temperature heating networks	(RVO, 2017)	15

A heat pump has an economic lifespan of 15 years, after which it has to be fully replaced. The heat exchangers necessary in houses to transfer the heat from the heating network to their own central heating system also have a lifespan of 15 years.

Table 3: Relative CO2 production per kWh heat in comparison to natural gas.

Technology	Source 1	Source 2	Average value
All electric	50% (Milieu centraal, 2018)	35-72% (Blum, Campillo, Munch, & Kölbel, 2010)	50%
Low temperature heating networks	32-73% (WarmteKoude, 2017)	35 – 63 % (Greenvis, 2017)	50%
High temperature heating networks	75% (Hoogervorst, n.d.)	74% (WarmteKoude, 2017)	75%

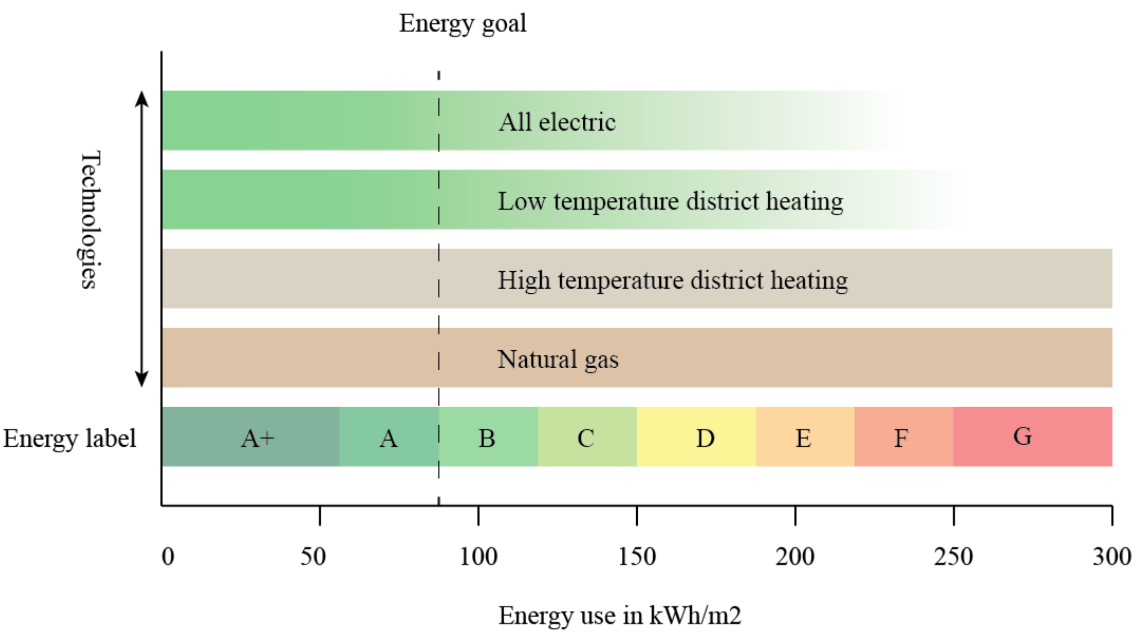
The relative CO_2 production is compared to the production of CO_2 per kWh of heat supplied by natural gas. For the value of the relative energy efficiency the coefficient of performance (COP) of a heat pump or the network efficiency improvements of the heating networks are taken into account. This gives the heat pump an advantage in terms of energy used to generate the heat in comparison to the heating networks. The average value was taken from two sources and rounded off to the nearest figure in steps of 5.

Table 4: Relative energy efficiency in comparison to natural gas (kWh).

Technology	Source	Value
All electric	(Bouw-energie, 2018)	40%
Low temperature heating networks	(Ensoc & RVO, 2018)	100%
High temperature heating networks	(TNO, 2017)	100%

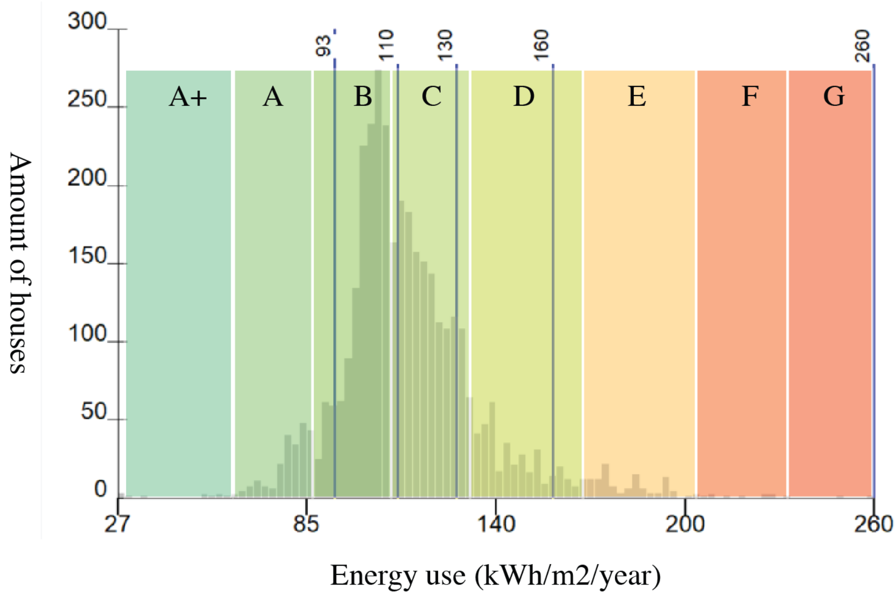
The thermal operating range of a technology determines which energy use per m2 of a building a technology is sufficient to implement. In figure 3 an overview is given of the technologies in comparison to natural gas heating and the corresponding average energy use per energy label (Bosch, 2011). The energy values in the table in kWh/m2 are the thermal energy values, and the energy goal is the average energy use of a residential building with an energy label A.

Figure 2: thermal ranges per technology and labels (Schurink & Nollet, 2018) (Ecofys, 2018), (Rijksoverheid, 2016) & (Bosch, 2011)



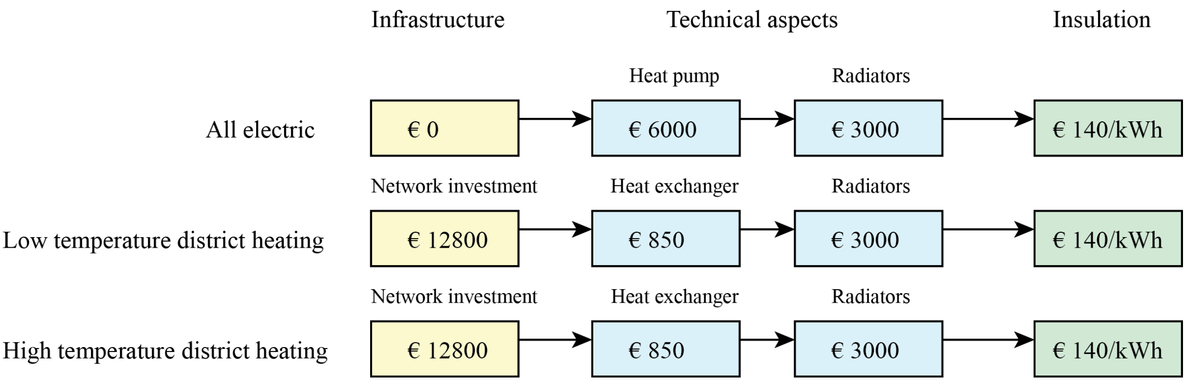
The all electric and low temperature district heating solutions both need a lot of insulation to compensate for the peak of energy use during the winter. In the heart of winter, the demand is higher than throughout the rest of the year. So during winter these technologies can struggle with delivering enough heat to generate a comfortable temperature. In this case a supporting technology could help with meeting this peak demand. In Figure 3 the building stock of the Merenwijk in Leiden and their energy label are shown. Only a few houses have the energy use of an energy label A or better, there is room for improvement.

Figure 3: current energy use of the residential buildings in the Meerenwijk in Leiden.



All the technologies are implemented in combination with an LTV energy system to prevent differences between the investment scenarios. Also, this is a more efficient way to heat a house in comparison to HTV and it will lower the transportation losses. All the houses have the same amount of insulation added, while the infrastructure and technical aspects will be the differentiating aspects. The infrastructure aspects for the all-electric technique were difficult to determine, as heat pumps are not the only product utilizing the electricity network. There are also other options to lower the impact of the increased electricity consumption. Solar panels, battery systems or solar boilers can alleviate some of this impact. The investment for the heating districts are solely for the purpose of supplying heat and could be calculated more easily. The overview is given in Figure 4.

Figure 4: Investment per energy technology buildup (RVO, 2018) (Ecofys, 2018) (Schurink & Nollet, 2018) (Haffner, 2018) (Interview Nuon) (Rijksoverheid, 2017).



The following indicator themes were chosen from the interviews and literature:

- Technical – measured in the energy use of a building per m2 functional area
- Financial – measured in the investment costs, relative investment to the WOZ value of a home and the payback time
- Environmental – measured in the change in CO_2 per year by implementing the technology

The technical aspects of the building are based on the energy use in kWh per m2 of functional area. This is an approach to the thermal performance of a building on which the technology selection can be compared to the existing situation (Bosch, 2011). The use of gas in m3 per year was converted to kWh and divided over the amount of functional area. A value for the cost of improved insulation per m2 in a residential building was calculated and implemented in the model (Appendix A).

The current situation was then compared to a situation in which those technologies were implemented, and the difference in thermal performance was calculated. From this difference the investment (variable and constant) and financial savings based on the improvements and technologies were calculated together with the potential in CO_2 reduction per year. The payback is based on the change of investment and technologies of the energy systems. The investment total per building was compared to the WOZ-value of a home to determine what percentage of the absolute value of the home needs to be invested to make the building energy neutral. The calculations in the model are based on the input from the spatial datasets and the key values in Table 6 and Figure 4.

Overview of the calculations used in the model:

<u>Energy savings</u>

$$\text{Energy savings} = \text{current energy consumption}\left(\frac{\text{kWh}}{\text{m2}}\right) - (\text{energy consumption after insulation}\left(\frac{\text{kWh}}{\text{m2}}\right) * \text{energy efficiency})$$

<u>Financial aspects</u>

$$\text{Investment} = \text{Infrastructure costs} + \text{technical aspects costs} + \text{technical aspects machines} * \frac{32}{\text{lifetime}} + \text{Insulation costs}$$

$$\text{Savings} = \text{energy savings} * \text{building area} * \text{price per kWh}$$

<u>CO_2 difference</u>

$$\text{CO2 savings} = \frac{\text{energy savings} * \text{building area} * \text{ CO2 per kW}}{\text{CO2}}\text{production}$$

2.2 Stakeholders

The municipality of Leiden made a document covering the intentions and stakeholders involved in the heating transition within their municipality. The infrastructure and energy companies are already involved in the early planning for certain neighbourhoods in Leiden. The meetings and joint interests are documented in a letter of intent and signed by the involved parties (Municipality of Leiden, 2017). The involved stakeholders have different roles in this process, some of them will bring in information and knowledge about projects done earlier within similar contexts. Housing corporations are participating in the planning as they possess a significant amount of buildings. From these documents roles of the stakeholders and their interests were derived for this research and summarized in Table 5. The investment in heating networks are funded by the heating network companies, while the home-owners are paying for the heat pumps and the insulation of their homes. The municipalities and the province of Zuid-Holland can support these parties with regulations and financial incentives. The housing corporations pay for their own building adjustments and carry over the costs of these investment to the tenants

Table 5: the stakeholders and their interests (Municipality of Leiden, 2017).

Stakeholder	Interests
Home-owners & resident associations	Heating their home in an affordable and comfortable manner. Ensuring that they reach the climate goals set by the government in the long run.
Municipality of Leiden	Reaching the climate goals and the governmental policies while keeping heating affordable.
Housing corporations	Heating their buildings, supplying heat to their residents and complying to the new governmental policies.
Heating companies	Selling heat to the consumers and other companies. Infrastructure investment & maintenance.
Province of Zuid-Holland	Reaching the climate goals and the governmental policies.
Horticulturist & other industry partners	Supplying leftover heat for the heating networks

2.3 Spatial data

For the input of the model public data of the Dutch built environment and its energy consumption was used. The data from the BAG and BAG3D register is largely complete, while the description of the building's use was sometimes absent. Elements like community heating and buildings that only use gas for cooking could not be filtered out. To prevent this data from polluting the rest of the stock, a filter was set on every building using less than 25 kWh/m2 per year.

Table 6: indicators and dataset sources.

Indicator theme	Description	Database	Source
Technical	Floor area	BAG	(Kadaster, 2018)
Technical	Energy use	CBS PC6 gegevens	(NRG, n.d.)
Technical	Residential buildings and shape	BAG3D	(Kadaster, 2018)
Financial	WOZ – value	WOZ values	(Municipality of Leiden)
Other	Municipality borders	CBS wijk en buurtkaart 2017	(CBS, 2018)
Other	Existing & future heating networks	Warmtenetten kaart	(Municipality of Leiden)

2.4 System dynamics

The modelling of the heating transition required a lot of assumptions about techniques, working principles and system dynamics. Some of these dynamics are not used in the modelling of the results but can influence the heating transition in the long run. A few of them are mentioned in this section.

Investment in phase change materials (PCM's), heat storage solutions or other energy buffer systems could influence the combination of heating technologies (Froemelt & Hellweg, 2018). At the moment these are not used on a large scale, but this technology could solve part of the urban problems related to heat. Especially during winter, when the demand for heat is the highest, while at other moments during the year the heating network does not even reach its maximum capacity. With a heating or energy storage solution less insulation is needed to make some technologies viable for the heating of a building. However, it will not lower the overall energy use. The heat battery of TNO is a possible future solution to this problem, it uses salt to store energy to level out some of the heat demand fluctuations. It can be integrated in the heating system of the house (TNO, 2018).

A natural gas HR+ boiler is a very efficient way to convert gas into thermal energy, this process can reach an efficiency of more than 100% (KIWA, 2017). Even though heating networks use leftover heat from the industry, the chain efficiency is much lower due to the energy loss during transport and transfer to the house (Colofon, 2017). A heat pump uses electricity to extract heat from the outside air or a water system and does that with an efficiency of 300-500% (Kieft et al., n.d.). This high efficiency can compensate some of the chain efficiency losses. The infrastructure necessary to deliver enough energy to the residential buildings differ per technology. The heating networks utilize an assigned heat network, while heat pumps utilize the electricity grid or more localized energy sources like solar panels. Home battery systems could lower the impact a large amount of heat pumps would have on the grid, while allowing solar panels to provide more sustainable electricity (Kieft et al., n.d.). These infrastructures require in investment of millions of euros, while maintenance also costs a constant amount of money (Rijksoverheid, 2017).

At the moment most heating systems are operated with one button, while smart home components can help with lowering the overall energy use of a house (Han & Lim, 2010). It is also important to look at the timing when upgrading a house to a more sustainable energy technology. The installation of a heat pump or some other heating technology could create a situation in which the building cannot be heated for a few days. For the residents this could be a huge problem as it is their living environment. It is advisable therefore to realise such a transition during the summer period to prevent the need for heat at that time or during moving between houses.

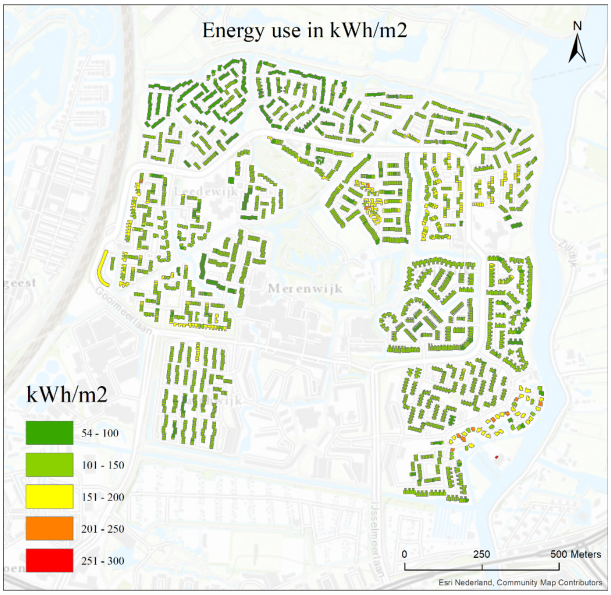
3 Scenario generation

Three different scenarios are chosen with each a different focus on technology. With these scenarios a comparison between choices for technologies have been made for the case study in the Merenwijk. Each scenario has 3 input parameters per technology and generates 4 output values per scenario. In the results each output parameter will be evaluated between the scenarios.

Table 7: technology division for the neighborhood per scenario:

	All electric (%)	Low temperature heating networks (%)	High temperature heating networks (%)
Leiden heating vision	45	55	0
Heat pumps	100	0	0
Heating networks	0	50	50

Figure 5: energy use in kWh/m2 in the old situation.



As described in the technology characteristics, all the residential houses will be insulated upto 80 kWh/m2. In Figure 5 the current energy use is shown to indicate the improvement in energy characteristics.

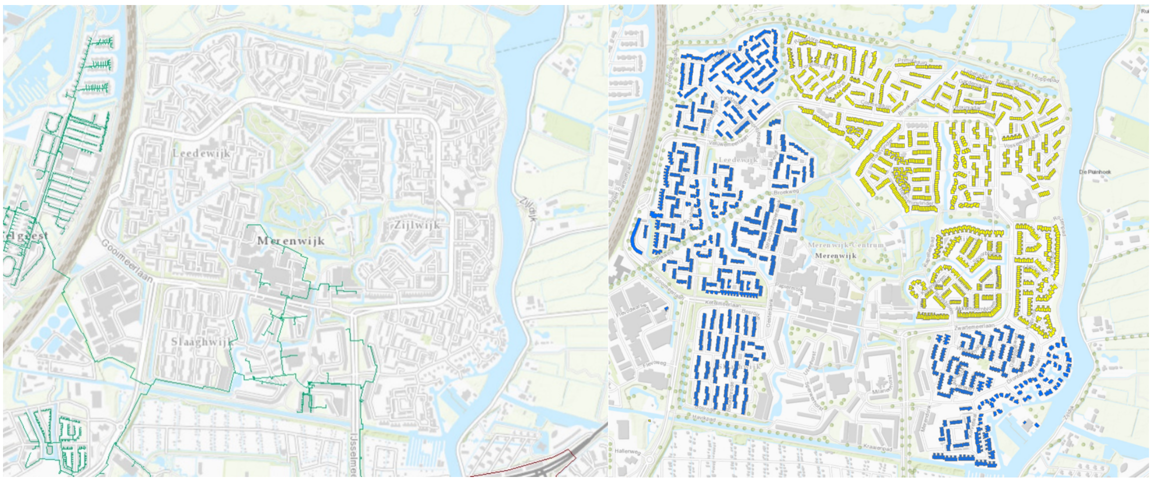
The investment per scenario are dependent on different stakeholders per technology combination. The connection to the heating network is paid for by the home-owners of people who live there. The necessary expenses for the infrastructure are funded by the heating companies, as they will create a business case with the municipality and invest in the construction of this network (Interview Nuon). The complete costs of the heat pumps are for the residents of the homes. The home owners and residents will have to pay for the heat pumps as well as the insulation.

To create an understanding of what could influence the investment and payback times in the future a financial evaluation is done. In this evaluation the carbon price, governmental influences and increasing gas prices are assessed.

3.1 Realising the heating vision of the municipality of Leiden

In this scenario the technologies that the municipality of Leiden has used in their *warmtevisie* are scrutinized (Gemeente Leiden, 2017). This will be a combination of low temperature heating networks and heat pumps. The southern section of the Merenwijk district is in close proximity to the existing heating network, and the network can therefore be relatively easily expanded. These houses will be added to a low temperature heating network. The rest of the neighbourhood will be connected to heat pumps and if necessary other supporting heating technologies. Combining these technologies will provide a lower CO_2 consumption, while still having the potential for all the residents to reach an energy neutral heat supply. The investment will be reasonable in comparison to the other scenarios. This scenario creates a balance between two relative CO_2 friendly heating technologies with the possibility to reach a CO_2 neutral heat supply with future network investment. The strain on the existing electricity network will be average in comparison to the other scenarios, as the rest of the heat is supplied by the expanded heating networks.

Figure 6: existing heating network infrastructure in the Merenwijk shown in green on the left (Gemeente Leiden, 2017) & the technology coverage for this scenario with low temperature heating network residents in blue and all electric solutions in yellow on the right.



3.2 Heat pumps

This scenario will describe a technology composition in which extra thermal heating capacity will not be available. This can result from other city districts already using the existing network capacity. The whole neighbourhood will need to use heat pumps with possible additional supporting technologies. The detailing around the *warmterotonde* and its capacity per city is not clear yet and can prove troublesome in a worst-case scenario for the plans of some municipalities (Interview Nuon). In this scenario the residents are dependent on their own solutions to deliver heating to their homes, as no public heating networks are used. The electricity use of the whole neighbourhood will increase significantly, even though some of it can be compensated by improved insulation and PV-panels. The neighbourhood has the potential to become fully CO_2 neutral, while the investment for this have to come from the residents and the electricity companies. This is a tricky scenario because the whole neighbourhood is dependent on one energy technology. If there are infrastructure problems or the technology reveals unforeseen drawbacks the whole neighbourhood will be affected. If there are any supporting heating technologies present some of these influences can be negated. During the winter season the electricity network will be heavily used or even overloaded if no improvements are made in the infrastructure or storage and PV solutions.

Figure 7: technology coverage for this scenario with all electric solutions in yellow.

3.3 Heating networks

This scenario envisions heavy use heating networks with a combination of low and high temperature. In this scenario it is assumed that the *warmterotonde* will deliver extra heating capacity in comparison to its current capacity. The *warmterotonde* is a high temperature heating network since using waste heat from the oil refineries in Rotterdam (Rijksoverheid, 2018). The Dutch government is very keen on using these types of networks for the coming years, in which a mixture of waste heat from the industry and renewable energy sources are used. The northern part of the neighbourhood is the newest part and selected for the use of the low temperature heating network. The investment for these technologies will however not be funded by the residents directly, but by the heating company delivering the waste heat. The existing electricity infrastructure will also be untouched, as the heat is supplied by the committed heating network.

Figure 8: technology coverage for this scenario; low temperature heating networks are blue while the high temperature networks are brown.

4 Results

4.1 Investment per building

Figure 9: the investment costs per building for scenario 1,2 and 3 (left, right, middle).

Table 8: investment per stakeholder per scenario.

Scenario	Total investment costs (million euro)	Investment home-owners/residents	Investment heating network companies
Leiden heating vision	76,7	51,1	25,6
Heat pumps	58,3	58,3	0
Heating networks	78,3	29,7	48,6

4.2 Payback time

Figure 10: payback time in years for the scenarios.

Table 9: average payback time per scenario.

Scenario	Average payback time (years)
Leiden heating vision	72,9
Heat pumps	45,1
Heating networks	119,2

4.3 Investment per WOZ-value

Figure 11: the investment as percentage of the WOZ-value of the buildings for the scenarios.

Table 10: average investment per WOZ-value.

Scenario	**Investment per WOZ-value (%)**
Leiden heating vision	8,1
Heat pumps	6,2
Heating networks	8,3

4.4 CO_2 savings per year

Figure 12: the CO_2 savings per building for the scenarios.

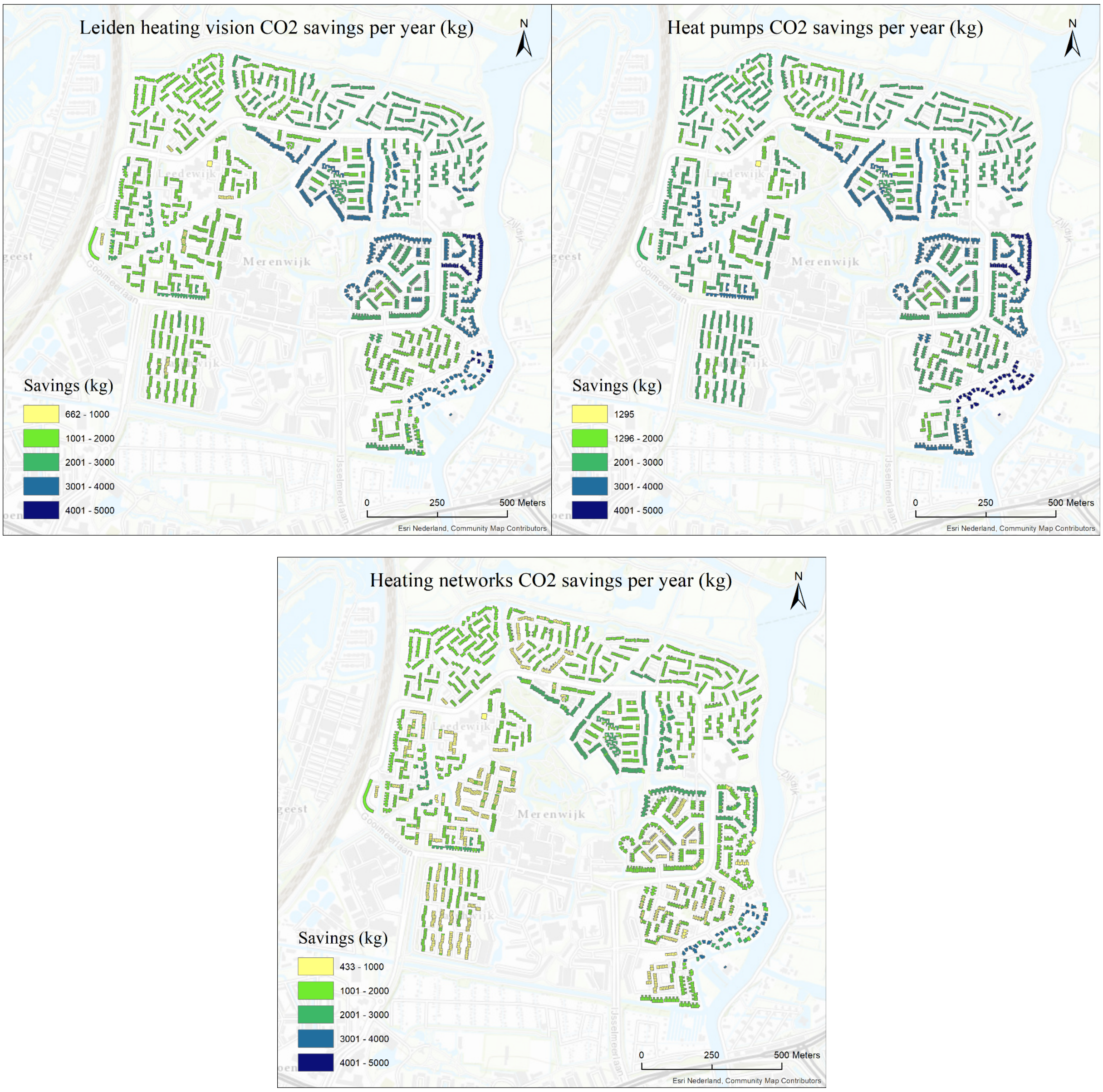


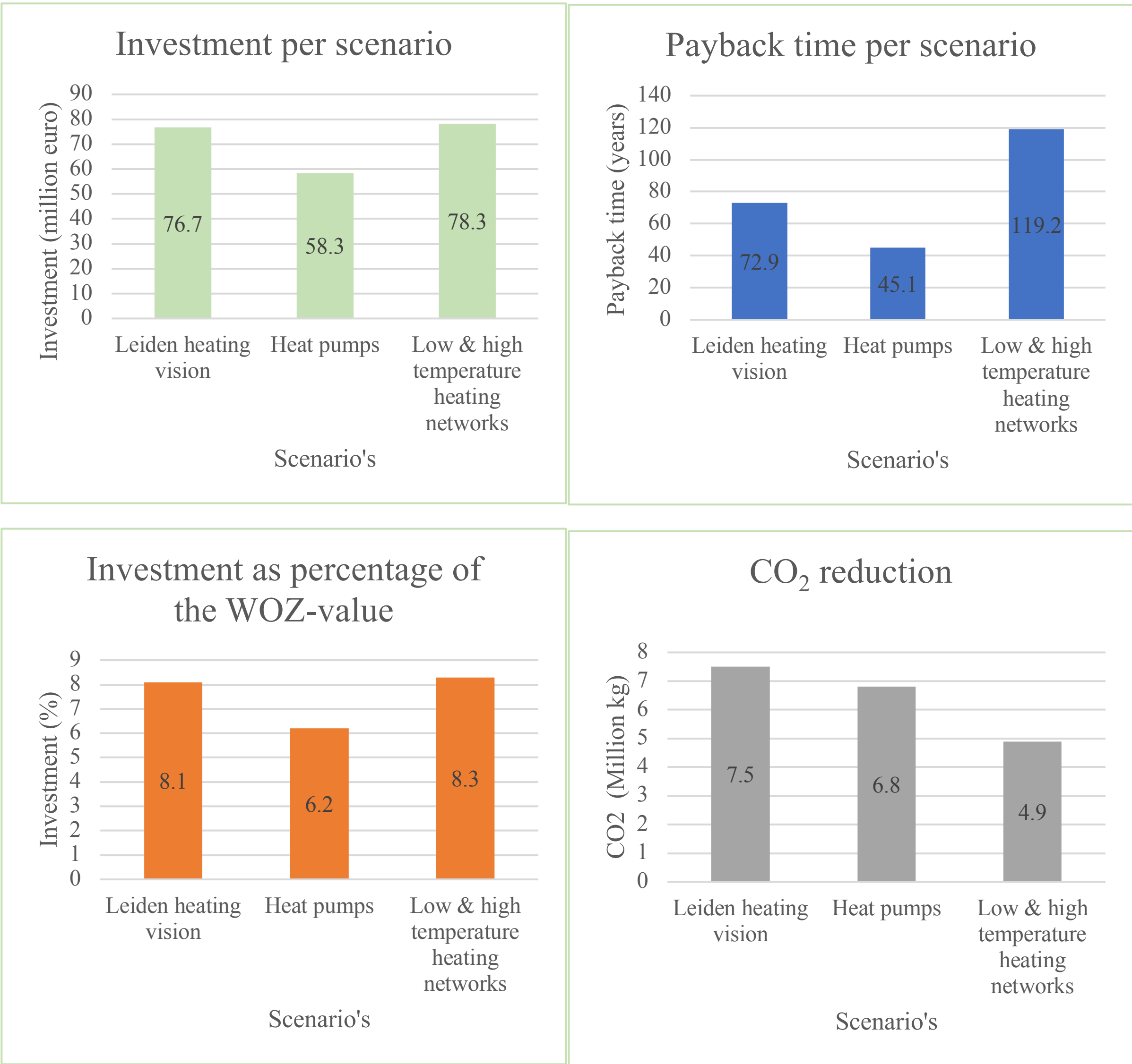
Table 11: the total CO_2 savings per year for each scenario.

Scenario	**Total CO_2 savings per year (million kg)**
Leiden heating vision	7,5
Heat pumps	6,8
Heating networks	4,9

4.5 Summarized results

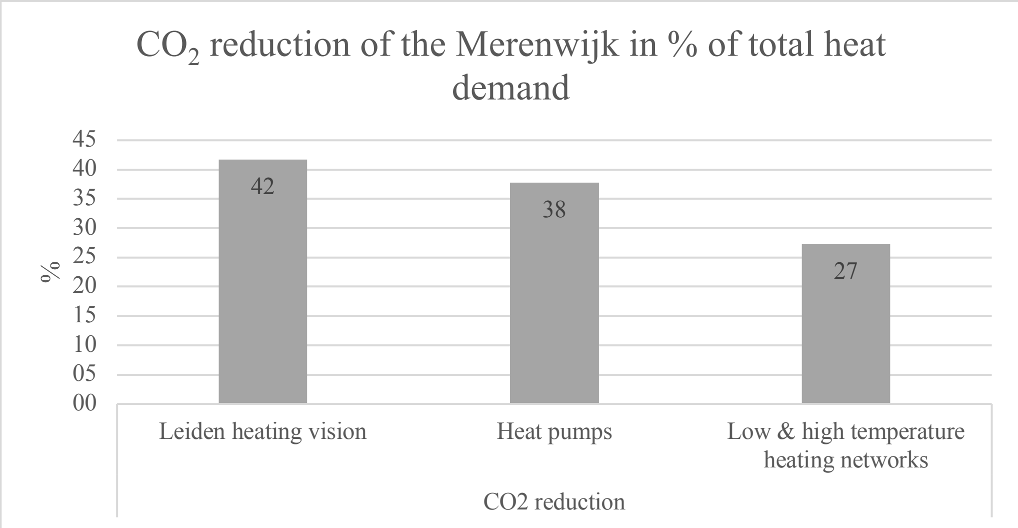
The investment differ per scenario, ranging from 58,3 to 78,3 million euro. Payback time is related to these investment. Moreover, payback time is much higher in the heating networks scenario while having almost the same investment as in the Leiden heating vision scenario. The investment as a percentage of the WOZ value directly corresponds with the total investment per scenario. The total CO_2 reduction is the highest in the Leiden heating vision scenario. In the heating networks scenario the CO_2 reduction is the lowest, which is similar to using the high temperature heating networks and their relatively high CO_2 emissions.

Figure 13: the outputs per scenario compared.



The savings per scenario as % of the total heat CO_2 production of the Merenwijk are given in Figure 14. The Leiden heating vision and the heat pump scenarios have the highest CO_2 reduction, while they both have the possibility to attain energy neutrality with an improved energy mix or heat sources. The heating networks scenario has limited sustainable potential due to the use of high temperature heating networks.

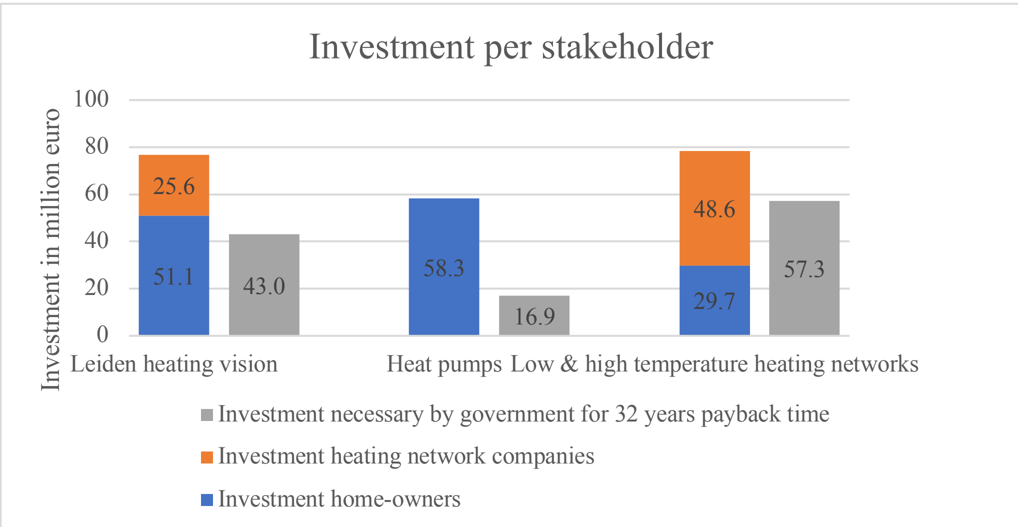
Figure 14: CO_2 savings as percentage of the total heating CO_2 impact.



4.5.1 Financial evaluation

The investment per stakeholder differ strongly per scenario. In the scenarios of the Leiden heating vision and the heat pumps, the home owners carry an investment of around 51-58 million euro, or around 15.000 per house in this analysis. The scenarios with the highest CO_2 reduction and the best payback time are also the ones with the highest investment from the home owner. In Figure 15 the summary is given.

Figure 15: the investment per stakeholder for each scenario and the investment necessary by the government or municipality to reach a 32-year payback time in grey.



The payback times per scenario without governmental grants are rather high, they do not fit within the 2050 scope of reaching energy neutrality in the Netherlands. In order to fit within the 32 years left, the government or the municipality needs to invest 17-57 million euro depending on the chosen scenarios shown in Figure 15. In the Netherlands a mortgage is taken out for 30 years at the most, payback times for investment in heating technologies should not be much longer than this.

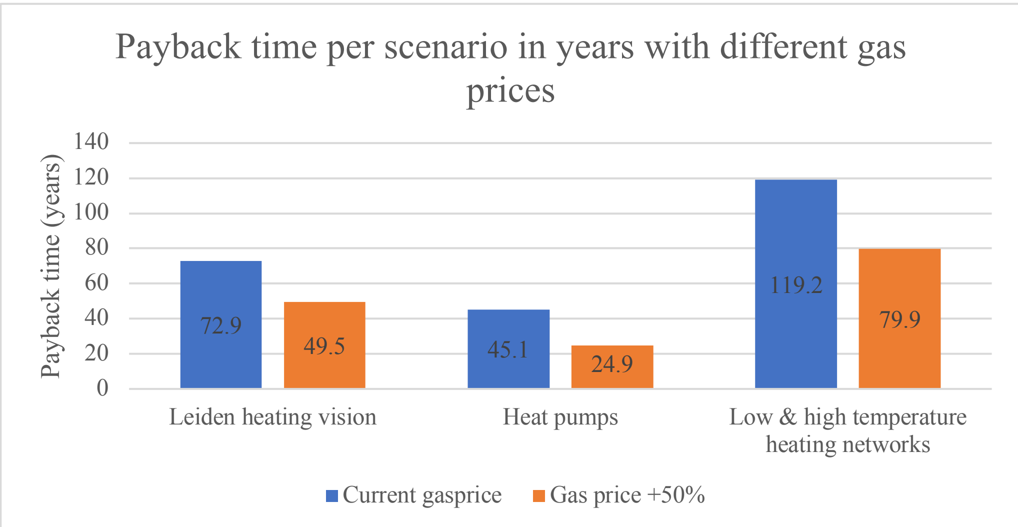
Table 12: Investment costs per ton of CO_2 saved and the carbon tax necessary to reach 32 years payback time (current carbon price is 30 dollar per ton CO_2).

	Costs per ton CO_2 spread out over 32 years	**Carbon tax necessary to reach 32 years payback time (euro per ton CO_2)**
Leiden heating vision	€ 319	€ 184
Heat pumps	€ 268	€ 80
Low & high temperature heating networks	€ 499	€ 374

Each scenario reduces the CO_2 production of the Merenwijk, but in order to make it comparable to other investment scenarios a CO_2-price comparison was made. The carbon price will be at a minimum of 30 dollar per ton per year from 2018-2050 (Carbon pricing leadership coalition, 2017), while it can also reach a height of 100 dollar per ton CO_2 per year. In Table 12 the costs per ton CO_2 for 32 years with a 30-dollar carbon tax and without the carbon tax are shown. At a certain point the carbon tax will be high enough to compensate for the investment necessary to reach the climate goals. In Table 12 the carbon tax is shown that allows the scenarios to have a payback time of 32 years. The heat pump scenario will be profitable if there is a carbon tax of 80 euro per ton or higher, which is within the range for 2018-2050.

Rising gas prices can also influence the outcome of the scenarios. In 2018 Dutch residents were paying €0,65 per m3 of gas. According to ECN and the CBS the price of gas can increase by 60% in the next 20 years (ECN & CBS, 2017). To calculate the impact of a rising gas price on the financial aspects of each scenario, an average increase of 50% for the next 32 years is assumed.

Figure 16: payback times for each scenario with the current gas price and a 50% average increase.

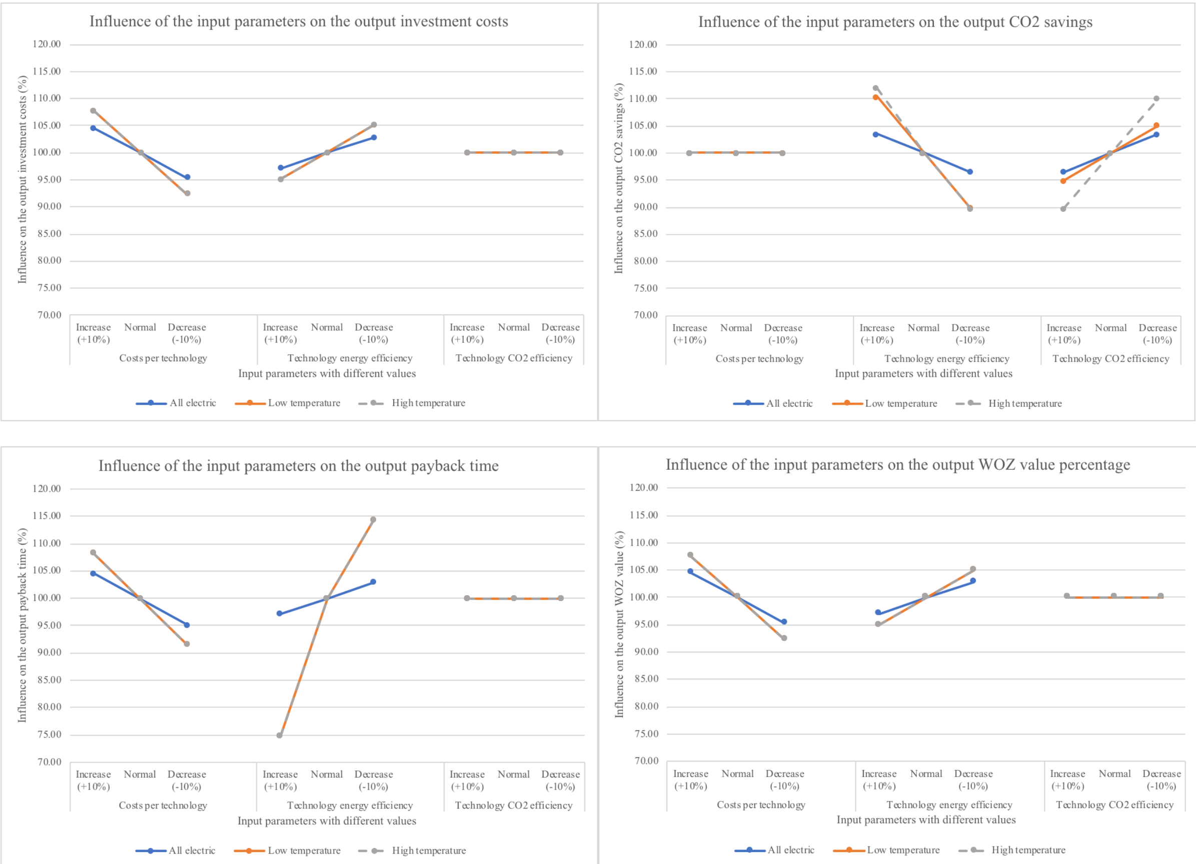


The rising price of gas could be a great incentive to accelerate the heating transition. For all scenarios a significantly better payback time is presented due to the higher financial savings in comparison to the consumption of natural gas. The heating networks scenario lost 40 years of its payback time while the Leiden heating vision scenario slips just to just under 50 years. A combination of the carbon tax, governmental funding and higher gas prices could result in an attractive business case for the Leiden heating vision and heat pumps scenarios. The government could also chose to increase gas prices with taxes, and use the collected money to invest in the heating and energy transition.

5 Sensitivity analysis

In order to determine which input parameters of the model were the most influential on the output a sensitivity analysis was done. ArcGis provided limited possibilities to do an automated sensitivity analysis which resulted in the manual application. The analysis was executed by changing one input parameter and measuring the impact on the output parameters. This provided information about which parameters influence the output, but not a composite result in which the combined input is shown (Saltelli, 2017). For the analysis each input parameter was increased and decreased with 10% in comparison to used values for the scenarios. The impact on the output is shown in the graphs divided per output value and in % on the scale of the axis.

Figure 17: the influence of the input parameters on the output per technology.



In Figure 17 it is shown that the input parameter technology efficiency has the most overall impact on the performance of the model, as it influences all the output parameters and has the most relative impact. The technology CO_2 efficiency input parameter only influences the CO_2 savings, and is most effective on the high temperature heating networks as these also have the lowest CO_2 savings. The impact of the costs per technology and the technological energy efficiency is more significant on the technologies with the highest costs and lower CO_2 savings. This seems to indicate a non-linear behaviour for these parameters and output, but without a more extensive analysis this is hard to tell.

5.1 Scenario sensitivity

To test the validity of the outcomes a few alternative development scenarios were generated. These new scenarios are based on possible future developments that can influence the input parameters.

5.1.1 Other heat pump technologies:

This scenario envisions a development in which the heat pumps are more heavily implemented, and their price higher than expected. The change in price can be due to a higher cost of implementing the technology, different technology implementations or a shortage of the heat pumps on the market. For the new prices 9.000 and 12.000 euro were chosen instead of 6.000 (Kieft et al., n.d.). To compare the impact of a possibly even more improved CO_2 efficiency due to the changing energy mix in the future, the CO_2 efficiency is improved with 20 and 10% for the heat pump.

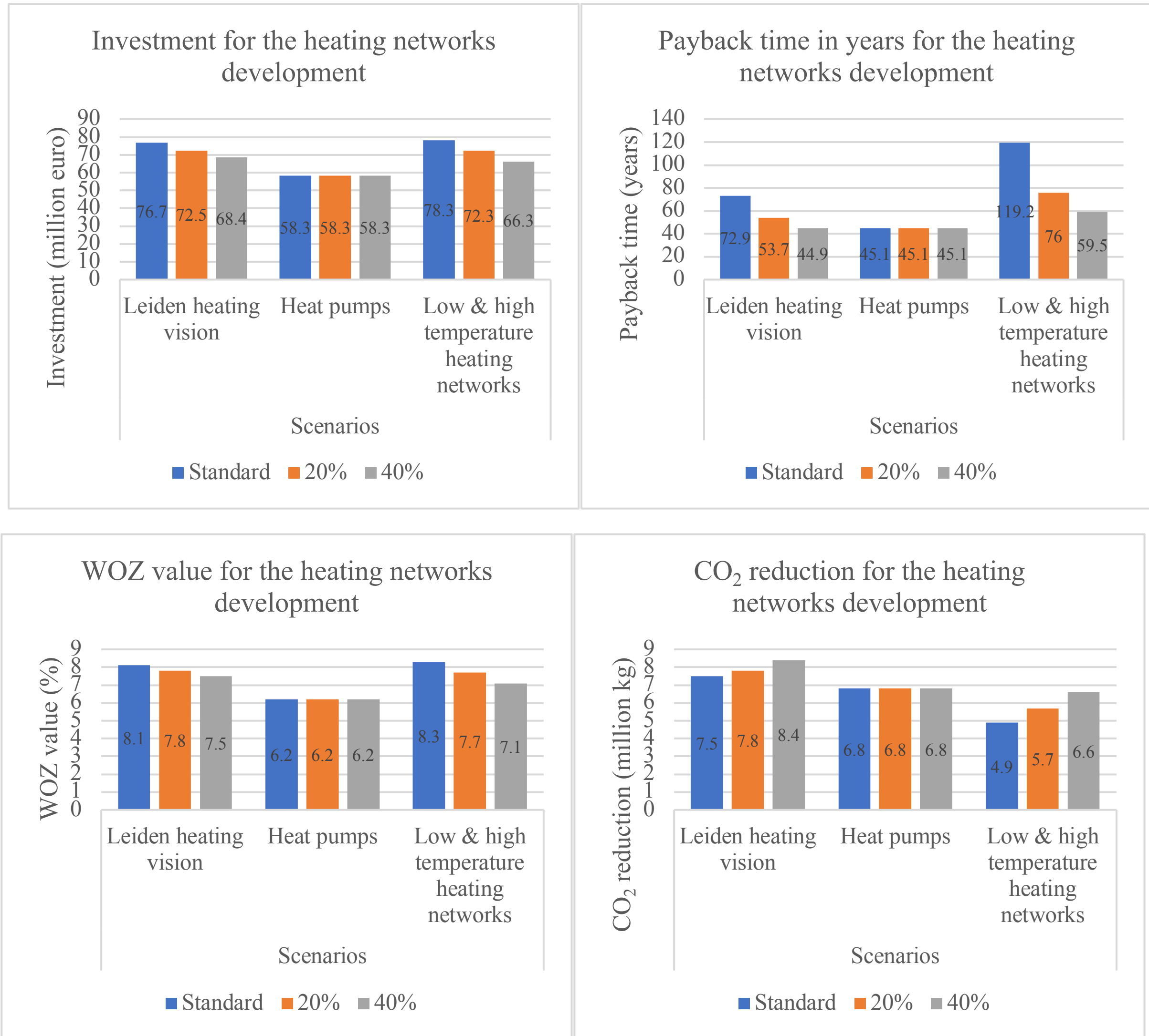
Figure 18: the changes in outcome with the different parameters for a more efficient and expensive heat pump technology.

The change in price and CO_2 efficiency for the heat pump has the highest impact on the cost and payback time for the heat pump scenario, which is only utilizing heat pumps. This scenario becomes comparable to the Leiden heating vision scenario in terms of costs and CO_2 reduction, while it still has a lower payback time. The Leiden heating vision scenario also has some improvements as the heat pumps are also implemented in this scenario. The heating networks scenario remains untouched as it does not use heat pumps in its comparison.

5.1.2 More efficient heating networks:

In this development low temperature heating network will be more energy efficient than modelled in the normal scenario. This can be achieved by lowering the overall network temperature and reusing the return loop of the heated water, potentially improving the heating networks with 20-40% in their energy efficiency (Hoogervorst, n.d.). Most of the energy of the high temperature heating networks will still be supplied by industrial waste heat instead of renewable or low temperature energy sources (Colofon, 2017). The goal of this analysis is to show the impact of optimizing the heating networks. At the moment there is a lot of interest in lowering the operating temperatures and reusing the return heat (Colofon, 2017).

Figure 19: the changes in outcome with the different parameters from the more efficient heating networks development.

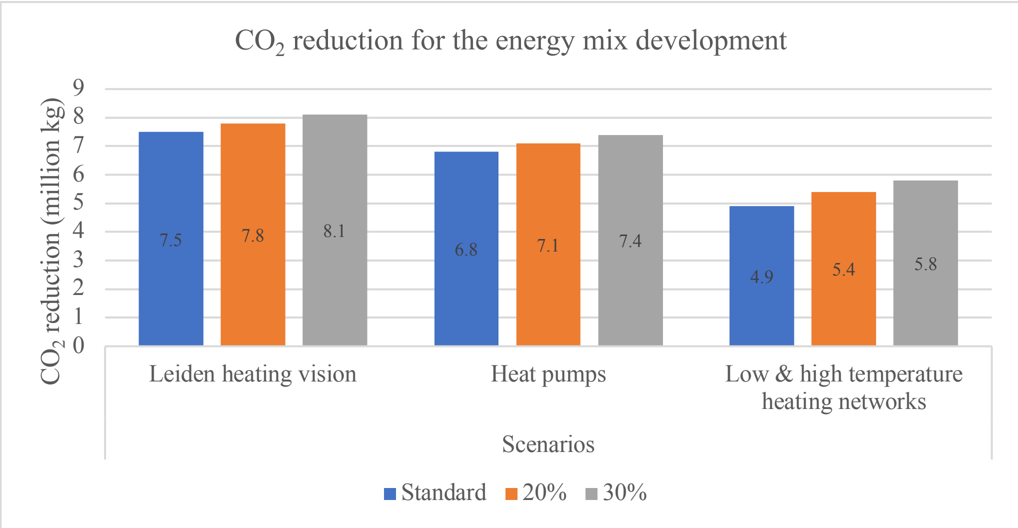


The influence of these changes is the most noteable in the scenario with the heating networks. This corresponds with the use of the high and low temperature heating networks in this scenario. The investment is less but, most of all the payback time is strongly reduced from 119 to 60 years due to the more efficient heating networks. This corresponds with the output of the sensitivity analysis. The CO_2 reductions of the Leiden heating vision scenario are also increased to a point that it surpasses the heat pumps scenario. The heating networks scenario CO_2 savings are almost comparable with the heat pumps scenario.

5.1.3 Improved Dutch energy mix:

This development envisions more CO_2 savings for all the technologies. The changing energy mix will provide the heat pump with more sustainable electricity (Urgenda, 2017), while heating networks will utilize more low temperature sustainable sources of heat. The technologies will all improve in this scenario with 20-30% in their efficiency (Urgenda, 2017). The goal of this analysis is to show the impact of a changing energy mix and adding more sustainable energy sources to the heating networks.

Figure 20: the changes in outcome with the different parameters from an improved energy mix.

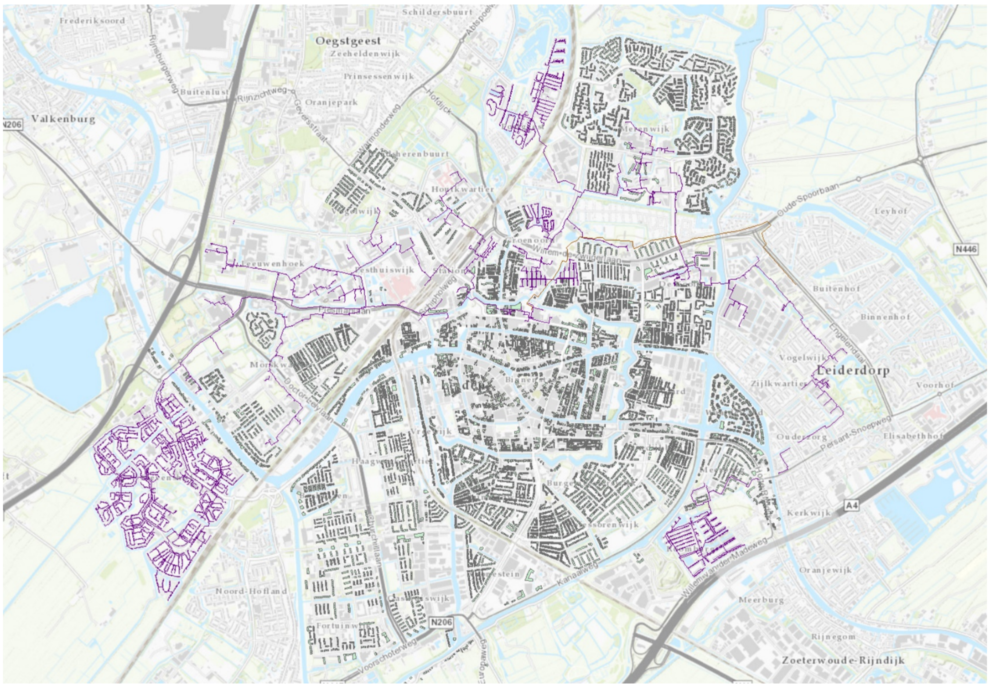


The only output parameter that changes with an increased CO_2 efficiency is the total CO_2 reduction. This corresponds with the sensitivity analysis which showed that this parameter only influences that particular output. The CO_2 efficiency has some impact on the CO_2 reduction per scenario, with the heating networks scenario gaining the most CO_2 savings, but still not achieving the same reduction as the other 2 scenarios. The savings in the Leiden heating vision scenario increase from 7,5 to 8,1 million kg CO_2, while the savings achieved in the heat pumps scenario increment from 6,8 to 7,4 million kg of CO2. The heating networks scenario have the biggest surge, gaining an increase in CO_2 savings of almost 20%.

6 Example scenario for the municipalities of Leiden

To test the performance of the model on a larger scale the whole municipality of Leiden was analysed. In their *warmtevisie*, a sustainable development scenario is described covering different technologies. The existing overview of Leiden in the model with the heating networks is shown in Figure 21.

Figure 21: the residential homes of the city of Leiden with its heating networks.



In this analysis only 23.000 buildings are shown as residential, while the city of Leiden has 56.000 residences. It is possible to have multiple residences in one building, and in the analysis the city centre (7000 residences) and the Stevenshof (6700 residences) were left out. The city centre was left out because the old buildings are more problematic to insulate and require different solutions. The Stevenshof did not show up in the existing data, so has most probably not been processed yet in the BAG3D register. Taking the above into account for the whole city of Leiden, it would need roughly 800 million euro to complete a heating transition towards more sustainable heating technologies. Unfortunately, this would only cover 40% of the current CO_2 production, or 55 million kilograms responsible for the production of heating for residential buildings. The average payback time would be around 75 years and the average WOZ value of the investment is 9,3 percent. This is not enough to reach the climate goals set by the government, and more developments and investment are needed to reach a higher CO_2 reduction.

7 Conclusion

The heating transition goals of the Netherlands are ambitious. To reach the goal of an 80% reduction of CO_2 emission by 2050, the total residential heat consumption would need to be drastically cut down. This can be achieved by better insulating the existing building stock, the implementation of low temperature energy systems and making the source for heating sustainable. However, insulating each home to energy label A and installing low temperature energy technology is not enough on its own. Besides, more sustainable energy sources need to be implemented on a large scale. Low temperature heating networks and heat pumps are already 50% more efficient in delivering heat to the residential buildings stock in terms of CO_2 production in comparison to natural gas. In the future, such technologies can be supplied with sustainable energy and the low temperature heat sources available in the Netherlands. This will increase their CO_2 savings significantly. High temperature heating networks have a lock-in with non-renewable energy sources and therefore have little potential to become more CO_2 efficient and improve on the existing situation. In the sensitivity analysis it is shown that the energy efficiency of the heating technologies is crucial to the contribution to the heating transition, as it affects the overall energy consumption and the CO_2 reduction directly.

The heating transition is a complex problem with many different elements and stakeholders. The goal of this paper was to describe and quantify the effects of different heating technologies and solutions. Three scenarios with three different technological combinations were used. The first scenario is based on the *warmtevisie* as developed by the municipality of Leiden, in which low temperature heating networks and heat pumps are combined. The second scenario only utilizes heat pumps to envision a situation without extra heating networks capacity. The third scenario implements low and high temperature heating networks as the heating source. From these scenarios, the investment costs, payback time, CO2 savings and the average WOZ value were calculated to be able to make a comparison. The investment in heating networks are funded by the heating networks companies, while the home-owners are paying for both the heat pumps and the insulation of their homes.

The first scenario based on the *warmtevisie* utilizing heat pumps and low temperature heating networks is the one requiring the highest overall investment with 76,7 million euro, 8,1% of the average WOZ value or 22.000 euro per residential building. However, this is also the scenario in which a 42% CO_2 reduction is achieved. Without governmental or municipal support, the payback time of this scenario would be 72,9 years. The second scenario utilizing heat pumps requires the lowest investment of 58,3 million euro. This is 6,2% of the average WOZ value or 20.300 euro per residential building with a payback time of 58,3 years. In this scenario a relative high 38% CO_2 reduction is achieved. The scenario in which high and low temperature heating networks are implemented is the least effective and requires 78,3 million euro to implement in the case-study. This translates to 8,3% of the WOZ value or 22.000 euro on average per residential building with a payback time of 119,2 years and only reducing the CO_2 emission with 27%. The costs required to implement annual savings in tons of CO_2 emission for a period of 32 years result in 319 euro for the Leiden heating vision scenario, 268 euro for the heat pump scenario and 499 euro for the heating networks scenario.

Whilst the scenario utilizing only heat pumps is the most efficient in terms of payback time, it is also the scenario which has to be completely funded by the home owners. Home-owners are however also the group of stakeholders that is financially the least able to make such sizeable investment in the heating transition. In the model used in the paper, the investment per residential building ranges from 16.000-22.000 euro, of which 14.000-16.200 is to be paid by the home-owners themselves. The CO_2 reductions achieved by these investment are most cost effective with the Leiden heating vision and the heat pump scenario. The heating network scenario is almost twice as expensive per ton CO_2 in comparison to the least expensive option and has no potential to become completely CO2 neutral. The payback times range from 45 to 73 years with the Leiden heating vision scenario and heat pumps scenario and it can achieve a significant CO_2 savings potential. With an average payback time of 119 years, the high temperature heating investment seems almost impossible to be financially achievable. In the Merenwijk the investment necessary to improve the existing building fluctuate around 6-8% of their average WOZ-value with the scope of this research. This gives an indication of how much it may financially burden a home owner. In this case the home-owner could also consider a total renovation or demolition of the property.

All technologies have specific characteristics which should be considered before implementing them on a large scale. Heat pumps should have a consistent heat supply from which they extract their energy. This can be problematic in winter season when outside temperatures are low. Supporting technologies such as pebble heaters or solar boilers can help prevent this problem. However this will increase the overall investment costs. Another option is to implement a warm water network which will help supply the heat pumps with a constant source of heat. However, this will require significant investment and therefore increase the payback time. Moreover, the strain on the electricity network and the investment necessary to accommodate this, is also something that should be seriously considered when implementing heat pumps on a large scale. It is important to note that heat pumps are not the only technologies that will strain the electricity network in the future; electric cars, battery systems and PV panels are also going to change the way the grid works. Low temperature heating networks have a strong potential to contribute to the heating transition. Their capacity and low temperature heat source availability determine their success to implement them. However, the implementation of this technology has a strong lock in effect: the network investment are significant (13000 euro per house) and require a long payback time. The heating network has to make a return on their investment and home owners therefore will be tied to this specific technology for several decades. Efficiency improvements in these networks or even lower operating temperatures have to be achieved in order to make them competitive with heat pumps and a changing energy mix. High temperature heating networks do not provide a significant advantage in terms of CO_2 emission in comparison to natural gas. Using this technology creates a lock in effect with heat sources which are less sustainable and provide limited energy savings, and therefore have a higher payback time. Ultimately this leads to a negative advice of the further implementation of this technology.

The heating vision of the municipality of Leiden is an excellent plan given the combination of technologies available for the Merenwijk. The use of high temperature heating networks for other neighbourhoods should be re-evaluated as it is heavily reliant on the *warmterotonde* (the initiative by the Dutch government to use the waste heat from the harbour of Rotterdam). This implementation has a potential to create a technological lock-in with oil and coal powered heat production. However, it also makes it possible to dramatically lower the number of houses depending on natural gas. This is a good short term solution. Unfortunately, it is less suitable for the long term given the fact that in 2030 the harbour of Rotterdam will have to close its coal fired power plants and oil refineries. The use of a tax on CO_2, governmental financial support and higher taxes on the consumption of gas could improve the business case for the heating transition by at least 30%. The investment costs and payback times are currently too high and will not be earned back before 2050 without any governmental interventions. Some Dutch politicians are aware of this situation and have argued for raising taxes on natural gas with 75% in the coming twelve years (Samsom, 2018).

Taking into account the financial investment, payback times, average WOZ values and the CO_2 savings, low temperature heating networks and heat pumps are most suitable to provide the Netherlands with a transition towards sustainable heating. Political courage however, is required to truly ignite the heating transition in the Netherlands.

8 Discussion

This paper provides a solid proof of the trade-offs of the three mentioned alternative heating technologies to be implemented during the heating transition. However, the limitation of this study certainly lies in the problematic availability of data and the corresponding spatial resolution. By making assumptions and working with incomplete datasets a lot of detail is lost in the modelling and the calculations. The model works best on terraced or single houses. Buildings with multiple floors like flats or with multiple addresses are more prone to create errors and calculation mismatches. The costs of the implementation of heating networks are also uncertain, as there is not a lot of information publicly available about this. Together with the unknown costs of investment in the electricity grid required to facilitate the heat pumps, make that the infrastructure investment are a limitation of this analysis.

Information on the efficiency of heat pumps is publicly available, while it is much more difficult to assess the performance of heating networks and the potential of low temperature options. The costs for insulating a house is something that increases quickly with each improvement. For the analysis in this study a linearization was used to be able to implement the values in ArcGis. This results in a higher payback time for houses with less insulation requirements in the model in comparison to real life, while houses that require more insulation are more prone to be representative of a real-world scenario. In this study the behaviour of the residents is not taken into account. This is something that can impact the energy use of a home and can also vary per energy technology implemented. Maintenance costs can also influence the financial outcomes of this study. For example, the maintenance of a heat pump can cost up to 120 euros a year, or a few thousand euro spread out over 30 years, but coherent sources on the implementation of these costs were difficult to retrieve.

In the report by Colofon (2017), it becomes clear that the expenses and the heat source are the main discussion points for heating networks and their development. The bulk of the heating networks is supplied by waste heat from the industry. This will slowly change in the future with a changing energy mix. It is mentioned that a reduction in operating temperature and availability of low temperature sources are needed to achieve this. This is in line with the findings of this report. The investment necessary to reach these goals are between 20.000-30.000 euro per home, which corroborates with the study done by CE Delft (2018). It also underlines the fact that home owners have to invest considerably. TNO (2018) also gives a critical view of the sustainability and CO_2 impact of high temperature heating networks. The payback times mentioned in this paper are long in comparison to the report by Urgenda (2017). The analysis utilized in this paper is based on more modern buildings which require less insulation investment in comparison to the analysis of the report by Urgenda. Also, by implementing the analysis of this paper on a large scale, some assumptions had to be made which resulted in a loss of detail on the level of individual buildings.

Finally, the Dutch government has to choose between a quick wins solution by reusing waste heat from the harbour of Rotterdam, or to implement a more long term sustainable energy transition with heat pumps and low temperature heating networks. In Sweden the heating transition took more than 40 years, while the Netherlands is trying to do it within 32 years (Werner, 2018). Luckily there resident associations, in the Hague for example, that are proposing their own solutions to the municipality for the heating transition (Haag, 2018). This way the residents can formulate their own vision and ask the municipality for financial support and approval. As this paper shows that home owners are vital to the heating transition, municipalities and the Dutch government should support home owners in order to accelerate the heating transition.

8.1 Future research

During this study assumptions were made to provide a comparative output. In order to increase the accuracy of the study, new research can be done on the individual technologies, their characteristics and their future potential. More knowledge about insight into human behaviour and the effects of government policy is also something that can contribute to the smooth implementation of the heating transition. Behaviour is an important part of the energy consumption of a building and people can be influenced by policies and technologies. Policies to stimulate the energy transition and financial incentives to implement the investment necessary to reach the climate goals could be improved. The old city centre of Leiden was not included in the analysis, as these buildings require a different approach due to their old age and the density of the inner city. It is however part of the heating transition and should be researched in a future paper. The impact of the heating transition on the electricity infrastructure is also something worth researching. A lot of developments utilizing the grid are taking place and the grid may possibly develop into a more decentralized network.

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10 Appendix

10.1 Appendix A: Insulation calculations

Costs summary						
		Investment	Savings (P.Y)	Savings (kWh/m3/year)	Payback time (years)	Price per kWh/m3
	Wall insulation (5-8cm)	€ 817,00	€ 277,00	44,82	2,95	€ 18,23
	Wall insulation (8-10cm)	€ 4.388,00	€ 27,00	4,37	162,52	€ 1.004,36
	Floor insulation (8-10cm)	€ 1.165,00	€ 87,00	14,08	13,39	€ 82,76
	Floor insulation (13-20cm)	€ 503,00	€ 29,00	4,69	17,34	€ 107,19
	Roof insulation (8-10cm)	€ 3.692,00	€ 122,00	19,74	30,26	€ 187,02
	Roof insulation (13-20cm)	€ 950,00	€ 61,00	9,87	15,57	€ 96,25
	HR++ glass living rooms	€ 2.307,00	€ 50,00	8,09	46,14	€ 285,15
	HR ++ glass bedrooms	€ 1.912,00	€ 42,00	6,80	45,52	€ 281,34
		€ 15.734,00	€ 695,00	112,46	22,64	€ 139,91

Source: https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/isoleren-en-besparen/

10.2 Appendix B: Interviews

Interview number	1
Name	Martijn Kosterman
Organisation	Municipality of The Hague
Functie	
Date	20-11-2017
Extra comments	

Interview Questions:

Hoe gaat zo'n verandering op particulier niveau?
Gas wordt volgend jaar ietsje duurder om het gebruik te ontmoedigen. Kostenverdeling is een moeilijk punt binnen de warmtetransitie. Den Haag is gunstig voor geothermie, 1 bron is gunstig voor 5000-7000 woningen. De ambitie van Den Haag is klimaatneutraal, daar is niet bij gezegd of het binnen eigen grenzen of niet gebeurt.

Hoe zien jullie deze verandering voor jullie?
CE Delft was een black box, te veel aannames, het was niet duidelijk waarom bepaalde wijken er op een manier uitkwamen. Te zwart-wit en niet simpel genoeg om uit te leggen aan bewoners en partijen in de stad. Bij het maken van de tijdlijn moeten er meerdere partijen betrokken worden, wie erbij wil mag erbij. In februari wordt er binnen de gemeente gestuurd richting een soort Haags energieakkoord. De gemeente Den Haag wil in 2040 klimaatneutraal zijn. De gemeente gaat niet investeren in duurzame energie, we motiveren, stimuleren. Net zoals bij het gasnet, lokale netbeheerders, kosten zijn voor iedereen hetzelfde en krijgen wettelijke taken om deze infrastructuur aan te leggen. Warmte wordt niet gesocialiseerd op dit moment. Wijkaanpakken wil de gemeente graag heen, op wijkniveau afspraken maken. Warmte is geen gelijk speelveld, gas en elektriciteit wordt over iedereen verdeeld. Bij gas en elektra kun je kiezen bij wie je je stroom inkoopt, bij warmte zit je verbonden aan wie er warmte levert. Het is raar dat de warmtenetten niet gesocialiseerd zijn en gas en elektra wel. Zolang het niet hun wettelijke taak is werken ze ook met andere rendementen.

Waar zien jullie de grootste knelpunten zitten voor de komende jaren?
Bij het bottom-up verhaal heb je te maken met verschillende schaalniveau's. Er zit wrijving tussen gebouw en straatniveau. Onze raad gaat natuurlijk tot waar onze grens loopt, maar het beïnvloedt elkaar wel. Gunstiger om collectief te werken als bewoners ipv 1 persoon die heel enthousiast met zijn eigen gebouw bezig gaat. De gemeente wordt geacht om te regisseren. De individuele oplossingen zijn over het algemeen duurder dan collectieve oplossingen, maar collectieve oplossingen beperken meer. Als één straat een mooi bottom-up initiatief heeft en daarmee een andere straat benadeeld moet de gemeente daarin inspelen. Dingen proberen om te leren, hoeveel bronnen hebben we in de stad en hoe kunnen we die verdelen? Is niet één oplossing voor, warmtepompen alleen is te veel energieverbruik. Techniek is niet het grootste probleem, energieopslag kan beter, de elektriciteitsnetten kunnen efficiënter, de basis ligt er wel.

De gemeente is bezig met een beeld te maken met welke oplossingen waar worden verwacht. Richtinggevend eindbeeld maken, deze week zal ongeveer zoveel op deze techniek gaan, en met dit beeld elke wijk het gesprek aangaan. Er is globaal wat over te zeggen maar geen houvast.

Er worden al gesprekken gevoerd met wijken, 4 prioriteitenwijken, Den Haag zuidwest = aardwarmtebron, Mariahoeve, Binckhorst en het CID (central innovation district). Mariahoeve en zuid-west hebben een hoog energieverbruik. Bij veel corporatiewoningen ligt er al een klein stukje warmtenet. Aardwarmtebron gaat volgend jaar warmte leveren. Jonge wijken worden later aangepakt wegens de economische levensduur van de aangelegde infrastructuur. Sommige wijken hebben eigen initiatieven en bieden die aan, waar zijn al actieve clubs die bezig zijn? Duurzaam Den Haag probeert een overzicht ervan te maken, en de gemeente wil hen ondersteunen.

Het is belangrijk om het eindbeeld te schetsen, zodat alles op elkaar afgestemd kan worden. Vanuit de woningen wordt er gekeken, wat is hier de beste oplossing? Als hier meer dan 60% collectief 60 graden nodig heeft dan kan dit hier. Als eruit komt dat 90% van de stad 90 graden nodig heeft, wat dan?

Hoe ging dit met de transitie van kolen naar gas? —> wie betaalde dat?
De transitie van kolen naar gas bracht vele voordelen, uniform verwarmde ruimtes, Centrale verwarming, douchen, omschakeling was gratis toen. Was een sociale verandering en vooruitgang van het comfort van mensen! Deze transitie werd betaald door de energiebedrijven en de overheid zelf.

Interview number	2
Name	Benno Schepers
Organisation	CE Delft
Functie	
Date	29-22-2017
Extra comments	

Interview Questions:

Wat zijn de betrokken partijen binnen de warmtetransitie?
Gemeente, corporaties, netbeheerder, warmtebedrijf (commerciele partijen), de grotere spelers, rijksvastgoeddienst en grootvastgoedbezitters, aanbodkant warmte bedrijfsorganisaties, of mensen die bij de business case betrokken kunnen worden. Eigenaars en bewoners worden in een veel later stadium pas aangehaald. Enorm gespreid beeld, verschillende leeftijd, kennisniveau en budget. In het begin met grootschalige plannen hoeft de individuele burger er niet bij, op een gegeven moment wel.

Wat is de afhankelijkheid van warmtenetten?
Het warmtenet wat wordt aangelegd is geen dom warmtenet, modern en slimme bronnen worden gebruikt. Wat zijn mogelijke ontwikkel strategieën van de haven van Rotterdam? Biobased economy en metalen smelten heb je restwarmte, er zal altijd wel een vorm van blijven en aangevuld met geothermie. Triasboring test in het Westland, zijn in principe tuinders die het doen. WKK is niet interessant omdat de electra prijs laag is en de gasprijs hoog. Tuinders die het gebruiken. Bijna alle tuinders hebben warmte nodig en veel hebben CO2 nodig, OCAP-leiding vangt CO2 uit Rotterdam. Anders produceert de gasketel het, zonder CO2 kan een gastuinbouwer dus niks. Gastuinbouw blijft veel CO2 uitstoten, ook al hebben ze CO2 nodig. Wat is aan de vraagkant je klant? Den haag heeft hoog/oudbouw en dat zijn hoge temperaturen. Tussen 90/110 of 70 graden, 20 graden overbruggen kost geld. Hogere temperatuur is kleinere buizen, meer capaciteit, lager kan je meer verschillende bronnen op aansluiten. Warmtealliantie van de *warmterotonde* gaan hierover over het warmtenet voor de basisvraag. Voor de piekwarmte moeten er lokaal oplossingen worden gevonden. Maar 10% van het volume levert 80% van het vermogen. 80% uit restwarmte, 20% kwam uit de piekketel. Geothermie was 70/30. Het dimensioneren dat je alle vraag aankunt. Vraag volume en prijs.

Hoe wordt GIS data gebruikt?
Model berekent de oplossingsrichtingen met de laagste kosten, per buurt rekent het de oplossingen uit. Wat voor woningen zijn daar? Hoe oud zijn ze? Wat kosten verbeteringen daar? Geaggregeerd naar een gemiddelde woning in een buurt. Verder wordt er gekeken naar potentiele energiebronnen, weinig kwantitatief.

Hoe is het onderzoek van CE Delft opgesteld?
Wat zijn de doelstelling? Wat moet je halen, welke sectoren en wat zijn de doorlooptijden? Welke problemen komen erbij, vervoersmaatregelen en elektricitieitsvoorzieningen zitten het er niet in. Warmte is onderdeel van het rapport, het was een lichte verkenning van de mogelijkheden. Kleiner ingestoken maar gaandeweg omvangrijker geworden.

Bij warmte hebben ze een paar scenario's, arbitrair en in overleg met de opdrachtgever. Randen van het speelveld was de insteek, welke extremen kun je verzinnen? Rotterdam *warmterotonde* benutten, kan Den Haag zonder de kolenwarmte van Rotterdam verwarmd worden? 5 scenario's om die randen te laten zien. Deze zijn op hoofdlijnen uitgewerkt op kosten, energieverbruik en doorlooptijd. Lage temperatuur warmtenetten was te weinig informatie over, daarom opgevuld met lokale oplossingen. Weten niet hoe groot lage temperatuur bronnen zijn, maar wel waar ze zitten en hoe continu ze leveren. Kijk op lokaal niveau naar de bronnen, wat is er mogelijk?

Macro-economische modellen zijn nooit berekend.

Hoe worden de scenario's in Den Haag bepaald in een situatie met vele oplossingen?
Duidelijke knelpunten, dat Den Haag niet zoveel woningen per jaar van het aardgas af kan halen. Advies wordt het combineren van oplossingen. Energietafel, overlegstructuur waarbij verschillende stakeholders aan tafel zitten en overleggen. Bewoners, corporaties, netbeheerders moeten betrokken worden. Soms moeten er ook dingen worden doorgezet zonder draagvlak. Bestaande warmtevraag weten we, van de toekomst weten we niet precies en de nieuwbouw gebouwen moeten bijna energieneutraal zijn, ook kantoorpanden. Met gas bouwen is de goedkope keuze, maar er is nog geen wetgeving. Voor nieuwbouw vervalt de aansluitplicht van gas, recht op warmte. Het zijn andere technieken, woonlasten tegen investeringskosten. Willekeurig pand, schil verbeteringen, schil in combinatie met warmte installaties.

Technische capaciteiten gaan niet veel meer veranderen. Wat sterk gaat veranderen zijn de kosten. In een model wordt geoptimaliseerd op kosten. Verschillende varianten warmtepomp, buiten staan niet mooi, ook een variant met bodem warmtewisselaar gesloten bodem energiesysteem. Open is WKO, dit is gesloten. Heeft een hoger rendement maar een stuk duurder. Ver weg van andere infrastructuur, alleen elektra en geen warmtenet. Groen gas Nederland verdeling is gebaseerd op het huidige gebruik. Voor groen gas zijn er beter productievere producten dan het verwarmen van woningen.

In de buurten wordt gekeken naar buurt specifieke situaties. Zijn er grote wijzigingen in buurten op stapel? Blokverwarmingen bij flatgebouwen etc. Wat zijn de toekomstplannen voor deze buurten? Fijnmaziger kijken heeft meerwaarde en kan meer opleveren.

Interview number	3
Name	Michiel Fremouw
Organisation	TU Delft – Architecture
Functie	Researcher
Date	08-03-2018
Extra comments	

Interview Questions:

Is de *warmterotonde* een lage of hoge-temperatuur warmtenet? En kan je mij meer vertellen over de werking hiervan?
De *Warmterotonde* is hoge-temperatuur netwerk, normaal zijn de terugverdientijden 50 jaar +-, komt door forse investeringen. 1 miljoen euro per kilometer. Restwarmte is opgewekt door fossiele brandstoffen, hoe ontwikkelt zich dit de komende 20 jaar? Als de vraag naar fossiel minder wordt door de gebouwde omgeving zal de industrie minder druk voelen om het af te bouwen, dus blijft het nog wel even. Lange termijn economische projectjes. Je wil landelijk van het gas af en wat doe je dan? In Amsterdam ben ik bezig met het CITIZEN-project. Monumentale panden zullen hoge temperatuur nodig hebben, bijvoorbeeld: elektrisch, gas, warmtenetwerken voor de warmte zijn. Alleen als het 100% geïsoleerd is en goedkoop kan je het elektrisch doen. Oude gebouwen kan het, sommige monumenten zijn onmogelijk. Realistisch is om 2-3 stappen omhoog te maken en niet alleen A-label proberen te maken. Gedeelte opknappen zodat je met lage temperatuur aan de slag kan gaan, hoe laag is de volgende vraag? Lage temperatuur is makkelijk op te slaan en beschikbaar, ook in de winter te gebruiken. Zonthermisch om daarmee geothermie bronnen weer op te laden, boren op een paar kilometer diep en dan haal je het daarmee weer uit. Warmtebedrijf heeft geen baat bij het individueel oplossen van huizen, schaalvoordeel, zoveel mogelijk kWh. Particulier en andere partijen meenemen, misschien sociale woningbouw gebruiken als aanzwengelpunt.

Planheat.eu —> zelfde onderzoek, toolkit

https://maps.amsterdam.nl/

Hoe is een GIS-model opgebouwd?
Je kan het zien als een pyramide in de opbouw. Robuust (resilience) opbouwen, technisch, realiteit, regelgeving zijn aspecten hiervan. Of iets bij veranderende omstandigheden nog steeds een interessant voorstel is. Het is belangrijk om een lange termijn resilience te definiëren voor het onderzoek, linken aan de indicatoren die ik ga gebruiken om het model op te zetten. Vergeet de eindgebruiker niet KPI's definiëren voor het model Energy performance in buildings directive (energielabel) Energie label is vergelijkbaar, gebouw per object -> hoe is de indicator opgebouwd? Energielabal is een redelijke indicator om te kijken wat er mogelijk is aan verbeteringen in een gebied/gebouw.

Hoeveel stakeholders/partijen kun je mee krijgen?
Onzekerheid van kiezen van indicators, low exergy, lage temperatuur bronnen zijn, LowEx low exergy (kijkt naar kwaliteit van energie) Wanneer is individueel logisch, wanneer zijn netwerken logisch?

Euro's en CO2 als KPI's die uit elkaar kunnen lopen. Hoeveel hinder levert het op, financieel investering, KPI's bepalen uit stakeholders, technieken, financiën, wetgeving, etc. Als er iets is waar geen harde indicator aan te hangen is, Kun je reflecteren en een abstract antwoord erover geven. Wat zijn de voor en nadelen van technieken en hierop indicatoren baseren. Vraag gewoon, welke indicatoren vinden jullie belangrijk? Waar maak jij je beslissing op?

Wat is de brondata, wat zijn de berekeningen en kan je er verder mee?

Energy potential mapping & urban energy transition (GIS?) Energy potential mapping (EPM) enabler of urban energy plans (koppelen van potentieel, welke waardes eraan gekoppeld? Combinatie van eigenschappen om ‘potentieel’ te meten. 3D heat maps —> uitleg over geven, waarom 3D en met welk programma? Betrekken van stakeholders in dit proces en naast technische potentie ook mogelijke sociale potentie plotten?

Transparanter opzetten, je wil juist zien hoe het opgebouwd is, samenstelling is heel erg van belang, zelfde overgang van paarden naar auto’s. De extreme keuzevrijheid en gemak van vroeger is waardoor het problematisch is. Smart homes, te veel opties, vraag en aanbod aan elkaar koppelen. Uitleg eigen thesis en wat ik wil onderzoeken, potentie van warmtetechnieken op particuliere woningen in Leiden met de Merenwijk als case study. Problematiek rondom de energietransitie mbt warmte.

Lage temperatuur warmtenetten + warmtepomp

Energy master plan —> waardevolle paper voor mijn opzet

http://www.cityzen-smartcity.eu/ focust zich op de complexe materie van wat is waar

http://episcope.eu/index.php?id=97 —> gebouwlabels en hoe ze bepaald zijn

http://episcope.eu/index.php?id=306

http://episcope.eu/building-typology/country/nl/ bepalen van energielabel

https://www.tudelft.nl/en/events/2016/knowledge-conference-the-future-of-the-ijsselmeer-region/thesis-defence-dasa-majcen-predicting-energy-consumption-and-savings-in-dwelling-stock/ —> Nederlandse bouwvoorraad

Interview number	4
Name	Thomas Engels
Organisation	Overmorgen
Functie	Data analyst
Date	13-03-2018
Extra comments	

Interview Questions:

Doel van de overmorgen kaart, visie en lange termijn erop, detailniveau (ruimtelijke resolutie)

Regio Holland-Rijnland

Kansrijkheid, hoe is dit per warmtetechniek gedefinieerd?
Hoe uitgebreid is dit gedaan en wat waren de speerpunten/guidelines hiervan? Kansrijkheid bij collectieve warmte (hoge en lage temperatuur oplossingen) en individuele oplossingen. Begonnen bij collectieve warmte alles samenvoegen omdat je met hoog kan beginnen en daarna richting laag kan gaan.

Indicatoren:

- Niet al stadsverwarming (geen gasverbruik)
- Niet al blokverwarming (laag gasverbruik)
- Vrijstaan (woningtypologie)
- Bouwjaar
- Label
- Gasverbruik (openbaar)
- Woningdichtheid wordt in het nieuwe model meegenomen

Op basis van selectiecriteria ipv if else, techniek opsplitsen in individueel en collectief, (geothermie (niet interessant vanwege de bodemdikte), hybride oplossingen en volledig elektrisch).

Het is grotendeels vraag gestuurd, wat wordt er aan energie gevraagd?

Op individuele oplossingen is het niet afgewogen, warmteboiler en hybride CV ketel bijvoorbeeld. De techniek verandert zo snel dat het moeilijk is om het daarop te baseren, gekeken naar gebouwen. Kijken naar de status en situatie van de bouwen ipv de warmtetechnieken. Woningtypen is wel beschikbaar maar moet je zelf nog verwerken Blokverwarming is een collectieve ketel. Individuele oplossingen bevatten all electric alleen Proberen zoveel mogelijk op pandniveau, maar aggregeren terug naar buurtniveau. Kleinschalige lage temperatuur warmtenetten (hoeveel huizen zijn dat?) De schaalgrootte van warmtenetten heeft te maken met de bron en investeringen.

Data.overmorgen.nl Storymap zit in de leiden link ook Wat is energieneutraliteit nou echt?

Betrekken van stakeholders?

Wordt gedaan bij scenario's schrijven maar verder niet.

Bron van de datasets naast kopen?

Beschikbaar stellen als GIS-data van sommige output namens de gemeente.

Kosten, uitstoot elementen ingevoegd, uitbreiden van de kaart. Veel data komt van openbare datasets maar gedeeltes worden ook ingekocht van private organisaties

Interview number	5
Name	Matthijs de Graaf
Organisation	Nuon
Functie	Manager warmte
Date	03-04-2018
Extra comments	

Interview Questions:

- Wat is het verbruik van technieken per m2 voor warmtenetten?
- Wat zijn de kosten voor het aansluiten van warmtenetten?
- Wat zijn de investeringen die nodig zijn voor de isolatie van het huis?

Waar komt de warmte van Leiden vandaan?
Eon Leiden valt weg over een paar jaar, 22.546 woningen (niet panden), het liefste praten ze over woning equivalenten. Vanuit Nuon zo'n hoog mogelijke aanvoertemperatuur, laag mogelijk terug voertemperatuur. Hoe warmer de pijp, hoe meer die uitstraalt, maar als je het terug rekent naar hoeveel je doorpompt. De gesprekken over de warmteaanvoer van Leiden, terugkomen naar lagetemperatuur warmte regime. Leveringsovereenkomst tot 2020.

Warmtebedrijf Rotterdam (WBR) is vanaf 2020 verantwoordelijk voor de warmtelevering aan Nuon Leiden, is soort van onderdeel van de *warmterotonde*. Hogetemperatuur in de bron, transportnet hoge temperatuur is aanvoertemperatuur 90-120 graden, retourtemperatuur is 67 graden. Retourtemperatuur wordt gebruikt voor een lage temperatuur aansluiting. Onder druk zodat het als water door de pijp stroomt.

Wat zijn de verschillen tussen gas en stadswarmte?
De binnenstad van Leiden wordt straks aangesloten op stadswarmte. Stadswarmte heeft als nadeel dat het onder de grond meer ruimte inneemt dan een gasaansluiting, risicovol en duur voor het centrum.

Bestaande bouw proberen ze steeds meer, oude binnensteden zijn heel moeilijk.

- Het bestaande warmtenet is eigenlijk uitgenut, thermische capaciteit limiet is bereikt.
- Het bestaande network kan nog heel veel efficienter gemaakt worden bij de klanten zelf.
- De leiding uit Rotterdam is niet voorzien op heel veel groei uit Leiden.

Transportnetten wijknetten 70 graden, niet warmer dan 40 graden terugkrijgen. Wordt behandeld water gebruikt, kan problemen opleveren met aluminium radiatoren.

Gaat de *warmterotonde* nog verder uitbreiden tov het bestaande netwerk?
Is nog niet bepaald, maar zou wel de intentie kunnen zijn. Heineken heeft ook restwarmte

Wat zijn de kosten voor het aansluiten op stadswarmte?
Woningen die aangesloten worden op stadswarmte mogen niet meer betalen dan op aardgas. Nuon is de goedkoopste, met stadswarmte kan je ook variabel ondernemen qua duurzaamheid. Stadswarmte doe je niet voor de rendementen van geld,

Wie gaat de business case maken?
Interactie tussen verschillende bedrijven, het is systematisch waarin het van boven besloten moet worden. Gemeente geeft grond uit en geeft voorwaarden eraan. Nuon zit als partij aan de tafel maar gaat niet over de keuze. Het streven naar lage-temperatuurs systemen gaat over de kant van de gebruikers. Het ligt niet aan het transport maar aan de verbruikkant. Verschil tussen capaciteit centrale en net. Hoe lager de temperatuur, hoe langzamer de temperatuurverandering. Staal in staal is complex

en duur maar wel robuust. Die leg je voor 50 jaar in de grond, voor de moeilijk te onderhouden plekken. Levensduur van een normale warmtenetpijp zijn voornamelijk afhankelijk van externe invloeden, anders doe je er ook 50 jaar mee. Storing afhankelijk onderhoud. 80-100 cm grond boven de leiding.

Interview number	6
Name	Joeri Oudshoorn
Organisation	Haagse stadspartij
Functie	Woordvoerder: economie, klimaat en duurzaamheid
Date	23-04-2018
Extra comments	

Interview Questions:

Wat is de aanloop naar Parijs met de huidige Nederlandse doelstellingen?
2 graden maximale stijging door CO_2 met huidige verdeling doelstelling en dat welvarende landen hier voorop in moeten lopen. Curve van de CO_2 uitstoot, PBL (planbureau voor de leefomgeving) heeft cijfers daarover gemaakt. In Den Haag zijn die cijfers geïnterpreteerd en budgetten voor DH aan gekoppeld.

Hoe kijk jij tegen de *warmterotonde* aan?
Warmterotonde als kritische noot, als je 2050 zet als doelstelling heb je 30 jaar om deze af te schrijven. Kijken naar de stadswarmte op gas in Leiden, investering die je nodig hebt om van bron tot afgifte, (van bron tot huis), als kader. Als tijdsduur zetten tot wanneer je de techniek terugverdient hebt. Piekwinter faciliteiten hoef je niet meer mee te nemen bij de laatste stappen van isolatie. Pas als het onder de 0 graden is een pellet kachel gebruiken. Systemen die lage kosten hebben, maar slecht voor luchtkwaliteit.

Wat zie jij als de knelpunten voor de warmtepomp?
Warmtepomp kan op vele labels, maar voor de piekvraag in de winter is isoleren verstandig. Als je een warmtepomp combineert met een pelletkachel of hybride systeem. Bij fossiele warmte kun je elke temperatuur aanleveren, en kies je dus ook voor hoge temperatuur verwarming. Bij duurzame warmte wordt de warmte duurder naarmate je de termperatuur hoger maakt, of is minder/minder efficient beschikbaar hoge temperatuur. Multipurpose warmtepomp, op lucht en water aan te sluiten. Welke timing kun je gebruiken om de veranderingen toe te passen? Bij een verhuizing, vervanging gasaansluitingen. Warmtepompen zijn 4-5x efficiënter, ook in energieverbruik en CO2 uitstoot dus kosten. Kijken naar all electric zonder water als energiedrager, infrarood paneel, stralingswarmte.

Is het een transitie naar warmtenetten of een transitie naar duurzaam?
Een hoge temperatuur warmtenet is bijna per definitie geen duurzame oplossing. Roosters tussen de muren met warmtewisselaar, kost 100-600 euro. De vraag is of de ventilatie volledig nodig is? Radiatoren op vaste temperatuur zetten heb je veel, of ventilatoren op je radiatoren zetten. Andere mindset over hoe je een huis verwarmt. Voor warmtenetwerken heb je een warmtewisselaar nodig, voor een paar huizen een verdeling van warmtegebruik, en kijken naar de piekwarmte en dus het verschil tussen een goed geïsoleerd huis en een minder goed geïsoleerd huis.