Transition to sustainable heating at neighbourhood level

Research in technical, environmental and financial feasibility and development of a process guide for municipalities

K. Neels

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Research in technical, environmental and financial feasibility and development of a process guide for municipalities

by

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Preface

This thesis is the final result of my graduation thesis of the Msc program Sustainable Energy Technology at the TU Delft. In this thesis, different sustainable heating options are studied and it is investigated how these alternative heating options could be implemented in neighborhoods. I hope that this study contributes to the needed energy transition in the Netherlands. I could not have finished this research without the help of some people, to whom I would like to express my deepest gratitude here.

First of all, I would like to thank my main supervisor: Laure Itard. Thank you for your positive attitude and the effort you put in guiding me during my thesis. The conversations with you helped me to clarify my goals and without your insight I could not have accomplished this work. Furthermore, I would like to thank my other supervisors: Kornelis Blok and Jaco Quist for their helpful feedback to improve my thesis. I also would like to thank Nynke Douma, for supervising me at the municipality The Hague.

Furthermore, I want to thank all my friends, my family, my husband and above all God, for helping me. Special thanks for Stephan, John, Lea, Iris and Bas who took the effort to read some parts and improve my English writing. I am grateful of everything I learned and have done during my study time. I look forward to put my energy in my future work and help to make the world a better place. I hope you will enjoy reading my thesis. Have fun!

Kind regards,

K. Neels
Delft, August 2018

Executive Summary

To decrease the amount of CO_2 emissions, secure the energy supply and deal with the limited amount of fossil fuels the current heating supply for the building environment needs to be made more sustainable and independent of natural gas. In the Dutch climate agreement it is stated that all municipalities in the Netherlands need to have an energy transition plan for every neighbourhood before 2021. There is a need for knowledge around how to successfully transform the current heating system into a sustainable one at neighbourhood level.

This thesis brings together different approaches, studies and stepping stones into one general calculation model for a municipality in the Netherlands. Moreover, the main question: *"How to create more insight into the financial and technical feasibility of different sustainable heating systems at neighbourhood level for municipalities?"* is answered. Three corresponding sub-questions are answered in this thesis as well:

1. *What is the current situation in the energy transition at neighbourhood level from a political, stakeholder and technical view?*
2. *What kind of approach can be developed to gain more information on how to bring further the energy situation at neighbourhood level?*
3. *How can different alternatives for the current heating system objectively be weighed by municipalities, taking technical and financial feasibility into account as well as district typologies (types of houses and ownership structures)?*

The method used to answer this research question is a literature study, which serves as basis for the development of a model, and a case study. The literature study assists in answering the first subquestion and the case study assists in answering the second and third subquestion.

Literature review
According to the literature study, decision makers in municipalities have to take the leading role and create a platform where stakeholders (energy companies, network operators, residents, housing association and home owners associations) can interact and discuss preferable future heating systems. The possible renewable heating systems can be divided into centralized or decentralized heating systems. Centralized heating systems supply sustainable heat for a group of buildings via a network. Decentralized heating systems generate their heat near the location of a building. Different methodologies such as, *Energy Potential Mapping* (EPM), *Spatial Transition Analysis* (STA) and city-zen approach gain insight into the energy transition at neighbourhood level. However, none of these methodologies give insight into the mismatch between the demand of heat and the supply of heat at neighbourhood level, which is is essential to characterize the CO_2 emissions of different alternatives. To gain more insight into this, a calculation model is needed. This answers the first sub-question.

Proposed approach
With the help of criteria, obtained from interviews of policy makers at the municipality, and the developed frameworks that give insight into the different possibilities for the heating system, the calculation model and an approach to use this calculation model is developed. The calculation model should be able to compare the hourly heating potential of different renewable heating technologies with the hourly heating demand of the buildings in the neighbourhood. It should give insight into the financial feasibility of different heating technologies and calculate the CO_2 emissions of different heating technologies.

To test the developed calculation model and the approach to use the calculation model a case study is used. The neighbourhood Mariahoeve, located in The Hague is used as case study in this thesis.

The developed approach (figure 1) consists of five steps:

1. Collecting input data for determining heating demand of buildings in a neighbourhood
2. Collecting input data for determining the heating potential of different sustainable heating technologies
3. Design scenarios
4. Run calculation model
5. Analyze outcome of scenarios

This answers the second sub-question.

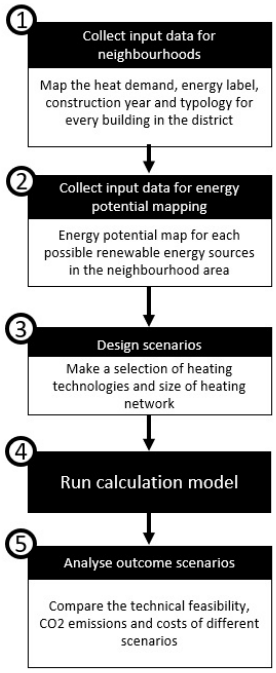

Figure 1: Developed approach (by author)

The first step of the approach, collecting input data to determine the hourly heating demand of each building in the neighbourhood, is accomplished by following the steps:

1. Map the current energy label, construction year and property ownership of the buildings in the neighbourhood
2. Determine the current energy consumption of the neighbourhood
3. Determine the typologies of buildings in the neighbourhood
4. Determine the theoretical hourly heating demand per typology
5. Calibrate the heating demand pattern

Ensuing these steps results in a hourly heating demand pattern for a complete typical climate year. An example of such pattern is given in figure 2 for the sum of all buildings of the neighborhood Mariahoeve:

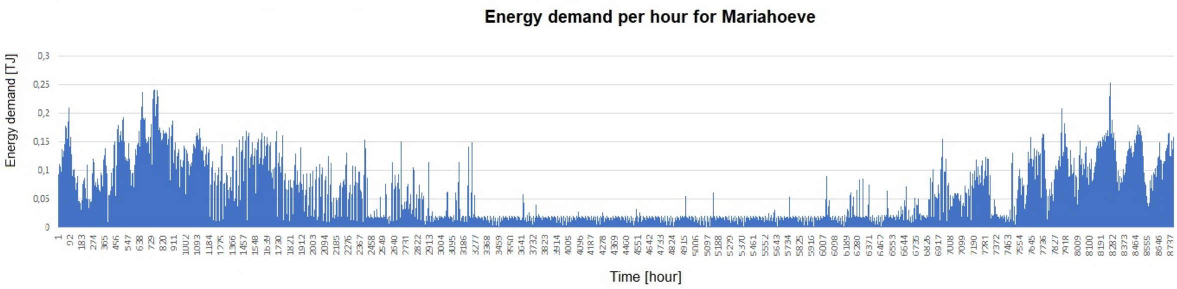

Figure 2: Energy pattern of the dwellings in Mariahoeve (by author)

In the second step input data of heating potentials of different sources is collected. The energy potential mapping (EPM) method is used to calculate the heating potential of different sources in the neighborhood. This results in the potential for the following heating sources in Mariahoeve (table 1).

Table 1: Heating potential for different sources in Mariahoeve (by author)

Heating source		Total heat potential
Solar heat	PV panels	101 TJ
	Solar collectors	186 TJ
	Asphalt collectors	39 TJ
Biowaste	Potential of biogas and wood	14.7 TJ
Geothermal	High or low outlet potential	104-280 TJ
Waste heat	Supermarkets and Offices	27 TJ

Step three is to determine scenario's to gain more insight into the feasibility of different heating technologies in the neighbourhood. The scenarios can be divided into scenarios for centralized heating systems and decentralized heating systems. Three what-if scenarios are developed for centralized heating systems. The difference in these scenarios are the size and the temperature levels of the heating network. The first what-if scenario connects all the high energy demand buildings to a high temperature network. In the second scenario the previous buildings are insulated to energy label B and connected, together with low energy demand buildings suitable for district heating, to a low temperature heating network. In the last scenario every building in Mariahoeve is insulated to energy label B and connected to the low temperature network. In all these what-if scenario the mismatch between demand and supply, the financial feasibility and the amount of CO_2 emissions are calculated. In the decentralized what-if scenario the financial feasibility and amount of CO_2 emissions for individual heating technologies are elaborated.

The fourth step is to run the calculation models. The intermittency calculation model calculates the match between the renewable energy supply and the heating demand using two indicators: on-site energy matching (OEM) and on-site energy Fraction (OEF). The net present value (NPV) method is used to calculate the financial feasibility and the CO_2 emissions can be calculated with the outcome of the (OEM) and (OEF) indicators. This answers, together with the calculation models, the third subquestion.

The last step of the approach is to compare the outcome of the scenarios. In this case study, the outcome of the centralized scenario shows that geothermal well gives the best match between supply and demand and highest financial feasibility for the heating network in Mariahoeve. However, the size of the heating network should not be too big, otherwise the NPV for network operators will become unprofitable. It is best to insulate the connected buildings to label B. Seasonal storage is needed, without storage heating neighbourhoods sustainably is impossible. The electricity demand also needs to be generated sustainably, otherwise the CO_2 emissions will only increase. The outcome of the decentralized heating system states that using sustainable heating systems lowers the average yearly energy costs, but because of the needed high investment costs, the NPV for sustainable heating system will not be better than gas. A PV panel could make the heating systems more profitable. It is even more important for individual heated system to generate the electricity sustainably, otherwise the total CO_2 emissions will only increase. With the current prizes of heating systems and energy, individual heating systems are cheaper for residents compared to connection to the heating network. The investment costs for individual heating systems are higher, but the operational costs are lower compared to the heating network.

Conclusion
The developed calculation model and the approach to use this model gives decision makers in municipalities insight into the possible financial and technical feasibility for different heating systems in a neighbourhood. With this calculation model it is possible to see in detail how much energy a sustainable source could provide, how much storage is possible and how much extra heat is needed from the grid. However, some generalizations are made in the

calculation model. For further studies, the real hourly energy demand of each building is needed. This can be done, by placing smart meters for heating in buildings and use the data form these smart meters. Also, information about regulations and restrictions for building energy plants or technologies is helpful for decision makers in municipalities and should be added in the calculation model. It is recommended for the municipality to start investing in possible seasonal heating storage and include the sustainability of electricity supply. Furthermore, time is needed to fully understand and work with the calculation model. Full understanding of the calculation model gives deeper insight into the possible energy transition for municipalities.

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List of abbreviation

MLP	multi-level perspective
TM	transition management
LTDH	low temperature district heating
HOA	home owners associations
HA	housing association
HTDH	high temperature district heating
CHP	combined heat and power
GSHP	ground source heat pump
WSHP	water source heat pump
ASHP	air source heat pump
ATES	aquifer thermal energy storage
IF	Infrastructural Footprint
TSO	Transmission system operator
DSO	Distribution system operator
DHW	domestic hot water
OEF	on-site energy fraction
OEM	on-site energy matching
OTEC	Ocean thermal energy conversion
EPM	energy potential map
STA	spatial transition analysis
BES	Building energy simulation
UBES	Urban building energy simulation
CES	City energy simulation
GIS	Geographical Information Systems
STES	seasonal thermal energy storage
PV	Photovoltaic
NPV	Net Present Value
FV	Future Value
COP	Coefficient of performance

1

Introduction

The first chapter of this thesis report introduces background information of the thesis subject, followed by the research objective, boundaries of the thesis and the methodology of this study. At last an outline of the report is given.

1.1. Background

It is commonly known that the current way of living is too exhausting for the earth. We emit an exceedingly amount of greenhouse gases that absorbs infrared radiation and re-emits it randomly back to the earth causing an increase in the average global temperature of the earth (MacKay, 2008). This increase in temperature has huge consequences for the earth and can result in extreme weather conditions and unlivable environments. If we want to give our future generations the same beautiful earth as we know it, action is needed.
One way to reduce the emission of greenhouse gases is reducing the use of fossil fuels. The burning of fossil fuel is needed to produce energy. However, when burning fossil fuels, carbon dioxide (CO_2) is produced which is a greenhouse gas. According to David JC MacKay (MacKay, 2008) this is one of the three commonly used reasons to decrease the use of fossil fuels. The other two are the limited amount of fossil fuels and the security of energy supply. The fossil fuels on earth are exhausting, so we need to be careful with the amount that is still left instead of using it with the current proportions. Governments also have the urge to secure their energy supply, they do not want to be dependent on instable countries who deliver their energy. It is therefore of great importance to reduce the use of fossil fuels.

However, change is coming. In the Paris agreement 195 countries agreed to do as much as possible to reduce the emission of the greenhouse gases in their country. The Netherlands is one of the 195 countries that has agreed to reduce their pollution. One possible measure is to change the current heating system of the built environment in the Netherlands into a more sustainable one. Currently, every building in the Netherlands is connected to a national gas grid. Some of this gas is extracted in the province Groningen, causing slight earthquakes in that area. Due to this, the government of the Netherlands wants to reduce the extraction and use of gas (NOS, 2018). They want to be independent of gas for residential heating by 2050(Rijksoverheid, 2016). Furthermore, in the Dutch climate agreement it is stated that all municipalities in the Netherlands need to have an energy transition plan for every neighbourhood before 2021 (Nieuwsuur, 2018). Because of those developments, the Netherlands is in need of a quick transition. Municipalities are searching how to start and successfully secure the transition from the old heating system into a more sustainable heating system that is independent of gas.

There is a lot of movement, nonetheless there is no success story of an existing neighbourhood which transformed its heating system into a sustainable one. It is unknown how to start this kind of energy transition. There is a need for knowledge how to successfully transform the current heating system into a sustainable one.

This thesis is meant to bring together different approaches, studies and stepping stones into one general calculation model for a municipality in the Netherlands to help them create more insight into the energy transition and accelerate the energy transition at neighbourhood level.

1.2. Research objectives

In order to create more insight, several research questions are set up. The main research question is:

> *"How to create more insight into the financial and technical feasibility of different sustainable heating systems at neighbourhood level for municipalities?*

To answer the research question a case study is used. A case study is a suitable method for in-depth research. This research will be applied to the neighbourhood Mariahoeve, located in the Hague. The following sub-questions are answered in this study:

1. *What is the current situation in the energy transition at neighbourhood level from a political, stakeholder and technical view?*

2. *What kind of approach can be developed to gain more information on how to bring further the energy transition at neighbourhood level?*

3. *How can different alternatives for the current heating system objectively be weighted by municipalities, taking technical and financial feasibility into account as well as district typologies (types of houses and ownership structures)?*

In this study sustainable heating systems are regularly mentioned. The use of sustainable heating systems is part of sustainable developments. The definition of sustainable development is: *"Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Keeble, 1988, p. 37)

1.3. Boundaries

This thesis only regards the heating demand and supply of buildings at neighbourhood level in the Netherlands. Storage and demand side management are out of the scope of this thesis project, but possible mismatches between energy supply and demand are considered though. Only current available sustainable technologies are considered (solar energy, wind energy, bio-energy and geothermal energy).

1.4. Methodology

A literature study answers the first sub-question. It gives insight into the existing policies for sustainable neighbourhoods, the different stakeholders involved in the transition, information on how sustainable heating systems operate and insight into the currently existing models and methods for the energy transition. To guide municipalities to attain understanding in the energy transition at neighbourhood level a calculation model and an approach to use this model is developed. To test if the approach is useful and give the information needed, the approach is applied on a case study. The results of the approach will be given, followed by a conclusion and discussion. In this way, the developed approach is examined for broader application in the field.

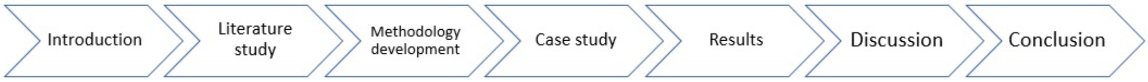


Figure 1.1: Methodology applied in this thesis (by author)

1.5. Outline of the report

The literature study is written in chapter 2. After the literature study, chapter 3 elaborates the design of the approach to the calculation model. Before the approach is applied, a description of the calculation model will be given in chapter 4. Chapter 5 introduces the case study. Chapter 6, 7 and 8 are results of the developed approach. Chapter 6 presents insight into the heating demand of a neighbourhood and chapter 7 provides insight into the sustainable heating supply for a neighbourhood. In chapter 8, the outcomes of the calculation model are given. In chapter 9 a conclusion with discussion and recommendation are presented.

2
Literature study

In this chapter a literature study is presented. The literature study is divided into four subjects:

1. Policies for sustainable neighbourhoods
2. Stakeholders involvement
3. Heating systems for buildings at neighbourhood level
4. Sustainable planning methodologies and models

The key words used during the literature studies are: sustainable district, sustainable district development, politics transition of district energy system, sustainable development transition management, sustainable heat supply district, solar district heating systems, Geothermal district heating system, model district heating system, Energy system optimization models district heating and GIS-based modeling for district heating.

During the literature review it is important to keep the boundaries of this project in mind. Only modeling decision planing on heating energy system at neighbourhood level is considered, including both the centralized as well as the individual solutions.

2.1. Policies for sustainable neighbourhoods

It is complex to create sustainable neighbourhoods in cities. A city is a competitive network that has to compete with other cities on one hand and has to focus on itself and the needs of its inhabitants on the other hand (Campbell, 1996)(Egger, 2006). The heating system in neighbourhoods is an important utility where both economic, social and environmental aspects come together (Monstadt, 2007). The transition of the heating system in a neighbourhood is therefore called a socio-technical transition, where multiple actors are involved (Geels, 2011). It is difficult to go through this kind of transition, because of the multiple actors involved and the different social and technical difficulties this transition meets. The multi-level perspective (MLP) explains why it is difficult to transform a social-technical systems(Späth and Rohracher, 2010)(Kern and Smith, 2008).

2.1.1. The multi-level perspective (MLP)

New technologies are needed for the transition of the current heating system at neighbourhood level. The current, gas based technologies, needs to be replaced by sustainable solutions. However, it is not easy for new technologies to replace the currently used, locked-in technologies. This is described in the MLP. The MLP consist of three levels: the micro, meso and marco level (figure 2.1).

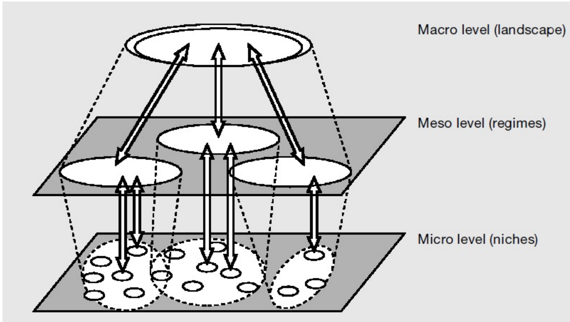


Figure 2.1: The three levels of MLP consiting of niche, regime and landscape level (Rotmans et al., 2001)

In the micro level (niche level), new technology innovations are emerging in protecting spaces. In this protected, so called market niches, they do not feel competition with the currently used technologies and they have the possibility to develop. In time they can compete with the currently used technologies in the second level.

The second level is the meso level (regime level). This level is the central element of the MLP. At this level the technologies are characterized as locked-in and stable. The technologies can compete with each other. When innovation happens, it happens in small steps with small modifications so the overall system remains a stable system.
The third level is called the macro level (landscape level). This level includes external factors that have influence on the macro level, but are beyond the control of the regime members. An example of this kind of factor could be the climate change.

When there is an interaction between the development on all the tree levels, system innovation can occur(Kern and Smith, 2008). The current gas heating systems in neighbourhood are locked-in, they have a high resistance to change. This is because all the dwellings in a neighbourhood are connected to the gas grid, when changing this system everybody will feel the change. Furthermore the gas grid is very cheap compared with alternative heat sources. The costs are very high for changing the current heating system into a sustainable heating system and it is unknown who should cover these costs. To transform the heating system there should be opportunities for "new renewable energy technologies" to grow in the niche market and become competitive with the technologies used in the current gas energy system. It is possible to cause a change in the regime level if their is a strong outsize pressure on the regime level(Rohracher and Späth, 2014).This can be done by niche innovations which destabilize regime or changes at the macro level that creates pressure on the regime. This means that either the new renewable technologies for heating are so efficient and technically developed that it can easily compete with the current technologies for heating, or government or municipalities are pushing the transformation from the landscape level. Climate change problems and mutual agreements made in the Paris Climate Kick can also push the regime level to change.

Unfortunately it is not that easy. Problems are formed when a government wants to manage the energy transition and push changes in the regime levels(Kemp et al., 2007a) (Kemp et al., 2007b). The government faces problems with the ambivalence of the goals (different agents have different perspectives), uncertainty about long-term effects, the distributed control (the control is distributed over different actors with different opinions), political myopia (transition takes one generation or more, so different political cycles are passed) and the determination of short-term steps for long-term changes and the danger of lock-in. Co-creation between practitioners, local government and knowledge institutes is needed. To manage this co-creation municipalities can use a management strategy, called the transition management (TM). The Dutch government is using this for changing the energy system into a low-carbon energy system (Kemp et al., 2007b).

2.1.2. Transition management (TM)

According to the study of (Loorbach et al., 2015) the TM framework consists of four different governance activities: strategic, tactical, operational and reflexive activities. TM is a governance model that creates micro-level initiatives that will transform a regime through a process of scaling up. The purpose of TM is: " *to develop informal networks in which individuals and,* *later, organizations are provided the mental, social, and physical space to develop new ideas, common language, and ambitions, as well as new joint projects."* (Loorbach, Frantzeskaki & Huffenreuter ,2015,p.53).

First a transition team has to be set up(Loorbach et al., 2015). This team needs to consist of motivated individuals with different backgrounds. A representative of the problem owner, an expert in the particular transition area and a transition management expert should be part of the team. The second step in the TM is to set up a transition arena wherein space is created for frontrunner's (niche players). In this arena partnership can be formed.It brings together different stakeholders working in different domains at different levels. The next step is defining the problem, creating pathways and transition agendas and develop sustainable visions. During this steps there will also be room for transition experiments. It is important to monitor the whole process to support the learning process of the transition. Long term thinking is used to create short-term policy (Rotmans et al., 2001). In the TM learning-by doing and doing by learning is commonly used.

Studies are positive (Kemp et al., 2007a) (Loorbach, 2009), although there are also some studies that show some criticism. (Meadowcroft, 2009) shows that in practice, transition initiatives are different compared to the theory of TM. First, the process is dominated by regime actors and outsiders are barely involved. Secondly, social issues are neglected. TM is not as open and reflexive as it is supposed to be, it can easily ignore inequalities and conflicts and neglect it own political aims(Shove and Walker, 2007). Another comment is that TM cannot control the future, because market forces are an important factor for changing the system(Kemp et al., 2007b). The transition debates have been too optimistic about the role of the governments(Kern and Smith, 2008). It is a more wide process that cannot be controlled. The current main drivers in the ongoing energy transition in the Netherlands are liberalization and Europeanization(Verbong and Geels, 2007). The climate change and environmental sustainability are not the main drivers. Thus, a municipality can use the TM methodology to manage the co-creation, but should be aware of the mentioned difficulties.

2.1.3. Role of the government and municipalities during the energy transition

The task of the government is to formulate a vision for the future, this vision is crucial for realizing a transition (Rotmans et al., 2001). The government should take the leading role by inspiring a collective learning process and encouraging other actors to think along and participate. This is specially important for local and regional governments, because they stand closer to the citizens. Governments have the task to create the right boundary conditions for the market process through tax policies. In each transition process the role of the government is different. In the preparation phase it must play the catalyst and director, with the emphasis on maintaining a wide playing field and organizing and stimulating discussions with other actors. In the take-off phase, other actors must actually be mobilized in the direction of the transition objective. Thus, there is an important role for the government. However, there exist some boundaries and limits for the interference of the government in the energy transition. The government does not have any influence in external landscape factors and cannot act freely as they wanted due to socio-cultural factors and they are limited by political structures.

There are three reasons why municipal authorities are the important actors when it comes to mitigation (reduction of greenhouse gases emissions) (Programme, 2011) . Their jurisdictional responsibility for important mitigation processes like transportation, waste collection and building planning is the first reason. The second reason is that a city is an area where one can easily try and test sustainable solutions because of its dense concentration of people and business. The last reason is that municipal governments are able to engage with stakeholders in both the private sector as in the civil society. They can play a key role in getting all the stakeholders together and fight climate change at urban level.

2.2. Stakeholder involvement in energy transition on neighbourhood level

As seen in figure 2.2 different stakeholders are involved in the energy network at neighbourhood level.

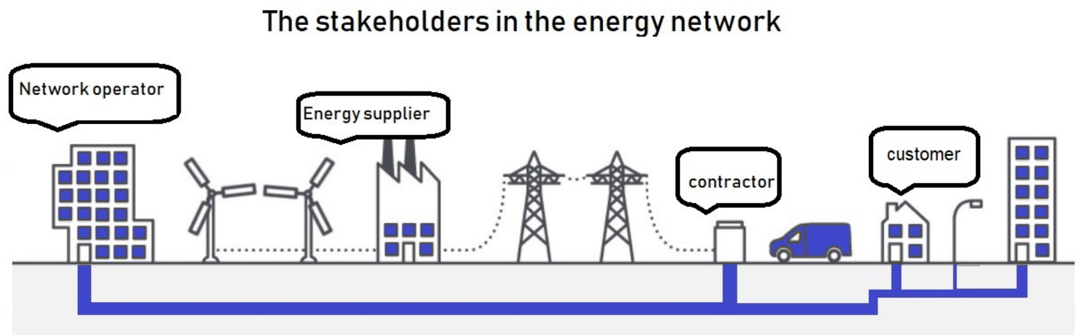


Figure 2.2: The stakeholders in the energy network consisting of network operator, energy supplier, contractor and customer (Stedin.nl, 2018)

The stakeholders are: the municipality, the network operator, the energy supplier, the contractor and the customer.

2.2.1. Municipality

The role of the municipality was already explained. They need to bring together all the stakeholders and inform the residents. They need to create a platform where stakeholders can come together en discuss the possibilities of the energy transition. They will form, together with all the stakeholders, different scenario's and choose the best alternative option for the current natural gas grid.

2.2.2. The network operator

The network operators in the Netherlands are responsible for the electricity and the gas networks and the heat distribution in district heating systems. They are responsible for the placing and the maintenance of cables and pipes (Stedin.nl, 2018). One cannot choose a network operator, it depends on where you live which network operator you get. Some network operators both supply gas and electricity, others only supply one of the two. Figure 2.3 gives an overview of which network operators delivers gas or electricity in the Netherlands. Network operators could have a big positive influence in the energy transition if they would cooperate in searching for alternatives for the current gas system. It is unknown what the role of a network operator for the gas grid will be in the future, if the gas grid disappears. Network operators for the electricity grid will remain though. The electricity grid will be more complex when more sustainable technologies will be use like solar panels and wind turbines. The grid will also become more complex because consumers can produce sustainable electricity and supply this to the grid. The network operators in the Netherlands are doing very good and are actively involved (Voormolen,2017).

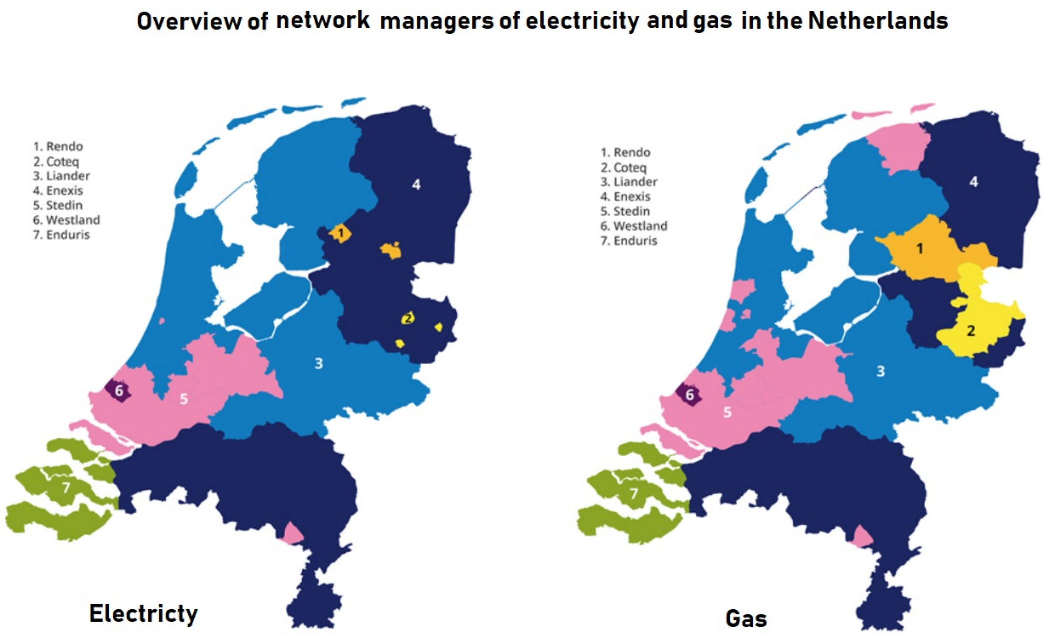


Figure 2.3: The network operators of gas and electricity in the Netherlands (Energieleveranciers.nl, 2017)

2.2.3. The energy supplier

Energy suppliers produce electricity, gas or heat and sell this to the consumer. One can choose its own energy supplier. The energy supplier uses the network of the network operator to supply their electricity or gas to the consumer. There are a few energy suppliers like 'Qurrent' and 'vandeBron' who deliver only green electricity, however they still supply natural gas. Other energy suppliers give the choice to choose for green energy, however these options are always more expensive compared to the non-sustaineble option and therefore unattractive for the market. In the Dutch electricity market model, energy companies could combine production and sales, but are not allowed to operate the distribution network as well. Retailers set the price of renewable energy in the market and often use certificates of production to prove their green energy. The role of energy suppliers in the energy transition could be that they only deliver green electricity. There is also a need for a company that supplies sustainable heat to dwellings in replacement of the current natural gas. Current energy suppliers could take this role, but it is also possible that new companies emerge who will provide this need.

2.2.4. The contractor

A contractor works for network operators and they carry out work on the grids and metering devices. They take care of the maintenance work of the grid. Their role will not change drastically during the energy transition.

2.2.5. The customer

Customers receive their energy from their chosen energy supplier.It is important to involve citizen with energy projects, because their behavior needs to be changed to reduce their energy demand ad they have to accept all the changes that are needed for the energy transition(Perlaviciute et al., 2018). An energy project can fail if citizens are not willing to accept the changes. Therefore, good communication between government and citizens is very important. Furthermore, a customer can become a prosumer, they could produce electricity and feed that into the grid with private owned PV modules or wind turbines. There are different groups of customers; a housing association (HA), a privately owned apartment with home owners association (home owners associations (HOA)), the individual home owners and tenants.

Housing association (HA)

A HA is an organization that builds, manage and rent affordable housing (Rijksoverheid.nl, 2016). The HA are responsible for making their houses sustainable. It is difficult to do this for most of the HA because they do not want to increase their rent prices too much because their houses must remain affordable for the inhabitants. Examples of HA are: Vestia, Duwo, Haag wonen and Steadion. The housing association need to find the balance between sustainable renovation and affordable renting prices. A HA is only a customer if there is a collective heating system. In case of an individual heating system per apartment, the tenants will pay the net manager instead of the HA and the tenants will turn into customers instead of the HA

The privately owned with HOA

When a building is split into different apartments that can be sold independently it is needed to create a HOA for this building. The residents living in the building will be automatically members of the HOA, it is therefore possible to have active and inactive HOA. An active HOA could invest in renewable energy production or renewable renovation of their building with each resident.

Individual home owners

The last group of customers are the citizens who bought their own dwelling. They are responsible of making their own dwelling more sustainable. There are some funds which helps individual home owners to renovate their dwelling.

Tenants

Tenants are people who rent their home form either HA or from private owners. If a tenant is connected to a HA, as explained before, it will pay either the HA or the net manager, depending on the heating system of the building(collectively or individually heated). Tenants from private owners pay the net manager.

It is important to bring all these stakeholders together to develop a sustainable heating system

2.3. Heating systems for a neighbourhood

Heating the neighbourhood is also called district heating. According to (Lund et al., 2014) a new 4th generation of district heating is needed with a smart energy system. In a smart energy system the district heating is integrated with the electricity sector. The first district heating generation was around 1880 till 1930 and the heat for buildings was generated with high temperature steam. In the second generation of district heating pressurized hot water around 100 ^0C was used as heat carrier. The third generation district heating started around 1980 and here pressurized hot water was used with a lower temperature compared to the second generation district heating. There is now a need for a fourth generation of district heating.

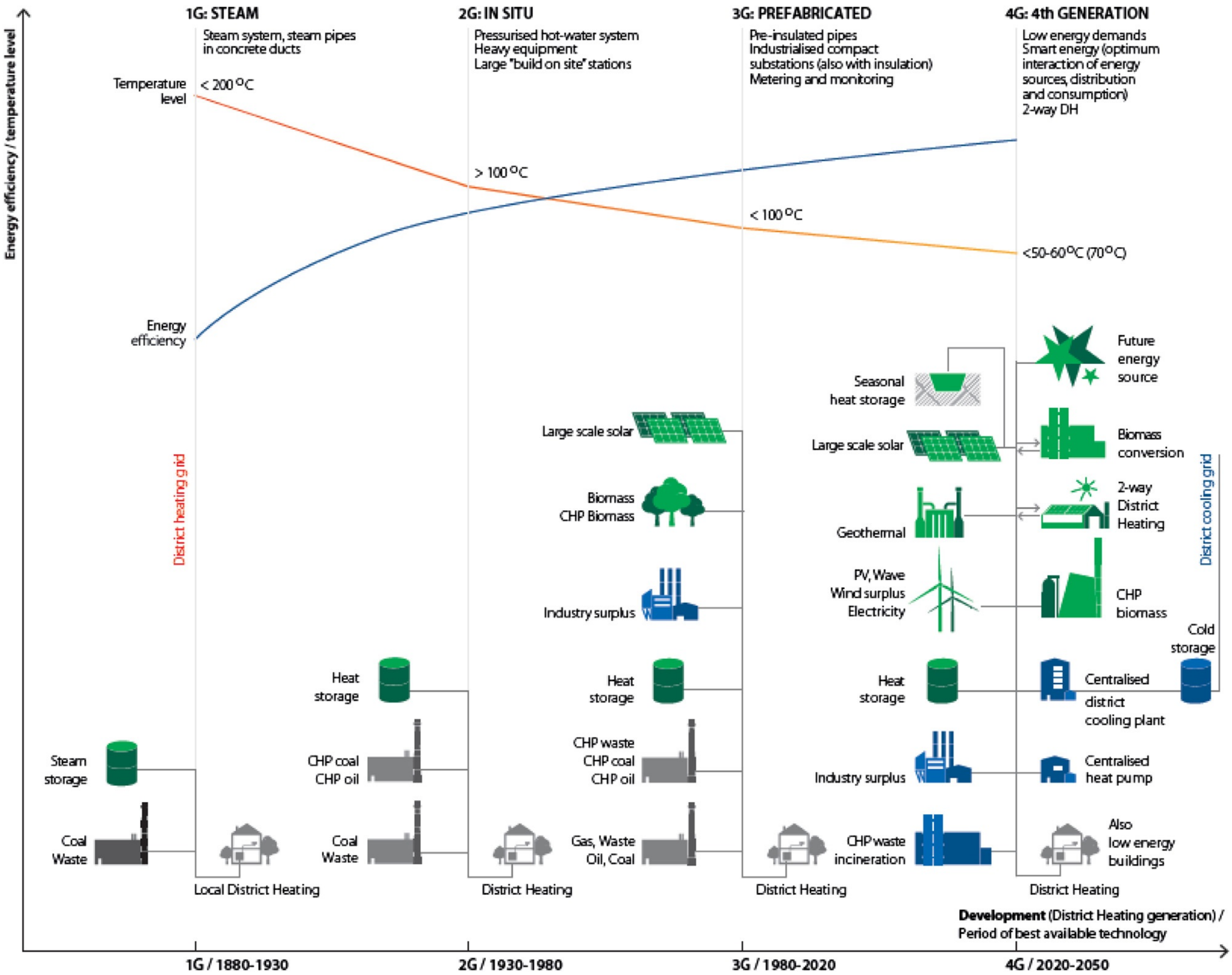


Figure 2.4: Overview of the 4th generation district heating compared to the other generations (Lund et al., 2014)

Figure 2.4 shows clearly that in the fourth generation an interaction between sustainable electricity supply and sustainable heat supply for a neighbourhood is needed. Furthermore, more low energy demand buildings are required. The figure clearly states that a lot of different renewable energy sources can be integrated in the network. This research will only focus on the heating of a neighbourhood and not on the electricity supply.

A heating system can be divided into three subsystems: the production of heat, the transportation of the heat to the end-user and the consumption of heat by the end-user (Rezaie and Rosen, 2012).

Figure 2.5: The three subsystems of a heating system consisting of production, transportation and consumption of heat (by author)

A heating system can be improved by making the production and distribution technology more efficient and by reducing the energy consumption of the end-users.The amount of heat that needs to be produced and distributed depends on the energy consumed by the end-users. If the end-users are living in well insulated dwellings and the conversion of heat is very efficient, the amount of production and distribution can be lowered compared to end-users who lives in bad insulated dwellings. The benefits of district heating can be found in the high efficiency and potentially low CO_2 emissions of the system (Gudmundsson et al., 2013). Multiple heat sources can be added to the system to generate heat when needed. When developing a sustainable heating system it is important that these sources are sustainable renewable sources, like geothermal energy, biomass etc. Unfortunately, when using sustainable energy a different problem occurs: intermittency.

The beauty of a renewable energy sources is that it gains its energy from infinite resources. The downside is that there are limits on the production of energy when natural sources are used. For example, a solar collector can only generate heat when the sun is shining, but an end-user will also needs energy when the sun is not shining. The demand of the end-user depends completely on the habits of the end-user and the state of the building he/she lives in. Each building has a personal pattern of energy demand. When renewable energy sources are used, the production and demand of heat does not always match, this is called the intermittency of production and demand(Holjevac et al., 2015).

A heating system for a neighbourhood can be centralized or decentralized. In a centralized heating system, the heat is produced far from the location of the end-users and it produces heat for multiple buildings via a large distribution network. This distribution network consists of a network of pipes under the ground. The downsides of centralized heating systems are the transmission and distribution costs and the heat losses through the network (could be around 10-30%). When the heat is generated close to the end-users the heating system is called a decentralized heating system. This heat can directly be used in a dwelling.

In this section first the currently used heating systems in the Netherlands will be explained followed by an elaboration of the different heat sources for centralized heating systems. After this the systems for decentralized heating will be explained.

2.3.1. Current situation in the Netherlands

In the Netherlands gas is used for space heating as well as for heating DHW and for cooking. Since 1960 the buildings in the Netherlands are connected to a gas grid (HIER, 2016). In 2016 33.6 billion cubic meters of natural gas was consumed in the Netherlands. Most of the energy consumption in the Netherlands comes from natural gas (40% Figure 2.6). Only 6% of the gross final energy consumption comes from renewable sources in 2016 (Eurostat, 2018).

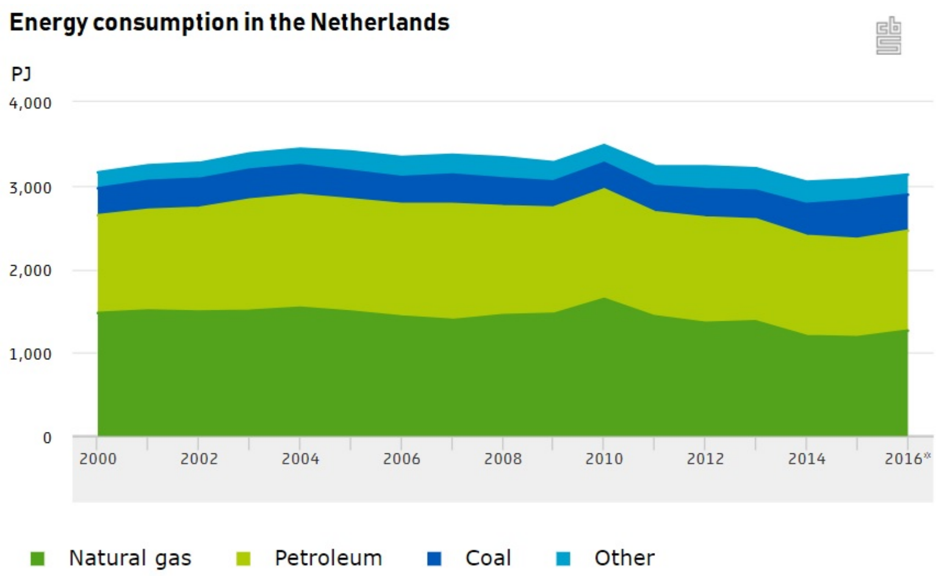


Figure 2.6: The energy consumption in the Netherlands (CBS, 2017)

In the residential sector the share of energy carriers for space heating can be seen in figure 2.7. Natural gas remains, also for space heating in the residential sector, the biggest energy carrier in the Netherlands with 86.9 %. Only 7% is coming from renewables and waste heat. Compared with other countries in Europa, The Netherlands is not doing so good. The 2020 target set by the Netherlands states that 14% of the gross final energy consumption needs to come from renewable sources (Eurostat, 2018). In 2018 the share of renewable sources is just 6%. This means that in two years time the share of renewable sources have to be more than doubled. Furthermore, the Dutch government wants to be independent of natural gas for residential heating by 2050(Rijksoverheid, 2016). There is a need for immediate action.

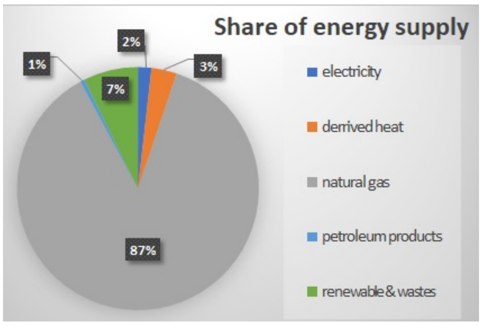


Figure 2.7: Share of energy carriers in the final energy consumption in the residential sector for space heating (Eurostat, 2017)

2.3.2. Centralized heating system

A network of a centralized heating system can be a high temperature district heating (HTDH) network or a low temperature district heating (LTDH) network. In a HTDH network the distribution temperature of heat are typically respectively 80-40 ^0C for supply and return (Brand, 2013). For a LTDH the distribution temperature for supply and return are typically respectively 50 ^0C and 20 ^0C (Lund et al., 2014). Only dwellings that are well insulated and have a low heating demand (low energy buildings) can be connected to a LTDH network (Lund et al., 2014). It is possible to create smaller networks with higher efficiency when LTDH network is used(Wahlroos et al., 2017). A supply temperature of 40-50 ^0C for heating DHW is only possible when a substation, without storage and a small volume between heat exchanger and taps is used. This is needed to prevent problems with legionella bacteria (Lund et al., 2014). Unfortunately, most of the dwellings are high energy buildings and cannot connect to a LTDH network. These buildings needs to be insulated before they could be connected, this costs time and money.

In the next subsections the different sustainable heat sources applicable on HTDH and LTDH will be elaborated. Sustainable sources that can be used for district heating are: geothermal heat, solar thermal heat, biomass, waste heat and combined heat and power systems. It is also possible to use non-renewable sources like fossil fuels, but this will not be considered in this study.

Geothermal energy (HTDH & LTDH)

The use of geothermal energy for heating water for bathing or cooking starts in the early prehistory. In the 14th century in France the first residential district heating can be found (Ozgener et al., 2007). The use of geothermal energy for district heating is becoming more popular in the last years. The energy coming from a geothermal well can be used for generating electricity and for direct uses. Geothermal wells, producing water with a temperature higher then 150 ^0C are used for generating electricity and geothermal wells producing water lower then 150 ^0C can directly be used (Kanoglu and Bolatturk, 2008). At difference ground depths different kind of geothermal energy systems can be applied. Figure 2.8 depicts the differences.

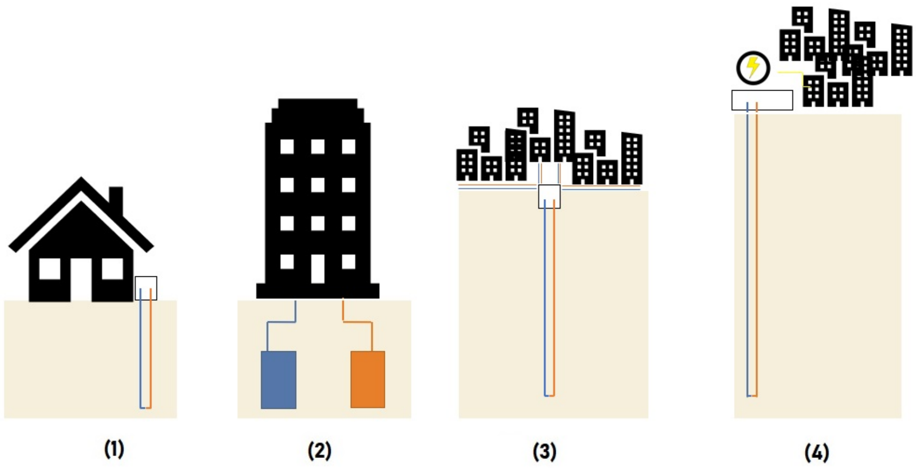


Figure 2.8: Different geothermal systems, 1: ground-source heat pump system, 2: Aquifer thermal energy storage (ATES), 3: doublet geothermal, 4: Enhanced geothermal system (EGS) (H.M.Nick, 2017 and by author)

Systems one and two are decentralized geothermal systems (figure 2.8). System one shows a ground source heat pump system (depth 2-100 m) and system two shows an aquifer thermal energy storage (ATES) system (depth 30-300m) (H.M.Nick, 2017)[1]. These two systems will be explained in section 2.3.3. System three is a doublet geothermal system and this system gets its heat from a dept of more than 1500 m. This kind of system is used to produce heat for a large area like a neighbourhood or city. The last system is an enhanced geothermal system (EGS) and this system can produce electricity, and will therefore not be elaborated in this study. In conclusion, only a geothermal doublet system can be used as centralized heating system. The average heat coming from the ground at a depth of 1500 m is around 80 degrees and is therefore usable for both HTDH and LTDH networks. A geothermal doublet system has a lifetime of 30-50 years and it may take around 5-7 years before a system becomes operational(Ozgener et al., 2005).

Using geothermal energy is good for the environment, as long as the electricity needed by the heat pumps and pumps are generated sustainably. and the system is very reliable(Greenmatch, 2018a). Another benefit is that a geothermal system has a high efficiency and the well needs little maintenance. However, there are some negative environmental impact that can occur when using a geothermal system, like possible disturbance of the surface,

[1]Source from Blackboard(not publicly accessible)

due to drilling. Also, thermal or chemical pollution (hot liquid on surface) can occur. Furthermore,drilling the wells can be competing with the existing flora and fauna (GEODH, 2014).

Solar thermal heat (LTDH)
The sun produces a lot of energy. This energy can be captured in a solar energy system. If more than 20% of the heat demand is to be met with solar energy, seasonal storage is needed (Lindenberger et al., 2000). Seasonal storage is needed due to the mismatch between the production of solar energy and the demand of the dwellings in a neighbourhood (intermittency). The sun produces energy especially during summer, while a dwelling needs heat especially during the winter. Therefore it is needed to save the produced energy in the summer so it can be used for dwellings in the winter. A solar energy system with seasonal storage is also called a seasonal thermal energy storage (STES). In a STES solar collectors capture the energy from the sun and heat up water. The solar collectors can be placed at a centralized location in the neighbourhood or on the roof of the buildings in the neighbourhood. A STES system is only possible in a LTDH because of the low outlet temperature of the STES. Figure 2.9 depicts the different options for STES systems.

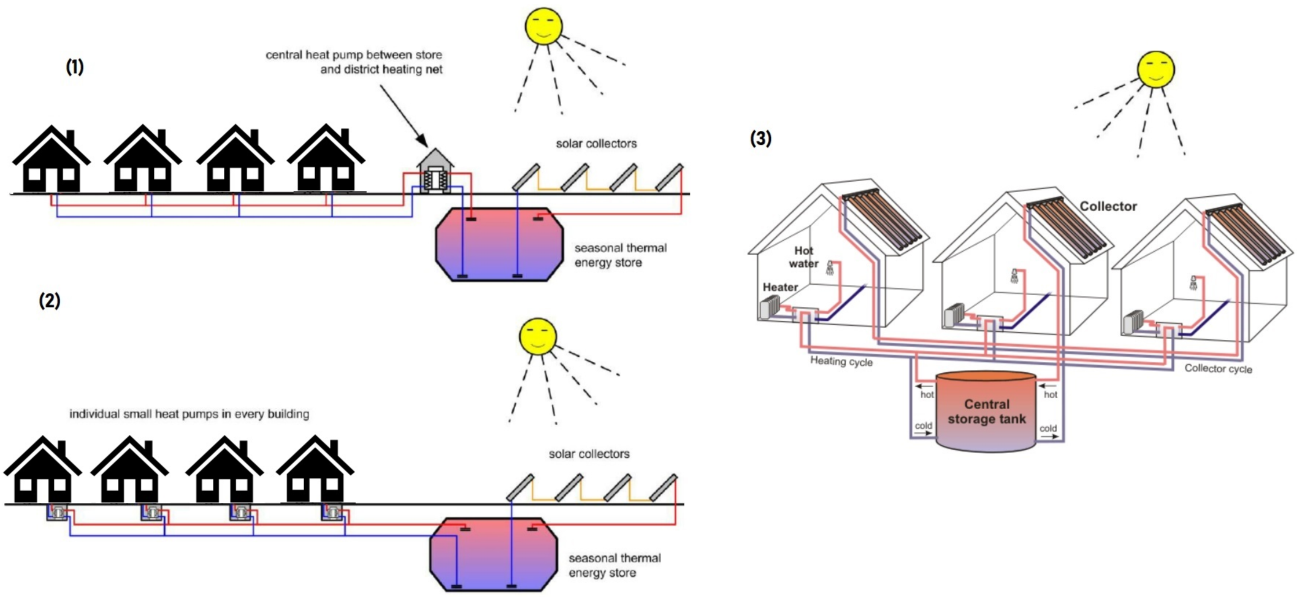


Figure 2.9: Simplified overview of different seasonal thermal energy storages (STES)(Bauer et al., 2014) (Quaschning, 2004)

In system one the water is centrally heated in a heat pump before the water is distributed to the different dwellings(Bauer et al., 2014). In system two every building has its own heat pump. In the third STES system the solar collectors are placed on the roof of the buildings. Here the distribution losses are lower because the solar collectors are placed closer to the buildings. The cheapest option is to install the solar collectors on the roofs of the buildings (Schmidt et al., 2004).

The downside of solar heating system is that it is not a very reliable system. It can only produce energy when the sun is shining, which is not a lot in the Netherlands. Secondly the big intermittency between production of solar heat (in summer) and the heat demand of the buildings (peak in winter) is a disadvantage of the system.

Biomass (LTDH)
A biomass feedstock can be converted into bio-energy via bio-chemical and thermo-chemical conversion processes, like combustion, gasification, pyrolysis and anaerobic digestion (Ellabban et al., 2014). Different biomass feedstocks can be used. As the study of (S.Broersma

et al., 2013) clearly explains the generated biofuels can be divided into first, second or third generation biofuels depending on the used feedstock. First generation feedstock consists of food-based biomass like palmoil, sugar cane, wood etc. Second generation biofuels consist of feedstocks that come from non-food or residual waste like manure, green waste, wood waste etc. The third generation biofuels use a feedstock of algae. The feedstock for first generation biofuels are considered unsustainable because they compete with the food industry and have negative changes to the biodiversity. The second and third generation of biofuels are better. The third generation is promoted as an ideal feedstock because *"of their rapid growth rate, greenhouse gas fixation ability (net zero emission balance) and high production capacity of lipids (fat). They also do not compete with food or feed crops, and can be grown on non-arable land and saline water"*(Firoz Alam et al , 2015,p. 764). The combustion of biomass produces heat that can be used to heat water for domestic use. The downside of biomass is that it is not a completely sustainable source because during the combustion still some pollution occur (Lundgren et al., 2004). Secondly, it has a low energy density (Ellabban et al., 2014).

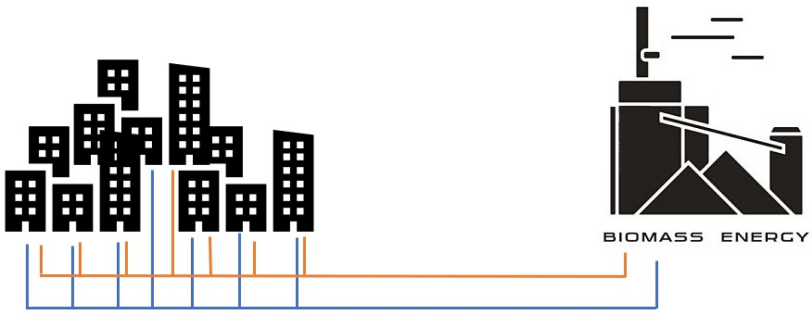


Figure 2.10: Overview of a Biomass district heating system (By Author)

Ocean heat (LTDH)
It is also possible to produce energy from the heat coming from the ocean. In the Netherlands there is an existing project, in the neighborhood Duindorp in the Hague, where heat from the ocean is used to heat 789 dwellings (van Binnenlandse Zaken en Koninkrijkrelaties, 2010). The temperature of the ocean in the Netherlands remains between the 0-4 ^{0}C during the winter months. With a central heat pump this temperature is heated to 11 ^{0}C. In the summer months the central heat pump is not needed, because the ocean gives high enough temperature. Every dwelling has an individual heat pump which heat this incoming temperature to 50-60 ^{0}C. This technique is only possible for LTDH networks.

Waste heat (HTDH & LTDH)
Waste heat consists of the rest heat from industries. According to the study of (Fang et al., 2013) the use of waste heat gives an improvement of the thermal energy efficiency of industrial factories and, compared to other heating modes, are cost-efficient. Furthermore, the use of waste heat gives a reduction of CO2 pollution and water conservation. Not only factories can provide waste heat, also data centers (DC) can provide heat for district use (Wahlroos et al., 2018) (Wahlroos et al., 2017). A data center needs cooling and the heat waste is, so far, not used sustainably. There are some barriers for using heat coming from a data center, like the low-quality of heat and the high investment costs. Most of the heat coming from industrial waste need to be thermally upgraded with a heat pump before it can be send to the district(Ajah et al., 2007). After this the upgraded heat is distributed to the central grid. In the central grid the heat is send to different district grids where each grid consists of a couple of buildings. The rest-heat from the buildings can be send back and be included with the waste-heat input and after upgrading can be resend to the system.

There are three participants involved when using waste heat from industries: industrial factories, the heat-supply enterprise and the society using the heat(Fang et al., 2013).Generally, the industrial factories sell their waste heat cheap or for free to the heat-supply enterprise. In

return they receive bonus under the frame of energy management contract (EMC). The heat supply enterprise provides eco-friendly heat to the society and get paid for that. Finally the society gives tax advantage and gives good reputation to the industrial factory while gaining energy-efficient products from the factories.
The cons of the waste-heat system is that it is not a completely CO2 neutral system. The industry who delivers the heat does not have to be a sustainable system and can give a high rate of pollution. Furthermore it is hard to implement waste heat in a network.

Combined heat and power systems (HTDH)
The combined heat and power (CHP), or in other words co-generation, is a good heat supply for district heating. It could run with fossil fuel, but more sustainable would be if renewable gas or biomass are used as fuel. A CHP is an upgraded version of the conventional power plant. To understand how a CHP works it is therefore needed to know how a power plant works. In a power plant a fossil fuel is burned and the produced heat is used to boil water and create steam. This steam drives a turbine which drives a generator. The generator produces electricity (Woodford, 2017). In this process after the evaporation of water, the steam needs to condense back to water to restart the cycle again. This is done in colossal cooling towers. The idea behind CHP is that the steam is used for district heating after driving the turbine instead of send to the cooling tower. Thus, a CHP produces both electricity and heat.

It is obvious that the high efficiency of a CHP is a benefit of a CHP plant. The efficiency is the highest when the distribution lengths are as short as possible. However, there are also some downsides of a CHP plant, namely the burning of fossil fuels or biomass. When burning is involved there are always some emissions. Therefore the CHP system can never be a zero emissions system. Another downside of the plant is the high initial and maintenance costs (Woodford, 2017).

2.3.3. Decentralized heating system

In a decentralized energy system the heat is produced at the residential place (individual houses or at block-level). The needed heating system in a dwelling depends on different aspects of the dwelling(Kieft et al., 2015).

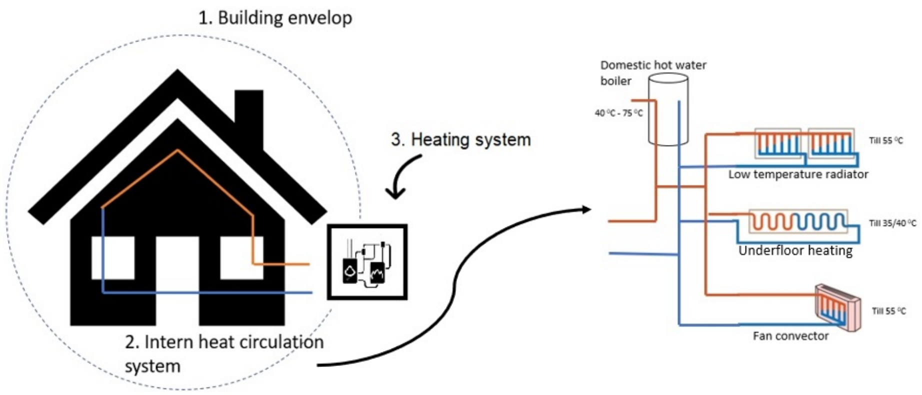


Figure 2.11: Different aspect that determine what kind of decentralized heat system can be used (by author)

The first aspect is called the building envelop and this determines how much energy is needed to heat up a building. This depends on the size of the building and the state of the insulation of the building. The second aspect is the internal heat circulation system. The most traditional heat circulation system are radiators, however radiators need high temperature supply and are therefore only logic to place in high energy demand dwellings. For a low energy demand building the internal heat circulation can consist of floor or wall heating or spacial low temperature radiators. The third aspect is the actual heating technology of the dwelling and depends on the type of dwelling (high or low energy demand dwelling). Aspect one and two will be further elaborated.

1. Building envelop

To built a low energy demand dwelling it is needed that the building is well insulated and efficiently built. The Trias Energetica is a strategy for energy efficient building. The strategy works as follows:

- Step 1: Reduce energy demand
- Step 2: Use sustainable renewable energy sources
- Step 3: Use fossil fuels in an efficient way

The first step in the Trias Energetica strategy is to reduce the energy demand. This means, reducing the gas consumption by reducing the activities that need gas. The second step is to use sustainable renewable energy sources instead of the fossil fuel based sources. If it is impossible to stop using fossil fuels, the last step states to try to use fossil fuels as efficient as possible. Try to increase the efficiency so less fossil fuel is needed.

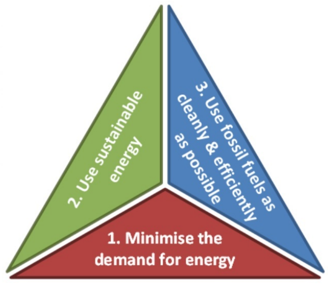


Figure 2.12: The Trias Energetica (watch, 2017)

The first step will be explained. One way to reduce the energy demand is to insulate the building so less heating energy is needed, meaning that less gas is needed. Since 2008, buildings in the Netherlands are certificated with energy labels (Majcen, 2016). An energy label gives more insight into the in and outflow of heat in a building. The label category goes from A++ to G, whereby A++ means the building is very efficient and good insulated and has a low energy demand and G means that a building has a high energy consumption and is not sustainable. The label depends on the energy index (EI) that correlates directly with the total primary energy consumption(Majcen, 2016).

$$EI = \frac{Q_{total}}{155 * A_{floor} + 106 * A_{loss} + 9560} \tag{2.1}$$

Where Q_{total} stands for the total primary energy consumption of a house and can be calculated as follow:

$$Q_{total}[MJ] = Q_{total,gas}[m^3] * 35.17[\frac{MJ}{m^3}] + \frac{Q_{total,el}[kWh] * 3.6[\frac{MJ}{kWh}]}{0.39} \tag{2.2}$$

With

$$Q_{total,gas} = Q_{gas,space-heating} + Q_{gas,tap-water} \tag{2.3}$$

and

$$Q_{total,el} = Q_{el,space-heating} + Q_{el,tap-water} + Q_{el,aux-energy} + Q_{el,lightning} - Q_{el,pv} - Q_{el,co-generation} \tag{2.4}$$

The following energy index corresponds with the following labels(Majcen, 2016)[2]:

Table 2.1: Value of energy index corresponding with energy labels (Majcen, 2016)

Energy label	A++	A+	A	B	C	D	E	F	G
Energy index	<0.50	0.51-0.70	0.71-1.05	1.06-1.30	1.31-1.60	1.61-2.00	2.01-2.40	2.41-2.90	>2.9

[2]These calculations have changed slightly recently due to the so-called '*nader-voorschrift*'(VABI, 2018).

The energy label depends on the primary energy consumption of a dwelling and the size and energy losses of a dwelling. (Majcen, 2016) has investigated if the actual energy consumption differs with the theoretical energy consumption. The study found that the actual primary energy consumption of gas in the better energy labels is higher compared with the theoretical primary energy consumption of gas. On the other hand the actual primary energy of gas in the poorer energy labels (E,F,G) does not differ much from each other while the theoretical energy consumption increases drastically with every label. Thus, energy-efficient dwellings use more gas than predicted while less energy-efficient dwellings use less gas than predicted (Figure 2.13).

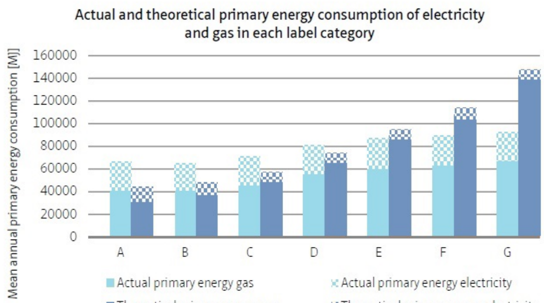


Figure 2.13: Actual gas consumption vs theoretical gas consumption per energy label (Majcen, 2016)

To improve the energy label one can reduce the energy losses of a house by improving the insulation of the house. This can be done by insulating the floor (10+ cm) and insulating the roof (10+cm). Furthermore, cavity wall insulation, indoor and outdoor insulation and changing the double glass into HR++ glass in living room and bedroom improves the insulation and thus the energy label (Thuiscomfort, 2017). Additionally, using floor or wall heating or special low temperature radiators improves the energy label. The study of (Majcen, 2016) has also investigated if the theoretical energy savings by different label steps differs from the actual energy savings when label steps are made. The study conclude that theoretical small improvement steps for high-efficient houses (from B to A) corresponds with the actual energy savings, whereas by low-efficient houses (from F to E) the theoretical improvement step differs from the actual improvement. The actual improvement is lower compared to the theoretical improvement. Moreover, small improvement steps are better predicted compared with high improvement steps (for example from G to B). In this study the actual energy savings given by the study of (Majcen, 2016) are taken to predict the energy savings per energy label step. Thus the building envelop determines how much gas is needed to heat the building and what kind of heating system is needed. There are different heating systems for different types of buildings.

2. Heating systems

A distinction between heating systems for high energy demand dwellings and low energy demand dwellings can be made. Another distinction of the heating systems can be made in systems that needs natural gas or are independent of natural gas. The study of (CEDelft, 2017) elaborated the different possible heating systems for dwellings.

High efficiency boiler

A high efficiency boiler generates heat by burning natural or green gas. If green gas is used, the efficiency boiler could be CO2 neutral. With this system both water for domestic heating as apartment heating is generated. This technique is operational in both high and low energy demand buildings.

Pellet boiler

An alternative for high efficiency boiler is a pellet boiler.In this system pellets are burned with a high efficiency. The pellets are stored and when heating is demanded, the system automatically burns the stored pellets. This system is applicable for badly insulated dwellings and well insulated dwellings. The downside of this system is that pellets are needed and the way to get to these pellets is not always sustainable. Sometimes the pellets need to come from Canada and the transportation cost gives high pollution. The production and transportation of pellets create pollution. Also, when burning the pellets emission occurs. This system is operational in high energy and low energy demand dwellings.

Micro-CHP

This system burns gas (natural, green or hydrogen) and produce heat and electricity. The electricity is produced by a small motor inside the boiler, the heat released for generating electricity can be directly used in the dwelling. The produced electricity could be used directly or sent to the grid. The efficiency of this system is much higher compared to the high-efficiency boiler, because more energy is generated from the gas because both heat and electricity can be produced. The system will require more gas feed, but has a higher efficiency. However, when natural gas is used, this system is not sustainable. In the future, it could become sustainable when green gas is used. This heating system is operational in both high and low energy demand buildings.

Electrical resistance heating radiator

In this type of radiator the electricity flows through a resistance producing heat. With this technology only spatial heating is possible, not heating the domestic hot water. For domestic hot water you need a boiler, an electric boiler can be applied. The electrical resistance heating radiator uses a lot of electricity and the CO_2 emissions of producing electricity is higher compared to producing gas, thus if the electricity is not produces sustainably this is not a very sustainable option. This heating system is only operational in low energy demand buildings.

Infrared panels

An infrared panel can turn electricity into radiant heat. This system does not heat the air, like all the other system, but heats objects. Therefore one can feel the heat immediately. Just like the electrical resistance radiator this system only heats space and no domestic hot water. Additionally, this system needs a lot of electricity, and when the electricity is not generated sustainable, the use of infrared panels is also not sustainably. This heating system is only operational in low energy demand buildings.

Heat pumps

A heat pump is a good alternative heating system for low energy demand buildings. There are different kinds of heat pumps: an air/air heat pump, an air/water heat pump a ground/water heat pump, a water/water heat pump or a hybrid heat pump.

Ground source heat pump system (GSHP)

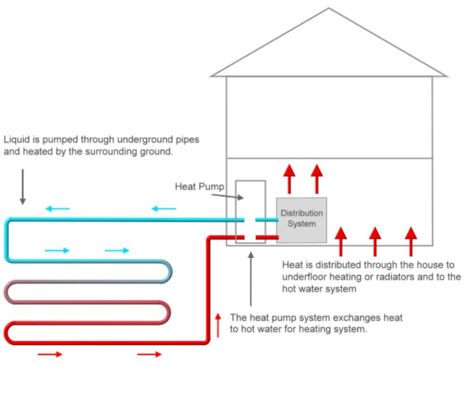


Figure 2.14: Operation of a ground source heat pump system (Nicholson and Watch, 2017)

In a ground source heat pump (GSHP) system water in combination with antifreeze circulates under the ground in a loop of pipes. The pipes are located at a depth of 2-100 m under the ground. Heat coming from the ground is absorbed into the fluid and a heat pump transport this heat to the dwelling (Trust, 2017). This system is operational throughout the whole year. When a household needs more heat the pipe system can be made longer. The system can be placed horizontal as well as vertical. In the figure 2.14 one can see the horizontal version. One needs a well insulated house for this system. It is a highly efficient system, the COP of the ground source heat pump is around three. It can be made even more sustainable when solar PV panels are used to supply electricity to the heat pump. According to (Bakema and Schoof, 2016) there are around 50 000 installed ground source heat pump systems in the Netherlands and this number is increasing yearly with 10%.

Water source heat pump system(WSHP)
In a water source heat pump (WSHP) system heat is extracted from water from a river,lake, sea or ground. Comparable with the GSHP system water in combination with antifreeze is circulating in a loop of pipes. However, these pipes do not lay under the ground, but in water (green age, 2017). The fluid in the pipes absorbs the heat from the water and a heat exchanger and heat pump transport the heat to a house. (green age, 2017) states that the efficiency of a WSHP is higher compared to the GSHP and the air source heat pump (ASHP). The downside of the system is that the house really needs to be located near a lake or river or other kinds of water. If this is not the case, it is impossible to use this system.

Air source heat pump system (ASHP)
An ASHP system looks a lot like the GSHP system and WSHP system. The main difference is that an ASHP system extract heat from the surrounding air (figure 2.15).

The heat is transported to the water system of the house through a heat pump. The heat can be used directly or stored for later use. There are two kinds of ASHP systems: Air-to-water heat pumps or Air-to-Air heat pumps. As the names implies an air-to-water heat pump transport the heat from the air to the water used in the house (direct and in radiators or floor heating) where an air-to-air heat pump transport the heat from the outside air to the air inside the house. To produce hot water only an air-to-water heat pump can be used. The downside of an ASHP is the noise of the heat pump and the efficiency drop in the winter(Greenmatch, 2018b).

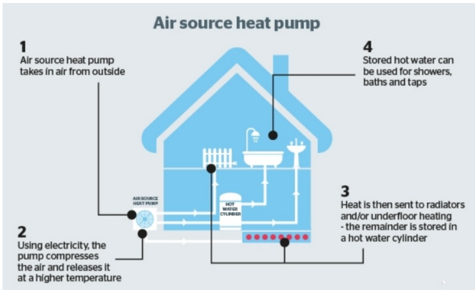


Figure 2.15: Operation of a air source heat pump system (Energy, 2017)

Hybrid heat pump
A hybrid heat pump is a combination between a heat pump and a natural gas fed high efficiency boiler. The system consists of two systems, the evaporator of the heat pump standing outside the dwelling, and the core of the heat pump and the high efficiency boiler standing inside the dwelling. When it is impossible for the heat pump to deliver the amount of needed heat the boiler helps the system with extra heat. The outside temperature determines if the heat pump or the boiler provides the most energy. In the winter the outside temperature is too low for a heat pump to extract heat, therefore the high efficiency boiler is needed to heat the dwelling. The advantage of the system is that a dwelling does not need the be perfectly insulated before this system can be implemented, thus this heating system is operational in high energy demand buildings(verwarminginfo.nl, 2015). A downside of the system is that it uses natural gas. Another downside is that in the winter, when heat is needed the most, the air heat pump cannot deliver the amount of energy needed and the high efficiency boiler is needed. Whereas in the summer, the heat demand is lower (even sometimes zero) but the heat pump's efficiency is much higher compared to the winter conditions. In other words, the heat pump works optimally when it does not have to work optimally.

There are also other ways to deliver heat to building which needs to be mentioned. Two other ways which will be discussed are the ATES and the decentralized solar heating system.

Aquifer thermal energy storage (ATES)
An ATES is an open system. The system can cool a building in the summer and heat the dwelling in the winter (figure 2.16). The system works as follow: two wells with a maximal

depth of 300 m are drilled, one well is used for cold storage and the other well for heat storage. The groundwater in the Netherlands have an average temperature of 11 ^{0}C (RVO.nl, 2017). In the summer the cold groundwater is used to cool the building and therefore the water heats up. This water is then stored in the warm well. In the winter the system works the other way around, the warm groundwater is used to heat the building and the cooled water is then stored in the cold well. A heat pump is needed in the winter to heat up the warm groundwater to 50 ^{0}C before entering the dwelling. This system is especially interesting for dwellings that have a high cooling demand in the summer, like supermarkets and offices. For this system a license of groundwater-law is required, because the quality and the state of the groundwater can change (RVO.nl, 2017).

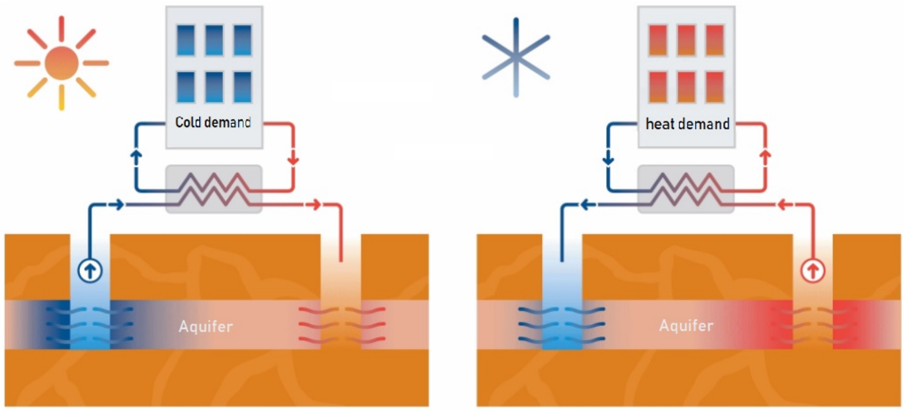


Figure 2.16: Open heat cold storage system (RVO.nl, 2017)

Decentralized solar heating system
Figure 2.17 shows an overview of the use of solar collector for heating residential buildings with seasonal storage. The idea of solar heating is that during the summer the heat is stored under the ground meaning that in the winter the stored heat can be used to heat a building. The study of (Sibbitt et al., 2012) reviews the drake landing solar community project in Canada where this system was positively implemented,it could provide up to 90% of the target needed for 52 households.

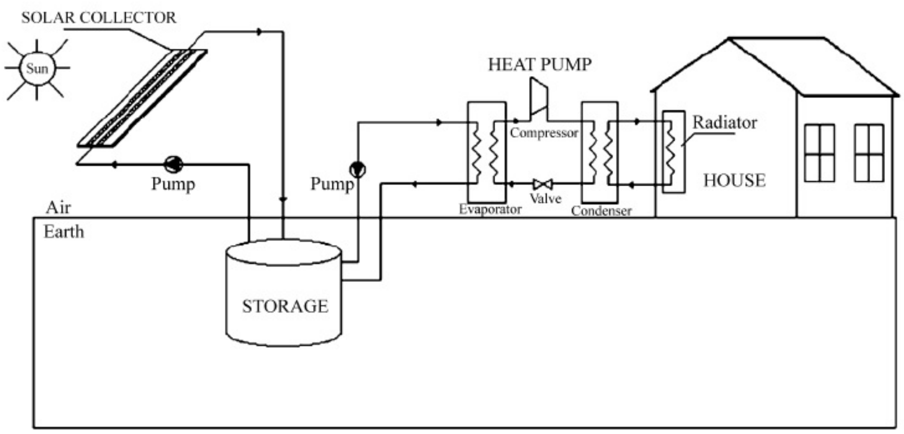


Figure 2.17: Overview of a solar heating system for residential building (Hepbasli, 2008)

Conclusion
In conclusion figure 2.18 gives an overview what kind of decentralized heat systems could be used for different buildings (high energy demand or low energy demand). It is good to

take into account that the electrical resistance radiator and infrared panels only provide for spatial heating and not for DHW heating.

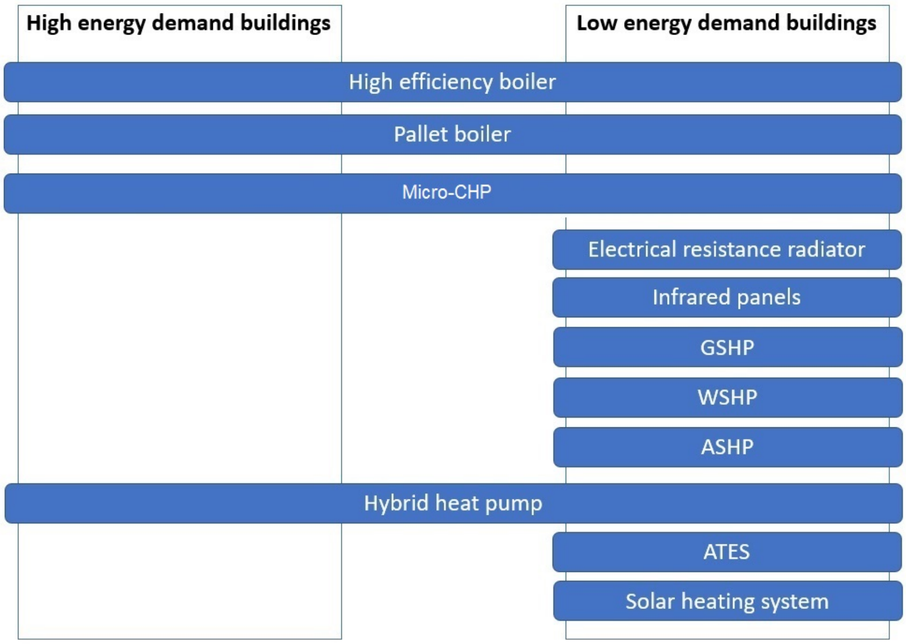


Figure 2.18: Different options for heat pumps depending on the energy label of dwelling (Kieft et al., 2015) and (by author)

2.3.4. District cooling

One cannot talk about heating without mentioning cooling. When buildings are better insulated the heat will remain longer in the building especially in the summer which is not comfortable. Therefore more cooling is needed. Currently cooling is mostly used in offices and factories, but when in the future more buildings will be better insulated it will become a bigger question.
Again a distinction between centralized and decentralized cooling can be made. Decentralized cooling, cooling near the building could be natural cooling or different types of air conditioning. Centralized cooling looks a lot like centralized heating, but instead of hot water, cool water is transported to the buildings. This cooled water is transported to the dwellings with a distribution system that looks like the heating distribution system.

The scope of this research is only on heating, because cooling can sometimes be avoid by using passive techniques like external solar blinds or night ventilation. Furthermore, the heating of a neighbourhood is a bigger question and it is more important than cooling. Nevertheless it remains important to take into account that the well insulated buildings may also need to be cooled in the summer.

2.4. Sustainable planning methodologies and models

To support the energy transition at neighbourhood level different methods and models are already developed.

2.4.1. Methods for creating sustainable transition

There are different kind of methods developed for creating a sustainable transition. In the Netherlands there is no example of a successful energy transition for existing areas. To come to a complete sustainable district different approaches are developed. Stremke (Stremke, 2015) developed a conceptual framework for the planning and design of the energy transition. Another approach is the Energy Potential mapping, this concept gives insight into the potential of sustainable energy in a specific area. The study of (Oudes and Stremke, 2018) inspired by these two methods built the method called spatial transition analyses which gives a step by step approach for stakeholders in the energy transition.

Conceptual framework

The conceptual framework is developed by Stremke (Stremke, 2015). Stremke wants to develop a conceptual framework to create a sustainable energy landscape (SEL). He defines a SEL as "*a physical environment that can evolve on the basis of locally available renewable energy sources without compromising landscape quality, biodiversity, food production, and other life-supporting ecosystem services*" (Strekme, 2015, p.5). The framework takes into account that an energy transition is not only a technical challenge, but other criteria like environment, socio-culture and economical aspect have to be considered also. The framework consists of four main criteria which can be divided into sub-criteria and in one minimum technical criteria (figure 2.19). The minimum technical criteria is the the minimal technical feasibility of a sustainable technology in a landscape. For example, the amount of area available for solar panels. When this minimum criteria is met then it is possible to check the other four main criteria. The first main criteria is the sustainable technical criteria like re-use of materials, safety of technology to minimize impact for humans, the use of renewable energy sources etc. The second main criteria is the environmental criteria like the reversibility of interventions, reduction of emission etc. The third main criteria is the socio-cultural criteria like landscape experience. Does it maintain or improve the positive experience of landscapes, is it accepted by the community etc. The last main criteria is the economical criteria and consist of criteria like the accessibility of affordable energy, the land use competition etc.

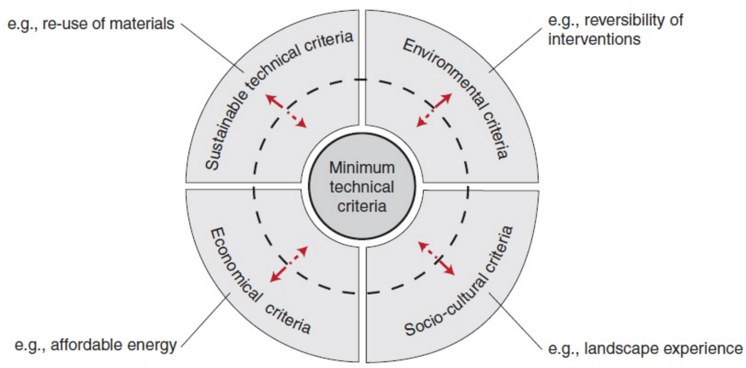


Figure 2.19: Framework for sustainable landscape (Stremke, 2015)

Energy Potential Mapping (EPM)

The energy potential map (EPM) methodology gives insight into the energy potential of different sustainable technologies in a specific area (Dobbelsteen et al., 2012). It visualizes and quantifies the renewable energy potentials in a specific area. The outcome of the EPM can help a municipality to propose an energy transition plan for specific neighbourhoods. The outcome of the method is a clear overview of the possible locations and the potential of different renewable energy technologies at that location. The potentials can be categorized in heat, cold, electric and fuel potentials. Figure (2.20) gives an overview of the process steps of EPM. It states that the energy based plan is determined by the energy demand of different sectors (residential, non-residential and transport) and the defined potential of different renewable sources. In this study the EPM can be used to determine the heat demand for the residential and non-residential sectors and to map the renewable heat potential for these sectors.

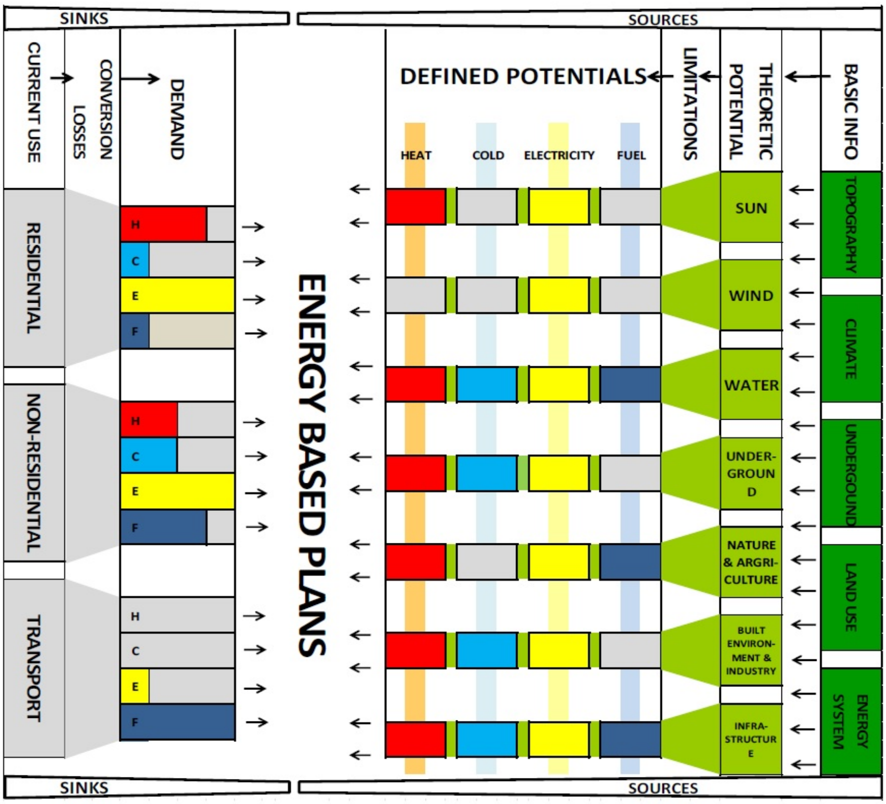


Figure 2.20: Process steps of energy mapping potential (Broersma et al., 2013)

Spatial Transition Analysis (STA)

The writers of the paper (Oudes and Stremke, 2018) state that there does not yet exist a methodology framework that can: *"help define energy transition targets that are spatially explicit, evidence based, and informed by qualitative stakeholders considerations"* (Oudes and Stremke, 2018, p.2). The spatial transition analysis (STA) is a methodology built by the writers of the paper that closes that knowledge gap (Figure 2.21).

Figure 2.21 gives an overview of all the steps that need to be considered for a successful energy transition at local scale. The first step is to conduct interviews with the local stakeholders. In this interview information of feasible renewable technologies and preferences of stakeholders are gathered. The second step is to conduct questionnaires with the help of the conceptual framework made by Stremke. With the help of the questionnaires the significance of certain criteria are discovered. In step three the potential of renewable energy technologies are considered and a selection of the best renewable energy technologies that can be used in the local area is made. In step four the stakeholders preferences will be made more explicit and the outcome of the step will be a list of spatially explicit considerations which can be used as input for energy potential mapping and scenario development. In step five the EPM methodology is used to determine the technical potential of each renewable technology in the specific chosen area. When the potentials are known different scenarios can be made. The last step is to determine the year of energy neutrality, the year in which the area has to

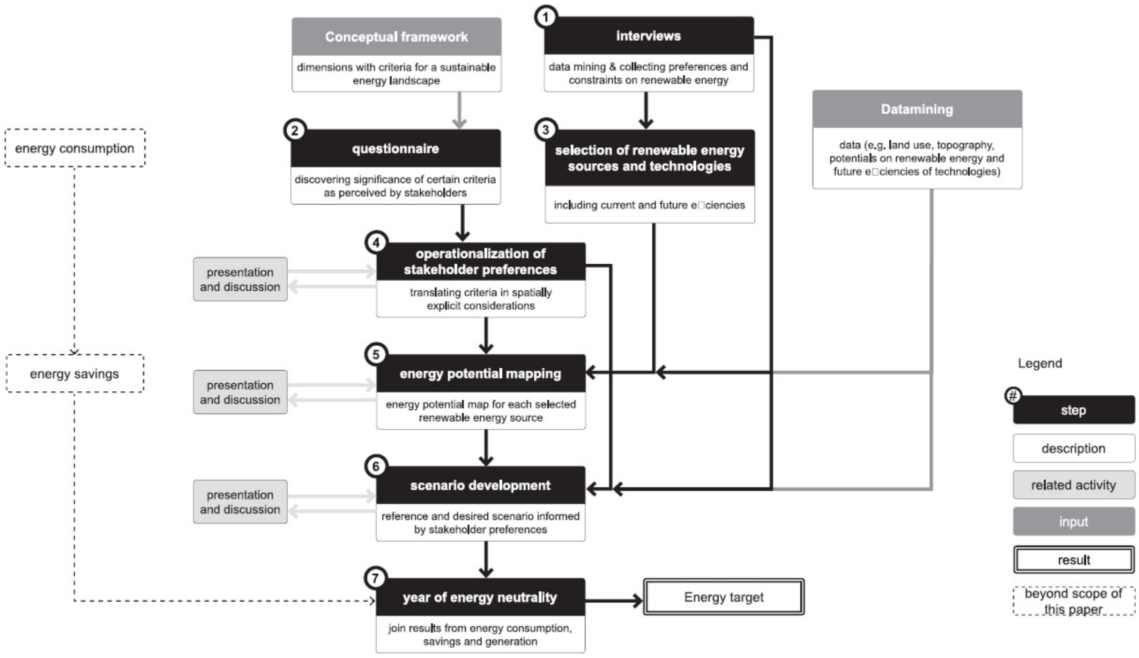


Figure 2.21: Methodology of Spatial Transition Analysis (Oudes and Stremke, 2018)

be completely independent of renewable energy sources. To determine this year information about the energy consumption and energy savings of the buildings in that area have to be known. The STA framework does not give insight into these steps yet. The proposed framework gives a good indication of the techniques that can be used in the specific area and gives insight into the variables that have influence on the transition target and the time needed to reach this target.

Zity-Zen approach

Another method that also uses the EPM is the city-zen approach. A 6 step methodology is created to develop a Energy Master Plan for decision makers that takes into account the technical, economic, social and political difficulties that occur when creating a sustainable heating systems (Broersma and Fremouw, 2011). The 6 steps are as follow:

1. Map the present and near future (this include data on geographical-physical environment, mapping of technical energy potentials, analyzing the economic system and financial situation, analyzing the social and political environment)
2. Determine scenarios
3. Select potentially suitable measures
4. Create a vision
5. Define the roadmap
6. Re-calibrate and adapt

All the given methodologies could create insight into the possible heating potential of different renewable energy sources in the neighbourhood and the heating demand of the buildings standing in the neighbourhood. However, no insight into the simultaneousness of the potential and demand are given. To create more insight into this mismatch calculation models estimating the demand and supply on hourly basis at least are needed.

2.4.2. Technical models

To help decision makers formulate the future renewable energy system of a neighbourhood different technical models or tools can be used. It is essential to model energy systems to analyze and gain insight into the future energy supply systems(Alhamwi et al., 2017). The article of (Frayssinet et al., 2018b) clarifies there are already different models for modeling the energy system. A model can be top-down or bottom-up.

Top down or bottom up modeling

Different studies (Frayssinet et al., 2018a),(Frayssinet et al., 2018b),(Pfenninger et al., 2014), (itard et al., 2012) explain the differences between top-down and bottom-up approaches for modeling future energy systems.

Bottom-up approaches look first at the energy demand for a single building. They take in account the technical components of the system like insulation, ventilation and occupant behavioral patterns but also historical data like energy supplier recordings and publications of governments. Statistical and engineering methods are used for building a bottom-up model, where statistical methods are used to include occupants behavior and engineering methods are used to calculate the demand of each energy system. A bottom-up model is very rich in detail. When the energy demand for a single building is calculated it can be aggregated over multiple buildings to regional or national level. According to (Pfenninger et al., 2014) well known bottom-up models are MARKAL and MESSAGE, these models are generally focusing on optimizing the energy systems.

A Top-down approach cannot calculate the energy demand of each individual urban building because a top-down approach focus on a city as entity. It treats the city and its energy users as an energy sink. It looks at all the possible sources of electricity and heat for a region and studies the inter-relationships between macro-economic parameters, demographic factors like population density and energy consumption in the region.
To get a clear picture of the energy demand in a system both bottom-up and top-down approaches should be used.

Scales of energy models

There are different kinds of energy system models, depending on their domain size(Frayssinet et al., 2018b). Building energy simulation (BES) models are a type of models that only focuses on one building. It simulates the heat transfer in different components of a building and simulates the energy demand of a building. Urban building energy simulation (UBES) models are a type of models that do not focus on a single stand-alone building but also simulate the effect of different buildings standing near each other. City energy simulation (CES) models are a type of models that focus on the energy demand of a whole city.

This study will focus on energy models at neighbourhood level, therefore only CES and Geographical Information Systems (GIS)-based simulation will be take into account. GIS models generate geometrical data.

Existing models

Netbeheer Nederland has developed a toolkit with an overview of calculation models that support the energy transition in the Netherlands(netbeheernederland.nl, 2018). The calculation models in the toolkit are divided into different subcategories: collecting information, exploration of spatial plans, holistic approach of energy issue, 3D visualization of the measures, detail approach of energy issues, impact of electricity market, impact on the grids and energy issues with focus on vision and strategy. For this study the calculation models in subcategories collecting information, holistic approach of energy issue and energy issue with focus on vision and strategy are interesting. The models belonging to these sub-criteria are shortly described in table 2.2.

Table 2.2: Possible supporting calculating models according to (netbeheernederland.nl, 2018)

Gathering information		
Calculation model	Short description	Author
$CBS_{inuwbuurt}$	This online tool maps the CBS data, like average income, average gas consumption, demographics. The tool gives a map of the Netherlands and the user can zoom in and determine what kind of information it wants to see of a neighberhood	CBS
CEgoia	This tool calculates the social cost of different sustainable heat options at district level. With this tool different scenario's can be made. It looks at the energy demand of a neighberhood and the possible sustainable heat sources and calculated the social cost for different scenarios. This model can only be used if you pay for it.	CE Delft
Energieinbeeld	This tool gives insight of the gas and electricity consumption of municipalities. The data is only given at postcode or neighbourhood level. The data comes from network operators.	Enexis, Stedin,Liander
NEA	NEA stands for national energy atlas, this atlas gives information of the actual energy consumption of the Netherlands and the actual energy potential of different renewable energy sources.	NEA
NOM kansenkaart	NOM stands for "nul op de meter". This map gives an overview of the potential for different dwellings for NOM renovations. The data is based on public information, however one has to pay for this tool.	kwtr mkrs in de bouw
PICO	Pico is an online open data GIS-tool and gives geographic and demographic details of district inclusive the potential of different renewable sources like wind, geothermal, heat cold storage potential and the potential for residual heat and heat network.	Geodan, TNO, Alliander NRG031/Waifer, Ecofys and Esri Nederland
Thermogis	Thermogis is a online tool built by TNO which gives insight of the geothermal potential on different layers in the earth.	TNO
Transform	With the transform tool a user can simulate different scenario's and determine the impact of CO2 emissions, renewable energy and costs. For now, only the city of Amsterdam is available in the tool.	Accenture, AIT, Macomi
VESTA	The Vesta model calculates the costs and revenuesof the energy supply of the built environment. The model focus on the measurements to make dwellings more sustainable. The Vesta model is an open model and can be used by anyone.	PBL
Warmteatlas	This online GIS-Tool gives information of different potentials of different renewable energy resources like Bio-residual heat, geothermal heat, heat or cold storage. It also gives insight where the current heat networks and gas pipes are and the average gas use per dwelling.	RVO
Holistic approach of energy issues		
Calculation model	Short description	author
DIDO	This open source model gives, through a Agent based model (ABM), insight into the price evolution for different stakeholders and interaction of stakeholders when a new energy system is given.	TNO
Energietransitiemodel	In this open source model, the user creates its own scenario's. It does not give insight into the interaction of the production/distribution and demand of heat system. Only percentual growth can be implemented	Quintel Intelligence
Gebiedsmodel	This model can be used during the first steps of an energy transition. It visualise effects of different energy carriers when a district wants to become more sustainable. It gives insight into the energy balance (how much is sustainable), the environment (CO2), costs (investment and operational) for district or national level. The model is no open source and cannot by purchased yet. Alliander should be contacted to use this model.	Alliander and D-Cision
Opera	This model gives an overview of the sustainabel energy potential of the whole Netherlands. It takes into account the fluctatuion of renewable energy and energy demand. It is no free open source data.	ECN
Vision and strategy for heat problem		
Calculation model	Short description	author
Cegoia	This tool calculates the social cost of different sustainable heat options at district level. With this tool,different scenario's can be made. It looks at the energy demand of a neighberhood and the possible sustainable heat sources and calculates the social cost for different scenarios. This model can only be used if you pay for it.	CE Delft
Energietransitiemodel	In this open source model, the user creates its own scenario's. It does not give insight into the interaction of the production/distribution and demand of heat system. Only percentual growth can be implemented	Quintel Intelligence
Powerfys	This tool gives an hour-based data set of the energy demand and sustainable energy supply. With this information the energy prices can be determind. The scope of the model are different countries of Europe. One has to pay to use this tool	Ecofys
Vesta	The Vesta model calculates the costs and revenuesof the energy supply of the built environment. The model focus on the measurements to make dwellings more sustainable. The Vesta model is an open model and can be used by anyone.	PBL

Besides the existing calculation models given by (netbeheernederland.nl, 2018) other models also give insight into different aspects of the energy transition. These are the IF model of STEDIN , the energy model of Overmorgen and different open data GIS models like EduGIS. A short description of these models will be given.

IF model: STEDIN, the network company, has developed the Infrastructural Footprint (IF) model. This IF model generates insight into which heating system has the lowest costs. It looks at the current energy demand of the dwellings in a district and calculate the cost of different renewable options. It includes all-electric renovations and residual heat. Geothermal, solar and biomass sources are not yet included.

Overmorgen: The company Overmorgen creates impact maps of possible solutions for the energy transition(Overmorgen.nl, 2017). In these maps the final image of the energy transition can be seen. The model analyses the current and future energy mix. It analyses the current heat demand and state of the dwellings in the district and determents the possible renewable renovations.

EduGIS:: EduGis is an online map that gives information of the current demographic state in the Netherlands(Edugis.nl, 2018). It does not give information of the possible renewable energy sources, but the tool can be used to create more insight into the current demographic state of a district.

2.5. Conclusion

This literature study covered four different subjects: policies for sustainable neighbourhoods, stakeholders involvement, heating systems for buildings at neighbourhood level and sustainable planning models en methodologies. The section policies for sustainable district clarified that it is very complex to transform the currently used heating system into a sustainable one because there are multiple actors involved and new sustainable technologies needed. The current used heating technologies are locked-in at the regime level and a safe niche level is needed to let new sustainable technologies develop and become more compatible with the sustainable targets at regime level. The role of the municipality should be a leading role and they need to create a platform where stakeholders can interact with each other. In the section of stakeholders involvement the tasks of the stakeholders are elaborated. The stakeholders involved in the energy transition in the Netherlands are the municipality, the network operator, the energy supplier and the customer. The role of the network operator could be very important and they are actively involved in the energy transition in the Netherlands. The municipalities need to have more insight into the technical and financial feasibilities of sustainable heating systems, to accelerate the energy transition in a neighbourhood. They especially need more insight into the mismatch between the heating supply and the heating demand of the buildings. The section heating systems for buildings at neighbourhood level gives an broad overview of the different technologies that can be used to heat a building. A difference between centralized heating system and decentralized system was made and elaborated. In the last section, modeling sustainable neighbourhoods, it became clear that different methodologies and models can be used to help the energy transition and create more insight into the current situation. However none of the methodologies or public models creates insight into the intermittency of the supply and the demand of heat when renewable energy sources are used.

From the literature study it can be stated that decision makers of municipalities need more knowledge to transform the currently used heating system into a sustainable one. It is a socio-technical transformation which is complicated to follow. A calculation model is needed that gives insight into the match between possible heating potentials and heating demand of the buildings in the neighbourhood. With information coming from the calculation model municipalities could, together with the stakeholders, develop future sustainable heating systems.

3

Design of an approach

This chapter introduces an approach for municipalities to attain insight into the possible heating systems in a neighbourhood.

From the literature study it is concluded that insight is needed into the match between heating supply and demand in a neighbourhood, because of the intermittency of renewable energy supply. This intermittency makes that, even with a high production of renewable energy, fossil fuels are still needed to cover the heating demand when these resources (for example the sun) are not available. To gain insight into the intermittency a calculation model is required. In advance of developing the calculation model, the goals of the model have to be identified. A step-by-step plan is set up to achieve these goals. After this an approach for decision makers to use the developed calculation model to gain more insight into the energy transition of heating system in neighbourhoods is given.

3.1. Steps to determine goals of calculation model

The calculation model should provide insight into the energy transition at neighbourhood level. What should the ability of this calculation model be? What kind of insight is needed? How can a calculation model help? To answer these question a step-by-step plan, complementary to the one described in figure 3.4, is developed.

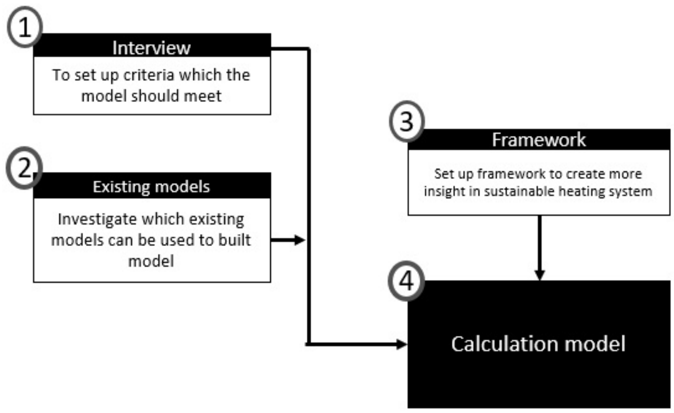


Figure 3.1: The steps to determine the needed properties of the calculation model (by author)

The first step is to interview decision makers actively involved in the energy transition in municipalities to set up criteria that the calculation model should meet. In order to develop the calculation model it is investigated which existing model could be used the support the calculation model. To determine the technical limitations of the calculation model more background knowledge of the interaction between possible sustainable production technologies is desired. This is realized by producing a framework (step three). The outcome of the three steps determines the properties of the calculation model.

3.1.1. Step 1: Interview

The first step is to conduct interviews. The purpose of conducting an interview with an expert working in a municipality for the energy transition, is to set up criteria the calculation model should meet. In this study a semi-structured interview technique is used(Wilson, 2013-11-25). A semi-structured interview can give enough insight and helps to uncover unknown issues. The weakness of this type of interview is that interviewers can dominate the interview by putting words in the participant mouth or guide the participant into a particular answer (Wilson, 2013-11-25). It is therefore important that an interviewer gives enough space and time for a participant to answer the questions. In this study four different experts working in the municipality on policies for the energy transition in the city are interviewed; Mark Bal (sustainable energy project developer of neighbourhood Mariahoeve), Johan Noordhoek (develops energy transition policy for the Hague), Henry Terlouw (develops strategy for the policy of the energy transition team of the municipality) and Bastiaan de Jong (manager of the neighbourhood Mariahoeve).

Criteria outcome of conducted interviews

The interviewed policy members all stated that there is a need for action (conducted interviews can be found in Appendix F). They would like to have more insight into the cost and benefits of the different heating systems. It should be possible to compare the sustainable heating system with the current gas-based heating system. This could give more insight into the feasibility of the sustainable heat system. Insight into the CO_2 emissions, the division of costs, profit distribution, social cost for different stakeholders and the influence of the transition to inhabitants is needed. Furthermore, insight into the stakeholder involvement is important. To comply with the research scope, as described in section 1.2, additional criteria had to be added by author. All the criteria are described in table 3.1.

Table 3.1: Criteria for the model conducted from interview (by author)

Criteria	Explanation	Source
CO_2 emission	The method should give insight into how much C02 the different sustainable heat production/distribution technologies produce.	Noordhoek
Costs	The method should give insight into how much the sustainable heat production/distribution technology costs (investment and operational).	Noordhoek, Terlouw
Social cost	The method should give insight into the social cost (private costs + external costs) of the sustainable heat production/distribution technology.	Bal, de Jong
Division of cost	The model should give insight into who should pay what.	Bal, Noordhoek, de Jong
Stakeholders	The method should give insight into which stakeholders are involved and what the role is of each stakeholder.	de Jong, Terlouw
Division of use	The model should give insight which buildings need to be connected to collective system and what happens if a building decide to ignore the collective system and create a individual system.	Terlouw
Comparable with current system	The model should compare the sustainable heating system with the current gas-based system in terms of costs and CO_2 emissions.	Terlouw, Bal, Noordhoek
Maturity of technology	The model should give insight into the maturity of the sustainable heat production/distribution technologies.	Noordhoek, Terlouw
Production technologies	The model should include all the possible sustainable heat production technologies like solar, wind, geothermal, biomass and waste heat.	Author
Distribution technologies	The model should include all the possible distribution technologies (centralized, decentralized).	Author
Demand side	The model should give information of the demand side (state of building, state of isolation etc).	Author
Demand change	The model should give insight into the influence of demand on the production and distribution technology.	Author
Intermittency	The model should give insight into the mismatch between the demand and supply.	Author
Phasing	The model should give insight of the phasing of different heat systems (flexible in time)	Author
Area distribution	The model should give insight into how much area a technology need.	Author
Time consuming	The calculation model should not need to much time to calculate outcomes (maximum 5 minutes).	Author
Price	The calculation model should be costless for the use of municipalities	Author
Heat/electricity	The calculation model focus on the heating technologies instead of electricity consumption in the neighbourhood	Author

In this study only four members of the municipality were interviewed. To gain a broader understanding of the needs of policy members for the energy transition in a neighbourhood more members should be interviewed from different municipalities. Unfortunately it was too time consuming for this thesis report to seek more members.

It is important to keep in mind that it is not feasible to develop a model which meets all the criteria. The calculation model should be able to calculate the most important criteria. The fundamental criteria for this study are calculating intermittency, calculating costs for different stakeholders, calculating CO_2, be costless and focusing on heat.
Insight into the intermittency is required to understand the differences in the heating demand and supply and to calculate the CO_2 emissions. The CO_2 emissions are a great concern for policy decisions, because decision makers want to meet the Paris agreement. Understanding the costs is required to determine the feasibilities of projects, especially for municipalities who have to work with limited budgets. The calculation model should be costless so municipalities can easily use the calculation model and finally the calculation model should give especially insight into the heating demand, not the electricity demand of a neighbourhood.

3.1.2. Step 2: Existing models

Step two is to investigate which existing models could be used to support the calculation model. In the literature study (section 2.4.2) the existing models were described. These supporting models should also meet the criteria set up in step 1. The existing models will be weighted against the criteria. The result are given in table 3.2:

Table 3.2: Outcome of the criteria analysis of all the possible supporting calculation models (by author)

Criteria	CBS	CE goia	Energie inbeeld	NEA	NOM kansen kaart	PICO	Thermo gis	Trans form	VESTA	Warmte atles	DIDO	Energie transitie model	Edu GIS	Gebieds model	Opera	Power fys	IF model	Over morgen
CO2 emissions									X		X	X		X	X		X	
Costs		X			X				X		X	X		X	X	X	X	
Social costs		X			X				X		X	X		X	X		X	
Division of costs									X		X			X				
Stakeholders		X			X				X		X		x	X				
Division of use					X			X						X				
Comparable with current system		X			X			X						X		X	X	X
Maturity of technology																	X	X
Production technologies		X		X		X	X[1]	X		1/2X					X	X	1/2X	X
Distribution technologies		X				X		X							X	X	1/2X	X
Demand side		1/2X	X		X	X		X	1/2X					X		X	X	X
Demand change		X	X			X		X	X							X	X	X
Intermittency															X	X		
Phasing		X														X		
Area distribution																		
Free to use	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No[2]	Yes	Yes	No	No	No	No	No
Heat/Electricity	Both	Heat	Both	Both	Heat	Heat	Heat	Both	Heat	Heat	Elec	Both	Both	Both	Both	Elec	Heat	Heat
Amount of categoria met	0	8.5	2	1	6	4	1	6	6.5	0.5	5	3	1	8	5	8	8	6

1:ThermoGIS only gives the potential of geothermal production. 3:The DIDO model is no open source yet, but will probably in the future be an open source data model.

The models CEGOIA, Transform, PICO, Vesta, DIDO,*Gebiedsmodel*, Opera, Powerfys, IF-model and the calculation model of *Overmogen* comply with the most criteria. Nonetheless, when looking at the fundamental criteria the only usable existing calculation is narrowed to PICO, Thermogis, Vesta and warmteatlas. These existing models can support the developed calculation model.

3.1.3. Step 3: Creating framework

The next step is to create more insight into the interaction of production and demand of heat. This interaction determines the technical limitation of the model.

As described in the literature study (section 2.3) a heating system can be subdivided into the production of heat, the transportation of heat and the consumption of heat by the end-user. The amount of consumed heat and the needed inlet temperature of heat by the end-user influence the possible technologies for producing and transporting the heat. A distinction between centralized and decentralized heating systems is made. For both types of systems the relation between consumption of heat and type of technology for production and distribution of heat is depicted in a framework.

Framework for centralized heating system for a neighbourhood

Figure 3.2 illustrate the framework for a centralized heating system for a neighbourhood. The framework consists of three parts: production, distribution and demand.

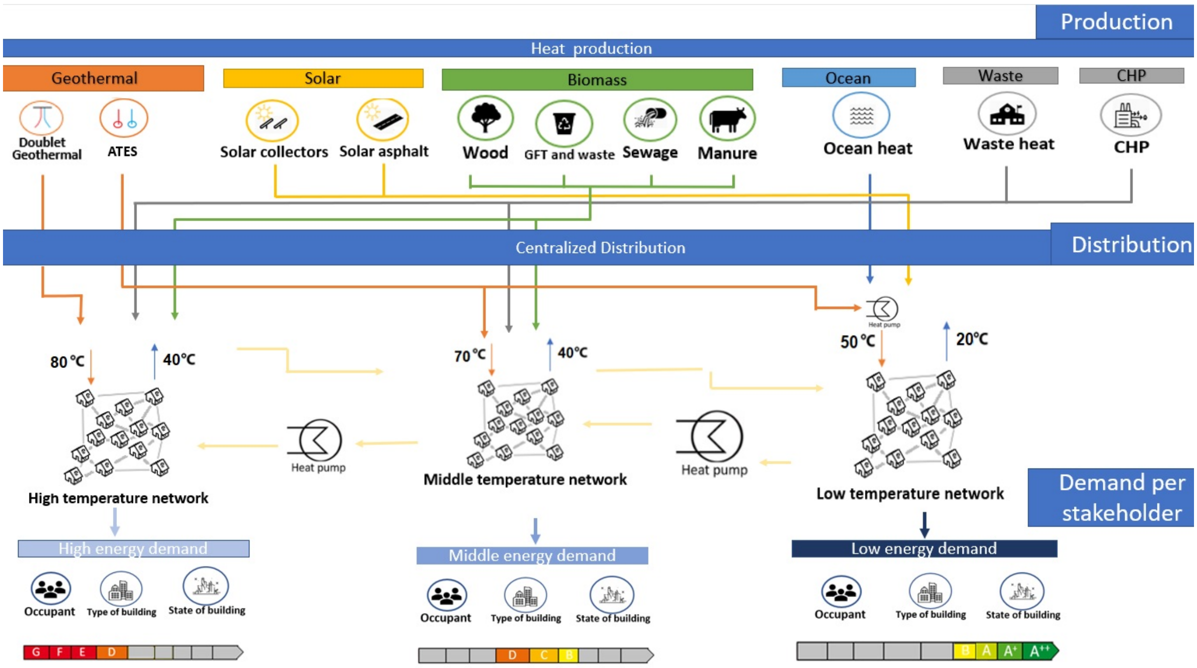


Figure 3.2: Graphical presentation of the framework of a centralized heating system for a neighbourhood consisting of different production technologies that can be connected to different distribution networks and different energy demand buildings(by author)

The figure clarifies the interaction of production, distribution and the demand of the buildings.

Production

There are different renewable technologies that can be used to generate sustainable heat. These technologies can be found in the framework under production and consist of geothermal, solar, biomass, ocean waste and CHP. However, not all the heat produced by these technologies can be used for every type of building, due to the different outlet temperature of the heating technologies. Heat from a geothermal well has a high outlet temperature, as well as heat produced by biomass, waste heat and CHP. Solar heat on the other hand gives, as well as ocean heat, a lower outlet temperature. The outlet temperature determines the type of temperature network.

Distribution

Three different heating networks are possible to distribute the heat from the renewable source to the end-consumer; high temperature network, middle temperature network and low temperature network. A high temperature network can only distributes heat around 80 degrees, a middle temperature network distribute heat around 70 degrees and a low temperature network distributes heat around 50 degrees. This means that a high temperature network should only provide heat to a high energy demand building, a middle temperature network to a middle energy demand building and a low temperature network to a low energy demand building.

Demand

Whether the building has a high or low energy demand depends on the building type (individual, block-building, high-rise or low-rise), the state of the building (how well insulated etc?), the year of construction of the building and the amount of people occupying the building. The type of building and the state of the building could be summarized in the energy label of the building. Buildings with an energy label of G-D can be connected to a high temperature network, buildings with an energy label of D-B to a middle temperature network and buildings with an energy label of B or higher to a low temperature network.

Framework for a decentralized heating system for dwellings

Figure 3.3 depicts the framework for decentralized heating systems for dwellings. This framework too consist of three parts: Production, distribution and demand.

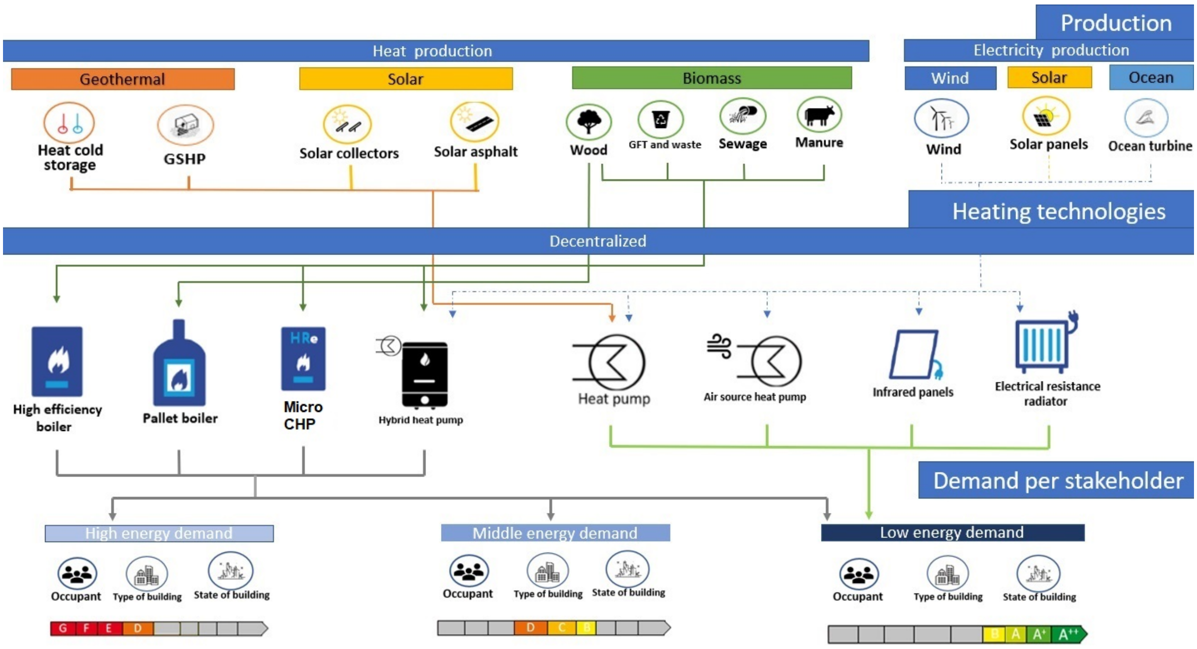


Figure 3.3: Graphical presentation of decentralized heating systems consisting of different sustainable heat production technologies that can be connected to different heating technologies and variable energy demand buildings. (By author)

Production

The production technologies for decentralized heating system can be found in the framework under production. The electricity production is also included in this framework, because some decentralized heating technologies demand electricity. This electricity production (especially wind and solar), could be produced by the home owners.

Heating technologies

In a decentralized heating system there is no need for a network, because the heat is produced very close to the building. Different heating technologies can be applied, needing different energy sources. Biogas and wood can be turned into heat with high efficiency boiler, pallet boiler, micro-CHP and a hybrid heat pump. The outlet temperature of these heating system is high. The heat pump could transport ground heat or solar heat into the building using electricity, the outlet temperature of the heat pump is low. The ASHP, infrared panels and electrical resistance radiators convert electricity into heat in a building, the outcome of these heating technologies are low. The outlet temperature determines in what kind of building the heating technology can be operational.

Demand

Just like the centralized heating systems their are three types of energy demand buildings: High energy demand, middle energy demand and low energy demand buildings. The energy demand of the building is dependent on the occupancy characteristics, type and state of the building. The high efficiency boiler, pallet boiler, micro-CHP and hybrid heat pump can only be used in high energy demand buildings. The other heating technologies are only operational in low energy demand buildings.

3.1.4. Step 4: Use gathered information to set up goals of calculation model

In step 4 all the gathered information from the previous steps are put together to set up the goals of the calculation model.

From the criteria it can be concluded that the calculation model should give insight into the match between heating supply and demand, the financial feasibility for different stakeholders for different heating technologies and the amount of CO_2 emissions per heating technology. From step 2 it can be concluded that the existing models PICO, Thermogis, Vesta en warmtealtas can be used to support the calculation model. The frameworks in step 3 have to be kept in mind when studying the interactions between heating supply and demand in the calculation model. It is important that decision makers can easily work with the model, therefore the calculation model has to be made in CSV-files, since these are plain, standard structured files.

Chapter 4 describes in detail how the calculation model is built and how the goals (give insight into intermittency, financial feasibility and CO_2 emissions) are calculated.

3.2. The approach to use the calculation model

The developed approach is inspired by the STA method, because the calculation model also include EPM methodology and sets up scenarios where heating technologies can be weighed for specific parts in the neighborhood (Oudes and Stremke, 2018) (Broersma et al., 2011). Figure 3.4 illustrates the steps of the approach.The firs step is to collect the needed input data of the neighborhood to determine the heating demand of each building standing in the neighborhood. Chapter 6 will elaborate the needed steps to collect these parameters in dept, including clarifying examples from the case study.

The second step is to collect input data to calculate the hourly heating potential of each renewable energy source using EPM methodology. Chapter 7 describes in detailed how the data is collected.

The third step is to develop scenarios wherein the supply of different heating technologies are weighted for specific areas of the neighbourhood. Different types of scenarios can be applied to investigate desired futures. In this study it is chosen to use predictive what-if scenarios. This type of scenarios can give an answer to the fundamental question: "*What will happen, on the condition of some specified events?* (Börjeson et al., 2006). In chapter 8 the created scenarios and their outcomes are given. Before these steps are

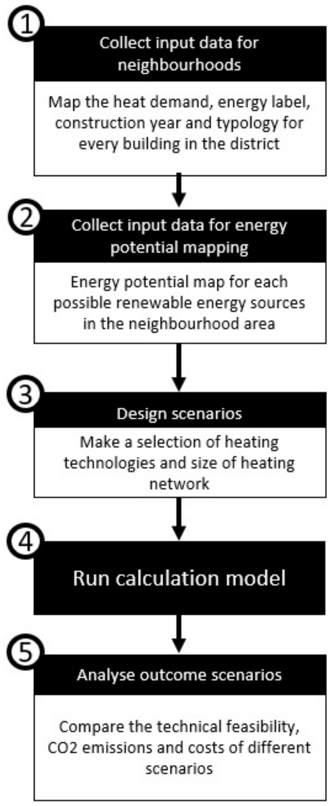


Figure 3.4: Developed approach (by author)

described further, more information of the calculation model is needed. Chapter 4 presents the calculation model and chapter 5 gives a general description of the case study Mariahoeve in the Hague.

4

Calculation model

This chapter describes the structure of the calculation model. Furthermore, it explains how the output of the calculation model is calculated and presents the collected background data needed for the calculations.

4.1. Structure of the calculation model

As investigated in section 3.1.4 the calculation model should calculate the intermittency of renewable production and the match with heating demand, technical feasibility for different heating technologies for different stakeholders and the amount of generated CO_2 emissions. The calculation model should calculate the energy demand of each building and the energy supply of each heating technology and compare these with each other. It should be possible to select specific heating technologies and define a part of a neighbourhood that gets it heat from that specific heating technology. In this way different scenarios can be set up and compared with each other. Figure 4.1 illustrates the structure of the calculation model.

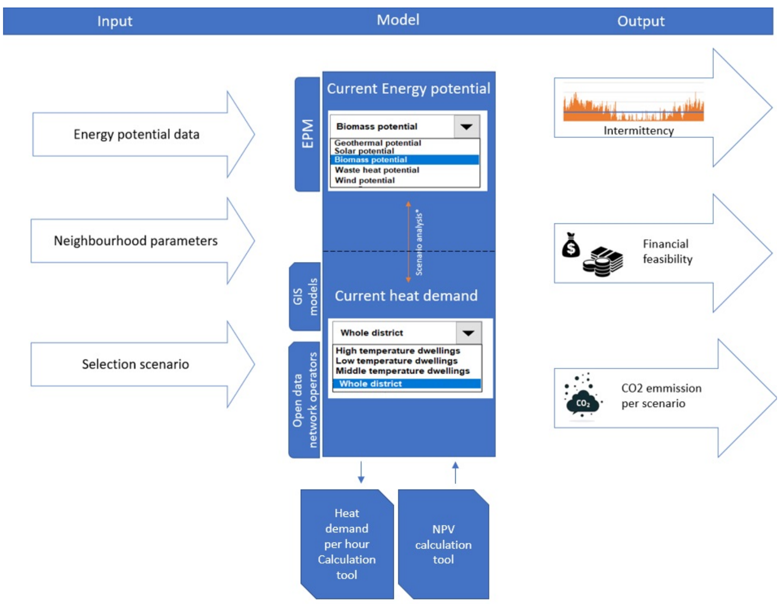


Figure 4.1: The structure of the developed calculation model. The input parameters consist of collected energy potential data and specified neighbourhood parameters. The calculation model calculates the current energy potential of the neighbourhood using EPM methodology and the energy potential data. Furthermore it calculates the current heating demand of the buildings in a neighbourhood with the neighbourhood parameters, online GIS models and data from network operators. The user can select different scenarios, to create insight in different heating options. In two additional files the hourly heating demand and the NPV values are calculated. The output of the calculation model is insight in the intermittency, financial feasibility and amount of CO_2 emissions.

The calculation model consists of two parts: calculating the current energy potential of renewable heating sources and calculating the current heating demand of the buildings.
The first part follows the EPM method to calculate the current energy potential of renewable sources in the neighbourhood. A decision maker has to collect and implement specific energy potential parameters of the neighbourhood. Chapter 7 describes how these specific energy potential parameters are collected.
The second part of the calculation model calculates the current heating demand with the input parameters of the neighbourhood (collected by the decision maker), the supporting calculation models (as described in section 3.1.2) and online data from network operators. How this is accomplished can be found in detail in chapter 6.
The calculation model consists of two other calculation scripts that calculate the heat demand per hour and the costs and benefits for different scenarios. In Appendix E a complete overview of the developed calculation model can be found.

To calculate the financial feasibility and amount of CO_2 emissions per heating technology, it is needed to collect specific background data. The following section describes how the background data is collected and how the output parameters are calculated.

4.2. Intermittency and match between supply and demand

The intermittency gives insight in the interaction between heating demand of the buildings and the heating supply of the heating technology per hour. Two energy matching indicators are used to determine the intermittency and the match between supply and demand(Cao et al. 2013). The first indicator, on-site energy matching (OEM), stands for the amount of energy coming from a renewable source that directly can be consumed. This fraction also indicates how much energy could be stored. In Figure 4.2 OEM stands for the fraction of the area of part lll over part ll and lll. An OEM of 30% indicates that 30% of the generated renewable energy can be directly consumed and 70% of the energy could be stored.
The second indicator, on-site energy fraction (OEF), gives an indication on how much heat a building (or multiple buildings) desires and how much of this desired heat could be delivered by a sustainable heating source. In figure 4.2 the OEF is the fraction of the area of part lll over the areas of part l and lll. An OEF of 40% indicates that, of the total energy demand, 40% of the energy demand is given by the renewable energy source simultaneously, without any storage, but still 60% is required from other renewable sources or fossil based systems.

$$OEF = \frac{\int_{t1}^{t2} Min[G(t); L(t)]dt}{\int_{t1}^{t2} L(t)dt}; 0 < OEF < 1 \quad (4.1)$$

$$OEM = \frac{\int_{t1}^{t2} Min[G(t); L(t)]dt}{\int_{t1}^{t2} G(t)dt}; 0 < OEM < 1 \quad (4.2)$$

With $G(T)$ being the total renewable energy power production and $L(T)$ being the total energy power demand of the buildings during an instantaneous time t. In this study dt is equal to one hour. The smaller the time frame dt the more accurate the outcome.

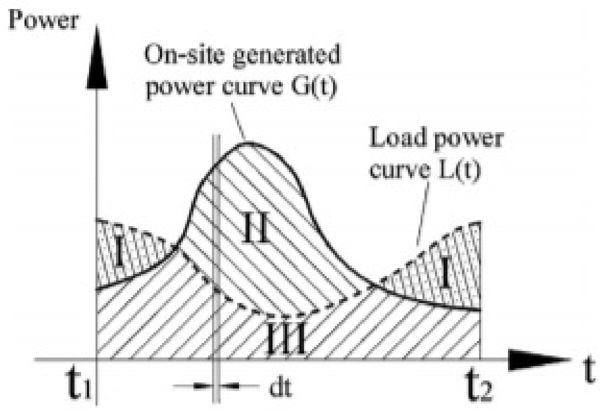


Figure 4.2: Principle of the indicators OEM and OEF (Cao et al. 2013). On-site energy matching (OEM) is given by the fraction of the area of part III over part II and III. On-site energy fraction (OEF) is given by the fraction of the area of part III over the areas of part I and III.

Preferably, both indicators OEM and OEF are as high as possible,this way the matching is the best. If a 100% score of both OEM and OEF is impossible, it is preferred that OEF is as high as possible, meaning that less gas or other heating systems are required. If OEM is not 100% it means that energy could be stored, and this is not necessarily undesirable.

4.3. Financial feasibility

The financial feasibility gives insight in the costs and benefits of different heating technologies taking into account the different stakeholders. The used method is the *Net Present Value* (NPV) method. This method indicates whether it is worth to invest in, for this study, different renewable energy technologies or district heating. If the NPV is negative or zero the investment is not profitable, when it is positive the investment is. This method is a widely used method because of its simplicity and transparency, however it is good to keep in mind that these calculations cannot replace detailed studies of specialized consultants (Willigers et al. 2017). The actual costs will be highly depending on the actual plant size and the location of the plants. The NPV can be calculated as follows (Willigers et al. 2017):

$$NPV_n = \sum_{i=0,n} \frac{FV_i}{(1+r)^i} = \sum_{(i=0,n)} \frac{(R-C)_i}{(1+r)^i}. \quad (4.3)$$

The NPV of year i is the Future Value (FV) in year i divided by the r (rate of return). The FV consists of the revenue flow (R) minus the cost flow (C) in that year. A high risk investment will have a high rate of return. Meaning, that when an investment has a high risk and it turns out well the investor may obtain a lot of money, but if it goes wrong the investor will lose a lot of money. The risk of renewable heating technologies and district heating can be considered low, because heat will always be required in buildings. However, the risk of district heating could become higher when it becomes more attractive to heat buildings decentralized, meaning that district heating will not be required.

The cost and revenue depend on the inflation rate j_1 and the increase in energy prices j_2 (Statistal 2018). The Future value can be calculated as follows:

$$FV_i = (R-C)_i = (R1*(1+j_1)^i + R2*(1+j_2)^i + ... - C1*(1+J_2)^i - C2*(1+j_2)^i - ...) \quad (4.4)$$

The NPV for the stakeholders will be calculated for 60 years (lifetime of a heating network). The used rates can be found in appendix C.

Different stakeholders are involved in the transportation of heat to buildings and each stakeholder has it own revenues and costs (see also section 2.2). The stakeholders consist of: the energy company (installing a renewable production plant and gaining revenues from consumers), the network operator (installing the heating network and gaining revenues from consumers) and the users (customers). To calculate the NPV for each stakeholder their revenues and costs need to be known.

4.3.1. Revenues and costs for customers

A user pays an energy company for producing heat. The energy company pays the network operator for transporting their heat to the customer. Therefore, a customers indirectly pays the network operator.
Users that are connected to a district network in the Netherlands cannot choose their energy supplier for heat and are obligated to use the district network instead of the gas grid. Therefore the *"Niet-meer-dan-anders"* rule is applied. This rule states that the costs for a user connected to a district network cannot be higher than when the user would be connected to the gas grid. The company ACM determines what the maximum prices of the district network can be (ACM 2018).
The costs for the consumer can be subdivided into four different parts:

1. **The costs depending on the consumption rate** (Revenue for energy company)
   A customer pays a fixed amount per consumed GJ heat to the energy company. Because of the *"niet-meer-dan-anders"* rule, customers connected to district heating will pay the same on average as customers connected to the gas grid.

2. **The costs for the rent of the heat delivery set** (Could be revenue for network operator)
   The heat delivery set is the installation needed to transport the heat from the network into the building. This installation could be provided by the network operator, in that case the consumer will rent the installation from the network operator and has to pay a yearly fee. It is also possible that the consumers will pay the delivery set by themselves. In this study it is assumed that every consumer pays the delivery set by himself.

3. **The costs for metering** (Revenue for network operator)
   Every year a customer needs to pay a fixed price to measure the consumed heat. The value for these costs are determined by ACM (ACM 2018).

4. **The connection costs** (Revenue for network operator)
   Every year a customer needs to pay the network operator for being connected to the grid. These costs consist of a single payment when the connection to the grid is made (single stage) and an annual payment to remain connected (yearly stage).

The customers could only lower their energy bill by consuming less heat.

A division between customers who use individual heating and network heating is made. A customer will not receive revenues, he only makes costs. One exception occurs when a customer has a PV panel. When a PV panel generates electricity and the customer can not directly use it, the electricity is sent back to the grid and gives a customer revenue.

Cost of customers connected to centralized heating system

When a customer is connected to a heating grid it has to have a heat delivery set consisting of installation techniques that transfer the heat from the grid to the building. For district heating a heat exchanger is used and for gas grid connection a high efficiency boiler. In this study the customer for the installation and maintenance of these techniques. The customer has to pay for the consumed heat and for the connection costs. Each year, the customer pays a fixed price for heating plus a price per consumed GJ heat. The fixed price consists of yearly fixed price for the delivery and transportation of gas plus the difference between the costs for using heat sources instead of gas. The connection costs consist of the measuring costs, single connection fee and yearly connection and are presented in table 4.1. The price for the connection fee dependents on the distance of the building to the network. If it is larger than 25 meters, the customer has to pay more.

Table 4.1: Maximum heat prices for consumers determined by ACM (ACM 2018)

	2017 (Euro, incl. btw)	**2018 (Euro, incl. btw)**
Maximum price	299.16 + 22.69 per GJ	309.52 + 24.05 per GJ
measurement costs	25.02	25.36
Single connection fee (untill 25 meters)	1011.73	1037.78
Single connection fee per meter larger than 25 meters	32.27	33.77

Table 4.2 presents the installation and maintenance costs for the heat exchanger and high efficiency boiler.

Table 4.2: Costs for heat delivery set (CEDelft 2017)

Technology	CAPEX	OPEX	Lifetime
Heat exchanger	750 EUR	0	15 Year
High efficiency boiler	1200 EUR	24 EUR	15 Year

Cost for individual heating systems

When a customer has its building heated by a decentralized heating system he or she has to pay for his/her own heating system. Different decentralized heating system can be used. Table 4.3 gives the investment and maintenance costs of different systems.

Table 4.3: Costs individual systems (CEDelft 2017)

	Investement costs (Euro)	Maintenance costs (Euro/year)	lifetime (year)
High efficiency boiler	1500-3000	100	15
PV Panel (Zonnepanelen-kennis.nl 2017)	170 $/m^2$	150 (offerte advisieur.nl 2018)	20-25
Pallet boiler	6000	100-150	5-15
Micro-CHP	11500	100	15
Electrical resistance radiator	1800-3800	-	15
Infrared panels	2500-3000	-	unknown
Ground source heat pump	8500-16500	50	15
Air heat pump	6500-14500	50	15
Hybrid heat pump	3600-4600	50	15

Costs for insulation

To make a building a low energy demand building it has to be insulated at least to energy label B. The costs for this insulation are presented by table 4.4. The calculation model assumes a defined percentage drop of energy demand when a building is insulated. When a building goes from one energy label to another, the energy demand of that building decreases with the given percentage drop (this percentage drop can be found in appendix C).

Table 4.4: Investment costs for insulation in dwellings (Schepers 2017)

Investment costs in EURO/(m^2 ground area) for insulation	high-rise dwellings	low-rise dwellings
G –>F	30	33
G –>E	57	66
G –>D	80	96
G –>C	102	123
G –>B	116	140
G–>A	141	170
G –>A+	441	303
F –>E	30	35
F –>D	61	72
F –>C	89	106
F –>B	107	128
F–>A	138	166
F –>A+	337	277
E –>D	43	49
E –>C	75	85
E –>B	96	107
E–>A	132	147
E –>A+	337	232
D –>C	34	49
D –>B	80	76
D–>A	160	122
D –>A+	253	198
C –>B	72	69
C–>A	157	185
C –>A+	267	218
B–>A	84	70
B –>A+	119	82
A –>A+	64	31

4.3.2. Revenues and costs for energy company

The revenues and costs for energy companies depend on the kind of heating technology they use. In the calculation model, four different kind of renewable heating technologies are possible: geothermal, biomass, waste heat and solar heat. The costs and revenues for a gas-based energy company will also be calculated. To simplify calculation costs only the *Capital Expenditures* (CAPEX) and *Operating Expenses* (OPEX) are considered. CAPEX stands for the investment costs and OPEX for the maintenance costs. It is assumed that the OPEX also consist of the cost for paying electricity to run a plant, when needed. Each of the renewable heating sources consist of investment costs (CAPEX), maintenance costs (OPEX) and revenues. It is assumed that all produced heat of the energy company is sold. If the neighbourhood does not need the heat it is assumed that the government will buy the heat and pay the energy company or the heat is stored by the energy company or sold elsewhere, meaning that the intermittency does not have any influence on the costs and revenues of the energy companies.

Costs

The costs for the energy company are presented in (table 4.5):

Table 4.5: Investment and maintenance costs for different sustainable sources (Sigfússon and Uihlein 2015), (Koppejan 2016),(Oyewo et al. 2017),(Zonnepaneel-weetjes 2017)

Source		CAPEX	OPEX
Geothermal doublet (Sigfússon and Uihlein 2015)		7,3 MEUR/MW	2 %
Biomass	Wood bio boiler(2.5MW) (Koppejan 2016)	560 EURO/kW	36 EUR/kW
	CHP,biogas (2.5 MW) (Oyewo et al. 2017)	503 EUR/KW	20.1 EUR/kW
Solar heat (collectors) (Zonnepaneel-weetjes 2017)		220 EUR/m^2	2.3 %

The costs for an energy company that sells waste heat is not mentioned in table 4.5. Waste heat is generated by offices, supermarkets, industries or data centers thus they should gain profit from selling this to the grid. However, most of these buildings will use the heat for themselves. Also, the heat is generated during the summer thus this heat must first be stored before it could be used in the winter for the buildings. Different appliances are needed to transport the waste heat to the grid. Because of the low production amount of waste heat and the high amounts of unknowns, waste heat is left out in the calculation model.

It is assumed that an energy company that sells gas does not need to invest in a gas production plant. It buys gas and sells it to the customer. When solar collectors are used, it is assumed that one energy company is responsible for all the installations of solar collectors in the neighbourhood. In reality it is possible that home-owners buy their own solar collectors and gain profit from it, without the interaction of an energy company.

Revenues

The revenues of an energy company depend on the amount of customers using their energy and how much energy these customers need. The maximum price for the consumers is determined by ACM (ACM 2018). The price paid by the consumer is not the price received by the energy company, because heat is subjected to energy taxes. These energy taxes are transferred from the energy companies to the government. The revenues for energy companies are as follows:

Table 4.6: Revenue of energy companies (ACM 2018)

	Consumer price	Total taxes (Rijksoverheid 2018)	Revenue energy company
Heat	309.52 (EUR) + 24.05 (EUR/GJ)	21%	244.52 (EUR) +18.99 (EUR/GJ)
Gas	0.58 (EUR/m^3)	21%	0.46 (EUR/m^3)

4.3.3. Network operator

The network operator is responsible for the maintenance of the network. In this calculation model a heat network will be compared with a conventional gas network. The costs can, again, be divided into investment costs and maintenance costs.

Costs

The investment costs for a heat network depends on the length of the network and the diameter of the tubes of the network. It can be calculated as follows(van der Spoel and Itard 2012):

$$I = L * (C_1 + C_2 * d) \tag{4.5}$$

With L, being the length of the district and C_1 and C_2 two variables that depend on the area where the neighbourhood lays. C_1 is 286 EURO and C_2 2022 EUR/m^2 in cities. The other values for C_1 and C_2 can be found in appendix C. d stands for the average pipe diameter. The length of the district and the pipe diameter can be calculated as follows(van der Spoel and Itard 2012):

$$L = \text{Total area of land}/(61.8 * pr^{(-0.15)}) \tag{4.6}$$

$$d = 0.0486 * \ln(\frac{3.6 * \text{total heat consumption}}{L}) + 0.0007 \tag{4.7}$$

With pr being the plot ratio, this indicates the total built area divided by the total land area. In city areas this plot ratio is equal to 1. The maintenance cost of district networks are 2% of the investment costs.

The investment and maintenance costs for a gas grid is respectively 300 EUR per meter and 2% of the investment cost (Enduris 2018).

Revenues

Again the the price paid by the consumer is not the price received by the network company, because heat is subjected to energy taxes. The revenues for the network operator consist of connection costs and measuring costs.

Table 4.7: Revenues for heat district network operators (ACM 2018)

	Single stage	Yearly stage
Connection costs consumers	1037.78 EUR	54 EUR
Measuring costs consumer	-	25.36 EUR
Taxes (Rijksoverheid 2018)	21%	21%
Revenues network operations	819.85 EUR	62.69 EUR

When a gas distribution network is used the following revenues are gained by the network operator:

Table 4.8: Revenue for gas distribution network operators(Enduris 2018)

	Single stage	Yearly stage
Connection costs consumers	1005.06 EUR	34.33 EUR
Measuring costs consumer	-	26.53 EUR
Taxes (Rijksoverheid 2018)	21%	21%
Revenues network operations	794 EUR	48.08 EUR

4.4. CO_2 emissions per technology

It is possible that CO_2 will be emitted when heat or electricity is generated. However the amount of emitted CO_2 varies per used technology. Table 4.9 gives an overview of the amount of emitted CO_2 per heating technology (CEDelft, 2014),(CEDelft, 2016),(Otten and Afman, 2015),(Milieucentraal et al., 2017):

Table 4.9: C02 emission per technology (CEDelft, 2014),(CEDelft, 2016),(Otten and Afman, 2015),(Milieucentraal et al., 2017)

Generation technology	CO_2 emission
Electricity	0.649 CO2/kWh
Gas	35.97 CO2/GJ
Geothermal doublet	25.05 CO2/GJ
Solar (electricity)	0 CO2/kWh
Biomass (electricity)	0.075 CO2/kWh
Biomass (burning wood)	25.82 CO2/GJ
CHP	26.49 CO2/GJ

Only the production of heat or electricity is taken into account in the calculation of the calculation model, not the emissions due to the production of the plants. Furthermore, only the emission of the amount of heat used in the neighbourhood is taken into account. If, for example, a geothermal well produces 100 TJ heat and only 50 TJ heat is directly used in the neighbourhood, then only the amount of CO_2 emission due to the 50 TJ is taken into account. This means that in theory more CO_2 would be emitted, but it is out of the scope of the neighbourhood.

5

Case study

This chapter introduces the case study. The case study is performed to test the developed calculation model and the approach to use this model. Background knowledge of the case study is given to illustrate the current situation.
The chosen neighbourhood for the case study is Mariahoeve, located in the municipality the Hague. This neighborhood is designated as one of the pilot neighbourhoods where the energy transition will start first, because the gas grid will be replaced before 2030. In this chapter the actual policies for the energy transition in The Hague are specified, followed by a brief overview of Mariahoeve and preliminary studies for the energy transition in Mariahoeve.

5.1. The actual policies for energy transition in The Hague

The municipality The Hague aims to supply sustainable heat to 250.000 residents and to every office in the city before 2040. They work together with housing associations, residents, network operators and energy companies in the *Het Haags Nieuwe Energie Akkoord.* On the second of February 2018 this collaboration is officially started. The Hague starts with the neighbourhood: Mariahoeve, Den Haag Zuidwest en CID/Binckhorst. Backcasting studies from CE Delft and ECN show that from 2018 yearly 10.000 residents needs to be disconnected from gas. This means that in the short-term information is needed on possibilities, costs and results of sustainable alternatives.

5.2. The story of Mariahoeve

Mariahoeve was designed by F. van der Sluijs in 1955. The design was unique and it differs from other after-war expansion plans for neighbourhoods due to large amount of variation in the buildings. From the start it was meant that different groups of people with different incomes were able to live in this neighbourhood (Haag, 2015).

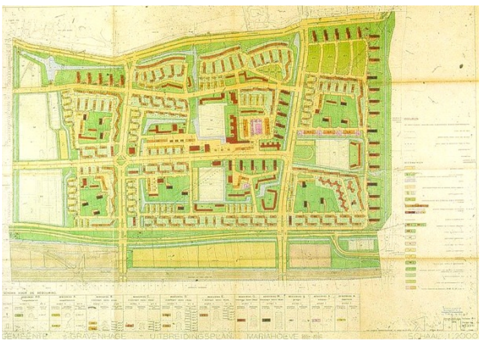


Figure 5.1: Design plan of the district Mariahoeve from F. van der Sluijs (Haag, 2015)

This is still characteristic for the neighbourhood. Mariahoeve is a green district which consists of four parts: Marlot, Landen, Burgen & Hosten and Kampen. Marlot was added to Mariahoeve in a later period and some still refers to this neighbourhood as Mariahoeve & Marlot instead of only Mariahoeve. The Mariahoeve is a cultural-historical valuable district. A mix between single-families homes, low-rise buildings with four residential layers and high-rise buildings with twelve residential layers can be found in the neighbourhood. The part Marlot is differing from this. It is a luxury residential neighbourhood with large villas and semi-detached buildings. It is the most expensive part of Mariahoeve and it even has a royal palace.

Table 5.1: Typical numbers of district Mariahoeve (Haag, 2017)

	Mariahoeve	Marlot	The Hague
Amount of inhabitants	13 100	810	507 000
% 0-25 year	16%	27%	30%
% 25-65 year	54%	49%	57%
% 65 year and older	24%	19%	13%
% non-western immigrants	30%	14%	35%
% western immigrants	17%	27%	16%
% natives	53%	59%	49%
Amount of dwellings	7900	350	244 000
% owner-occupied	37%	87%	45%
% social rent	46%	0%	33%
% particular rent	16%	13%	21%
Average spendable income [euro]	21 800	49 500	23 300

Table 5.1 gives an overview of some characteristics of Mariahoeve. Note that the average spendable income differs a lot between Marlot and the other parts of Mariahoeve. Marlot is wealthier compared to the other parts of Mariahoeve. Western immigrants are immigrants coming from Europe (Turkey as exception), North-America, Oceania, Indonesia or Japan. Non-western immigrants are coming from Africa, Latin-America, Asia (except Indonesia and Japan) or Turkey.

5.3. Stakeholders involved in Mariahoeve

The stakeholders involved in the heating system are the municipality (The Hague in this case study), network operators, energy companies and customers. The network operator in Mariahoeve is Stedin. Which energy companies are involved depend on the decisions of the residents. The energy companies active in the *Haags Energieakkoord* are Engie, Eneco, Uniper, Alliander and 070Energiek (Haag, 2018). The customers can be divided into the Housing association (HA), privately owners with HOA, individual home owners and tenants. The HA involved in Mariahoeve are: Haag wonen (+/- 1000 dwellings), Steadion (+/-1700 dwellings), Vestia (+/- 700 dwellings) and Vidomes (1 dwelling).

5.4. Preliminary studies

It is important to base this work on up-to date knowledge on existing data and vision on Mariahoeve. The municipality of the Hague has finished some studies for the Mariahoeve with the help of different partners. TNO, IF technology and the REBEL group have done some research in the energy transition of Mariahoeve.

5.4.1. TNO: Transition pathways for fossil free Mariahoeve

TNO works together closely with the municipality and supports the decision making for the Energy District Plan (EDP) for Fossil Free Mariahoeve. They help creating an open platform where stakeholders can interact with each other and together find solutions for the energy transition in Mariahoeve. TNO has also done a preliminary study following their six-step approach. Their six-step analyses contains: Determine ambitions, determine scenarios, determine desired system, determine roadmap, determine masterplan and executing & monitoring. The first three steps of their six-step approach have already been carried out for Mariahoeve (determine ambitions, determine scenarios and determine desires systems). TNO investigated how to make both the heating, electricity and mobility more sustainable. Their study concludes that Mariahoeve can be made almost energy neutral. Wind electricity is necessary for seasonal balance and heat pumps and electric vehicles could help balancing energy during the day. Energy transition is affordable, nevertheless high investment costs are needed. Their conclusion on heating is that a more detailed study for heating system is required (especially for low temperature networks), particularly to investigate seasonal balance for heating.

5.4.2. IF technology

IF Technology has investigated the possible geothermal potential for the whole city (Willemsen et al., 2016). In the scope of the city 6-11 PJ of heat can be withdrawn if the return temperature is cooled to 25 degrees. A geothermal system can have a heat potential of 280 TJ at city level. This means that, when keeping in mind the practicable placing feasibility, around 10-15 systems with a heat potential of 280 TJ can be built in the Hague. The investment cost per system is around 33 million euro. The return time of the investment is around eight years. The study does not give possible location options of the geothermal systems.

5.4.3. REBEL group

REBEL group works closely together with the energy transition team of Mariahoeve. They help to make contact with the residents, HA, HOA and with companies. They created a step-by-step plan to actively involve these four different stakeholders groups in the energy transition. Furthermore, they are calculating the heating demand of Mariahoeve. Their study is not finished, thus no conclusions can be made.

5.4.4. CE DELFt & Overmorgen

CE Delft and Overmorgen have investigated which short-term heating solutions are best applied to the current buildings. The possible short term heating solutions depend on the year of construction of the building and the type of the building (figure 5.2).

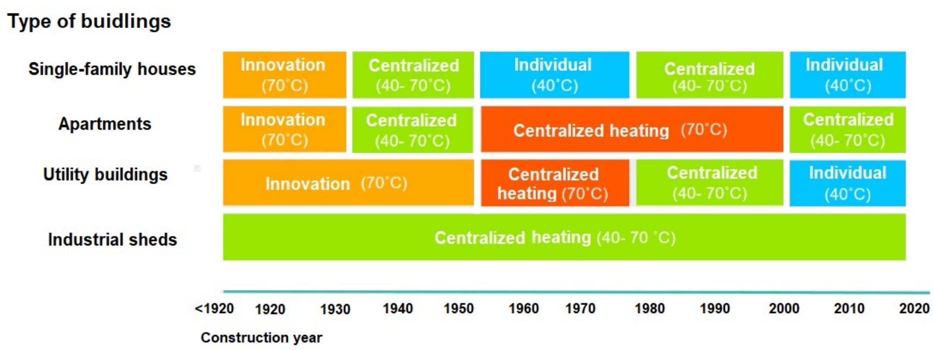


Figure 5.2: Heating solutions for buildings depending on the type of buildings and its year of construction(Overmorgen.nl, 2017)

The study of CE Delft and Overmorgen state that there are four different short-term heating solutions for buildings: high-temperature centralized heating, low-temperature centralized heating, individual heating and innovation heating.
Innovation heating are for buildings that cannot be insulated easily and need a new, individual high temperature heating solution, like a hybrid heat pump. Buildings who are best suited for individual heating systems are single-family houses built from 2000 till now, but

also single-family houses that are built between 1950-1980. The last group of buildings are built short after the second world war and are badly insulated. It is easy to insulate these buildings in short time and provide it with individual heating. Centralized low-temperature heating systems are interesting for buildings that are built between 1980-2000 because these buildings are well insulated. The buildings built between 1930-1950 could be suitable for centralized heating, if the home owner agrees to insulate their building. The last possible heating is high-temperature centralized heating and this is suitable for apartments buildings built after 1950. This should be a temporarily solution and all the buildings need to better their insulation so the heating can be lowered to low-temperature centralized heating system. The above given connection between year of construction,type of building and heating solution is for a short-term solution.

For Mariahoeve the possible short-term heating solution per building according to the study of CE Delft and Overmorgen is given in figure 5.3.

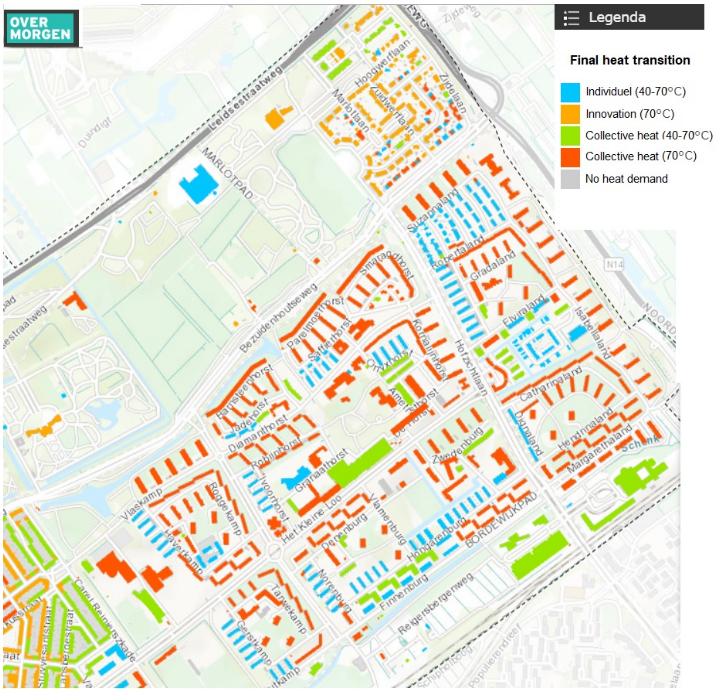


Figure 5.3: Graphical presentation of the short term heating solution for buildings in Mariahoeve (Overmorgen.nl, 2017). The red colored buildings are suitable to be connected to a middle temperature network and the green colored buildings to a low temperature network. The orange colored buildings need innovation before sustainable individual heating systems could be applied and the blue colored buildings are suitable for individual heating systems.

5.4.5. Conclusion of the preliminary studies

The study of TNO concludes that Mariahoeve can be made almost energy neutral. The study also includes the electricity demand of the neighbourhood. They state that more detailed study for heating system is required, particularly to investigate seasonal balance for heating. The IF technology study calculated the possible heating potential of geothermal wells in the city. The study of REBEL group is not completed yet, they work closely together with the energy transition team of Mariahoeve to make contact with residents, HA,HOA and companies. The study of CE Delft and Overmorgen explains which short-term solutions for heating buildings in Mariahoeve can be applied.

6 Heating demand of district

This chapter describes the first step of the developed approach: collecting the neighbourhood's parameters to determine the hourly heating demand per building in the neighbourhood.

The hourly heating demand of each building in the neighbourhood is needed to create more insight into the mismatch between supply and demand. The mismatch may have financial consequences in the future and it determines for a large part how efficient renewable energy sources are. Furthermore it determines how large buffers must be. To calculate the hourly heating demand of the buildings more insight into the neighbourhood and its heat consumption is needed. Municipalities need to know the ownership of the buildings so they know who they need to work with to transform the heating system. Furthermore they need to know the current state of the buildings and their current energy demand. The yearly energy consumption consumed by the buildings are given by their network operators in an online file at postcode 6 level.To preserve the anonymity of consumers the sum of at least 9 consumers are added in this postcode 6 data. It is therefore not possible to know the exact heat consumption per consumer, only the average heat consumption from the given postcode 6 data. The heating consumption at postcode 6 level is the yearly one. However for this study it is necessary to know the hourly heating consumption. In this chapter general steps to gain more insight into the current state of the buildings in a neighbourhood and its hourly heating demand will be given. To clarify how to implement these steps its application to Mariahoeve will be given directly. The general steps are:

1. Map the current energy label, year of construction and property ownership of the buildings in the neighbourhood
2. Determine the current energy consumption of the neighbourhood
3. Determine the typologies of buildings in the neighbourhood
4. Determine the theoretical hourly heating demand per typology
5. Calibrate the heating demand pattern

6.1. Map the current energy label, year of construction and property ownership of the buildings in the neighbourhood

The first step is to gain more insight into the current situation of the neighbourhood. What kind of buildings stand in the neighbourhood, who are the owners of these buildings and what are the properties of these buildings? Google maps can be used to easily form an idea of what the neighbourhood looks like and what kind of buildings stand in the neighbourhood. Before knowing the ownership of the building the property ownership type must be known.

As mentioned in section 2.2.5 the owners can be divided into three categories: the housing association (HA) and their tenants, the privately owners with home owners association (HOA) and the individual home owners. Municipalities have datasets of the buildings belonging to the HA, thus it is known which buildings belong to which HA. The buildings that do not belong to the HA either belong to HOA or individual home owners. The ownership of the buildings can be determined using Google maps and the following assumptions:

1. Apartments that do not belong to HA belong to private owners with HOA.
2. Single-family-homes that do not belong to HA belong to individual home owners.

To determine the current state of the buildings the energy label and year of construction of the buildings need to be known. It is important to know that an energy label can be certified or modeled. A building with a certified energy label is tested by an official firm and is therefore probably more accurate than a non-certified one. Not all buildings are officially tested and have a certified energy label. If not, then a building gets a modeled energy label and this can differ from the actual certified energy label. The year of construction of each building and the certified and modeled energy labels can be found in the open data tool PICO (Pico 2018a). In addition, the open data tool *energielabelatlas*(energielabelatlas 2018) can be applied to determine the certified and modeled energy labels of the buildings and the open data tool *EduGIS* can be used to determine the year of constructions of the buildings (Edugis.nl 2018).In future studies the energy labels should all be certified.

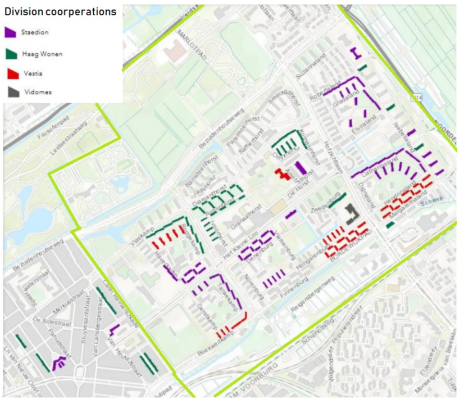
Applied to Mariahoeve

The open data *energielabelatlas*(energielabelatlas, 2018) is used to obtain the energy label of every building (figure 6.1). Approximately 85% of the buildings in Mariahoeve have a certified energy label. Most of the modeled energy labels are in the part: Marlot (87% of the buildings in Marlot have a modeled energy label). The second step is to determine the ownership of the buildings. The municipality of The Hague has a clear overview of which buildings belong to the HA (figure 6.2a). Google maps is used to check if the other buildings that are not belonging to the HA are apartments (and therefore privately owned with (HOA) buildings) or if they are single-family-homes (and therefore privately owned). To map the ownership of the buildings in the neighbourhood the buildings pictured in figure 6.1 are framed with different colors, each color represents an owner category.

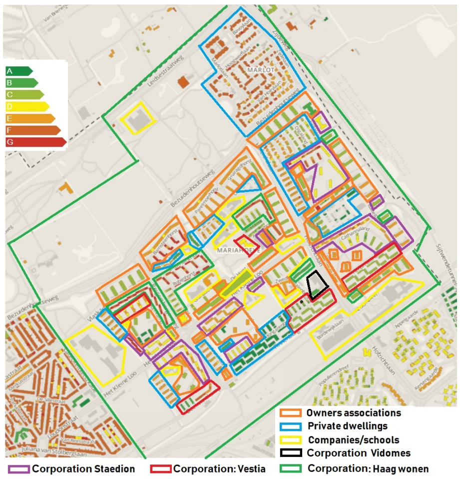
Figure 6.1: Energy label of the buildings obtained by *energielabelatlas*(energielabelatlas, 2018)

Figure 6.2b gives an overview of the energy label of each dwelling in the district Mariahoeve and the division of ownership of the buildings.

At last the year of construction of the buildings in Mariahoeve are obtained from *EduGIS* (Edugis.nl, 2018) (figure 6.3).



(a) The (HA) obtained by municipality the Hague



(b) Energy label of the buildings and division of buildings obtained by author and (energielabelatlas, 2018)

Figure 6.2: The (HA) as given by municipality of the Hague and the overall figure of the owners and energy labels of the buildings in Mariahoeve

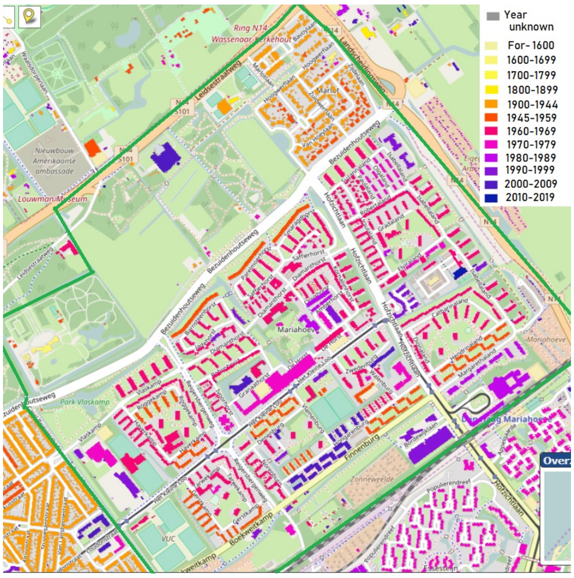


Figure 6.3: Year of construction of buildings in Mariahoeve (energielabelatlas, 2018)

6.2. Determine the current energy consumption of the neighbourhood

Every network operator publishes the energy consumption data of its small consumers yearly. This data contains both the electricity and gas consumption at postcode 6 level. A small consumer has a connection value for electricity smaller than 3x80 ampere and for gas a connection value smaller than G25 and a maximum transmission value of 40 m^3 gas per hour. The data gives the average amount of gas consumption per connection where one connection stands for one dwelling (single-family-house or apartment). Table 6.1 explains where to find these open data files.

Table 6.1: Links to generate open data of network operators (by author)

Network operator	Link open data	Last checked
Stedin	https://www.stedin.net/zakelijk/open-data/verbruiksgegevens	20-7-2018
Liander	https://www.liander.nl/partners/datadiensten/open-data/data	20-7-2018
Rendo	https://www.rendonetwerken.nl/algemeen/opendata/disclaimer/beschikbare-data/	20-7-2018
Coteq	https://coteqnetbeheer.nl/over-coteq/open-data/	20-7-2018
Enexis	https://www.enexis.nl/over-ons/documenten-en-publicaties/open-data	20-7-2018
Westland	https://www.westlandinfra.nl/over-westland-infra/open-data	20-7-2018
Enduris	https://www.enduris.nl/over-enduris/energietransitie/open-data.htm	20-7-2018

Besides buildings from small consumers, a neighbourhood also consists of big consumers. Big consumers, like offices, schools, hospitals or high-rise buildings with block-heating, are not included in the datafiles. However, it may happen that in apartment buildings with collective heating, data is present in the small consumer file. This happens when individual apartments are still connected to the gas grid for DHW and/or cooking. The space heating demand of these big consumers needs to be added to the data to gain an overall overview of the heat consumption of the neighbourhood. Statistically, there will always be unrealistic values in data sets. Before using the data from the network operators, the data needs to be cleaned up. The following steps are followed:

a Use the online data tool PICO to determine which buildings belong to the different postcode at postcode 6 level (Pico, 2018a). *Point of author: "Some high-rise buildings are linked with multiple postcodes"*

b Determine how many connections have a gas consumption lower or higher than a certain threshold. In this study lower than 300 m^3/year and higher than 10000 m^3/year was taken. Buildings with a gas consumption lower than 300 m^3/year are probably large consumers and the given amount of gas consumption is only for heating DHW and/or cooking and not for space heating. If a building gives an unrealistic value for space heating the data can be cleaned using the next assumptions:

- Assumption 1: If a building has multiple postcodes and one of the postcodes gives a realistic gas consumption, than the other (unrealistic) postcodes will have the same values as the realistic one.
- Assumption 2: If a building has an unrealistic gas consumption for space heating, but another building (with the same year of construction and building style) has a realistic value, than the unrealistic building will have the same value as the realistic building.

c Use the online data tool PICO to check if every postcode is given in the online data from the network operator. If not, add the missing data from the data given by PICO (PICO also gives gas consumption gained from the open data from the network operator) (Pico, 2018a).

Once these steps have been followed, the overview of the yearly heat demand per building can be actualized.

Applied to Mariahoeve
The network operator in Mariahoeve is STEDIN. Therefore the online data from STEDIN can be used to determine the yearly heat demand of the neighbourhood. It is known that most high-rise buildings of the HOA have collective block heating and are therefore large consumers. The high-rise buildings of the HA Steadion use individual heating and therefore have realistic space heating value. Some of their building are heated with collective block heating. All the high-rise building of the HA of Haag wonen are individually heated, as well as all the high-rise buildings of the HA Vestia. The data from STEDIN consists of 386 postcodes and 238 of these postcodes had a realistic value for the gas consumption for space and DHW heating. 148 postcodes needed to be cleaned up. 13 of postcodes of this data could be cleaned by assumption 1 and 135 postcodes by assumption 2. The

following data is gathered:

Table 6.2: Heating demand for the buildings in Mariahoeve and distribution of dwellings per label and per construction year (results of steps 1 and 2) (by author)

Kind of building	Gas demand [$*10^6 m^3$]	Heat demand [TJ]	Amount dwellings linked	Label A	Label B	Label C	Label D	Label E	Label F	Label G	Label Unknown	Built before 1965	Built 1970 1979	Built 1980 1989	Built 1992 2019
HA Staedion	1.9	65.12	1748	0	71	225	635	681	136	0	0	1580	0	0	168
HA Haag wonen	1.00	36.42	943	0	55	271	53	0	286	278	0	831	0	57	55
HA Vidomes	0.02	0.76	26	0	26	0	0	0	0	0	0	26	0	0	0
HA Vestia	0.7	24.02	690	0	43	451	32	125	39	0	0	658	0	32	0
Individual home owners	2.5	86.78	1114	206	27	147	47	307	319	42	19	709	60	20	325
Privately owned with HOA	4.24	157.2	3975	0	78	245	818	2319	431	84	0	3499	233	152	91
Offices/ schools/ hospitals	0.7	25.9	223	5	1	5	0	0	0	0	212	163	36	19	5
Sum	**11**	**396.2**	**8719**	**211**	**301**	**1344**	**1585**	**3432**	**1211**	**404**	**231**	**7466**	**329**	**280**	**644**

The primary energy of 1 M^3 gas is equal to 35.17 MJ heat. The total heating demand for the district Mariahoeve is 396 TJ per year.

6.3. Determine the typologies of the buildings in the district

Once the yearly heating demand, year of construction and energy label of the buildings are determined the hourly energy demand per building can be calculated. However, in order to do so, it is necessary to know what type of buildings are standing in the neighbourhood.

The type of building has influence on the heat demand of the building. The European project EPISCOPE supports the energy transition in the housing sector by creating more insight into building typologies of different European countries and the effect of energy savings per building(EPISCOPE, 2016b). The building typologies of the Netherlands can also be found in this project (EPISCOPE, 2016a). Generic information per building typology can also be found in (NL, 2011a), including the average amount of glass, surface area and the corresponding RC-values and U-values of the type of buildings. In combination with Google Maps, these studies can be used to create insight into the type of buildings in the neighbourhood. A detailed typology is not needed. Only the main characteristic relevant to energy use have to be determined.

Applied to Mariahoeve

In Mariahoeve three types of buildings are common. These main types are generated by the author using Google maps. The building types of (EPISCOPE, 2016a) are not used, because in Mariahoeve there are only three different main types, thus it was easy to construct the typology without using (EPISCOPE, 2016a). The first type of building is high-rise buildings with four to six floors. The second type of building is high-rise buildings with more than six floors and the third type of building is low-rise buildings.

Table 6.3: Number of types of buildings in Mariahoeve (by author)

	Type 1: high rise buildings with 4-6 floors (+/- 32 apartments)	Type 2: high rise buildings with more than 6 floors (+/- 54 apartments)	Type 3: low-rise buildings
Amount of buildings in Mariahoeve	154	53	1387

Typology 1: high-rise buildings with 4-6 floors

The first types of building consist of high-rise buildings with four to six floors. One flat has approximately 32 apartments. Figure 6.4 gives an overview of the dimension of these buildings.

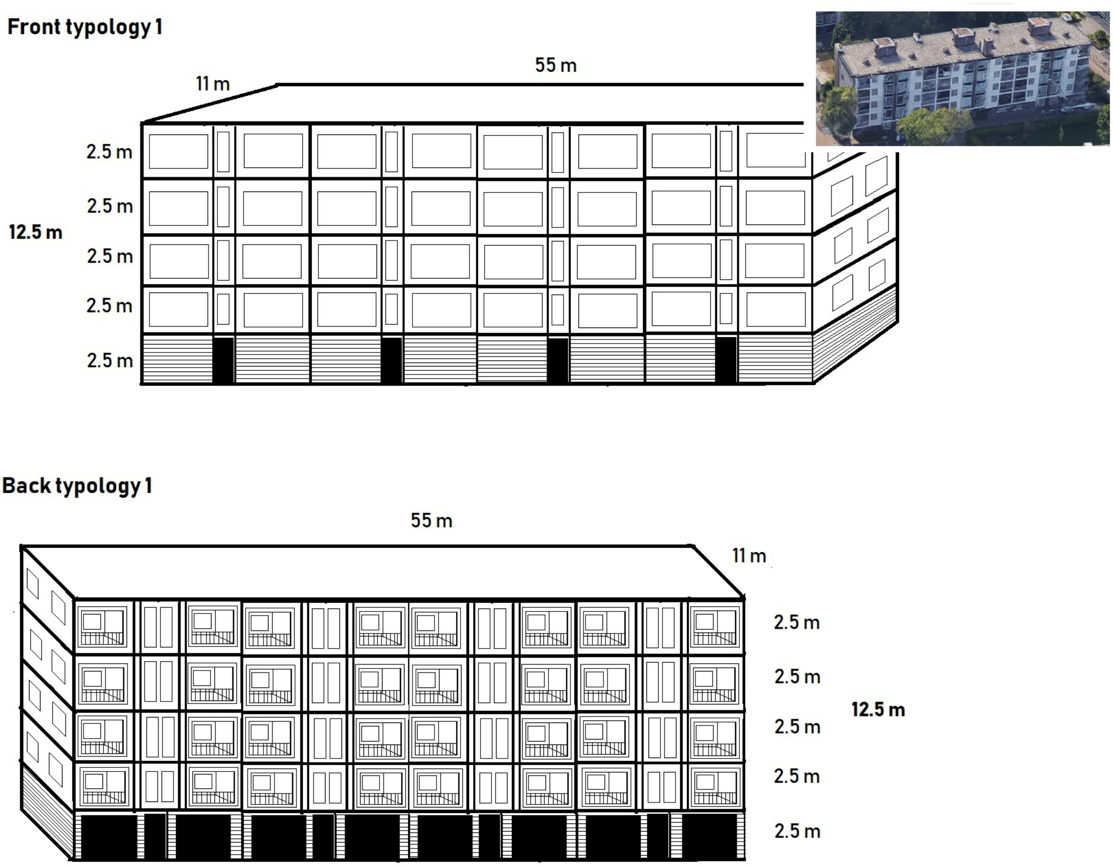


Figure 6.4: Dimensions of the first typology building(by author)

Typology 2: high-rise buildings with more than 6 floors

The second type of building in Mariahoeve are high-rise buildings with more than 6 floors. Figure 6.5 gives an overview of the type of building of the second typology. The building consists of approximately 54 apartments.

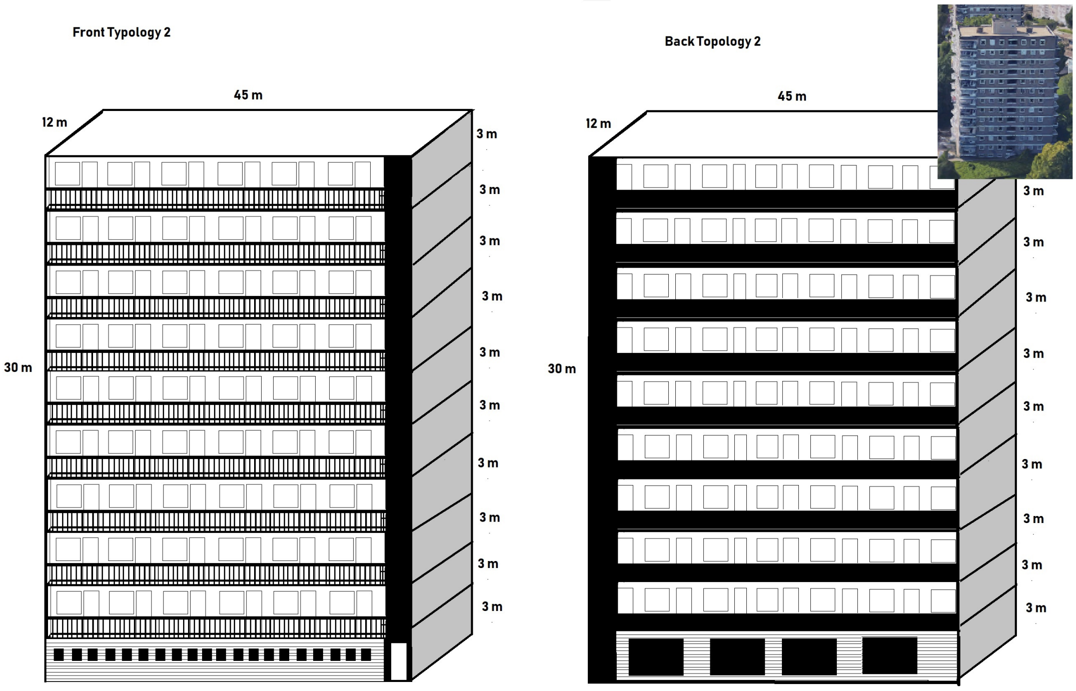


Figure 6.5: Dimensions of the second typology building (by author)

Typology 3: Low-rise buildings The third type of building is low-rise buildings (figure 6.6). These buildings consist of an average of four households per block.

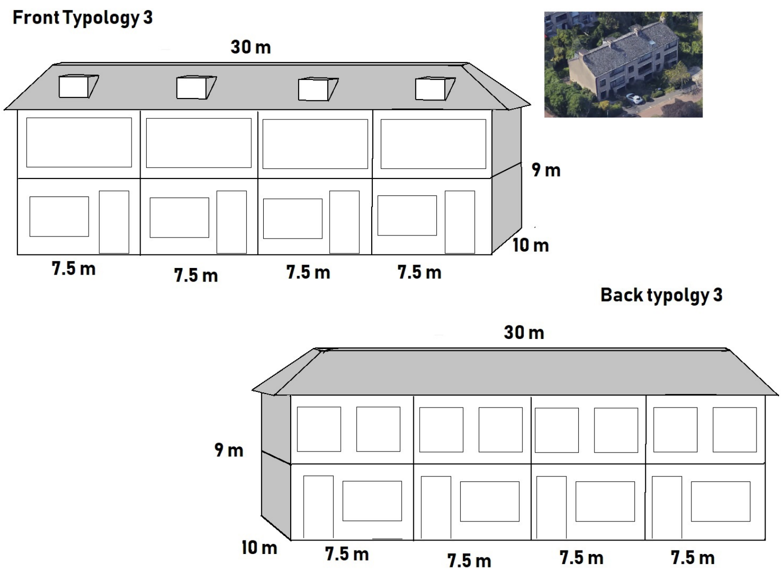


Figure 6.6: Dimensions of the third typology building (by author)

6.4. Determine the theoretical hourly heating demand per typology

Once the building typology is mapped the theoretical hourly heating demand can be estimated. To estimate the hourly space heating demand a BES calculation model is used. Many different BES models can be used, for example simple steady-state models as used in energy labeling software, or more precise dynamic ones like energy+, TRNSYS or LEA. In this study a simply steady-state excel model[1] is used for the sake of demonstration and its simplicity. This model calculates the space heating demand of a building by looking at the heat losses and gains in the building and by looking at the occupancy of people in a building. It calculates the space heating demand with the following formula:

$$Q_{balance} = -(Q_{trans} + Q_{inf} + Q_{vent}) + Q_{sol} + Q_{int}[W] \tag{6.1}$$

Where Q_{trans} stands for the transmission losses. This includes the transmission losses from the windows, floors, walls and roofs of the building, taking into account the hourly difference between the outdoor temperature and the desired indoor temperature. Q_{inf} stands for the infiltration losses and Q_{vent} for the ventilation losses, which also depend on the amount of people in the building. Q_{sol} stands for the solar heat that goes into the building and Q_{int} stands for the increase of internal heat in the building due to the amount of people, lighting and appliances in the building. The solar heating and outdoor temperature are given by the Reference Climate year of '64-'65. This is outdated data and should be updated when further studies are done. It is good to keep in mind that the hourly space heating demand depends on the occupancy of the people in the building which differs between buildings and can only be determined statistically. Therefore, the outcome of this model is also theoretical. In the future, the software used could be replaced by data from smart meters in dwellings or other more advanced software.

The model calculates the hourly space heating demand, taking the surface amount of floor, walls, roofs, windows and their thermal resistance values into account. The magnitude of these surface areas depends on the type of building. The resistance value of the floor, walls, roofs and windows are depending on the year of construction of the buildings. These different resistance values can be found in (ISSO, 2015). Meaning that, to know the amount of surface area, the type of the building is required and to know the resistance value of the building, the year of construction of the building is required. The years of construction are categorized as before 1965, between 1975-1983,between 1983-1988 and between 1992-2014 (same categorization as in ISO-publication 82-1, section 6.6.6. (ISSO, 2015)). It is important to keep in mind that only the space heating per hour is calculated with this model and that it does not give insight into the hourly DHW heating.

Applied to Mariahoeve

In this study an average of two inhabitants per dwelling is assumed. The year of construction of each building in Mariahoeve was already determined in the previous step. The hourly heating demand is constructed by looking at the type of building (one of the three predefined typologies) and the year of construction of the building which determines the resistance values of the floor, wall, roofs and windows.

As an example an energy pattern for a dwelling in Mariahoeve with typology 1 (high-rise building, with four floors) built before 1965 will be given (figure: 6.7). The resistance values for the wall, roof, floor and windows are respectively 0.19, 0.22, 0.15 and 2.9 $m2K/W$. The building has 24 apartments.

[1] This model is currently being used in courses at TU Delft (4413UEINFY and AR0097).

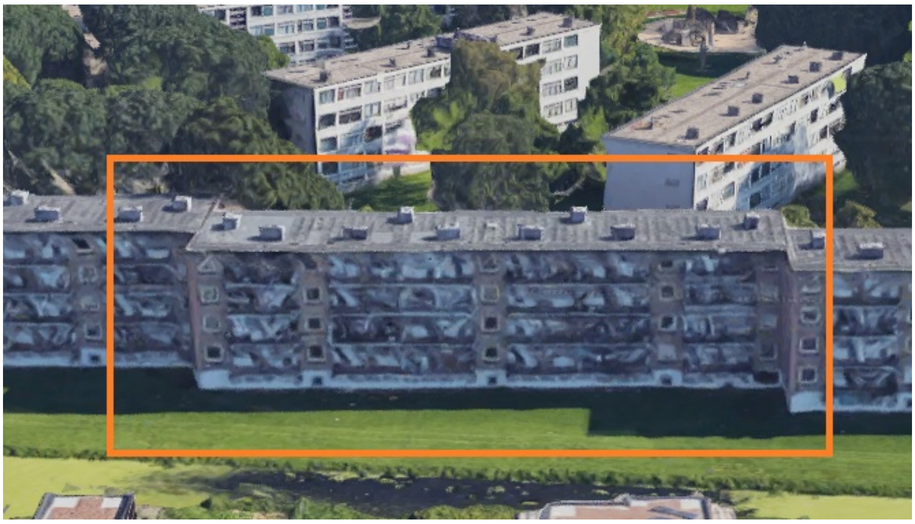


Figure 6.7: The example building to determine the energy pattern for buildings of typology 1 built before 1965 (by author and google maps)

Implementing the parameters of this building in the calculation model gives the following theoretical hourly heating demand all over the typical climate year de Bilt 64-65:

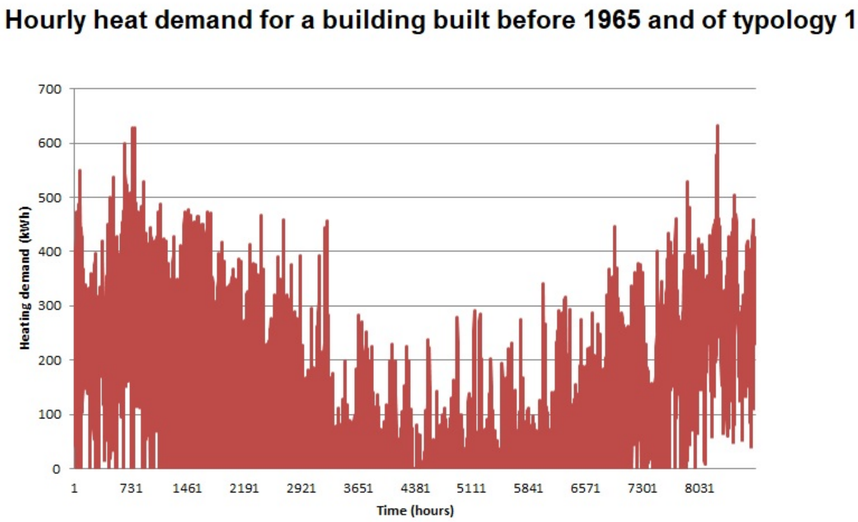


Figure 6.8: The hourly heat demand during one year for a building built before 1965 of typology 1 (by author)

This calculation is done for each categorized year of construction . Meaning that for each type of building in Mariahoeve, four different hourly heating patterns are calculated, depending on their year of construction.

6.5. Calibrating the heating demand pattern

The hourly energy demand as calculated in the previous step is a theoretical demand. The sum of all the hourly demand over one year should be the same as the actual yearly demand as given by the data of the network operator minus the heating demand for DHW. This is not the case and therefore the hourly energy demand needs to be calibrated. A distinction between the hourly space heating and the hourly DHW heating is made.

6.5.1. Hourly heating demand for space heating

The sum of the estimated hourly space heating demand must be the same as the sum of the actual heating demand given by the network operator minus the heating demand for DHW. It is known that an average household uses around 375 m^3 (13185 MJ) gas for heating DHW(Menkveld, 2009) yearly . Differences between theoretical and actual energy demand have been shown to arise mainly from wrong values of indoor temperature or wrong RC-values (Majcen, 2016). Furthermore, the consumption data given by the network operators are the so-called SJV values, meaning that the actual gas use are corrected for degree days and recalculated with a standard climate year(SJV). It may be that the network operator used another climate year for their SJV values as the used climate year of '64-'65 in this study. This could also result in a difference between the actual heating demand given by network operators and the calculated heating demand by the BES model. In this study it is decided to change the sum of the estimated hourly space heating demand by changing the indoor temperature. The RC-values are parameters that are linked to the building and when changing these values in the calculation model you change the type of the building, which is undesirable. The indoor temperature parameter does not depend on the building and can therefore be changed easily without changing the type and year of construction of the building.

6.5.2. Heat demand for domestic hot water(DHW)

One study was found (Friedel et al., 2014), in which a hourly DHW heating pattern per day for a two-person household was described (figure A.22).

This hourly demand pattern can be copied to the hourly heating demand for space heating to create a total hourly heating demand.

It is essential to keep these two hourly heating demands separated for further energy saving calculations. Increasing the insulation of a building will only have influence on the hourly space heating demand and not on the DHW heating demand. Therefore it must be made possible to change the hourly energy demand for space heating without changing the DHW heating demand.

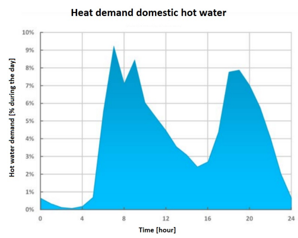


Figure 6.9: Demand of domestic hot water per hour over a day (Friedel et al., 2014)

Applied to Mariahoeve

We continue with the example started in subsection 6.4, where the hourly space heating demand was calculated for one of the buildings (typology 1). The sum of this calculated hourly energy demand is 517590 kWh. The actual average heating demand of each apartments in the building given in figure 6.7 is 1147 m^3 per year (as given by cleaned data from network operator). This is the heating demand for both space heating and DHW heating. The average heating demand for only space heating becomes 772 m^3 per year. This gives a total gas demand for the whole building of 18528 m^3/year which is equal to 181008 kWh/year (on the basis of a gas specific heat of 9.78 kWh/m^3). Thus, the sum of the hourly data of the calculation model must be changed from 517590 kWh to 181008 kWh. This is achieved by changing the indoor temperature in the calculation model from 20 degrees to 10.67 degrees. This changed indoor temperature is an average indoor temperature including non-heated spaces and night lowering. It is good to keep in mind that although it is not realistic, it can be seen as an overall correction factor allowing to get realistic time patterns. This gives the following hourly heating pattern for buildings of type 1 built before 1965:

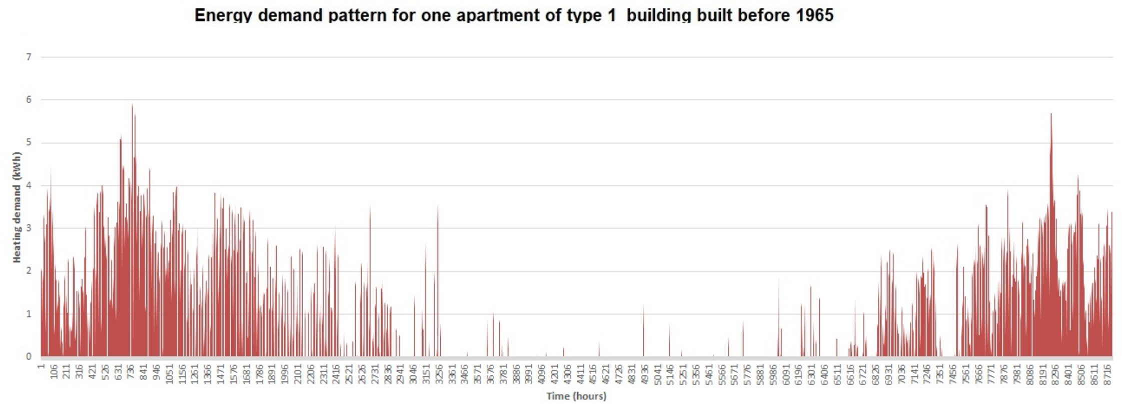


Figure 6.10: The energy pattern for a apartment in building type 1 built before 1965 (by author)

As explained in appendix A.2 the heat demand pattern for one dwelling for heating DHW is as follows:

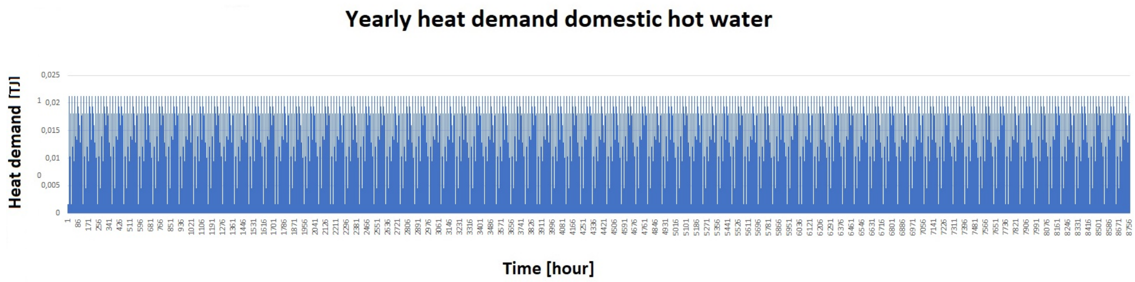


Figure 6.11: Demand of domestic hot water for a year (Friedel et al., 2014)

Adding these two patterns give the actual hourly heating demand for a dwelling.

This calibration is done for every type of building with different years of construction. These calculations can be found in Appendix A.1. With the calibrated heating pattern for each building type the total hourly heating demand for the whole neighbourhood can be calculated:

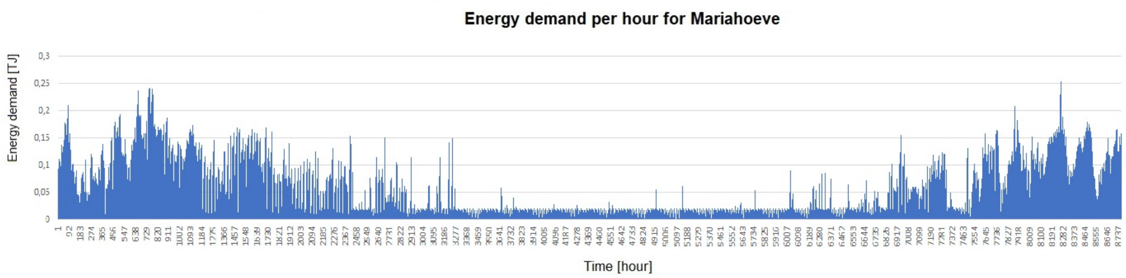


Figure 6.12: Energy pattern of all the buildings in Mariahoeve (By author)

7

Heating potential in neighbourhood

This chapter demonstrates the second step of the developed approach: calculating the hourly potential of renewable energy sources located in the neighbourhood using the EPM methodology. The same structure as the previous chapter is used. First the solar potential of the neighbourhood will be specified, followed by the biowaste potential. Subsequently the geothermal potential is calculated and at last the waste heat potential is calculated.

7.1. Solar potential

To calculate the solar potential of a neighbourhood it is necessary to know the global radiation in this neighbourhood. Global radiation is the sum of diffuse and direct sunlight and this differs per hour. To calculate the hourly energy potential in the neighbourhood the global radiation, as given in the reference climate year deBilt '64-'65, is used. This is outdated data, but because the calculations for heating were also made with this data it will also be used to calculate the solar potential. For further studies it is recommended to use data from the new climate year (NEN5060).

There are different ways to obtain solar energy in a neighbourhood. PV panels and solar collectors are both technologies that can be placed on a roof and generate energy. The biggest difference is that PV panels generate electricity while solar collectors generate warm water. Since both technologies require roof surface area they compete with each other. The benefit of a solar collector is the higher efficiency and the lower investment costs. However with a PV panel more money can be saved, due to lower electricity costs(Greenhome, 2017). The use of PV panels in combination with a heat pump could result in an all-electric house. This is a popular option for heating individual owned buildings. It is also possible to use a hybrid PV panel. This system generates both heat and electricity. The downside of this system is that the costs are higher and the electricity efficiency lower.
Another way of obtaining solar energy is with an asphalt collector. This technology consists of heat spirals beneath the asphalt surface. During the summer the asphalt is heated and the water spirals beneath the surface are heated up. This system is only interesting when storage is used. However, according to (S.Broersma et al., 2013) even though the temperature of the asphalt can become around 60 ^0C in the summer, the outlet temperature in the pipes will be a lot lower. When the heat is stored during the summer the maximum stored temperature is around 20 ^0C. The efficiency of asphalt collectors are lower compared to solar collectors (S.Broersma et al., 2013). It is assumed that a road could deliver 0.4 GJ$/m^2$, which equals an average efficiency of 11%. An interesting application of this system is in combination with an ATES system. The heat coming from the asphalt could be stored in the warm well of the ATES system during the summer to heat dwellings throughout the winter.

PV Panels

To calculate the potential of solar energy when PV panels are applied the following formula can be used:

$$E_{\mathrm{PV}_{panels}} = A * \eta_{panel} * S \tag{7.1}$$

A stands for the available rooftop surface area $[m^2]$, S for the hourly global radiation on horizontal plane $[J/m^2]$ and η for the efficiency of the panel (around 19%).

The available rooftop surface area determines how many PV panels can be placed. Google maps and the online data tool PICO can be used to determine the rooftop area (Pico, 2018a). According to (S.Broersma et al., 2013) only 29% of the total roof surface is available for PV panels or solar collectors. This percentage takes into account the limiting factors like public acceptation, orientation and exclusion because of windows, chimneys etc.
The orientation of the panel has influence on the power outcome of the PV panels. The efficiency of the panel can drop if it is not placed correctly. Table 7.1 shows an overview of the efficiency drop depending on the orientation of the panel. The PV panels perform best when placed faced south under a slope of 36 ^{0}(Centraal, 2017). The potential of the PV systems depends on the type of roof.

Table 7.1: Efficiency of PV panel depending on the orientation of the panel (Centraal 2017)

Orientation of panels	Slope of the panels						
	10 ^{o}	20 ^{o}	36 ^{o}	50 ^{o}	60 ^{o}	70 ^{o}	85 ^{o}
West	90 %	90%	85%	80%	75%	70%	65%
South-west	95%	95%	100%	95%	90%	85%	80%
South	95%	100%	100%	100%	95%	90%	80%
South-East	95%	95%	95%	95%	90%	85%	80%
East	90%	90%	85%	80%	75%	70%	65%
North-East	85%	80%	70%	60%	55%	50%	45%
North	85%	75%	60%	50%	45%	40%	35%
North-West	85%	80%	70%	60%	55%	50%	45%

Solar collectors
To calculate the potential of the solar collectors the following formula applies:

$$E = A * S * \eta_{collector} \tag{7.2}$$

With A, being the amount of available rooftop area, S the global radiation per hour in $[J/m^2]$ and a potential $\eta_{collector}$ of 35% (S.Broersma et al., 2013). Again, the roof type determines the maximal potential of solar collectors.

Asphalt collectors
To calculate the potential for asphalt collectors the following formula can be used:

$$E = A_{road} * S * \eta_{road} \tag{7.3}$$

With E, being the energy from the asphalt collectors, S the global radiation per hour in $[J/m^2]$ and η_{road} of 11%. Its good to keep in mind that this technology is not often applied. This system is only usable when seasonal storage is included and only usable for low energy demand buildings(due to the low outlet temperature).

Applied to Mariahoeve
Available roofs

Figure 7.1: The amount of roof surface in Mariahoeve (Pico, 2018b)

GIS platform PICO (Pico, 2018b) is used to determine the amount of roof surface in Mariahoeve. It is assumed that if a roof area is flat, 80% of the area is applicable for panels or collectors. If the roof area has a slope, only 29% is applicable. The total available roof surface in Mariahoeve is around 180 000m^2. Around 20 km of road surface is available with a width of 6 meters .

PV Panels potential

To compute the maximum potential of PV panels it is assumed that the panels are oriented as efficiently as possible, resulting in no efficiency losses. This leads to the maximum theoretical potential of PV panels in Mariahoeve. If a rooftop area is flat, the maximum potential can be reached because it is easy to orientate the panel freely on a flat rooftop. However, on a sloped roof it depends on the orientation of the roof which orientation the panel has. Assuming a maximum potential for a sloped roof is not very realistic and in further studies an in dept study of the orientation per sloped roof is needed. The hourly solar production per year is:(figure 7.2):

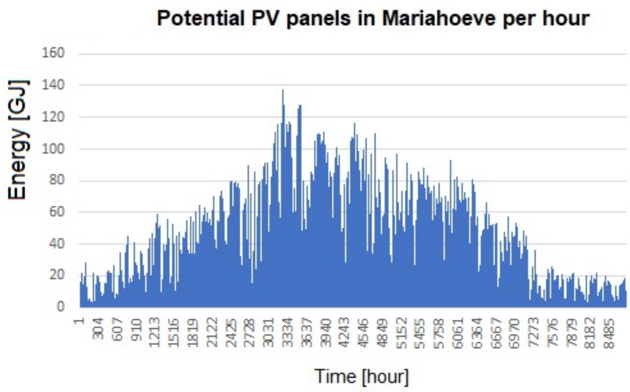


Figure 7.2: Energy potential of PV-panels in Mariahoeve per hour (by author)

The total energy potential of the PV panels is 101 TJ per year. In this study 6% of the total roof surface area comes from sloped roofs meaning that 6% of the data could have a lower efficiency.

Solar collectors potential

For the potential of solar collectors the maximum efficiency is assumed. This gives the following energy potential per year:

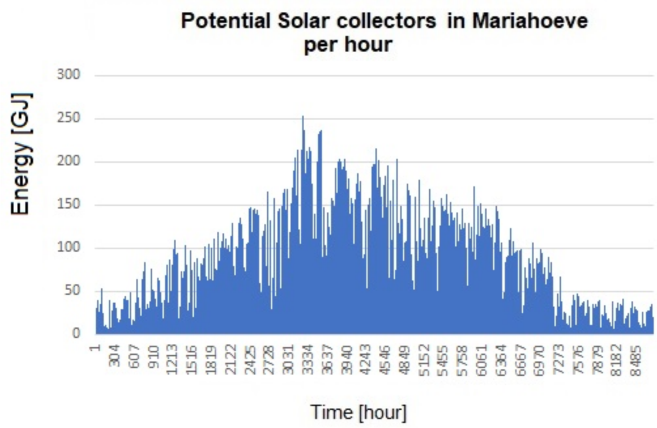


Figure 7.3: Energy potential of PV-panels in Mariahoeve per hour (by author)

The total energy potential in a year is 186 TJ. However, this can only be obtained at the expense of the PV-panels potential.

Asphalt collectors

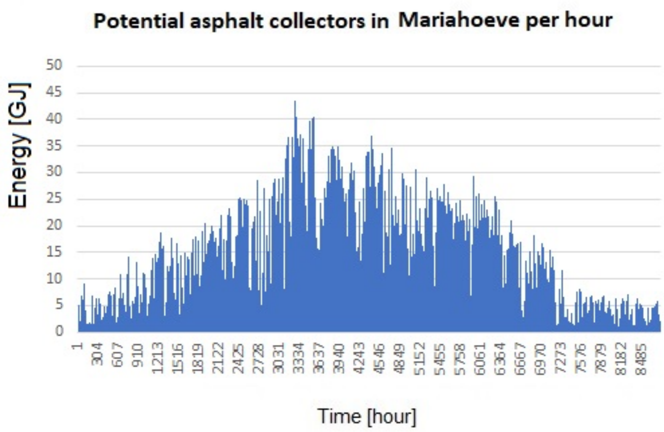


Figure 7.4: Energy potential of asphalt collectors in Mariahoeve per hour (by author)

The total energy potential of the solar asphalt collectors in Mariahoeve is 39 TJ per year, taking into account that there is 20 km of roads in Mariahoeve with an average width of 6 meters according to a preliminary study of TNO. However, because the outlet temperature of this system is too low for the average household in the neighbourhood this technology will not be taken into account.

7.2. Biowaste potential

As mentioned in section 2.3.2 energy from biomass can be generated from different feedstocks. In this study the potential of energy from wood rest, biodegradable waste, green waste, manure and sewage treatment plants is calculated. Only feedstocks that are produced in the area of Mariahoeve are used for generating heat, with one exception: energy from sewage treatment plants. The overall potential of biomass could be higher if feedstocks from other neighbourhoods are taken into account to generate heat for one neighbourhood. This will not be considered in this study.

7.2.1. Wood rest

To estimate how much energy can be received from wood it is needed to know how much green forest is available in a neighbourhood. The harvested part of a forest is around 8 $\frac{m^3}{ha}$ where 50% is dry and can be collected for the energy process. 60% of this collected wood is suitable to generate energy. The energy content of dried wood is 19 GJ/ton.

Applied to Mariahoeve
In Mariahoeve there is a relative large area of forest (1.22 km^2 or 122.4 ha). According to (S.Broersma et al. 2013) one can calculate the energy from forest area as follow:

Table 7.2: Energy from wood from forest (by author)

Forest area (ha)	122.4
grow/ha	8 (m^3/ha)
% dry wood	50
Amount of dry wood	489.6 ton of d.w.
Energy per ton	19 GJ
Harvestable part (%)	60
Energy from forest area for Mariahoeve	5581.44 GJ
Energy per ha for whole district	18.62 GJ/ha

Thus, with the area near the district of Mariahoeve 5.6 TJ could be harvested.

7.2.2. Biodegradable and green waste

Bio energy can also be harvested from residential green waste. How much biodegradable waste residents produce depends on the kind of living environment. This can be non-urban, hardly-urban, mediocrity-urban, strongly-urban and very strongly urban. The type of environment determines how much green waste per kg per inhabitant could be generated. Data from CBS gives more insight into the amount of waste generated per inhabitant (CBS, 2016). There are three types of waste a person generates; biodegradable waste consisting of vegetables, fruit and garden waste, coarse garden waste and wood waste. 50% of coarse garden is bio degradable waste, all of which is fermentable. The other 50% of coarse garden consist of wood. Of the fermentable waste the biogas production is 100 m^3/ton. The energy content of biogas is 23 GJ/m^3. Thus, if the amount of production of fermantable waste in kg is known, the energy one can generate from this waste can be estimated. To calculate the energy coming from wood, the same method applies.

Applied to Mariahoeve
Mariahoeve is a very urban area. The data of CBS (CBS, 2016) states that on average in a very urban area an inhabitant produces 22 kg of biodegradable waste consisting of vegetables, fruit and garden waste per year. Furthermore, it produces 5 kg of coarse garden waste and 14 kg wood per year. The same assumption as made in the study of (S.Broersma et al., 2013) are made, meaning that all the biodegradable household waste is fermentable, 50% of the coarse garden is wood and 50% is fermentable. This means that in The Hague, per citizen 24.5 kg waste is fermentable and 16.5 kg waste consist of wood. Additionally, (S.Broersma et al., 2013) states that the biogas production is 100 m^3 per ton waste and the energy content of biogas is 23 GJ per m^3. From section 7.2.1 it is known that the energy content of dry wood is 19 GJ per ton. Thus, the energy from household waste is as follows:

Table 7.3: Energy from waste households (by author)

Population Mariahoeve	13718 (2014)
Fermentable production	24.5 (kg/inhabitant)
wood waste	16.5 (kg/inhabitant)
total fermentable production	336.091 ton
total wood waste	226.347 ton
Biogas production	100 m^3/ton
Energy content biogas	23MJ/m^3
Energy content wood	19 GJ/ton
Harvastable part from wood energy	60%
Energy from biogas	773 GJ
Energy from wood waste	2580.35 GJ

The energy produced yearly from biogas yields 0.78 TJ and the energy from the wood waste from households is 2.6 TJ.

7.2.3. Manure from city farms

If a neighbourhood has a city farm, energy can be generated from the manure produced by the animals living in the city farm. Different kind of animals produce different amounts of biogas. The study of (N.Verdoes et al., 2013) gives an overview of different kinds of animals and their biogas production.

Applied to Mariahoeve

In Mariahoeve there is one petting zoo. According to (Broersma et al., 2011) the amount of manure produced yearly per animal type is known. Every type of manure has its own energy potential. After a telephone conversation with the petting zoo the amount of animals are known. There are 6 goats, 7 sheep's, 2 cows, 2 rams, 5 rabbits and eleven chickens. Besides the two rams all the animals are female. The collected manure could be used to fertilize the ground, however in this study the aim is to generate renewable heat, therefore it is assumed that all the manure is collected and fermented. With the data given in (N.Verdoes et al., 2013) the amount of energy can be calculated.

Table 7.4: Potential city farms (by author)

Type of animal	Data given by (N.Verdoes et al., 2013)		Amount of biogas per animal [m^3/animal]	Amount of animals in petting zoo	Energy content biogas [MJ/m^3]	Energy content [GJ]
	Amount	m^3 biogas				
Cattle	94921	24798620	261.26	2	23	12.02
Cheeps and goats	14881	370275	24.88	15	23	8.6
Rabbits	29422	58844	2	5	23	0.23
Chickens	6761043	15888451	2.4	11	23	0.607
					Total	21.5

Table 7.4 states that 0.02 TJ could be produced by the petting zoo if all the manure would be collected and fermented.

7.2.4. Sewage treatment plant

Sludge from a water treatment plant can be fermented to biogas(Blom, 2018). The highest amount of energy could be generated when grey and black water are collected separately, because black water contains a lot of organic matter that can be fermented to biogas. One person produces 13 liters of methane per day which gives, when fermented at 20 ^{0}C, 189MJ per year per person(Blom, 2018). The treatment plant needs a part of this energy for its treatment process. 25% of the produced gas can be used as energy supplier for district heating. The amount of biogas produced from sludge depends on the amount of inhabitants connected to the treatment plant and is independent of the amount of inhabitants in a neighbourhood.:

$$E_{biogas} = \texttt{inhabitants connected to plant} * 189MJ * 25\% \tag{7.4}$$

Applied to Mariahoeve

In the area of the district Mariahoeve, The Hague, there are two sewage treatment plants:*Defluent Houtrust* and *Defluent: Harnaschpolder*. The amount of inhabitants connected to the Hanaschpolder plant is 1.26 million and 0.39 million for the Houtrust plant. Table7.5 gives the amount of biogas produced for the district. For Mariahoeve this could be 77.96 TJ if both plants were used. The municipality has decided it will only use the heat produced by the biogas coming from the Houtrust plant (the so called *warmterivier*)

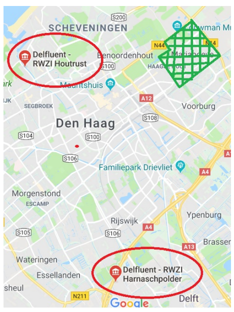


Figure 7.5: Sewage treatment plants in the area of the district Mariahoeve (by author)

Table 7.5: Energy from sewage treatment plant (Delfluent 2018a) & (Delfluent 2018b)

	Number of Connected residents ($x10^6$)	Amount of biogas produced per year[TJ]	Amount of biogas for the district [TJ]
Harnaschpolder (Delfluent, 2018a)	1.26	238.14	59.53
Houtrust (Delfluent, 2018b)	0.39	73.71	18.43
Total	1.65	311.85	77.96

Techniques for processing biomass

Different feedstocks can be used to determine the heat potential of a neighbourhood. However, biomass is an energy carrier that has to be processed before it can be applied for heating buildings in a neighbourhood. In this study two process techniques are considered: The burning of biogas in a CHP plant producing electricity, and heat and the burning of wood in a heat only boiler producing only heat.

CHP plant

When biogas is burned in a CHP plant around 38% of the energy is converted into heat and around 62% into electricity (DHV, 2012). The heat that can be produced from biogas in a CHP plant is calculated as follow:

$$E_{heatfrombiogas} = E_{biogas} * 0.38 \tag{7.5}$$

Heat only boiler

Wood is burned in a bio-energy plant and can be turned into electrical energy and heat or into heat only. In this study wood is used as fuel for heat-only boilers which produce only heat for district heating. The efficiency of this kind of plant is around 90%. Therefore the heat coming from burning wood can be calculated as follow:

$$E_{heatfromwood} = E_{wood} * 0.90 \tag{7.6}$$

Applied to Mariahoeve

Table 7.6 shows the total potential energy of the biowaste in Mariahoeve. A division is made between energy from biogas and energy from wood. This is because these two different energy carriers need two different processing techniques to generate heat. Wood will be burned in a boiler and the released heat can be sent to a district network. The biogas can be burned in a CHP plant and the product will be electricity and heat. The released heat will be used in the district network. When the sewage treatment plant of *Houtrust* is used only the potential of heat will be taken into account.

Table 7.6: Overview potential biomass (by author)

Type	Energy biogas [TJ]	Energy wood [TJ]	Total Energy [TJ]
Wood		5.58	5.58
GFT and green waste	0.77	2.58	3.35
Manure from petting zoo	0.0215		0.0215
Sewage treatment plant	18.43		18.43
Total produces biogas and wood	19.22	8.16	27.38
Total heat produced	7.36	7.34	14.7

Thus, 7.36 TJ of heat can be generated from biogas and 7.34 TJ from wood. It is assumed that the the production of heat from biowaste is continuous over the whole year. This result in the following hourly heating potential from wood and biogas:

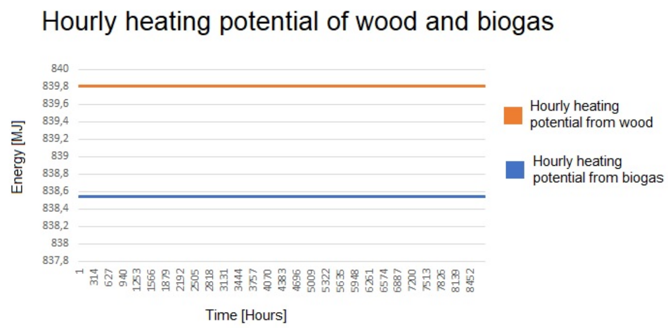


Figure 7.6: Hourly heating demand biomass from wood and biogas (by Author)

7.3. Geothermal potential

Different systems for generating geothermal energy in a neighbourhood can be implemented(see also section 2.3.2): doublet geothermal system, ATES system or GSHP system. Doublet geothermal systems generate heat for a whole neighbourhood, ATES systems for offices, supermarkets, block-buildings or apartments that also have high cooling demand, and GSHP for single-family houses.

First the doublet geothermal potential will be determined, followed by the potential of the ground source heat pump system and finally the ATES system.

7.3.1. Doublet geothermal potential

To calculate how much energy a geothermal doublet can produce it is necessary to understand what the potential of the area is where the doublet is placed, and the energy potential of the doublet itself. The geothermal potential is based on, amongst other parameters, permeability, thickness and the depth of the geothermal reservoir. ThermoGIS program can be used to find the position with highest potential in the area of the neighbourhood (TNO, 2013). The lifespan of a geothermal doublet is around 30 years and only 30-50% of the heat in an area can be harvested.

The power of one doublet can be calculated as follow (H.M.Nick, 2017)[1]:

$$P_{doublet} = \rho_w C_w Q(T_{production} - T_{injection}) \tag{7.7}$$

With ρ_w, being the specific density of water, around 1000 $[\frac{kg}{m^3}]$. C_w, the specific heat of water, around 4200 $[\frac{J}{kg^0C}]$ and Q, the flow rate. According to TNO the $T_{injection}$ for spatial heating is assumed to be 40 ^{0}C. $T_{production}$ depends on the average surface temperature and the geothermal gradient. The geothermal gradient is the rate of increasing temperature with respect to increasing depth, which is 30 ^{0}C/(km depth) in the Netherlands. $T_{production}$ can be calculated as follows:

$$T_{production} = T_{averagesurface} + \Delta T * depth \tag{7.8}$$

Applied to Mariahoeve
In a preliminary study, a quick-scan was made for the municipality of the Hague to determine the amount of geothermal energy that can be produced (see section 5.4.2).

This preliminary study states that at a depth of 1.5-2.5 km there is a suitable sand layer (*Delft Zandsteen*) which has a good permeability and sufficient heat (60-80 degrees) (

[1] Source from Blackboard (not publicly accessible)

Willemsen et al., 2016). Within the municipality boundaries 6-11 PJ heat can be produced if the water coming form the sand layer is cooled to 25 ^{0}C. The study assumes a supply heat of district heating of 90 - 50 degrees. The sand layer produces water with a temperature of 75 ^{0}C. To achieve the maximum potential of the geothermal well the inlet temperature is 25 ^{0}C. First the water from the geothermal well needs to be upgraded with a heat pump to become 90 ^{0}C. After this the water goes through the district network and returns with a temperature of 50 ^{0}C. This temperature of the geothermal water will be cooled to 25 ^{0}C and with this energy water will be heated to 90 ^{0}C. The GK in figure 7.9 stands for gas boiler. With this gas boiler the peak potential will be supplied. According to this study one system could produce 350 GJ heat whereas 280 TJ comes from geothermal heat(Willemsen et al., 2016). This amount of heat should be enough for heating 9000 households. In this study the doublets are placed outside the boundaries of the district Mariahoeve.

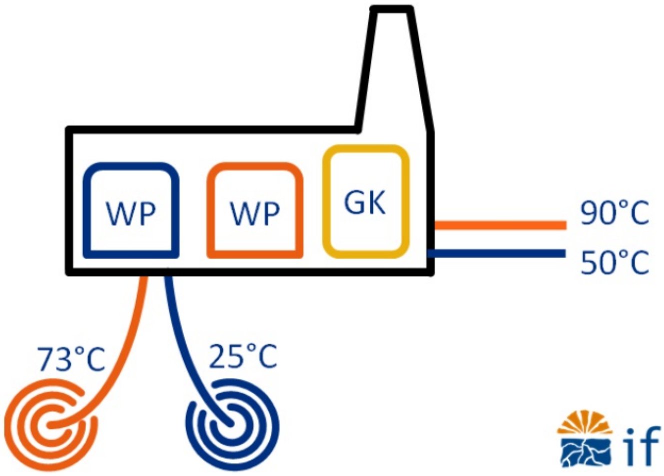


Figure 7.7: Concept of the geothermal system in The Haque according to (Willemsen et al., 2016)

What would be the geothermal potential if the scope would be narrowed from the whole municipality The Hague to the district Mariahoeve?

Potential of area

According to ThermoGIS the average heat in place is around 11.0 $\frac{GJ}{m^2}$ this is equal to 0.11 $\frac{PJ}{ha}$ (figure 7.8). To prevent exhaustion this energy can only be used for 30 years. It is known that only 30 to 50 % of the heat in a place can be harvested. Thus, the final potential can be calculated as follows:

$$\frac{0.11\frac{PJ}{ha} * 299.8ha * (30\% - 50\%)}{30years} = 0.33 - 0.55\frac{PJ}{year} \tag{7.9}$$

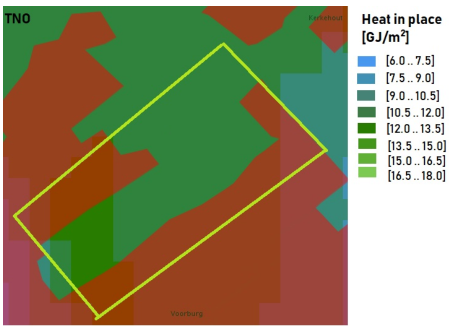


Figure 7.8: The heat in place in the Delft Sandstone Member in Mariahoeve (TNO, 2013)

Potential of doublet

The average depth of the well is around 2 km and the flow rate is 300 $[\frac{m^3}{h}]$ (Willemsen et al., 2016). This gives a $T_{production}$ of

$$T_{production} = T_{averagesurface} + \Delta T * depth = 10+30*2 = +-70^0C \tag{7.10}$$

The standard doublet flow rate is around 150 $[\frac{m^3}{h}]$ (S.Broersma et al., 2013). The value of the flow rate has an impact on the potential of the geothermal doublet. A lower flow rate will result in a lower potential. In this study the standard doublet flow rate and a standard inlet temperature for spatial heating, as given by TNO of 40 degrees is used(TNO, 2013). This gives a doublet potential of:

$$P_{doublet} = 1000\frac{kg}{m^3} * 4200\frac{J}{kg^0C} * 150\frac{m^3}{h} * (70 - 40^0C) = 1.89 * 10^{10}\frac{J}{h} = 5.25MW. \quad (7.11)$$

According to the study of (Willemsen et al., 2016) one doublet has 5958 of full load hours. This means that in one year one doublet could produce:

$$E = P * t = 5.25MW * 60 * 60 * 5500 = 104TJ \quad (7.12)$$

The potential of the area is 0.33- 0.55 PJ per year, therefor it is possible to create 2-4 systems in the district. The energy output of one system differs from the energy output according to the study of (Willemsen et al., 2016). This is because that study took an inlet temperature of 25 ^{0}C and a flow rate of 300 instead of 150 m^3/h and an inlet temperature of 40 ^{0}C. Another difference is that in the TNO study the heat is used directly to heat the buildings, whereas in the study of Willemsen, uses the geothermal potential as source for the heat pump. Therefore the potential would be around two times higher in the study of (Willemsen et al., 2016) compared to the above mentioned potential.

In conclusion, according to the study of (Willemsen et al. 2016) in the municipality the Hague 10 to 15 geothermal systems can be built with a geothermal potential of 280 TJ per system (around 9000 households). According to that study, one system should be enough to provide heat for the whole district. It remains a question whether this is really true. If the geothermal system would be built in Mariahoeve and the doublet has a standard flow rate of 150 $[\frac{m^3}{h}]$ and a standard inlet temperature of 40 degrees and no use of a heat pump, the system could only produce 104 TJ heat per year for thirty years. Geothermal energy provides continuous energy and the hourly potential difference between the two calculated geothermal well is as follows:

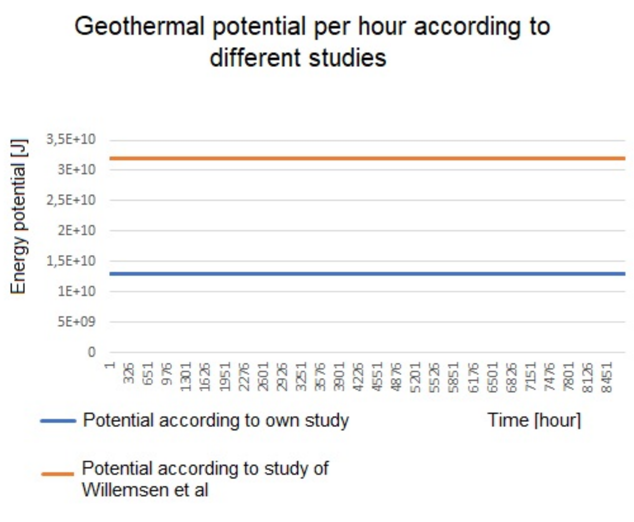


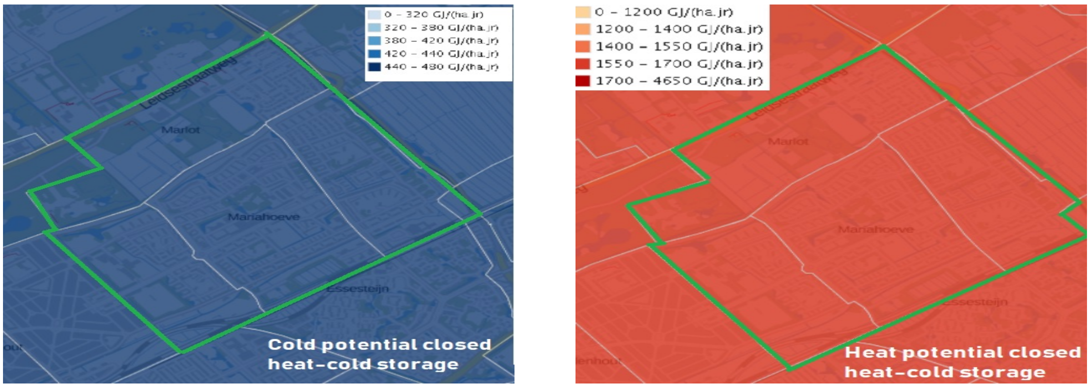
Figure 7.9: Geothermal potential per hour according to the different studies (Willemsen et al. 2016) & (by author)

The two different doublet systems will be used in this study to clarify the influence of the flow rate and the outlet potential of the doublet system to the potential for the neighbourhood.

7.3.2. Potential of GSHP systems

As explained in the literature study a GSHP system consists of small tubes under the ground which extracts heat from the ground to be used as a source for the heat pump. The heat atlas of RVO gives more insight into the heat potential of the area for a GSHP system (RVO.nl, 2017). The amount of power of a GSHP system depends on the ground layer type. This can vary from 20-60 W/m. In this study an average ground layer power of 35 W/m is chosen. One tube withdraws heat from an area of the ground with a radius of 5-6 meter. Therefore, the minimum difference between boreholes must be 5 meter for systems wit a depth smaller than 50 meters and 6 meter for systems with a dept deeper than 50 meters (L.François et al., 2015).

Applied to Mariahoeve
According to the heat atlas of RVO the following potential in Mariahoeve is possible for a GSHP system (warmteatlas.nl).



(a) Cold potential for a closed ground source heat pump system(RVO.nl, 2017)

(b) heat potential for a closed ground source heat pump system(RVO.nl, 2017)

Figure 7.10: Cold and heat potential for closed ground source heat pump system (RVO.nl, 2017)

The figure shows that in Mariahoeve the heat potential for a GSHP is 1550-1700 GJ/ha.yr or 0.15-0.17 GJ/m^2/year and the cold potential is 440-480 GJ/ha.yr.

The amount of power that can be extracted from the ground depends on the type of ground layer. The amount of power can differ from 20-60 W/m. In this study an average power of 35 W/m is chosen. The maximum length of tube is 150 m.
The minimum distance between two boreholes is 5 meters. An average garden for single family houses in Mariahoeve is around 5 * 10 m. This means that at most two boreholes could be placed in a garden.

One borehole withdraws its heat from an area with a radius of 5 meter, thus the two boreholes withdraw their heat from an area of 157 m^2. This gives a maximum heat potential of:

$$0.17\frac{GJ}{m^2} * 157m^2 = 26.69GJ \tag{7.13}$$

The maximum power of the GSHP is:

$$P = 35[\frac{W}{m}] * 2[boreholes] * 150[m] = 10500W. \tag{7.14}$$

This is a very high power output and is probably not really necessary for heating a single-family house. A GSHP system is often used in combination with a PV panel to generate a all-electric house.

7.3.3. Potential of ATES system

To calculate the potential of an ATES the potential of the area for an ATES system as given by the heat atlas of RVO must be known(RVO.nl, 2017). As explained in section 2.3.3 an ATES consists of a doublet system with a maximum depth of 300 m. One well contains warm water to heat a dwelling in the winter and the other well contains cold water to cool a dwelling in the summer. According to (NL, 2011b) the average temperature of the cold well is 6-8 ^{0}C and the temperature of the warm well is 18-20 ^{0}C.

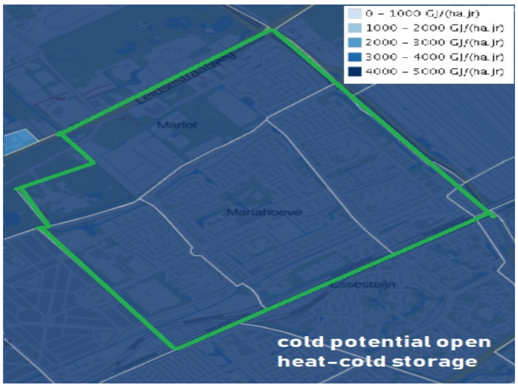
The potential of an ATES can be calculated as follow:

$$P_{doublet} = \rho_w C_w Q(T_{ww} - T_{cw}) \tag{7.15}$$

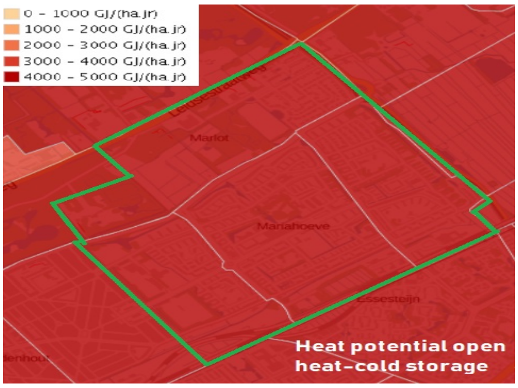
With ρ_w, being the specific density of water, around 1000 $[\frac{kg}{m^3}]$. C_w, the specific heat of water, around 4200 $[\frac{J}{kg^0C}]$ and Q, the flow rate. The value of the flow rate depends on the kind of ground. The maximum flow is around 160 m^3/hour and the average flow rate around 75 m^3/hour (S.Broersma et al., 2013). When the power of the doublet and the full load hours of the system are known the potential of an area can be calculated.

Applied to Mariahoeve

The potential of an ATES is given in the following figures:



(a) Cold potential for a heat cold storage system (RVO.nl, 2017)



(b) Heat potential for a heat cold storage system (RVO.nl, 2017)

Figure 7.11: The energy potential for open ground source heating system (RVO.nl, 2017)

The maximum difference between the T_{ww} and T_{cw} is around 6 ^{0}C. This gives a maximum power potential of:

$$P_{doublet} = 1000 * 4200 * 75 * 6 = 1.89\frac{GJ}{h} = 0.525MW \tag{7.16}$$

The maximum energy potential according to figure 7.11 is around 4-5 TJ/ha/year (0.4-0.5 GJ/m^2/year). This potential is calculated taking into account limiting factors, like ground porosity, limiting heat extraction of the ground due to the filter length through the ground layers of the ATES and limited amount of usable surface area (RVO.nl, 2017).

7.4. Waste heat potential

Some buildings, like supermarkets, schools or offices need to cool their buildings during the year and by doing so they generate waste heat. A cooling machine works like a heat pump, where heat is extracted at the evaporator side (thus cooling occurs) and heat is released at the condenser side. For different sectors it is known how much waste heat they generate on average, as well as the percentage of electricity they use for cooling their buildings. In this study of (Pennartz and van den Bovenkamp, 2016) one can find for different sectors their average energy need. In the rapport of (J.M.Sipma, 2016) the average electricity demand per sector per m^2 is given.

Table 7.7: Potential waste heat (Pennartz and van den Bovenkamp, 2016)

Sector	Total electrical demand [PJ]	Total electricty needed foor cooling [PJ/year]	Percentage electricity needed for cooling [%]	Released condensor heat (T = 30-45 ^{0}C) [PJ/year]	Full load hours Cooling machines [hours/year]
Supermarkets	3.1	2.7	87	10.7	4500
Offices	10.8	1.8	17	9.0	1500

Applied to Mariahoeve
Supermarkets
According to (J.M.Sipma, 2016) the average electricity demand for supermarkets is 254 kWh/m^2. In the district Mariahoeve there are five supermarkets.With the help of google maps and Edugis (Edugis.nl, 2018) the size of the supermarkets can be determined. When the surface of the supermarkets are known it is possible to know the electricity demand. From table 7.7 it is known how much of the electrical energy is needed for cooling. From the same table it is known how much condensing heat is released at the same time.. It is then possible to calculate the waste heat of supermarkets in the district Mariahoeve:

Table 7.8: Waste heat from supermarkets (J.M.Sipma, 2016) & (Pennartz and van den Bovenkamp, 2016)

Supermarket	Amount of surface [m^2]	Total electricity demand [GJ]	Total electricity needed for cooling [GJ]	Released condensor heat (T = 30-45 ^{0}C) [GJ/year]
Coop	714	652.88	568	2259
Hoogvliet	1935	1769.36	1539	6123
Albert Heijn	2976	2721.25	2367	9417
Spar	391	357.53	311	1237
Hoogvliet	1449	1324.97	1153	4585
Total	7465	6826	5939	23621

Thus, a total of 23 TJ of heat comes from supermarkets in Mariahoeve.

Offices
The same method as for the determination of the waste heat of supermarkets can be used to determine the amount of waste heat of offices. There is one part of the district that has a lot of offices (AEGON and insurance companies). According to (J.M.Sipma, 2016) the average electricity demand for offices is 60 kWh/m^2. This gives the following waste heat potential:

Table 7.9: Waste heat potential of offices (J.M.Sipma, 2016)

	Amount of surface [m^2]	Total electricity demand [GJ]	Total electricity needed for cooling [GJ]	Released condensor heat (T = 30-45 ^{0}C) [GJ/year]
Offices	22142	4783	813	4065

Thus, a total of 4 TJ with a temperature of 30-45 ^{0}C per year can be generated by offices.

8 Scenario analyses

This chapter describes the developed what-if scenarios and their outcomes. The development of the what-if scenarios is step three in the developed approach to work with the calculation model and the outcome of the what-if scenario is step five.

8.1. Scenario description

The formed scenarios can be divided into two groups: the what-if scenarios for centralized heating and the what-if scenarios for decentralized heating. Section 3.1.3 already described that it depends on the type of buildings (year of construction and energy label) what kind of heating system could be applied (high, middle or low temperature network or individual heating). In Mariahoeve, the short term heating systems that should be applied to specific buildings are presented in the preliminary study of CE Delft and Overmorgen (section 5.4.4) (figure 8.1). Based on this study different what-if scenarios are developed.

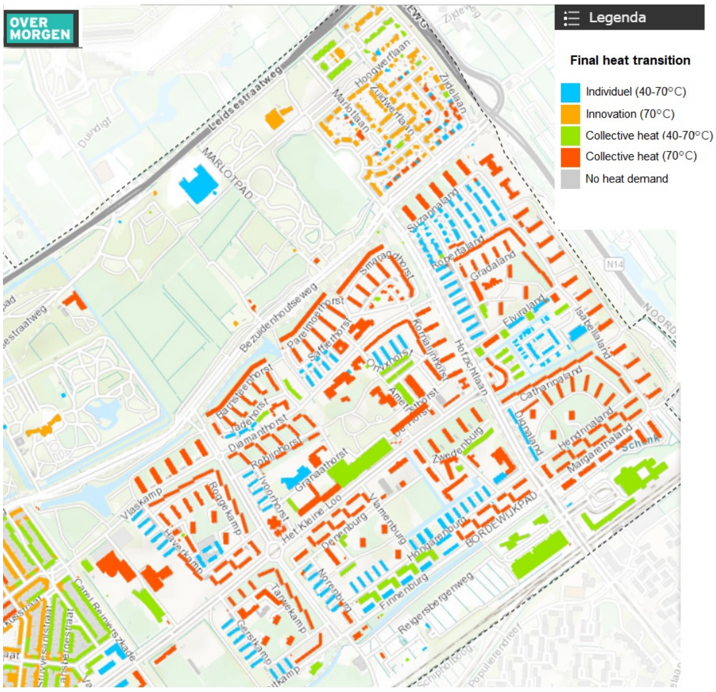


Figure 8.1: Graphical presentation of the short term heating solution for buildings in Mariahoeve (Overmorgen.nl, 2017). The red colored buildings are suitable to be connected to a middle temperature network and the green colored buildings to a low temperature network. The orange colored buildings need innovation before sustainable individual heating systems could be applied and the blue colored buildings are suitable for individual heating systems.

8.1.1. Centralized heating scenarios

In the centralized heating scenarios, it is investigated what possible heating technologies could be applied to supply heat to the buildings connected to district heating. The size of the heating network is different per scenario. In each scenario the different possible sustainable heating technologies are compared with the current situation wherein the neighbourhood is heated with gas.

Scenario 1: middle temperature network

In the first scenario all the buildings that are suitable for being connected to a middle temperature network (all the red colored buildings in figure 8.1) will be connected to a middle temperature network. In this scenario the different sustainable heating alternatives that can supply heat for middle temperature networks (see chapter **??**) are applied to the network. The rest of the buildings in the neighbourhood will be heated with gas and nothing changes for these buildings.

Scenario 2: low temperature network

In the second scenario the high energy demand buildings that can be connected to district heating (all the red buildings in figure 8.1) will be insulated to energy label B (so they turn into low energy demand buildings). When a building is insulated the energy demand drops with a certain percentage. The value of this percentage depends on the original energy label of the dwelling. Table C.2 (see appendix C) presents an overview of these percentages. Together with the currently low energy demand buildings for district heating (green buildings in figure 8.1) they will be connected to a low temperature network. It is assumed that all the low energy demand buildings will change their gas boiler for heating DHW (with an efficiency of 90%) into an electric boiler (with an efficiency of 100%). This will reduce the total gas consumption but increase the total electricity consumption. In this scenario different heating alternatives that supply low heat to low temperature networks are applied (see section 3.1.3). The rest of the buildings in the neighbourhood will be heated with gas and nothing changes for these buildings.

Scenario 3: low temperature network for the complete neighbourhood

In the third scenario all the buildings in the neighbourhood are insulated to energy label B and connected to a low temperature network. It is assumed that all the buildings change their gas boiler for heating DHW into an electric boiler. This network will be heated with sustainable heating (see section 3.1.3.

For these three scenarios the following questions are investigated:

1. Which sustainable heating technology gives the best match between demand and supply and what are the corresponding financial costs (for network operator, energy company and residents)?
2. Which combination of heating technologies gives the best match between demand and supply and what are the corresponding financial costs (for network operator, energy company and resident)?
3. What is the overall emission of CO_2, how much gas is consumed in the total neighbourhood and how much CO_2 and gas is saved when applying sustainable heating alternatives?
4. How many geothermal wells are needed to supply the total heating demand of the network?

8.1.2. Decentralized scenario

The decentralized scenario presents possible heating solutions for the buildings suitable for decentralized heating systems (the blue and orange buildings in figure 8.1). In this scenario only the financial feasibility and the total amount of CO_2 is calculated assuming that all individual buildings are heated with a decentralized heating system and there is no intermittency problem (which is a rough assumption).

8.2. Outcome scenarios

First the outcome of the centralized heating scenarios will be described, followed by the outcome of the decentralized scenario.

8.2.1. Outcome of the centralized scenarios

For each scenario alternative heating technologies are calculated. To illustrate how each heating system is calculated per scenario, an elaboration of one sustainable heating technique that applies heat to the heating network as defined in scenario one, will be described. In this example two geothermal wells for the high temperature network of scenario one are chosen as heating technology. After this example the outcomes of all scenarios are presented.

Elaboration of calculation for one heating system in the first scenario

In this example the network as defined in the first scenario is taken into account, meaning that only the buildings with high energy demand and suitable for a middle temperature network (red buildings in figure 8.1) are connected to the heating network. In this example it is assumed that two geothermal wells (with a high potential as calculated by the study of (Willemsen et al., 2016))are connected to this network.

Intermittency review

Filling in the collected data given in chapter 6 and 7 in the calculation model, the following match between the two geothermal wells and the buildings connected to the the network is calculated:

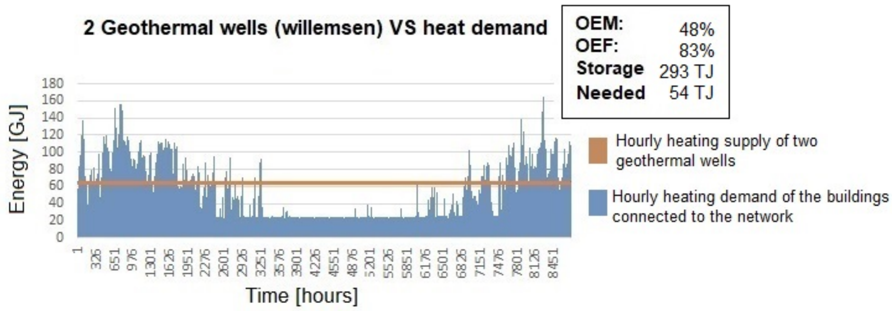


Figure 8.2: The match between heating supply of geothermal well and heating demand of the buildings connected to the network (by author)

Figure 8.2 depicts that when two geothermal wells are used 83% of the heating demand is supplied by the geothermal wells (OEF of 83%, see section 4.2). In the winter these sources do not provide enough heat to the dwellings connected to the network. Still 54 TJ is required from the gas grid. During the summer the two geothermal wells generate an abundant amount of heat and the residuary heat can be stored. In this situation 293 TJ heat can be stored, which is really a lot considering that the yearly heating demand of the neighbourhood is 396 TJ.

Financial feasibility review
The financial feasibility for the three different stakeholders are determined by calculating their NPV over 60 year (lifetime of a network). The NPV for an energy company that produces and sells geothermal energy, is illustrated in figure 8.5. This NPV is compared with the NPV of an energy company that buys and sells gas. The investment costs for the energy company to built two geothermal wells is around 100 MEUR. It is assumed that if the energy company would produce gas, they would not have any investment costs.

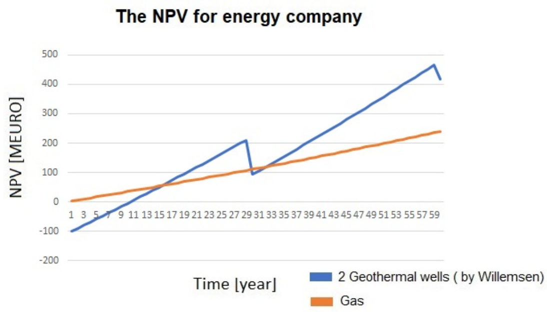


Figure 8.3: The NPV for energy companies if they would produce and sell heat from geothermal wells or from gas (by author)

The figure depicts that, although the investment costs are higher, the NPV for an energy company that invests in geothermal energy are better in year 60 compared to an energy company that invests in gas. This is concluded, assuming that all the produced energy is sold. The drop in the NPV for energy companies who sell geothermal heat occurs because new wells are needed to be build (life time of geothermal well is 30 years). Furthermore, after approximately 30 years, geothermal heat is more profitable than gas.

The NPV values for network operators are as follows:

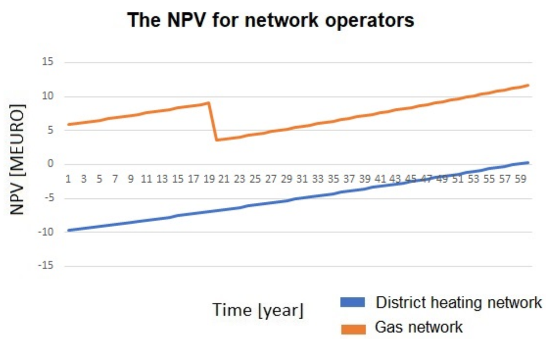


Figure 8.4: The NPV for network operators for district heating and for gas network (by author)

STEDIN will replace the current gas network before 2030 (STEDIN 2018). In this scenario it is assumed that this happens in 2028. This results in a drop in the NPV for companies after 18 years. Furthermore it is assumed that a network will be replaced after 60 years. The investment costs for placing a district network is around 15 MEUR. It can be seen in the figure that it is more profitable for a network operator to build a gas network instead of a district network. The costs of the installation and maintenances of a district network are much higher.
At last, the average cost for residents for district heating can be calculated:

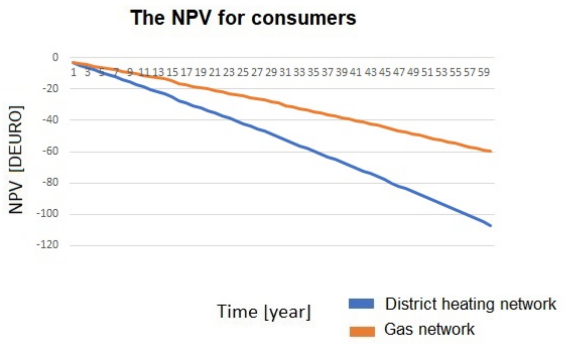


Figure 8.5: The NPV for consumers when connected to district heating or gas network (by author)

The figure shows that it is more profitable for customers to be connected to the gas grid instead of being connected to the district network. This is because of the high costs of the district network for the customer. To protect customers the so-called *niet meer dan anders* rule is applied, which states that the costs for a customer when connected to district heating cannot be higher compared to gas grid. However, as can be seen the price for heat is much higher compared to the price of gas resulting in a higher costs for district heating (section 4.3). The price of heat should become cheaper to promote district heating or the price of gas should increase.

Emissions review

At last, the amount of emissions due to the heating technology can be calculated. The required amount of gas and electricity changes when sustainable heating technologies are used, meaning that the amount of emitted CO_2 changes. Table 8.1 shows the differences in consumption when district heating is applied.

Table 8.1: Changes in electricity and gas consumption when district heating is applied instead of gas (by author)

Situation	Amount buildings linked	Total electricity consumption [GWh]	Total gas consumption [TJ]	Renewable energy consumption [TJ]	CO_2 emission due electricity [*10^6 kg]	CO_2 emission due gas [*10^6 kg]	CO_2 emission due renewable source [*10^6 kg]	Total CO_2 emissions for heating [*10^6 kg]
No district heating	**8719**	**24.6**	**396.16**	**0**	**16.0**	**14.3**	**0**	**14.3**
				With district heating				
Buildings connected to district	7346	18.7	48	267	12.16	1.7	6.7	8.4
Buildings not connected to district	1373	5.9	95	0	3.8	3.4	0	3.4
Total	**8719**	**24.6**	**143**	**267**	**16**	**5.1**	**6.7**	**11.8**

It is known how much buildings are connected to the district network and what their total heating demand is. From the OEF factor it is known how much sustainable heat is consumed. The extra heat needed for the buildings (calculated with OEF, in this example 54 TJ see figure 8.2) includes the heating losses of the district network (in this study around 10%). The gas grid does not have this same amount of losses. The needed amount of gas is calculated by subtracting the heating losses from the extra needed heat. The amount of CO_2 emissions per heating technology are calculated with the emissions factors as given in table 4.9. Table 8.1 presents the amount of required gas and renewable heat for buildings connected to district heating and the amount of emissions that are produced when generating this heat. Because of the intermittency, still 48 TJ of gas is needed, and the production of gas results in CO_2 emissions. The production of geothermal energy results in lower CO_2 emissions. The table states that around 17% less CO_2 is emitted for heating the buildings if district heating is applied to Mariahoeve. However, the overall CO_2 emissions (taking the production of electricity into account) only decreases with 8%.

In this given example only one alternative for heating (two geothermal wells with a high potential) is studied. In the scenarios all possible alternative heating technologies are calculated. In appendix D the detailed outcomes of all alternative heating technologies per scenario can be found.

Every scenario presents the match between demand and supply, possible storage, gas consumption, investment costs for energy companies, the NPV for energy companies and network operators after 60 years, the average costs for residents, the reduction of CO_2 emissions and the needed electricity for every possible alternative heating technology that can be connected to the network. The quality of the match between supply and demand will be presented below with pluses and minuses. Table 8.2 describes the interpretation of these pluses and minuses.

Table 8.2: The description of interpretation of pluses and minuses for the intermittency (by author)

Value	Meaning
++	OEM and OEF both 100%
+	OEF above 50%
-	OEF under 50%
- -	OEM and OEF both under 20%

In chapter 7 two different output potentials for geothermal doublet systems are calculated, one with a high potential (according to study of Willemsen et al., 2016) and one with a lower potential. To investigate the effect of the potential drop, both systems are taken into account in the scenarios.

Scenario 1: middle temperature network

The outcome of the first scenario is presented in table 8.3. For a more detailed outcome the reader is suggested to read appendix D.1. In this scenario only the geothermal wells, biomass heat and combinations between these two technologies are analyzed. These heating technologies have an outlet temperature suitable for a middle temperature heating network. All the heating technologies and combination of heating technologies are compared to the situation wherein only gas is consumed. The total amount of CO_2 emissions for using the gas system for the complete neighbourhood is $14 * 10^6 kg\ CO_2$ due gas consumption and $16 * 10^6$ kg CO_2 due to electricity consumption (see also appendix D.1).

Table 8.3: Outcome of the first scenario (by author)

Source	For buildings connected to district network								Influence of implementing district network to neighbourhood			
	Intermittency	To Storage [TJ]	Heat needed from grid [TJ]	Sustainable heat to district heating [TJ]	Investment costs for energy companies [MEURO]	NPV for energy company after 60 years [MEUR]	NPV for network operators after 60 years [MEUR]	Average yearly costs for residents [*10^3 EURO]	Gas reduction [%]	CO_2 reduction for heating [%]	Total CO_2 reduction (heating + electricity) [%]	Electricity needed [GWH]
gas	++	0	301	0	0	240	11.6	0.74	0	0	0	24.7
Two geothermal wells with high potential (Willemsen)	+	293	54	267	110	419	0.3	1.3	64	17	8	24.7
Two geothermal wells with low potential (author)	+	54	167	154	77	87	0.3	1.3	38	11	5	24.7
Biomass (biogas)	-	0.05	313	7	1.3	150	0.3	1.3	5	4	2	24.7
Biomass (wood)	-	0.05	313	7	1.4	121	0.3	1.3	5	4	2	24.7
Biomass (biogas+wood)	-	0	306	14	2.7	125	0.3	1.3	7	4	2	24.7
Two geothermal wells (Willemsen) + Biomass (biogas+wood)	+	305	50	270	112	392	0.3	1.3	65	17	8	24.7
Two geothermal wells (author)+ Biomass (biogas+wood)	+	62	160	160	79	74	0.3	1.3	40	12	5	24.7

Intermittency review
Compared to the current gas-dependent situation the intermittency becomes worse when renewable heating technologies are applied. The geothermal wells have the best intermittency. This heating alternative produces an exceeding amount of heat. However, because the match between demand and supply is not perfect, a substantial amount of heat can be used for storage. When biomass is turned into heat, the heat production all over the year is much smaller than the demand and therefore all produced heat is consumed resulting in no heat for storage.

Financial feasibility review
The heating technology with the highest investment costs are geothermal wells. Still, an energy company will receive the highest NPV after 60 years for geothermal wells. But this stands only if all the heat produced by the wells is sold. The NPV for network operators is independent of the heating technology. A network operator receives higher profits when it invests in a gas grid instead of a district network. The average yearly costs for residents increases when they are connected to district heating, because the costs of heat is higher than gas.

Emissions review
It can be seen in the table that the use of a geothermal well gives the biggest reduction of CO_2 emissions. Because the electricity production does not change in this scenario the best overall CO_2 reduction is only 10%.

Further conclusions
The differences in possible potential of the two calculated geothermal wells has an influence on the intermittency, costs and CO_2 emissions. It can be seen that if the geothermal well has less potential the CO_2 reduction drops from 17% to 11%.
The use of multiple sources does not give exceptional better outcomes. For example, when both geothermal wells and a biomass plant is used; 4 TJ less heat is needed compared to when only two geothermal wells are applied. It is therefore not worth the effort to use multiple heating technologies.

In this scenario it can be concluded that the best alternative for heating buildings centralized is the implementation of geothermal energy. However, still 54 TJ (or 167 TJ when the potential of the geothermal well is lower) is required from another source. Around 293 TJ can be stored, meaning that if seasonal storage is possible two geothermal wells should be enough to provide all the high energy demand buildings connected to the district with heat. Yet, if the potential of the geothermal well is lower, this is unfortunately not possible.

Optimization of geothermal wells
Each scenario also investigates the maximum amount of geothermal wells needed to provide the total heating demand of the network. For this scenario the following is true:
six geothermal wells are required to heat the buildings completely (if the potential as given by the study of Willemsen is taken into account). Figure 8.6 illustrates that, when six geothermal wells are applied, 1360 TJ of heat is available for storage. This is extremely high. When the geothermal well has a lower potential, 16 geothermal wells are required and 1434 TJ of heat can be stored. It is calculated in chapter 6 that a maximum of 4 geothermal wells can be applied in Mariahoeve.

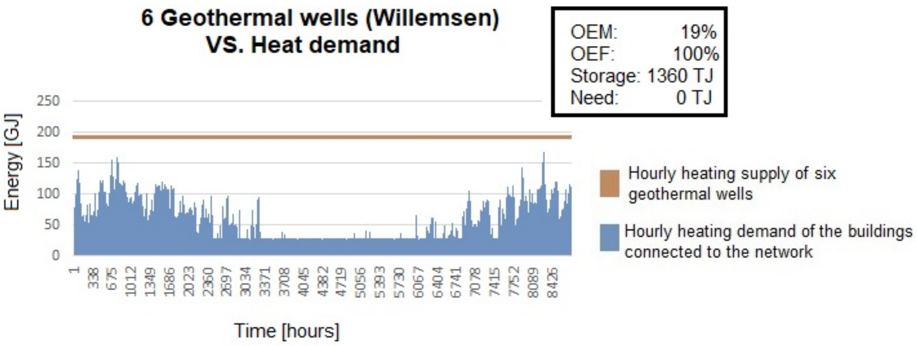


Figure 8.6: The intermittency between heating supply of six geothermal wells and heating demand of the buildings connected to the network (by author)

It can be concluded that it is not possible to meet the total energy demand of the high energy buildings with geothermal wells. **Seasonal storage is definitely needed to heat the buildings sustainably**.

Scenario 2: Low temperature network

In the second scenario the buildings that were connected to the network in the first scenario are insulated to energy label B. Therefore these buildings can be connected to a low temperature network. All the low energy demand buildings will change their DHW heating system into an electric boiler system. Additionally solar energy can be applied for heating the buildings in this network.

Table 8.4: Outcome of the second scenario (by author)

Source	For buildings connected to district network								Influence of implementing district network to neighbourhood			
	Intermittency	To Storage [TJ]	Heat needed from grid [TJ]	Sustainable heat to district heating [TJ]	Investment costs for energy companies [MEURO]	NPV for energy company after 60 years [MEUR]	NPV for network operators after 60 years [MEUR]	Average yearly costs for residents [*10^3 EURO]	Gas reduction [%]	CO_2 reduction for heating [%]	Total CO_2 reduction (heating + electricity) [%]	Electricity needed [GWH]
gas	++	0	315	0	0	253	8,5	0.4	0	0	0	24.7
Two geothermal wells high potential (Willemsen)	+	397	17	163	110	488	-0.04	0.9	83	54	-34	52.4
Two geothermal wells low potential (author)	+	124	95	84	77	137	-0.04	0.9	65	50	-36	52.4
Biomass (biogas)	-	4	176	4	1.3	159	-0.04	0.9	46	46	-38	52.4
Biomass (wood)	-	4	176	4	1.4	127	-0.04	0.9	46	46	-38	52.4
Solar collectors	- -	178	171	9	50	164	-0.04	0.9	47	47	-37	52.4
Biomass (biogas+wood)	-	7	172	7	2.7	134	-0.04	0.9	47	44	-39	52.4
Two geothermal wells (Willemsen) + Biomass (biogas+wood)	+	411	15	164	112	515	-0.04	0.9	83	54	-34	52.4
Two geothermal wells (author)+ Biomass (biogas+wood)	+	134	90	89	79	164	-0.04	0.9	66	50	-36	52.4
Two geothermal wells (Willemsen) + Solar heat	+	584	17	163	160	362	-0.04	0.9	83	54	-34	52.4
Two geothermal wells (Author) + Solar heat	+	307	91	88	127	249	-0.04	0.9	68	52	-35	52.4

Intermittency review

The match between demand and supply is worse for the alternative sustainable heating technologies compared to the gas based system. The added solar heating technology gives the lowest intermittency, since a solar collector produces a lot of heat during the summer and hardly any during the winter. The buildings are better insulated and have electric boilers providing heat for DHW. This results in a lower gas consumption, meaning that less heat is needed. None of the alternative sustainable heating technologies can provide enough heat, in every situation additional heat from the gas grid is required.

Financial feasibility review
The investment costs for geothermal wells are the highest, but the use of geothermal wells results in the highest NPV in year 60. The NPV for network operators decreases when using district heating compared to the gas based network, because it costs more to built and maintain district heating. The average yearly costs for residents is higher when they are connected to district heating. The investment costs for residents (not presented in the table 8.4) increases when they are connected to a low heating network. They have to pay for their insulation costs and for their heat exchangers and electric boilers. This gives an average investment costs of 6000 EUR. In case of HA or HOA these costs should be bear by the HA/HOA instead of the occupants.

Emissions review
A high gas reduction is possible for this scenario if two geothermal wells are applied. The gas consumption drops, due to the insulation and use of the electric boiler. Nonetheless, the total CO_2 emission increases, since more electricity is required to feed the electric boilers. The production of electricity emits more CO_2 compared to the production of gas. It is therefore only sustainable to use an electric boiler if the electricity is produced sustainably, otherwise the CO_2 emissions will only increase.

Further conclusions
The potential differences of the geothermal wells influence the intermittency, costs and emissions. The use of multiple heating technologies is not worth the effort. The combination of solar heat with geothermal heat results in a large amount of heat to storage. The heat that can be stored is almost high enough to supply two neighbourhoods like Mariahoeve with sustainable heat. Altogether, two geothermal wells will give the best solution for heating the district if seasonal storage is possible. In conclusion, the gas demand decreases when buildings are better insulated and using an electric gas boiler. This results in a higher reduction of CO_2 emissions for heating. However, this is only really better if green electricity is used, otherwise the total CO_2 emission will only increase. It is therefore recommended to place enough PV-panels. The total electricity needed is 52.4 kWh, which is equal to 188 TJ. From section 7.1 its known that if every roof in the Mariahoeve would have a PV-panel 101 TJ electricity can be generated, which is not enough. Furthermore, the match between demand and supply of electricity is not taken into account, storage would probably be needed because a PV panel would generate especially electricity during the summer.

Optimization geothermal wells
Five geothermal wells are required to heat the buildings completely (if the potential according to the study of (Willemsen et al., 2016)is taken into account). It is possible to store around 1225 TJ, which is extremely high. If the potential of the geothermal well would be lower, 12 wells are required and around 1207 TJ could be stored.

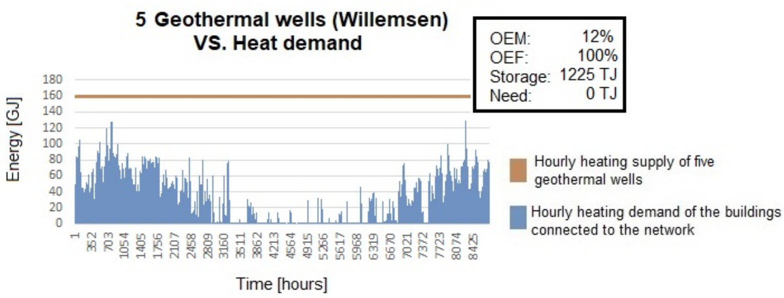


Figure 8.7: The intermittency between heating supply of five geothermal wells and heating demand of the buildings connected to the network (by author)

Scenario 3: low temperature network for the complete neighbourhood
In the third scenario all the buildings in the neighbourhood are insulated to energy label B and all the DHW is warmed with an electric boiler.

Table 8.5: Outcome of the third scenario (by author)

Source	For buildings connected to district network								Influence of implementing district network to neighbourhood			
	Intermittency	To Storage [TJ]	Heat needed from grid [TJ]	Sustainable heat to district heating [TJ]	Investment costs for energy companies [MEURO]	NPV for energy company after 60 years [MEUR]	NPV for network operators after 60 years [MEUR]	Average yearly costs for residents [*10^3 EURO]	Gas reduction [%]	CO_2 reduction for heating [%]	Total CO_2 reduction (heating + electricity) [%]	Electricity needed [GWH]
gas	++	0	396	0	327	6.8	0.4	0	0	0	24.7	
Two geothermal wells high potential (Willemsen)	+	373	48	187	110	506	-5	0.98	89	56	-36	53.6
Two geothermal wells low potential (author)	+	120	148	88	77	155	-5	0.98	66	50	-38	53.6
Biomass (biogas)	-	3	231	4	1.3	175	-5	0.98	46	46	-41	53.6
Biomass (wood)	-	3	231	4	1.4	143	-5	0.98	46	46	-41	53.6
Solar collectors	- -	178	226	9	50	181	-5	0.98	48	48	-40	53.6
Biomass (biogas+wood)	-	7	228	8	2.7	151	-5	0.98	47	45	-41	53.6
Two geothermal wells (Willemsen) + Biomass (biogas+wood)	+	384	45	190	112	532	-5	0.98	89	56	-36	53.6
Two geothermal wells (author)+ Biomass (biogas+wood)	+	129	143	93	79	180	-5	0.98	67	51	-38	53.6
Two geothermal wells (Willemsen) + Solar heat	+	558	47	189	159	379	-5	0.98	89	56	-36	53.6
Two geothermal wells (Author) + Solar heat	+	302	143	93	127	266	-5	0.98	67	51	-38	53.6

Intermittency review
The match between demand and supply decreases when sustainable heating technologies are used. If all the buildings are insulated to energy B than the total heating demand decreases compared to the gas based situation. Therefore, more heat can be stored and less heat is needed from the grid. The use of two geothermal wells in combination with a biomass plant gives the highest possible storage and lowest heating demand from the grid.

Financial feasibility review
The NPV for the energy company is very high, because more residents are connected to the energy company resulting in high profits. However, this is only true if all the generated heat is sold. If the neighbourhood does not require the heat, it is assumed that the company will sell the heat elsewhere or store it to increase the coverage in the neighbourhood. The NPV for network operators decreases, because the size of the network increases and therefore also the maintenance and investment costs. The yearly average costs for residents also increase.

Emissions review
The gas reduction (and therefore the CO_2 emissions due to heating the neighbourhood) decreases. However, the overall CO_2 emissions increase because more electricity is needed. The best heating technology in this situation is the use of the geothermal wells. Exactly as in the other scenario, PV-panels should be added to provide sustainable electricity. The overall electricity demand becomes in this scenario 53.6 GWh, which is equal to 192 TJ. If every roof in the Mariahoeve would have PV-panels the total electricity demand is around 101 TJ (when the intermittency is not taken into account). This is not enough electricity to meet the demand.

Optimization geothermal wells
Six geothermal wells are required to meet the total heat demand for the whole neighbourhood in the third scenario (if the potential of (Willemsen et al., 2016) is taken into account). Around 1450 TJ could be stored, which is extremely high. If the geothermal well would have a lower potential 15 wells are needed and around 1350 TJ could be stored. These are both unrealistic amounts of needed geothermal doublets.

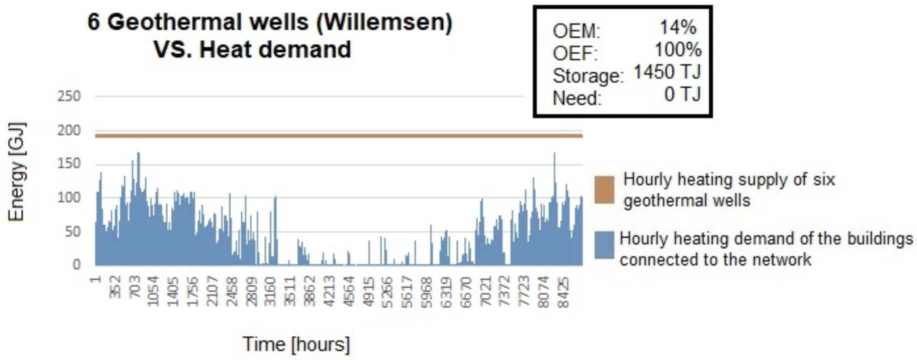


Figure 8.8: The intermittency between heating supply of six geothermal wells and heating demand of the buildings connected to the network (by author)

It is only possible to completely heat the neighbourhood with sustainable heating technologies if seasonal storage is applied.

Conclusion

To compare the three scenarios with each other the best heating technology per scenario is presented in table 8.6.

Table 8.6: Conclusion of centralized heating systems (by author)

Scenario	For buildings connected to district network									Influence of implementing district network to neighbourhood			
	Amount of linked houses	Intermittency	To Storage [TJ]	Heat needed from grid [TJ]	Sustainable heat to district network [TJ]	Investment costs for energy companies [MEURO]	NPV for energy company after 60 year [MEURO]	NPV for network operators after 60 years [MEURO]	Average yearly costs for residents [*10^3 EURO]	Gas reduction [%]	CO2 reduction for heating [%]	Total CO2 reduction (heating+ electricity) [%]	Electricity needed [GWh]
Scenario 1: High temp.	7346	+	293	54	267	110	419	0.3	1.3	64	17	8	24.7
Scenario 2: Party low temp.	7712	+	397	17	163	110	488	-0.04	0.9	83	54	-34	52.4
Scenario 3: Total low temp.	8719	+	373	48	187	110	506	-5	0.98	89	56	-36	53.6

It can be concluded that when a network increases in size and transits to a lower energy demand network, more heat can be stored and less heat is needed from the gas grid.
The investment costs for energy companies do not change, but their profits increase because more people are connected to the heating plant. However, this is only true if all the heat that is produced is sold. The profits for network operators decrease, if the network increases. Although more people are connected to the network, the costs for building the network results in a negative NPV after 60 years. The yearly costs for residents also increase when the network increases. This is because more buildings are connected to the network, including the buildings with an average higher heat consumption resulting in a higher energy bill. Therefore the average yearly costs of the residents increases.
The gas reduction increases when more buildings are connected to the sustainable plant, but as long as the needed electricity is not produced sustainable the total CO_2 emissions will increase.

It can be concluded that a low heating network is preferred over a high heating network, because more gas and CO_2 is reduced and more buildings are receiving heat in a low temperature network. Although, the network should not be too large. A large network is unprofitable for network operators. A right balance between the size of the network and the buildings connected is needed. Furthermore, the electricity demand must be produced sustainably, otherwise the CO_2 emissions will only increase when electric boilers are used. To further decrease the electricity consumption, heat pump boilers could be used for DHW. However, this would increase the investment costs. Finally, seasonal storage is needed, without seasonal storage sustainable heating is impossible.

8.2.2. Decentralized scenario

In this scenario the sustainable energy solution for buildings belonging to individual home owners are elaborated. Only decentralized heating systems are taken into account. Only low energy demand buildings can be heated decentralized, meaning that first all the buildings need to be insulated to energy label B. The use of pallet boilers are left out of this scenario, because this heating system require wood pallets that have to be imported from Canada, this is very unsustainable and therefore left out.

Financial feasibility review

The costs and benefits of a decentralized system depend on the heating consumption of the individual home owners. This heating consumption depends on the behavior of the home owner and is therefore different for each building. To gain insight in the financial feasibility of the different decentralized renewable energy technologies, an outcome of one building is discussed in this section. The outcome of the other individual buildings are given in appendix D.4.
The elaborated building is located in Mariahoeve with postal code 2591GX (figure 8.9).

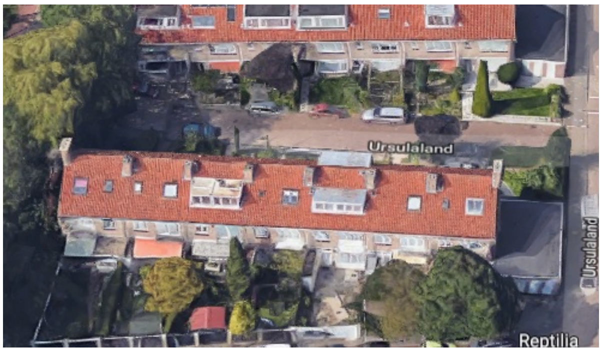


Figure 8.9: The building with postal code 2591GX (Google)

This building has a sloped roof, therefore only 29% of the roof is available for placing PV panels. This results in 6 PV panels (of 2.5 m^2). It depends on the kind of decentralized heating system if it uses gas or electricity(or both). The COP of the system determines how much gas/electricity is needed. The COP of the systems are given in table 8.7.

Table 8.7: COP of different decentralized heating systems (CEDelft, 2017)

Heating area		Heating DHW	
Technology	**COP**	**Technology**	**COP**
GSHP	5	GSHP	3
ASHP	3,5	ASHP	2
High efficiency boiler	1.04	High efficiency boiler	0.72
micro CHP	0.83	High efficiency electric boiler	0.72
Electric resistance	1	Electric boiler	0.95
Infrared panels	1		

This results in the following fuel demand from the grid for different decentralized heating technologies (table 8.8):

Table 8.8: Fuel demand for different decentralized heating systems for a house in postcode 2591GZ (by author)

Postal code	Electricity demand' [kWh]	Current gas system [m^3]	GSHP		ASHP		Elec. resistance		Infrared panels		Hybrid HP			micro CHP			Districht heating (with elec.boiler)		
			No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	Gas [m^3]	No PV [kWh]	With PV [kWh]	Gas [m^3]	No PV [kWh]	With PV [kWh]	Gas [m^3]	No PV [kWh]	With PV [kWh]
2591GX	2774	1629	3473	2872	5049	4183	15117	13706	12865	11454	652	1930	1841	1906	2342	4714	1153	3856	2448

The table expresses that if the building would be heated with gas it needs 1629 m^3 gas. This is still a high heating demand for a building that is well insulated. The reason for this is that in this study when a building is better insulated a percentage drop of heating demand is assumed (see table C.2). This building already had a high heating demand before insulation, therefore the heating consumption remains relatively high.

Some heating systems use electricity to generate heat. These systems would need less electricity from the grid if PV panels are applied. Not all the electricity generated from the PV panels can be used to feed the heating system. Sometimes the PV panels generates more electricity than the heating system would need at that moment and the extra generated electricity is sent to the grid. It could also be stored or used for supporting the electricity needed for appliances in the building. However, the electricity demand for appliances in buildings is strongly dependent on the occupancy behavior and this is unknown in this study. Therefore it is assumed that the generated electricity from PV panels is only used to power the heating systems. The surplus is sent to the grid.

The needed amount of electricity from the grid drops for the heating system if a PV panel is used. One exception is the micro-CHP. This heating system generates electricity when burning gas to heat a building. Therefore more electricity is generated when it also has a PV panel. The electricity and gas demand is calculated for all the buildings suitable for individual heating and can be found in appendix D.4

When the needed supply of gas or electricity from the grid is known the financial feasibility can be calculated. The investment costs consists of insulation costs, costs for the heating technology, and if used, costs for the PV panels. The financial NPV for the different technologies are calculated for three different situations:

1. Situation wherein no PV panels are used
2. Situation wherein PV panels are used, but no net metering is possible
3. Situation wherein PV panels are used, with possible net metering

When a building generates more electricity than needed, the surplus can be sent to the grid. The amount that is sent to the grid can be subtracted from the total yearly electricity demand, meaning that the costs of the total electricity drop. This is called net metering. This rule is applied nowadays in the Netherlands, however in 2030 this rule will much probably disappear. Therefore it is interesting to see how that influences the financial feasibility.

The NPV for the resident, when heating technologies are used without PV panels are illustrated in figure 8.10:

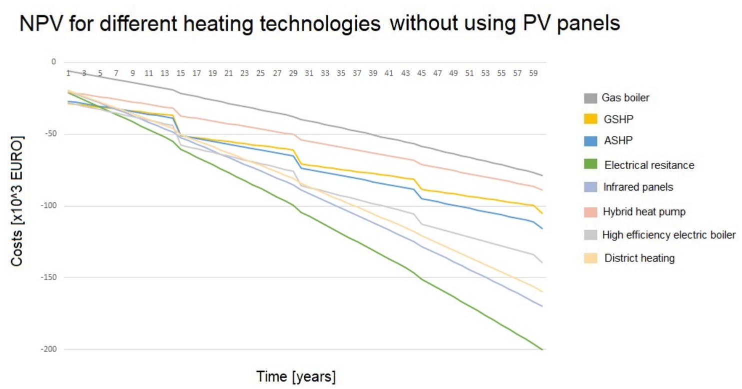


Figure 8.10: The NPV for decentralized heating systems without using PV panels (by author)

The current gas based heating system remains the cheapest solution for an individual home owner. This is a result of the low investment costs for the gas boiler. The two most expansive heating systems are the electric resistances and the infrared panels. These two systems have high investment costs and need a lot of electricity which results in low NPV values. District heating is not very profitable for individual home owners compared to the other heating systems. Of all the heat pumps the hybrid heat pump has the highest NPV. The NPV for micro-CHP could be higher if the generated electricity is sold to the grid. The yearly energy costs for sustainable heating technologies can be lower than gas, however because of the high investment costs the lower yearly energy costs do not result in a higher NPV in year 60.

To present the outcome of the financial feasibility, the possible decentralized heating systems are ranked in each situation (table 8.9). The order of ranking changes when PV panels with and without net metering are applied. ”1” means that the heating technology has the best NPV after 60 years and ”8” means that the heating technology has the worst NPV. In appendix D.4 the corresponding figures can be found. Table 8.9 also presents the average yearly energy costs per system.

Table 8.9: Classification of best heating system for decentralized heating (by author)

Classification	Heating system without PV		Heating system with PV (no net metering)		Heating system with PV (with net metering)	
	NPV after 60 years	Average yearly energy costs [EURO]	NPV after 60 years	Average yearly energy costs [EURO]	NPV after 60 years	Average yearly energy costs [EURO]
1	Gas system	1000	Gas system	1000	Gas system	1000
2	Hybrid HP	800	GSHP	500	GSHP	200
3	GSHP	700	Hybrid HP	700	CHP boiler	600
4	ASHP	900	ASHP	700	ASHP	500
5	CHP boiler	1200	CHP boiler	1200	Hybrid HP	200
6	District heating	2200	District heating	2000	District heating	1800
7	Infrared panels	2400	Infrared panels	2100	Infrared panels	1900
8	Electrical resistance	2700	Electrical resistance	2500	Electrical resistance	2300

When PV panels are applied the GSHP will turn into a more profitable heating system, especially when net metering is possible. The average yearly energy costs reduces when PV panels are used. However the investment costs increases when PV panels are used, resulting in a higher NPV for sustainable heating systems compared to gas systems.

CO_2 emissions review

To investigate the decreases or increases of the amount CO_2 emissions due to the application of decentralized heating systems it is assumed that all buildings belonging to the individual home owners are connected to one kind of decentralized heating systems. For the rest of the buildings standing in the neighbourhood, the situation does not change. Both the situation wherein a PV panel is used or not are elaborated. In appendix D.4 the detailed analysis of the CO_2 emissions can be found.

Table 8.10: The amount of CO_2 emissions for decentralized heating system without using PV panels (by author)

Decentralized heating system	CO_2 reduction due to electricity [%]	CO_2 reduction due to gas [%]	Total CO_2 reduction [%]	Total CO_2 reduction if green electricity used [%]
Gas	0	0	0	0
GSHP	-19	20	0	63
ASHP	-27	20	-5	63
Electrical resitance	-82	20	-34	63
Infrared panels	-69	20	-27	63
Hybrid heat pump	-11	13	0	59
Micro-CHP	0	-2	-1	52

Table 8.11: The amount of CO_2 emissions for decentralized heating system with PV panels (by author)

Decentralized heating system	CO_2 reduction due to electricity [%]	CO_2 reduction due to gas [%]	Total CO_2 reduction [%]	Total CO_2 reduction if green electricity used [%]
Gas	0	0	0	0
GSHP	-15	20	2	63
ASHP	-22	20	-2	63
Electrical resitance	-75	20	-30	63
Infrared panels	-62	20	-23	63
Hybrid heat pump	-10	13	0	59
Micro-CHP	0	-2	-1	52

Some sustainable heating systems demand more electricity, resulting in an increase in the amount of CO_2 emissions. When PV panels are used the amount of CO_2 emissions decreases a little bit. A GSHP system could give the highest CO_2 reduction, because this system needs the least electricity. Because the electricity demand for appliances in the buildings are unknown, the influence on using electricity from the PV panel cannot be calculated completely. Presumably the total electricity demand decreases, when PV panels are used. If all the consumed electricity would be produced sustainable, the total CO_2 reduction could be around 63%. It can be stated that when buildings are heated with decentralized heating systems, it is very important to make sure the electricity is generated sustainably, otherwise the total amount of CO_2 emission will only increase, although less gas in needed.

8.3. Conclusions

From the centralized heating scenarios it can be concluded that from all alternative sustainable heating options a geothermal well gives the best match between demand and supply and the highest NPV for energy companies. A low-temperature network is preferred over a high-temperature network, because in a low-temperature network more gas en CO_2 is reduced and more buildings can receive heat. A right balance between the size of the network and the buildings connected is needed, for the profitability of the network operators. The electricity must be produced sustainably, otherwise the CO_2 emissions will only increase when electric boilers are used. If all the roofs in Mariahoeve would have a PV panel the produced electricity would not be enough to meet the electricity demand, but it could reduce the amount of total CO_2 emissions. Most importantly, seasonal storage is needed. Without seasonal storage, sustainable heating is impossible.

From the decentralized heating scenario it can be concluded that, because most decentralized heating systems require electricity, it is of great importance that the consumed electricity is produced sustainably, otherwise the amount of CO_2 emissions will only increase. The use of PV panels could help reducing the total amount of CO_2 emissions and reduce the yearly energy costs for residents. However, the investment costs increase when PV panels are used. The best profitable system for individual home owners remains a gas based system. The best sustainable heating system, if no PV panels are used, is a hybrid heat pump. If PV panels are used, the GSHP becomes the most profitable heating system. The most expensive heating systems with the highest amount of CO_2 emissions are infrared panels and electrical resistances.

9 Conclusions

This chapter presents the main conclusions of this thesis. First the answers to the research questions are given, followed by a discussion. In the end a recommendation for municipalities is presented.

9.1. Conclusions

This thesis answers the following main question: *"How to create more insight into the financial and technical feasibility of different sustainable heating systems at neighbourhood level for municipalities?"* This question is relevant for municipalities who need to develop an energy transition plan for each of their neighbourhoods before 2021. To answer this main question different sub-questions are established. First the answers to the sub-questions are presented, followed by the answer to the main question.

9.1.1. What is the current situation in the energy transition at neighbourhood level from a political, stakeholder and technical view?

The literature study provides answers to this sub-question. Currently, it is very complex for political makers to transform the current heating system into a sustainable one. The current system is locked-in at the regime level and a safe niche level is needed to let new sustainable heating technologies develop and become more compatible with the sustainable targets at regime level. The role of municipalities should be a leading role and they need to bring together different stakeholders and create a platform where the stakeholders and the municipality could interact. The stakeholders consist of the residents of the neighbourhood, the active housing associations, the home owners associations in the neighbourhood, the network operator of the neighbourhood, energy companies and experts in the field of renewable heating techniques. Together they should propose new solutions for a renewable heating systems for a neighbourhood. More knowledge is needed for decision makers to transform the heating system into a sustainable one. In particular, the mismatch between the supply and demand of heat needs to be clarified.

Different renewable heating solutions are possible. A difference between centralized and decentralized heating systems can be made. Centralized heating systems supply heat for a large part of the neighbourhood via a heating network and decentralized heating systems supply heat for one building and are located near the building. Examples of centralized heating systems are geothermal energy, biomass energy, solar heat, waste heat and combined heat and power. Examples of decentralized heating systems are GSHP, ASHP, hybrid heat pump, electrical resistances, infrared panels, hybrid heat pumps and high electric efficiency boilers.

To model sustainable neighbourhoods different methods could be applied. Thee energy potential mapping (EPM) gives insight into the potential of renewable heat in the neighbourhood. The spatial transition analysis (STA) methodology can be used to develop a plan to transform the energy heating system in a neighbourhood. The zity-zen approach creates an energy master plan for decision makers, taking the technical, economical, social and political difficulties into account.Furthermore, different calculation models can be applied to create more insight into possible heating technologies in a neighbourhood. However, none of these methodologies gives detailed insight into the differences between the potential heating supply and the heating demand of the buildings. A calculation model is needed to create insight into the match of possible heating potentials and heating demand of buildings in a neighbourhood, which is essential to characterize the CO_2 emissions of different alternatives.

9.1.2. What kind of approach can be developed to gain more information on the energy transition at neighbourhood level?

This study has developed a calculation model and an approach to use this calculation model to gain more information on the needed energy transition at neighbourhood level. This calculation model has to meet different criteria formulated by decision makers and the author. Table 9.1 explains how many of these criteria complied with the calculation model.

Table 9.1: Criteria for the methodology conducted from interview (by author)

Criteria	Explanation	Complied by Method?
CO_2 emission	The method should give insight in how much C02 the different sustainable heat production/distribution technologies pollute.	Yes
Costs	The method should give insight in how much the sustainable heat production/distribution technology costs (investment and operational).	Yes
Social cost	The method should give insight in the social cost (private costs + external costs) of the sustainable heat production/distribution technology.	No
Division of cost	The method should give insight in who should pay what.	Yes
Stakeholders	The method should give insight in which stakeholders are involved and what the role is of each stakeholder.	Yes
Division of use	The method should give insight which buildings need to be connected to collective system and what happens if a building decide to ignore the collective system and create a individual system.	No
Comparable with current system	The method should compare the sustainable heating system with the current gas-based system in terms of costs and CO_2 emissions.	Yes
Maturity of technology	The method should give insight in the maturity of the sustainable heat production/distribution technologies.	No
Production technologies	The method should include all the possible sustainable heat production technologies like solar, wind, geothermal, biomass and waste heat.	Yes
Distribution technologies	The method should include all the possible distribution technologies (centralized, decentralized).	Yes
Demand side	The method should give information of the demand side (state of building, state of isolation etc).	Yes
Demand change	The method should give insight in the influence of demand on the production and distribution technology.	Yes
Intermittency	The method should give insight in the mismatch between the demand and supply.	Yes
Phasing	The method should give insight of the phasing of different heat systems (flexible in time)	No
Area distribution	The method should give insight in how much area a technology need.	No
Time consuming	The calculation method should not need to much time to calculate outcomes (maximum 5 minutes).	Yes

It can be seen that the calculation model meets most criteria. The approach to use the calculation model is given in figure 9.1. The first step in the approach is to collect data to determine the heating demand of each building in the neighbourhood. The second step is to collect the heating potential of different heating technologies in the scope of the neighbourhood. Using the EPM method helps to determine these potentials. The third step is to determine the scenarios the calculation model should calculate. In this study a difference between centralized and decentralized scenarios are developed. The fourth step is to run the calculation model. The last step of the developed approach is to analyze the outcome of the scenarios.

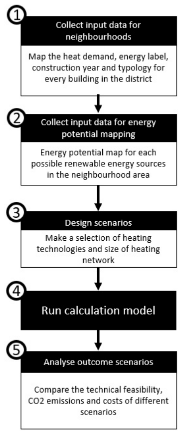


Figure 9.1: Developed approach (by author)

9.1.3. How can different alternatives for the current heating system objectively be weighted by municipalities, taking technical and financial feasibility into account as well as district typologies (types of houses and ownerships structures?)

The calculation model objectively compares alternative heating technologies for buildings in a neighbourhood. It calculates the match between demand and supply with two indicators: OEM and OEF. The financial feasibility for different stakeholders is calculated using NPV methodology. The outcomes of the OEM and OEF is used to determine the amount of CO_2 emissions.

In the applied case study outcomes of different scenarios are weighted objectively. The outcomes of centralized scenario show that a low-temperature heating network is preferred in Mariahoeve, resulting in a low amount of CO_2 emissions. The size of the heating network cannot be too large, otherwise the costs are too high for network operators. The best heating technology for district heating in Mariahoeve is the use of geothermal wells. Seasonal storage is needed, otherwise sustainable heating is not possible. If electric boilers for domestic hot water (DHW) are used it is also necessary to make the supply of electricity sustainable, otherwise the amount of CO_2 emissions will only increase.
For decentralized heating system the GSHP has the lowest costs and lowest amount of CO_2 emissions. If gas can still be used it is preferable to use hybrid heat pumps. The use of PV panels is very interesting for individual heating system as the electricity from the PV panel could supply electricity to the heating system. When heating the neighbourhood sustainably it is important to also make the electricity supply sustainable, otherwise the CO_2 emission will only increase.

9.1.4. How to create more insight into the financial and technical feasibility of different sustainable heating systems at neighbourhood level for municipalities?

The calculation model calculates in detail how much heat from alternative heating technologies is generated and consumed by buildings. It gives in depth knowledge of the possible amount of heat can be stored and how much heat is still needed from the grid per heating technology. A decision maker can easily select alternative heating technologies and define the buildings that have to be connected to district heating. A lot of insight is created and more understanding of the pros and cons of alternative heating systems is given. With this calculation model it is possible to choose the best possible heating system for the heating system in a neighbourhood and understand the difficulties of heating a neighbourhood.

9.2. Discussion

The developed calculation model extends the existing STA methodology (Oudes and Stremke, 2018) and zity-zen approach (Broersma and Fremouw, 2011) by including detailed insight in the mismatch of sustainable heating supply and heating demand. However, this study only focuses on heating the neighbourhood sustainably. As explained in the literature study, for future studies possible cooling technologies and insight in the cooling demand should be included for the energy transition at a neighbourhood level. Additionally, the electricity production for appliances and lighting should be taken into account. In this thesis some generalizations are made that need to be discussed.

9.2.1. Generalizations

This study mapped the current heating demand of buildings using online data form network operators and supporting models like PICO (Pico, 2018a) and energielabelatlas (energielabelatlas, 2018). The approach to map this heating demand is sufficient for now, however in future studies the real heating pattern per building is needed. This can be done using smart meters in buildings. Furthermore, real data of the insulation of buildings is needed. With real data the real hourly energy demand can be determined and when compared to the heating demand of possible sustainable heating sources better conclusions for the energy transition can be made.

The calculated NPV for energy companies are generated by assuming that all the heat generated by the energy companies is sold. This is why the NPV of energy companies are independent on the intermittency between supply and demand. In reality, the profits of energy companies depend on how much heat can be consumed by a neighbourhood. In future research more in-depth knowledge of how much heat is really sold is needed, to calculate the realistic NPV for energy companies per alternative heating technology.

The calculated NPV and mismatch between demand and supply for the geothermal wells as defined by the study of Willemsen does not include the costs and the electricity demand of the used heat pump. The electricity demand would probably be higher, when this system is used, because a heat pump requires electricity. This means that, if the electricity used for the heat pump is not gained sustainably, the overall CO_2 emissions increase in this scenario. Furthermore, the costs for this geothermal system would also be higher, because the costs of the heat pump is not yet included. In further research the effect of the used heat pump should be included.

The calculation model only calculates the amount of CO_2 emission that is emitted when specific heat is produced. It does not take the amount of CO_2 emissions into account that are emitted when specific plants or heating technologies are build. To really compare the corresponding CO_2 emissions per technology the complete amount of emitted CO_2 during the production chain is needed.

When, in the calculation model, a building improves it energy label to a higher energy label the energy demand drops with a percentage as given in appendix C. The study of (Majcen, 2016) the actual percentage drops can be found which are much lower, meaning that the energy demand for insulated buildings should have been higher in this study resulting in less heat to storage and a higher heating demand from the gas grid. However, in reality it depends on the type and state of the building what the effect of insulation can be on the heating demand of a building. Further in-depth research is needed to really understand the influence of insulation for each building.

The calculation model does not give information on regulations and restrictions that occur when specific renewable heating plants or technologies are built. This information is very convenient during the planning phase for the energy transition in a neighbourhood for municipalities. Knowing how long it takes to build a plant and if it is allowed to build a plant in the neighbourhood are fundamental questions for decision makers. In further studies this should be applied.

At last, the costs for residents connected to district heating are higher compared to the costs of a gas grid. To make district heating more profitable for citizens the heating price should be decreasing, or the gas price increasing. Further studies are needed to find the best solution to make district heating more profitable for citizens.

9.3. Recommendations

To understand and work with the developed calculation model, insight into the model is required. This could be a time consuming step, but a vast amount of information can be obtained when the user of the calculation model understands it clearly. It is recommended to start to create a safe platform and investigate together with the stakeholders (energy companies, network operators, housing associations and residents) what the needs of the neighbourhoods are and what their opinion is on the possible renewable heating possibilities.

When working together a lot could be achieved. Furthermore it is strongly advised to investigate the possibilities for storage because without storage it would never be possible to create a sustainable heating system. Lastly, in order to prevent the increase of the amount of CO_2 emissions the electricity demand should also become more sustainable, especially for decentralized heating systems.

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A

Data individual dwellings

A.1. Energy heating pattern for heating apartment per typology

In this section it will be explained how the example energy pattern for different buildings are determined.

A.1.1. Typology 1

In Mariahoeve the first construction year of the first types of building can be divided into three groups: Buildings with construction year under 1965 (91%), buildings with construction year between 1980-1983 and buildings with a construction year between 1992-2014. For each of these groups an example pattern is constructed. In this section the example patterns will be given.

Buildings with construction year before 1965

To built the pattern the following example building is chosen (figure: A.1). The building consist of 24 apartments and the total average gas demand per apartment is 1147 m^3 per year. This gas demand is inclusive the heat needed for heating domestic hot water. The heat needed to heat only the apartment becomes 772 m^3 per year. The energy label of this building is E and the construction year of this building is 1962. The total gas demand for the whole building is 18528 m^3/year. This is equal to 181059 kWh/year. A calculation model will be used to determine the energy demand pattern.

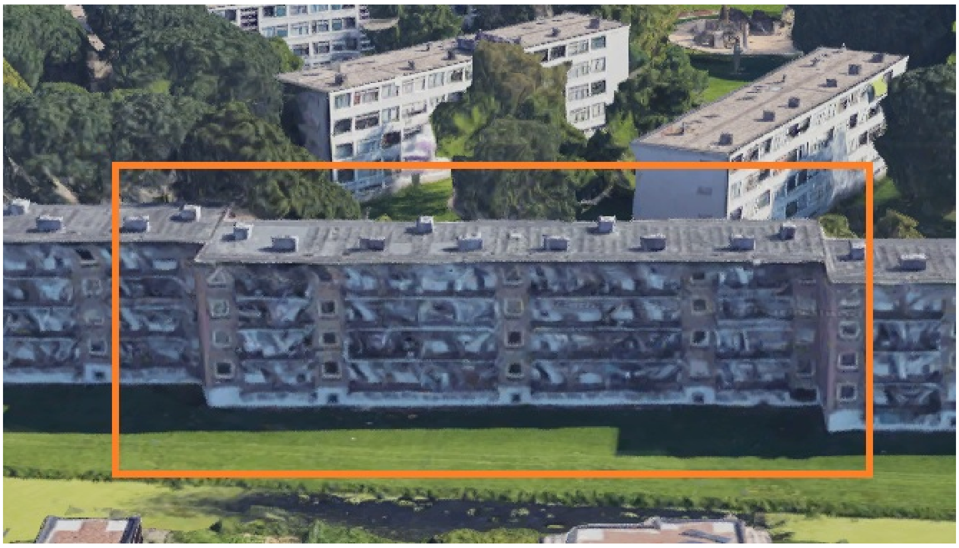


Figure A.1: The example building for determine the energy pattern for buildings of typology 1 built before 1965 (by author and google maps)

For this type of building, built before 1965, the RC-values as given in table **??** can be used. When filling these values into the calculation model the following total theoretical energy demand is given: 522718 kWh. This is too high compared with the real total energy demand. The demand can be lowered by lowering the indoor temperature, as seen in section **??**. When changing the indoor temperature to 10.6069 the total energy demand is 181059 kWh/year. The heating pattern for heating the apartment is as follow:

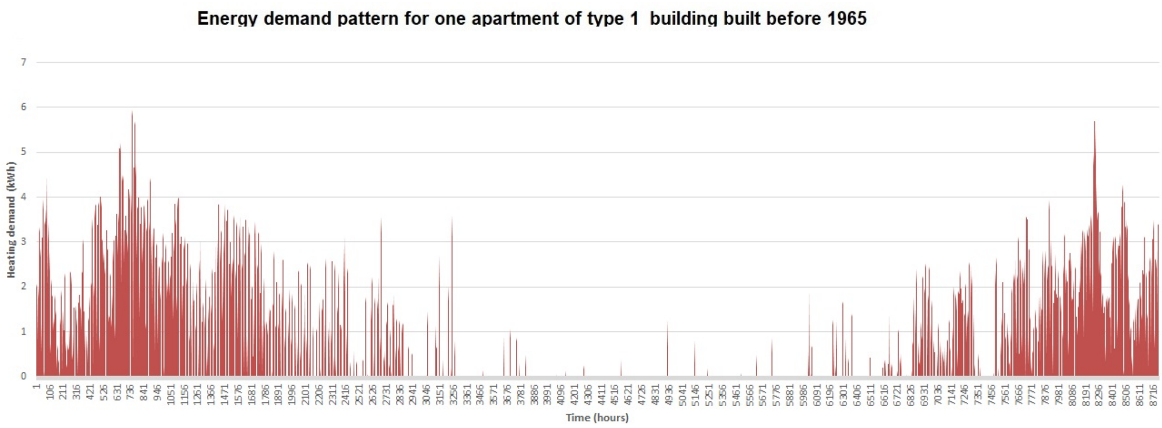


Figure A.2: The energy pattern for a apartment in building type 1 built before 1965

Thus, every type 1 building in the Mariahoeve built before 1965 will have the same pattern as in figure A.2.

Dwellings built between 1980-1989

The same method as before will be used to determine the pattern of the buildings of typology 1 built between 1980-1989 (figure A.3). In Table A.1 the changed RC-values can be found. The representative building is built in 1986. It consist of 30 apartments and it has a modeled energy label of C. The real energy demand for this building is 30570 m^3/year. The energy demand exclusive heating domestic hot water becomes 19320 m^3/year. This means that the theoretical energy consumption need to be 188746 kWh/year.

Figure A.3: The example building for determine the energy pattern for buildings of typology 1 built between 1980-1989 (by author and google maps)

Filling in the values as given in table A.1 in the calculation model gives a theoretical gas consumption of 363761 kWh/year. This means that the calculation model needs to be lowered. When decreasing the indoor temperature to 14.17828 ^{0}C the new theoretical energy demand becomes: 188746 kWh/year. The energy demand pattern per apartment becomes:

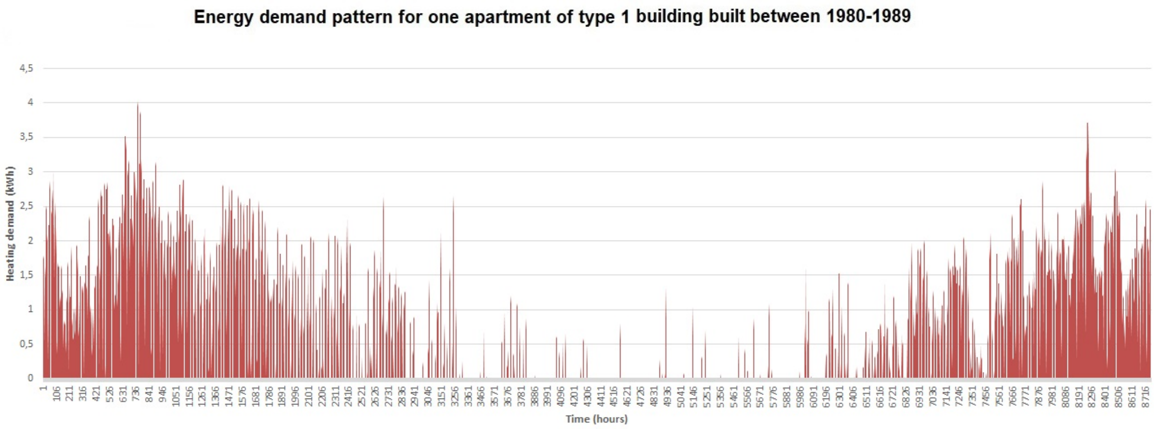


Figure A.4: The energy pattern for a apartment in building type 1 built between 1980-1989

Dwellings built between 1992-2014

The third group of dwellings of type 1 are the dwellings built between 1992-2014. The representative building is built in 2003 (figure A.5). It consist of 55 apartments and the modeled energy label is B. The real gas consumption is 39215 m^3/year. The energy demand exclusive heating domestic hot water becomes 18590 m^3/year. This means that the theoretical energy consumption need to be 181614 kWh/year.

Filling in the values as given in table A.1 in the calculation model the model gives a theoretical energy consumption of 539012 kWh per year. Lowering the indoor temperature to a temperature of 11.6813 ^{0}C gives a theoretical energy consumption of 181614 kWh/year. The energy pattern per apartment is pictured in figure (A.6).

Figure A.5: The example building for determine the energy pattern for buildings of typology 1 built between 1992-2014 (by author and Google maps)

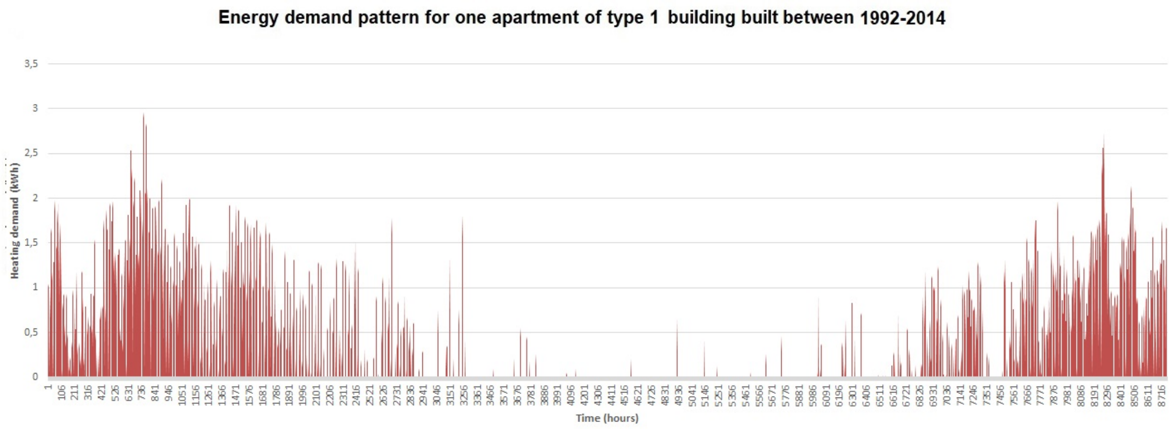


Figure A.6: The energy pattern for a apartment in building type 1 built between 1992-2014

Table A.1: The parameters (ISSO 2015)

Outside parameters	Typology 1 before 1965	Typology 1 1980-1989	Typology 1 1992-2014
Total,façade area (incl. glass) North	624 m^2	726 m^2	1150 m^2
Total,façade area (incl. glass) North-East	0	0	0
Total,façade area (incl. glass) East	120 m^2	144 m^2	150 m^2
Total,façade area (incl. glass) South-East	0	0	0
Total,façade area (incl. glass) South	624 m^2	726 m^2	1150 m^2
Total,façade area (incl. glass) South-West	0	0	0
Total,façade area (incl. glass) West	120 m^2	144 m^2	150 m^2
Total,façade area (incl. glass) North-West	0	0	0
Total roof area (incl. glass)	520 m^2	726 m^2	1725 m^2
Total ground floor area (incl. glass) North	520 m^2	726 m^2	1725 m^2
Number of floors	4	4	4
Floor,height	3	3	2.5
Window,percentage North	60 %	60 %	60 %
Window,percentage North-East	0	0	0
Window,percentage East	30 %	30 %	30 %
Window,percentage South-East	0	0	0
Window,percentage South	50 %	50 %	50 %
Window,percentage South-West	0	0	0
Window,percentage West	30 %	30 %	30 %
Window,percentage North-West	0	0	0
Window,percentage roof	0	0	0
Transmission paramters			
Rc façade wall	0.19	1.30	2.5
Rc roof	0.22	1.30	2.5
Rc floor	0.15	1.30	2.5
U window (double glass)	2.9	2.9	2.9
Internal heat parameters			
Number of people	48	60	110
Number of apartments	24	30	55

A.1.2. Typology 2

The second typology of buildings can be divided into three subgroups; buildings built before 1965, building built between 1975-1983 and buildings built between 1992-2014. The same methodology as for typology 1 will be used to determine the energy demand pattern per subgroup.

Buildings with construction year before 1965

As representative building a dwelling built in 1965, consisting of 72 apartments, will be chosen (figure A.7).

Figure A.7: The example building for determine the energy pattern for buildings of typology 2 built before 1965 (by author and google maps)

The modeled energy label of this dwelling is C. The input value for this type of building can be found in table A.2. The real gas demand for this building is 68364 m^3/year. The energy demand exclusive heating domestic hot water becomes 41364 m^3/year. This means that the theoretical energy consumption need to be 404103 kWh/year. Filling in the value of table A.2 in the calculation model gives a theoretical energy consumption of 1034462 kWh/year. When the indoor temperature drops to 12.07286^{0}C the theoretical energy demand becomes: 404103 kWh/year. This gives the energy pattern per apartment as pictured in figure (A.8).

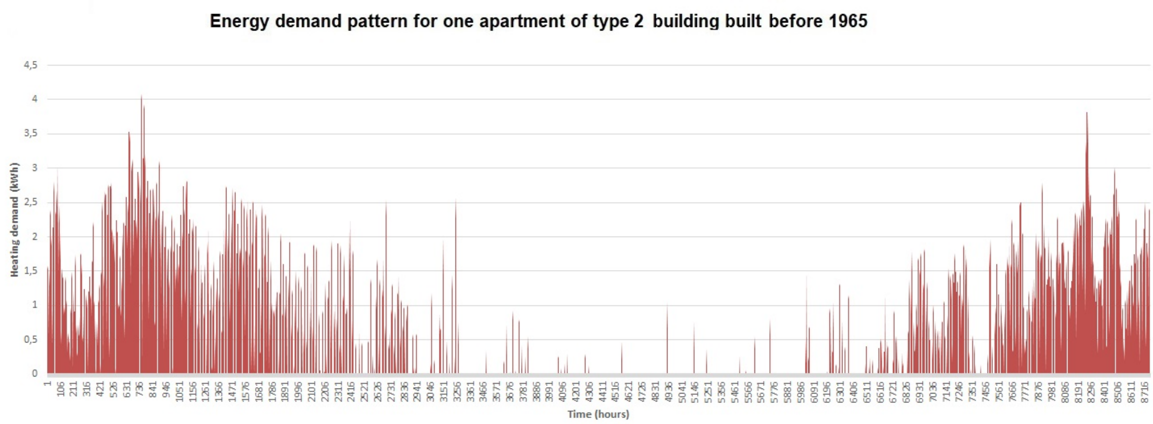


Figure A.8: The energy pattern for a apartment in building type 2 built before 1965

Thus, every building of type 2 built before 1965 will have the same pattern as the figure above.

Buildings with construction year between 1975-1983

The representative building for type 2 built between 1975-1983 is a building with a construction year of 1975.

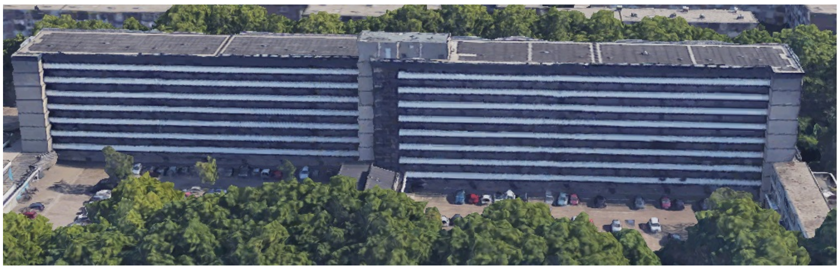


Figure A.9: The example building for determine the energy pattern for buildings of typology 2 built before 1965 (by author and google maps)

It contains of 175 apartments and the modeled energy label is C. The actual energy consumption for this building is 124250 m^3/year. The energy demand exclusive heating domestic hot water becomes 58625 m^3/year. This means that the theoretical gas consumption need to be equal to 572734 kWh/year. Filling in the values as given in table A.2 in the calculation model gives a theoretical yearly energy demand of: 1776470 kWh/ year. Lowering the indoor temperature to 11.166789 ^{0}C gives an energy demand of 572734kWh/year. This gives an energy pattern per apartment as follow:

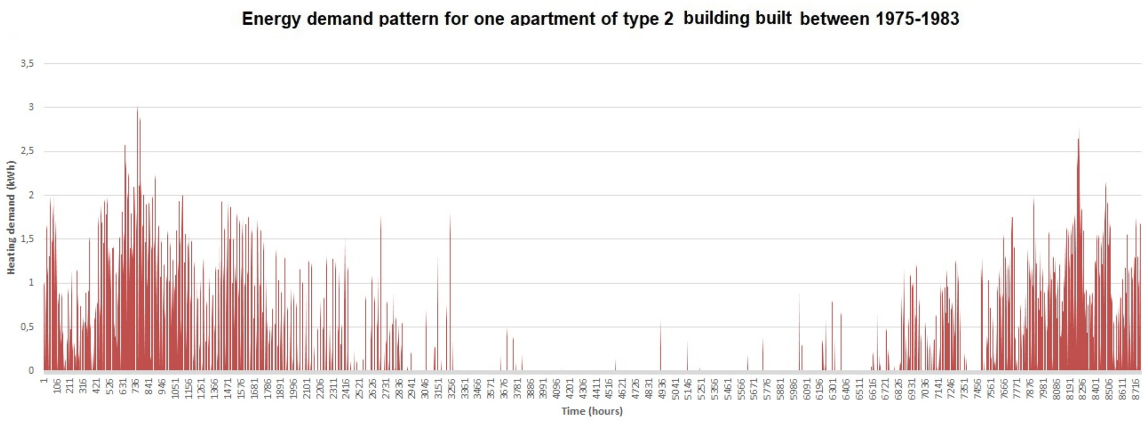


Figure A.10: The energy pattern for a apartment in building type 2 built between 1975-1983

Buildings with construction year between 1992-2014

The last subgroup consist of buildings built between 1992 and 2014. As example the following building is chosen:

Figure A.11: The example building for determine the energy pattern for buildings of typology 2 built between 1992-2014(by author and Google maps)

This building is built in 1999 and consist of 63 apartments and it has a modeled energy label A. The actual energy demand is 46431 m^3/year. The energy demand exclusive heating domestic hot water becomes 22806 m^3/year. This means that the theoretical gas consumption need to be equal to 222802 kWh/year. Filling in the parameters as given in table A.2 in the calculation model gives 471348 kWh/year. Decreasing the indoor temperature to 13.88456^{0}C gives a yearly energy demand of 222802 kWh. The year the energy pattern per apartment becomes:

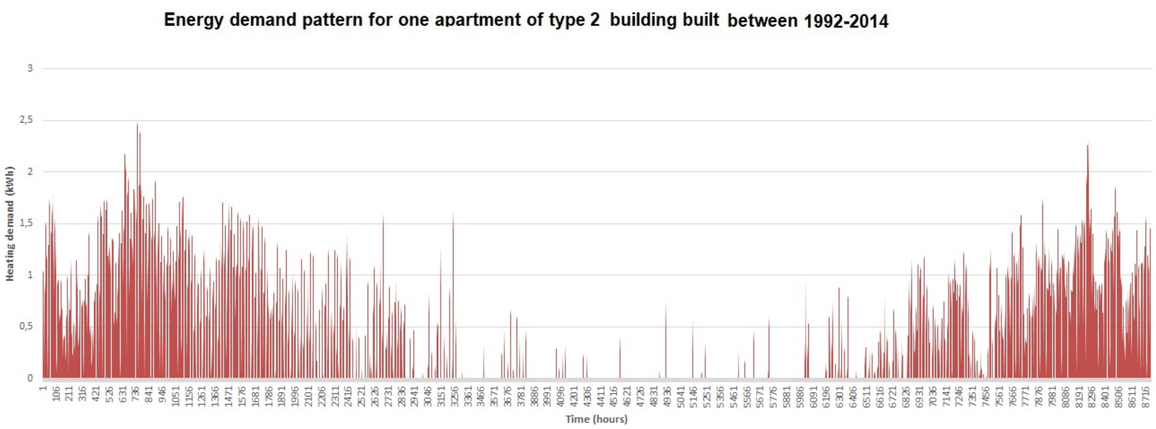


Figure A.12: The energy pattern for a apartment in building type 2 built between 1992-2014

Table A.2: The parameters of type 2 buildings(ISSO 2015)

Outside parameters	Typology 2 before 1965	Typology 2 1975-1983	Typology 2 1992-2014
Total,façade area (incl. glass) North	1350 m^2	3058 m^2	1045 m^2
Total,façade area (incl. glass) North-East	0	0	0
Total,façade area (incl. glass) East	360 m^2	459 m^2	283.5 m^2
Total,façade area (incl. glass) South-East	0	0	0
Total,façade area (incl. glass) South	1350 m^2	3058 m^2	1045 m^2
Total,façade area (incl. glass) South-West	0	0	0
Total,façade area (incl. glass) West	360 m^2	459 m^2	283.5 m^2
Total,façade area (incl. glass) North-West	0	0	0
Total roof area (incl. glass)	528 m^2	2599 m^2	671.6 m^2
Total ground floor area (incl. glass) North	528 m^2	2599 m^2	671.6 m^2
Number of floors	12	8	7
Floor,height	2.5	3	3
Window,percentage North	60 %	60 %	60 %
Window,percentage North-East	0	0	0
Window,percentage East	0	0	0
Window,percentage South-East	0	0	0
Window,percentage South	60 %	60 %	60 %
Window,percentage South-West	0	0	0
Window,percentage West	0	0	0
Window,percentage North-West	0	0	0
Window,percentage roof	0	0	0
Transmission paramters			
Rc façade wall	0.19	1.30	2.5
Rc roof	0.22	1.30	2.5
Rc floor	0.15	0.52	2.5
U window (double glass)	2.9	2.9	2.9
Internal heat parameters			
Number of people	144	350	126
Number of apartments	72	175	63

A.1.3. Typology 3

The last typology can also be divided into four subgroups. The first subgroup consist of buildings built before 1965, the second group of buildings built between 1975-1983, the third group of buildings built between 1983-1988 and the last group of buildings built between 1992-2014. The same method as with typology 1 and 2 will be used.

Buildings with construction year before 1965

A representative building belonging to typology 3 built in 1960 is as follow:

Figure A.13: The example building for determine the energy pattern for buildings of typology 3 built before 1965 (by author and google maps)

This block building consist of seven dwellings. The modeled energy label is F. The actual energy demand is 13832 m^3/year. The energy demand exclusive heating domestic hot water becomes 11207 m^3/year. This means that the theoretical gas consumption need to be equal to 109486 kWh/year. Filling in the values as given in table A.3 gives an theoretical energy demand of 288295 kWh/year. Lowering the indoor temperature to 10.58419 ^{0}C gives an energy demand of 109486 kWh/year.This gives an energy demand pattern per dwelling as follow:

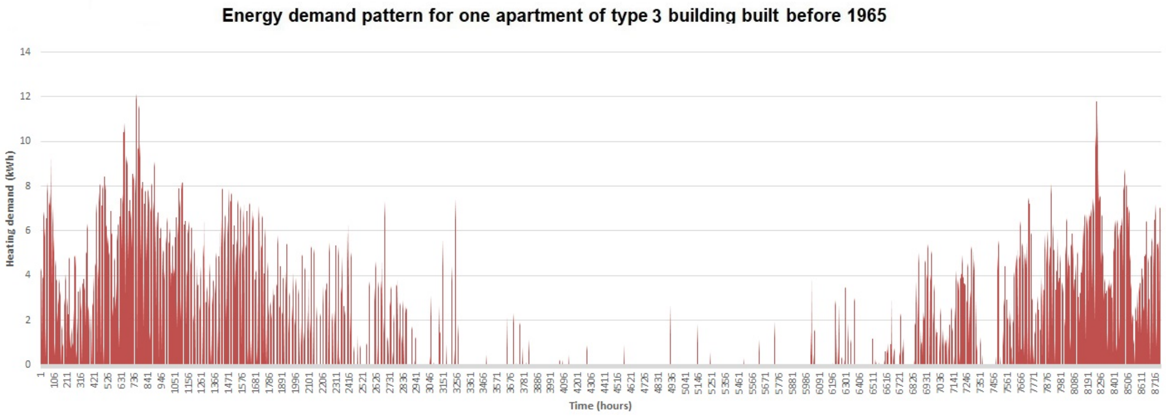


Figure A.14: The energy pattern for a apartment in building type 3 built before 1965

Buildings with construction year between 1975-1983

A example building for the second subgroup is a type 3 building that is built in 1970. This group will belong to the group built between 1975-1983.

Figure A.15: The example building for determine the energy pattern for buildings of typology 3 built between 1975-1983 (by author and google maps)

This block buildings consist of 4 dwellings. The energy label of this building is E and the actual energy demand is 14180 m^3/year. The energy demand exclusive heating domestic hot water becomes 12680 m^3/year. This means that the theoretical gas consumption need to be equal to 123876 kWh/year. Filling in the values as given in table A.3 in the calculation model gives an theoretical demand of 141679 kWh/year. Decreasing the indoor temperature to 19.7414 ^{0}C gives a theoretical energy demand of: 138531 kWh/year. THis gives an energy pattern per dwelling of:

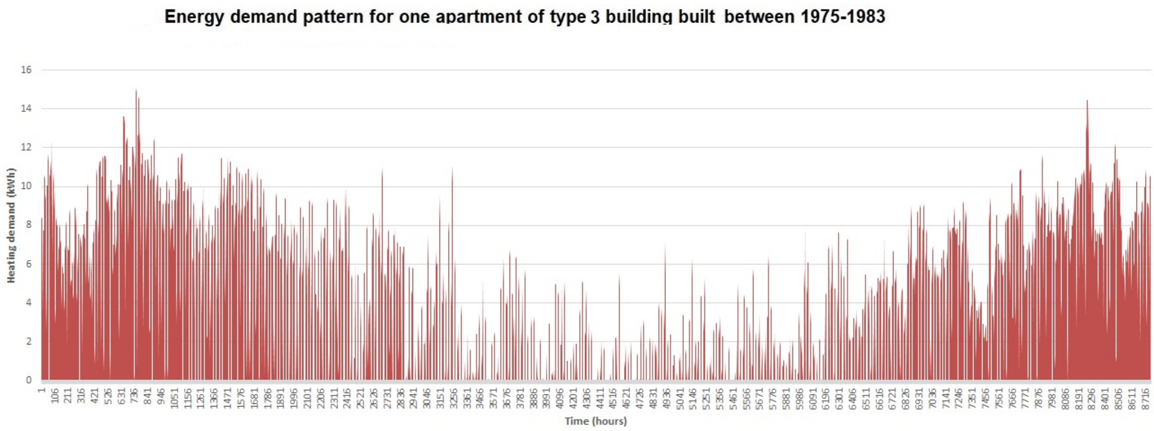


Figure A.16: The energy pattern for a apartment in building type 3 built between 1975-1983

Buildings with construction year between 1983-1988

As example to determine the energy pattern for this types of building the following building will be taken:

Figure A.17: The example building for determine the energy pattern for buildings of typology 3 built between 1983-1988 (by author and google maps)

This building is built in 1988 and consist of 12 dwellings. The modeled energy label of this building is C. And the actual yearly gas consumption is 11472 m^3/year. The energy demand exclusive heating domestic hot water becomes 6972 m^3/year. This means that the theoretical gas consumption need be the same as 68113 kWh/year. Filling in the values as given in table A.3 the calculation model gives a theoretical consumption of 169965 kWh/year. Lowering the indoor temperature to 12.0499 ^{0}C gives an energy consumption of 68113 kWh/year. This gives an energy pattern per dwelling of:

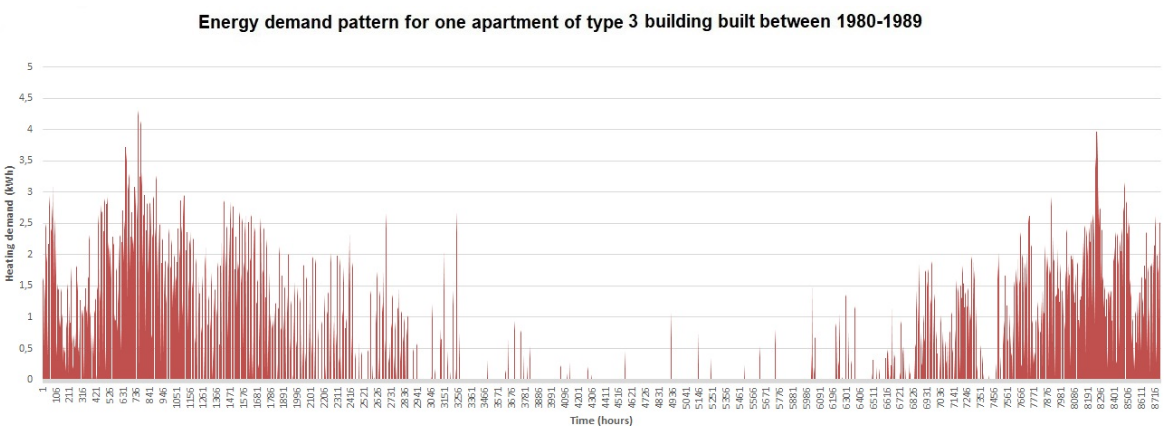


Figure A.18: The energy pattern for a apartment in building type 3 built between 1983-1988

Buildings with construction year between 1992-2014

The last group consist of building built between 1992-2014. The example building is built in 2009 and the modeled energy label is A. The building consist of eight apartments.

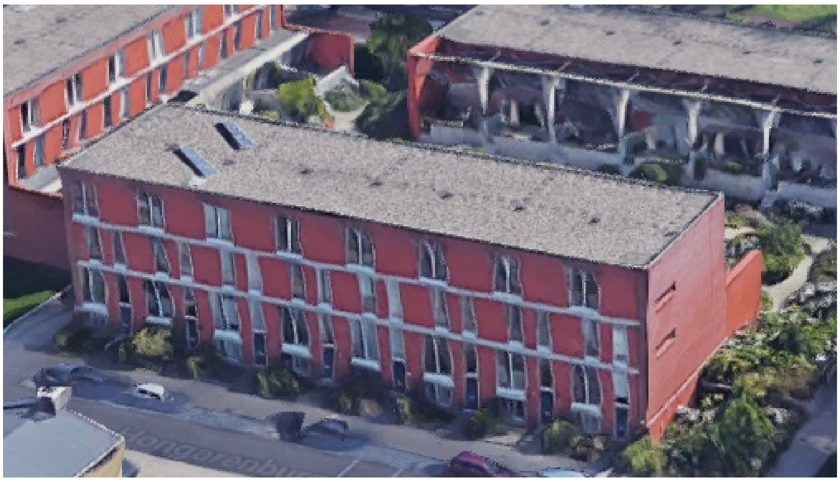


Figure A.19: The energy pattern for a apartment in building type 3 built between 1975-1983

The actual gas consumption of this building block is 9920 m^3/year. The energy demand exclusive heating domestic hot water becomes 6920 m^3/year. This means that the theoretical gas consumption need be the same as 67605 kWh/year. Filling in the values of table A.3 the calculation model gives a theoretical energy demand of 174308 kWh/year. Changing the indoor temperature to 12.2029 ^{0}C the energy consumption changes to 67605 kWh/year. This gives a theoretical energy pattern per dwelling as follow:

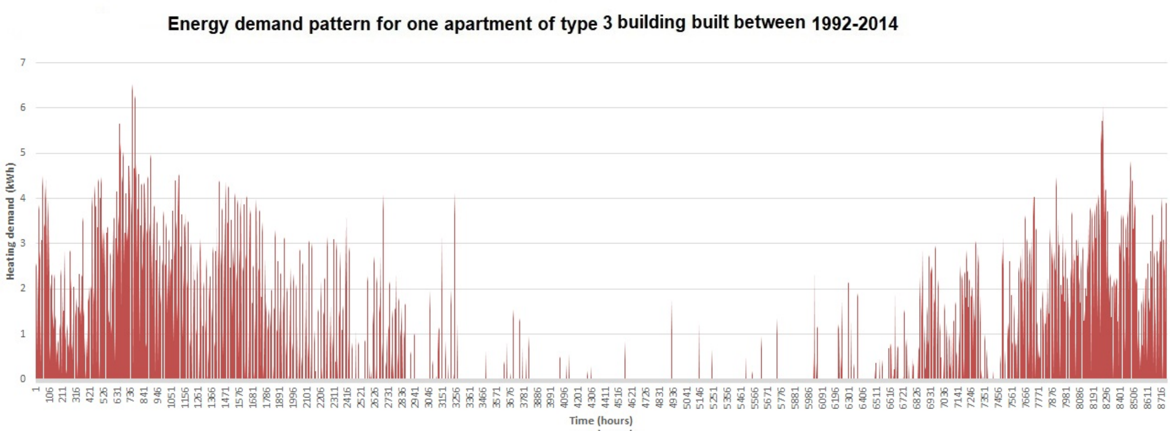


Figure A.20: The energy pattern for a apartment in building type 3 built between 1992-2014

Table A.3: The parameters of type 3 buildings(ISSO 2015)

Outside parameters	**Typology 3 before 1965**	**Typology 3 1975-1983**	**Typology 3 1983-1988**	**Typology 3 1992-2014**
Total,façade area (incl. glass) North	300 m^2	270 m^2	295 m^2	342 m^2
Total,façade area (incl. glass) North-East	0	0	0	
Total,façade area (incl. glass) East	51 m^2	81 m^2	57,5 m^2	162 m^2
Total,façade area (incl. glass) South-East	0	0	0	
Total,façade area (incl. glass) South	300 m^2	270 m^2	295 m^2	342 m^2
Total,façade area (incl. glass) South-West	0	0	0	
Total,façade area (incl. glass) West	51 m^2	81 m^2	57,5 m^2	162 m^2
Total,façade area (incl. glass) North-West	0	0	0	
Total roof area (incl. glass)	467,5 m^2	297 m^2	678,5 m^2	684 m^2
Total ground floor area (incl. glass) North	425 m^2	270 m^2	678,5 m^2	684 m^2
Number of floors	2	3	2	3
Floor,height	3	3	3	3
Window,percentage North	60 %	60 %	50 %	50 %
Window,percentage North-East	0	0	0	0
Window,percentage East	0	0	0	0
Window,percentage South-East	0	0	0	0
Window,percentage South	60 %	60 %	50 %	50 %
Window,percentage South-West	0	0	0	0
Window,percentage West	0	0	0	0
Window,percentage North-West	0	0	0	0
Window,percentage roof	30 %	30%	0	0
Transmission paramters				
Rc façade wall	0.19	1.30	1.30	2.5
Rc roof	0.22	1.30	1.30	2.5
Rc floor	0.15	0.52	1.30	2.5
U window (double glass)	2.9	2.9	2.9	2.9
Internal heat parameters				
Number of people	14	8	24	16
Number of apartments	7	4	12	8

A.2. Heat demand domestic hot water pattern

Also the energy pattern for heating the domestic hot water per hour per day is needed. The study of (Friedel et al. 2014) gives a daily pattern for the heating of domsetic hot water for an average household. Table A.4 gives an overview of the share of demand for the household.

Table A.4: Share of demand for domestic hot water for hourly pattern (Friedel et al. 2014)

Hour	0-1	1-2	2-3	3-4	4-5	5-6
Share of demand	0.7%	0.4%	0.1%	0.1%	0.2%	0.7%
Hour	6-7	7-8	8-9	9-10	10-11	11-12
Share of demand	5.6%	9.3%	7.2%	8.5%	6.1%	5.3%
Hour	12-13	13-14	14-15	15-16	16-17	17-18
Share of demand	4.5%	3.6%	3.1%	2.4%	2.7%	4.4%
Hour	18-19	19-20	20-21	21-22	22-23	23-24
Share of demand	7.8%	7.9%	7.0%	5.8%	4.1%	2.0%

The daily pattern is than given as follow:

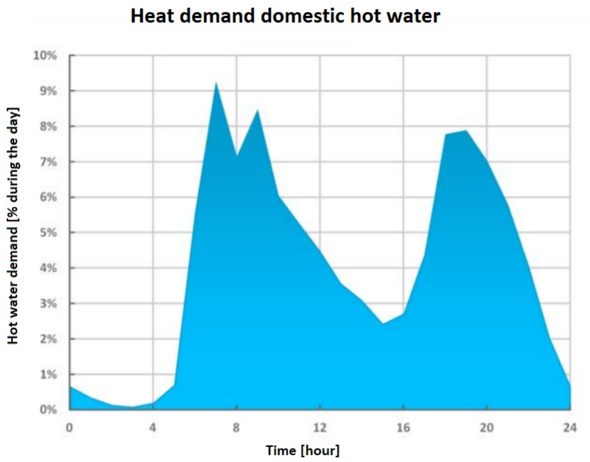


Figure A.21: Demand of domestic hot water per hour over a day (Friedel et al. 2014)

If it is known that the yearly energy demand for heating domestic hot water is equal to 375 m^3 per year than the daily demands becomes: 1.027 m^3. The daily demands follows the pattern as given in figure A.22. The yearly pattern for the whole Mariahoeve for heating domestic hot water:

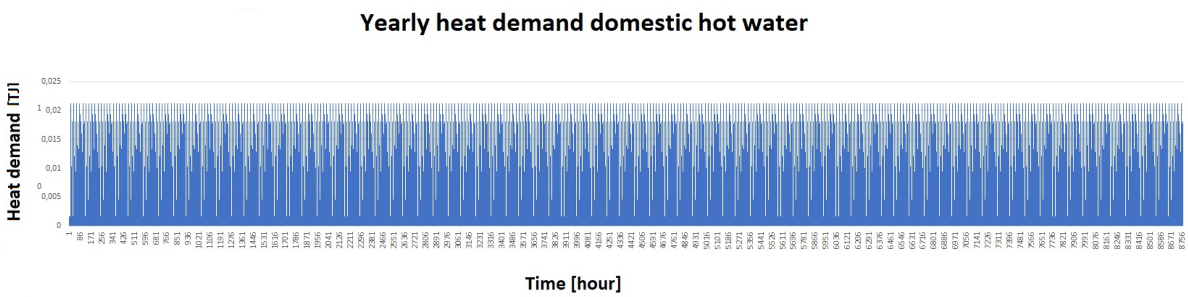


Figure A.22: Demand of domestic hot water for a year (Friedel et al. 2014)

This is a heat demand pattern for one dwelling or apartment, assuming an average household of two persons.

B

Simplified model heat district network

To know the losses of a heat district network some assumption where made to simplify the model. First, assumed is that the outer temperature is always around 10 ^{0}C. Furthermore the system is steady state, there is negligible resistance of the pipe wall and for convection from the water. With the help of (Mills 2014) the relation between the length of a insulated pipe and the heat loss can be given.

A water tube for heat district lays beneath the ground surface (figure B.2).

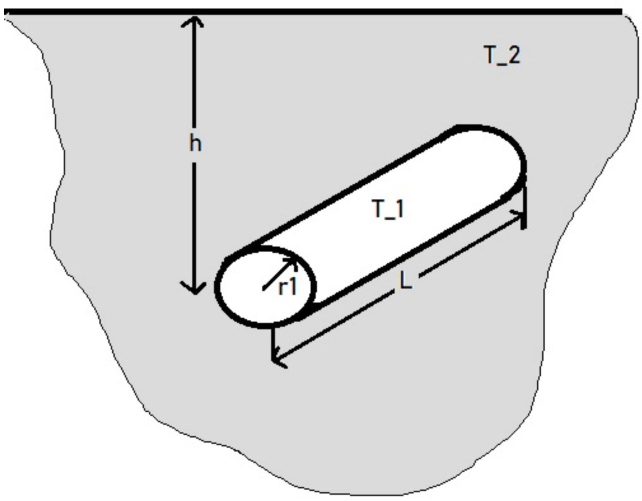


Figure B.1: Water tube under the ground surface (by author)

Assumed is that the pipe lays 1.5 m under the ground, thus $h = 1.5m$. Furthermore the diameter of the tube is 45 cm (Nijmegen 2016). The tube has an insilation layer of PUR (polyurethaan). There is assumed that the insulation layer has a thickness of 20 mm.The heat loss can be calculated as follow:

$$\Delta\dot{Q} = \dot{m}\Delta h \tag{B.1}$$

With Q the heat loss in W, m the mass flow and h the heat transfer coefficient. The formula can be written as:

$$k\Delta S\Delta T = \dot{m}c_p\Delta T \tag{B.2}$$

With k the thermal conductivity, S the shape factor, c_p the specific heat and ΔT the temperature difference.

The shape factor depends on how deep the tube lays under the ground (Mills 2014). If $h > 3r_1$ the following shape factor can be used:

$$S = \frac{2\pi L}{\ln(\frac{2h}{r_1})} \tag{B.3}$$

If the tube lays higher than the shape factor becomes:

$$S = \frac{2\pi L}{\cosh^{-1}(\frac{h}{r_1})} \tag{B.4}$$

Since $h > 3r_1$ is true, equation B.3 will be used. When an insulation layer is added the heat transfer can, according to (Mills 2014), rewritten in:

$$\Delta\dot{Q} = \frac{T - T_s}{\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}\Delta x} + \frac{1}{k_{soil}\Delta S}} \tag{B.5}$$

Thus, combining equation B.1 with equation B.5 gives:

$$\dot{m}c_p(T|_{x+\Delta x} - T|_x) = \frac{T - T_s}{\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}\Delta x} + \frac{1}{k_{soil}\Delta S}} \tag{B.6}$$

Here $x + \Delta x$ is the length of the tube. Filling in the shape factor S (B.3)and dividing by Δx gives:

$$\dot{m}c_p(\frac{T|_{x+\Delta x} - T|_x}{\Delta x}) = \frac{T - T_s}{\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}} + \frac{\ln(\frac{2h}{r_2})}{k_{soil}2\pi}} \tag{B.7}$$

Letting $\Delta x \to 0$ and rearranging gives the desired differential equation for T(x):

$$\frac{dT}{dx} - \frac{1}{\dot{m}c_p[\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}} + \frac{\ln(\frac{2h}{r_2})}{k_{soil}2\pi}]}(T_s - T) = 0 \tag{B.8}$$

Integrating with $T = T_in$ at $x = 0$ gives:

$$T - T_s = (T_{in} - T_s)e^{[-\frac{1}{\dot{m}c_p[\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}} + \frac{\ln(\frac{2h}{r_2})}{k_{soil}2\pi}]}]x} \tag{B.9}$$

Thus, to know the outlet temperature at the end of a pipe the following formula is true:

$$T_{out} - T_s = (T_{in} - T_s)\exp(-\frac{1}{\dot{m}c_p[\frac{\ln(\frac{r_2}{r_1})}{2\pi k_{ins}L} + \frac{\ln(\frac{2h}{r_2})}{k_{soil}2\pi L}]}) \tag{B.10}$$

With:

- T_{out} The temperature of the water when it goes out the tube in ^{0}C
- T_s the temperature outside the tube in ^{0}C
- T_{in} the temperature of the water inside the tube at the beginning in ^{0}C.
- $\dot{m}$ the mass flow of water in $\frac{kg}{s}$
- c_p the specific heat of water in $\frac{J}{kgK}$
- r_2 the outer diameter of the tube in m

- r_1 the inner diameter of the tube in m
- k_{ins} the thermal conductivity of the insulation material in $\frac{W}{mK}$
- k_{soil} the thermal conductivity of the soil in $\frac{W}{mK}$
- L the length of the tube in m
- h the depth of the tube under the ground surface in m

First the mass flow of the water need to be known: According to (Olsen et al. 2014) the maximum velocity of water in a heat water tube is 2 m/s. With the following formula's the mass flow can be calculated:

$$\dot{V} = v * A = 2m/s * 2\pi r_1 \tag{B.11}$$

$$\dot{m} = \dot{V} * \rho_{water} \tag{B.12}$$

Thus, when water flows with a velocity of 2 m/s it means that it has a mass flow of:$2.83 * 10^3$ $\frac{kg}{s}$

Furthermore the other parameters are:

Table B.1: parameters to calculate heat loss in tube under the ground

Parameter	Value	Unit
T_{out}	unknown	^{0}C
T_s	10	^{0}C
T_{in}	80 (High Temp) 50 (Low Temp)	^{0}C
ρ_{water}	1000	$\frac{kg}{m^3}$
$\dot{m}$	$2.83 * 10^3$	$\frac{kg}{s}$
c_p	4190 (350 K) 4174 (320 K)	$\frac{J}{kgK}$
r_2	0.47	m
r_1	0.45	m
k_{ins}	0.026	$\frac{W}{mK}$
k_{soil}	1.5	$\frac{W}{mK}$
h	0.5	m
L	To be determent	m

Thus the energy drop depends on the Length of the tube. For high temperature district network the temperature drop looks as follow:

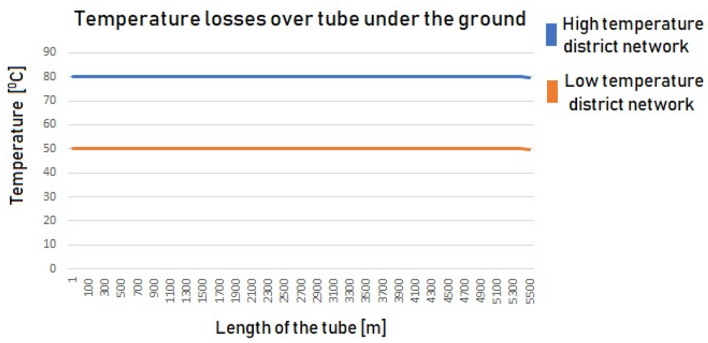


Figure B.2: Temperature drop over distance tube length (by author)

C

Additional data

Table C.1: Used rates in calculation model (by author)

	For the Netherlands	Source
Inflation rate	3	(van der Spoel and Itard 2012)
Increase in energy prices	3.0	(van der Spoel and Itard 2012)
Rate of return	2.5	(van der Spoel and Itard 2012)

Table C.2: Saving heating demand due increase in energy label (Schepers 2017)

Current envelop of building	A++	A	B	C	D	E	F	G
G	73%	45%	34%	28%	18%	10%	3%	0%
F	69%	43%	32%	26%	15%	7%	0%	-
E	62%	39%	27%	20%	8%	0%	-	-
D	54%	34%	20%	13%	0%	-	-	-
C	43%	24%	8%	0%	-	-	-	-
B	33%	17%	0%	-	-	-	-	-
A	23%	0%	-	-	-	-	-	-
A+	0%	-	-	-	-	-	-	-

C1 and C2 variables

	Inner city area (pr ≥0.5)	Outer city area 0.3≤ pr<0.5	Park area (pr≤0.3)
C1 (EUR/m)	286	214	151
C2 (EUR/m^2)	2022	1725	1378

Figure C.1: The values for C1 and C2 parameters

D

Specific outcome scenarios

D.1. Outcome scenario 1

D.1.1. Intermittency

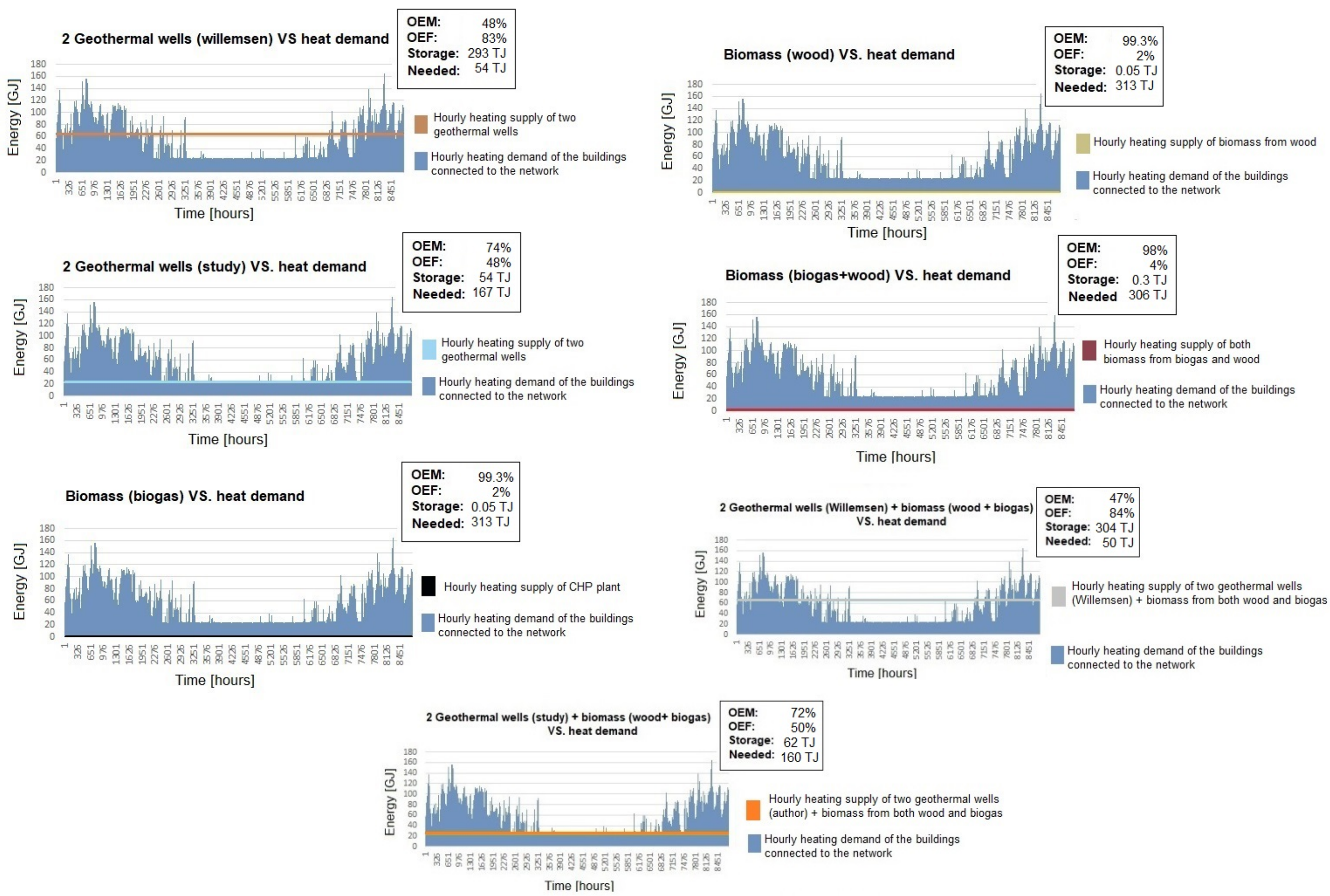


Figure D.1: Intermittency between supply and demand (by author)

D.1.2. Financial feasibility

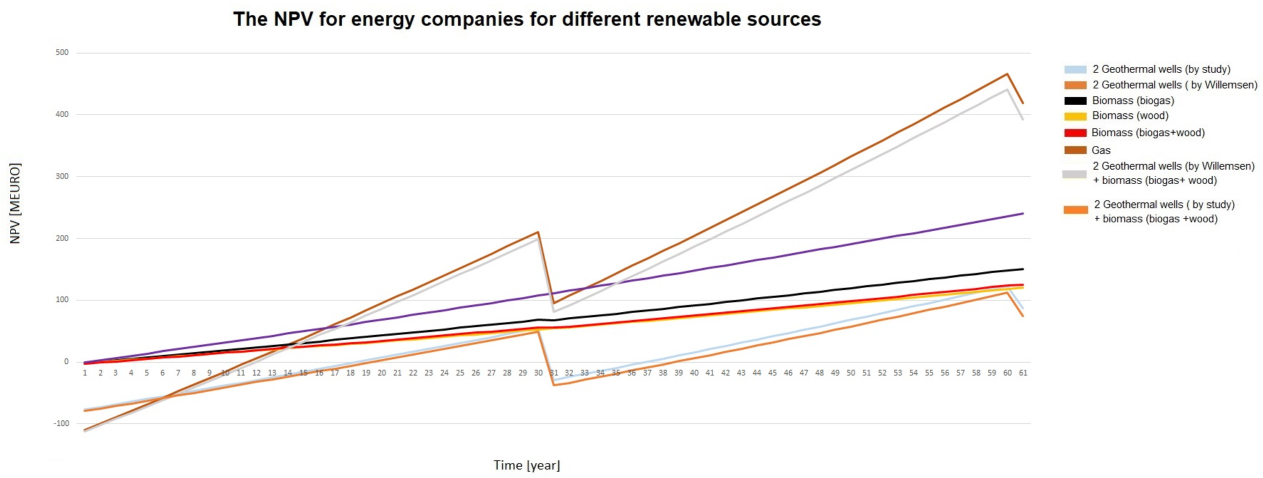
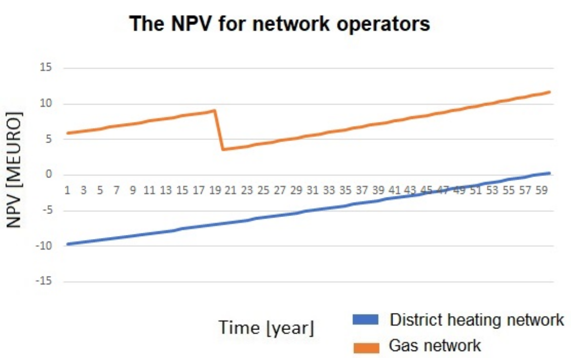
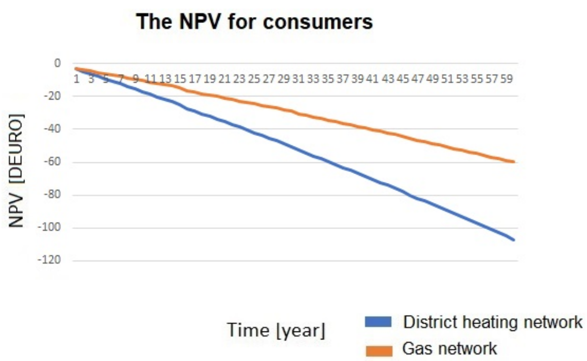


Figure D.2: The NPV for energy companies for different renewable sources





(a) The NPV for energy companies for different renewable sources (by author)

(b) The NPV for energy companies for different renewable sources (by author)

Figure D.3: The NPV for network operators and consumers (by author)

D.1.3. CO_2 emissions

Table D.1: Detailed outcome of CO_2 emissions of the first scenario (by author)

Situation	Amount buildings linked	Total electricity consumption [GWh]	Total gas consumption [TJ]	Renewable heat consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission due gas [*10^6 kg]	CO2 emission due renewable source [*10^6 kg]	Total CO2 emissions for heating [*10^6 kg]	Total CO2 emissions (heat + Electricity) [*10^6 kg]
No district heating	8719	25	396	0	16	14	0	14	30
Two geothermal wells with potential according to study of Willemsen									
Buildings connected to district	7346	19	48	267	12	2	7	8	21
Buildings not connected to district	1373	6	95	0	4	3	0	3	7
Total	8719	25	143	267	16	5	7	12	28
Two geothermel wells with potential according to author									
Buildings connected to district	7346	19	149	154	12	5	4	9	21
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	244	154	16	9	4	13	29
Biomassa (biogas)									
Buildings connected to district	7346	19	280	7	12	10	0.2	10	22
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	375	7	16	13	0.2	14	30
Biomass (wood)									
Buildings connected to district	7346	19	280	7	12	10	0.2	10	22
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	375	7	16	13	0,2	14	30
Biomass (wood + biogas)									
Buildings connected to district	7346	19	273	14	12	10	0.4	10	22
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	368	14	16	13	0.4	14	30
Two geothermal wells (WIllemsen) + biomass (wood + biogas)									
Buildings connected to district	7346	19	45	270	12	1	7	8	21
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	140	270	16	5	7	12	28
Two geothermal wells (author) + biomass (wood+ biogas)									
Buildings connected to district	7346	19	143	160	12	5	4	9	21
Buildings not connected to district	1373	6	95	0	4	3		3	7
Total	8719	25	238	160	16	9	4	13	29

D.2. Outcome scenario 2

D.2.1. Intermittency

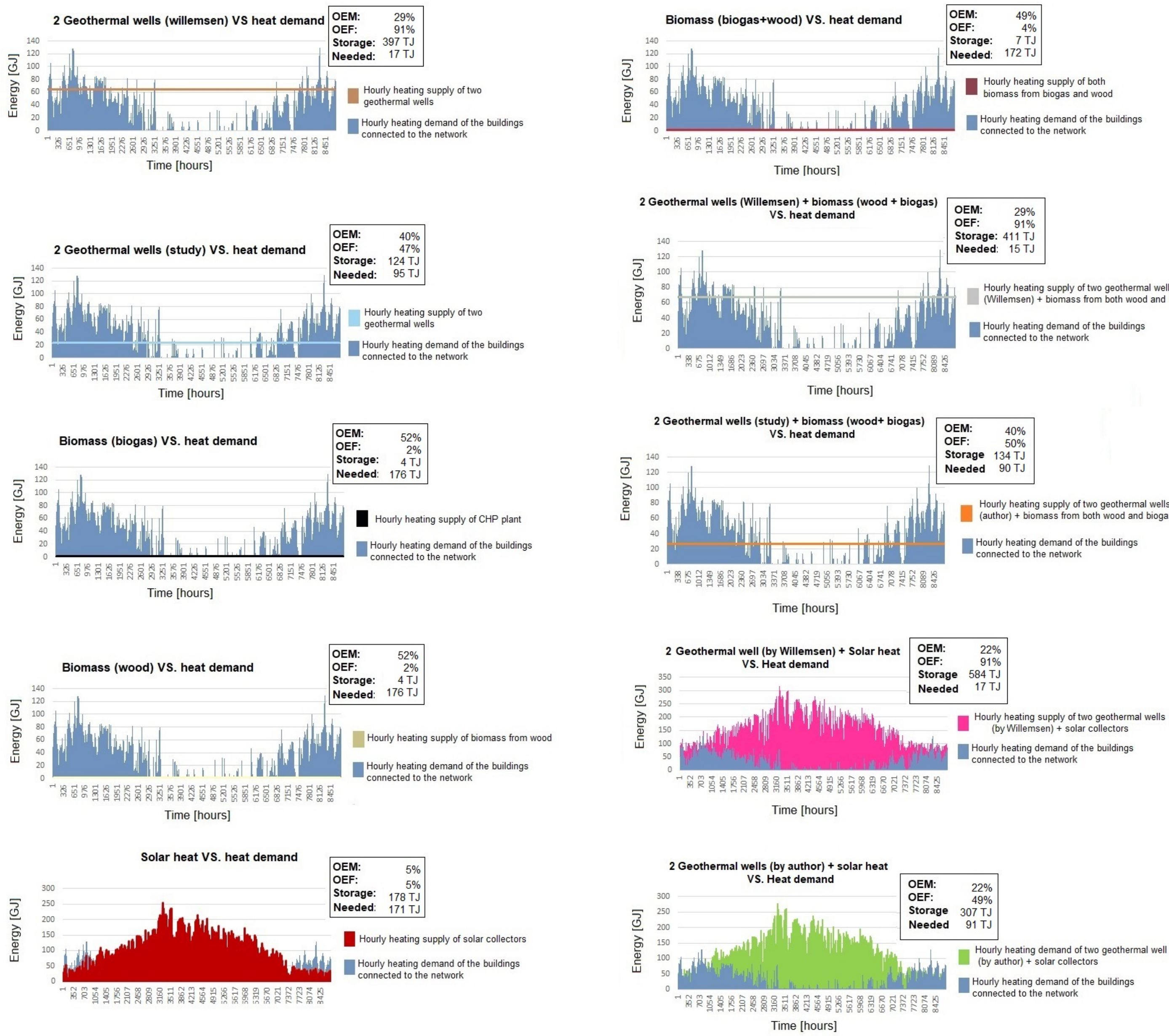


Figure D.4: Intermittency between supply and demand (by author)

D.2.2. Financial feasibility

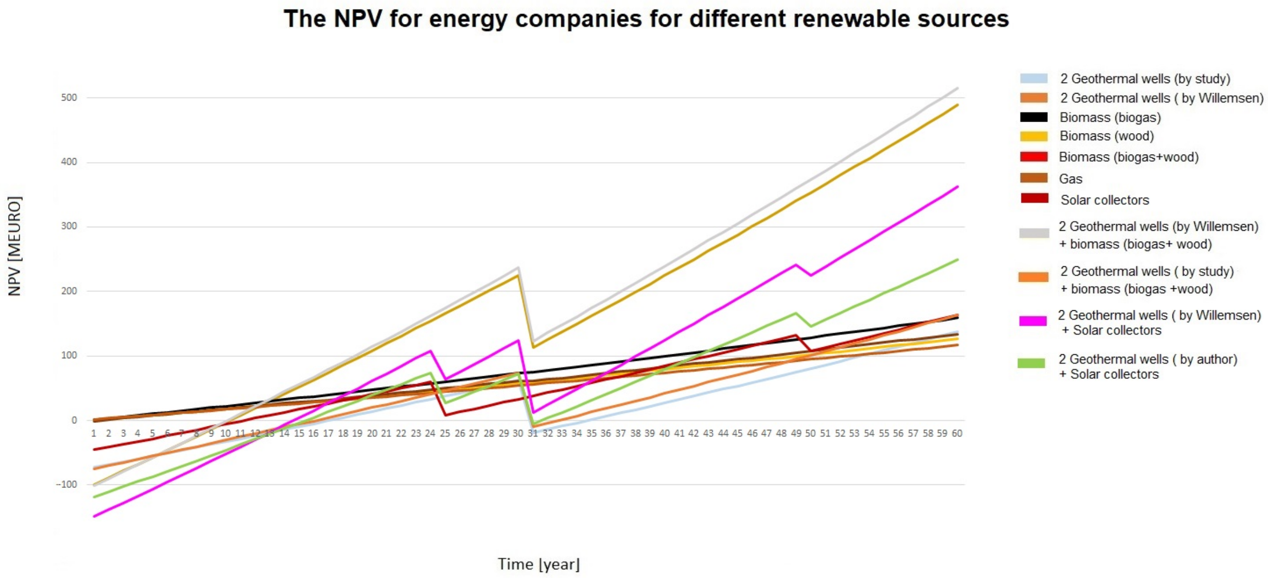
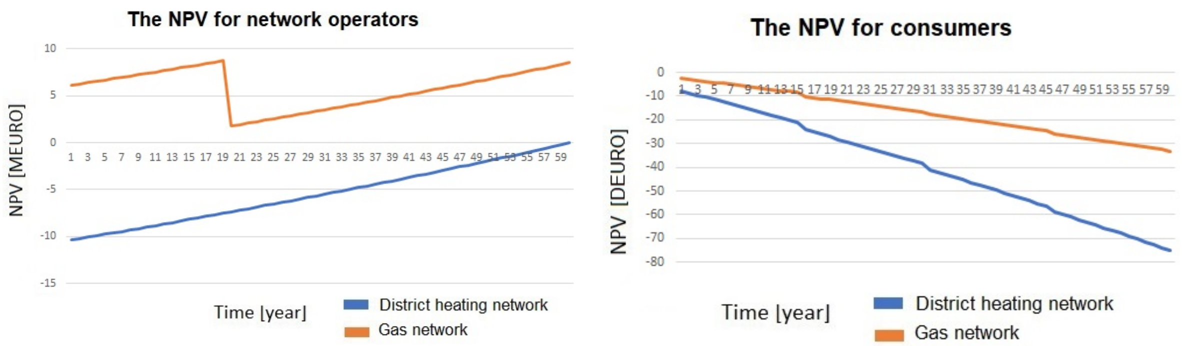


Figure D.5: The NPV for energy companies for different renewable sources



(a) The NPV for energy companies for different renewable sources (by author)

(b) The NPV for energy companies for different renewable sources (by author)

Figure D.6: The NPV for network operators and consumers (by author)

D.2.3. CO2 emissions

Table D.2: Detailed outcome of CO_2 emissions of the second scenario (by author)

Situation	Amount buildings linked	Total electricity consumption [GWh]	Total gas consumption [TJ]	Renewable heat consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission due gas [*10^6 kg]	CO2 emission due renewable source [*10^6 kg]	Total CO2 emissions for heating [*10^6 kg]	Total CO2 emissions (heat + Electricity) [*10^6 kg]
No district heating	8719	25	396	0	16	14	0	14	30
Two geothermal wells with potential according to study of Willemsen									
Buildings connected to district	7712	47.9	16	162.6	31	0.6	4	4.6	35.7
Buildings not connected to district	1007	4.6	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	67.7	162.6	34	2.4	4.1	6.5	40.5
Two geothermal wells with potential according to author									
Buildings connected to district	7712	48	87	84	31	3	2	5	36
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	139	84	34	5	2	7	41
Biomass (biogas)									
Buildings connected to district	7712	48	161	4	31	6	0.1	6	37
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	213	4	34	8	0.1	8	42
Biomass (wood)									
Buildings connected to district	7712	48	161	4	31	6	0.1	6	37
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	213	4	34	8	0.1	8	42
Solar heat									
Buildings connected to district	7712	48	156	9	31	6	0	6	37
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	208	9	34	7	0	7	42
Biomass (wood + biogas)									
Buildings connected to district	7712	48	158	7	31	6	0.4	6.0	37
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	210	7	34	8	0.4	8	42
Two geothermal wells (Willemsen) + biomass (wood + biogas)									
Buildings connected to district	7712	48	14	164	31	1	4	5	36
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	66	164	34	2	4	7	41
Two geothermal wells (author) + biomass (wood+ biogas)									
Buildings connected to district	7712	48	83	89	31	3	2	5	36
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	135	89	34	5	2	7	41
Two geothermal wells (Willemsen) + Solar heat									
Buildings connected to district	7712	48	15	163	31	1	4	5	36 1
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	67	163	34	2	4	7	41
Two geothermal wells (author) + Solar heat									
Buildings connected to district	7712	48	84	88	31	3	2	5	36
Buildings not connected to district	1007	4.5	52.2	0	2.9	1.9	0	1.9	4.8
Total	8719	52.4	136	88	34	5	2	7	41

D.3. Outcome Scenario 3

D.3.1. Intermittency

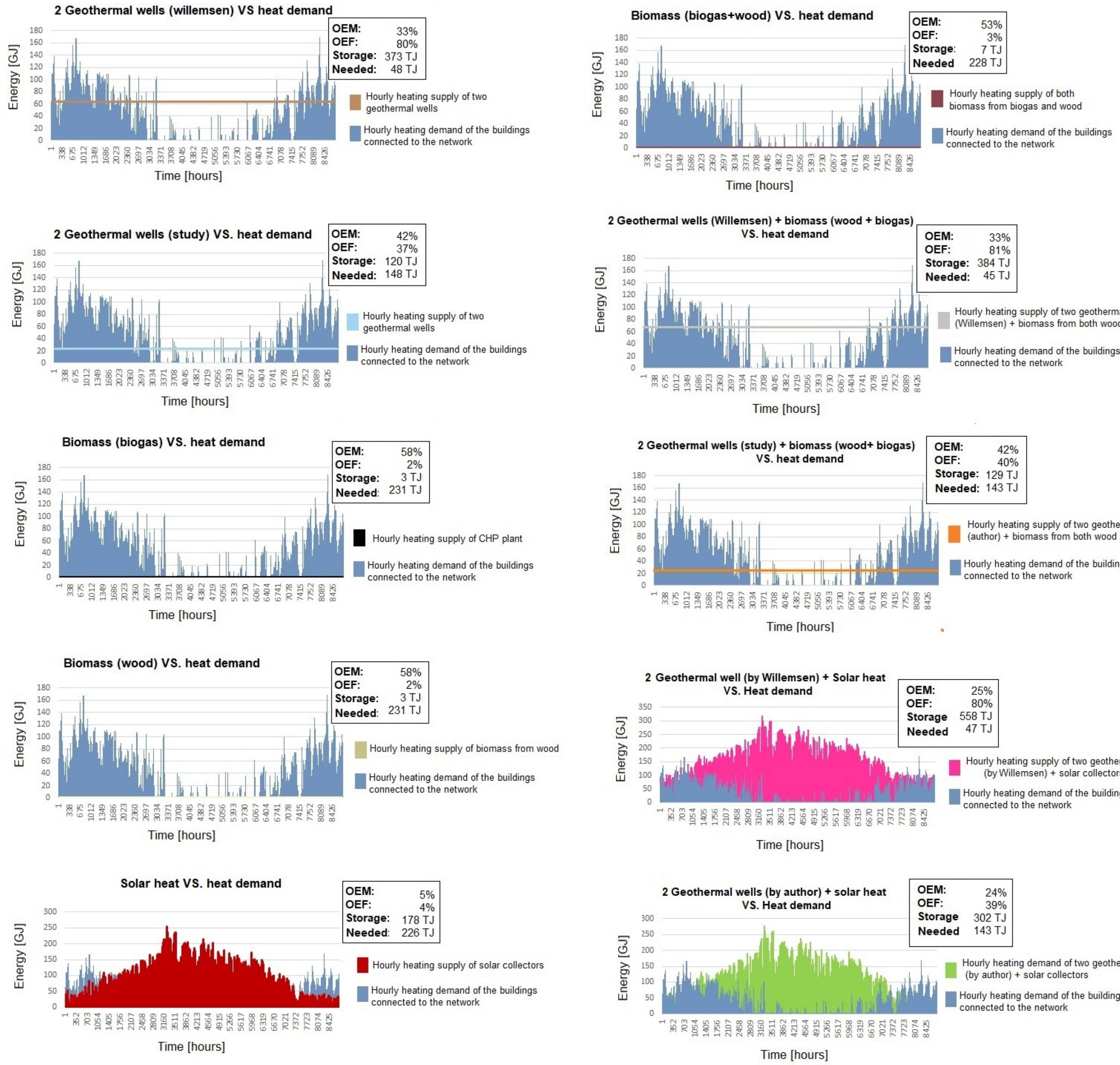


Figure D.7: Intermittency between supply and demand (by author)

D.3.2. Financial feasibility

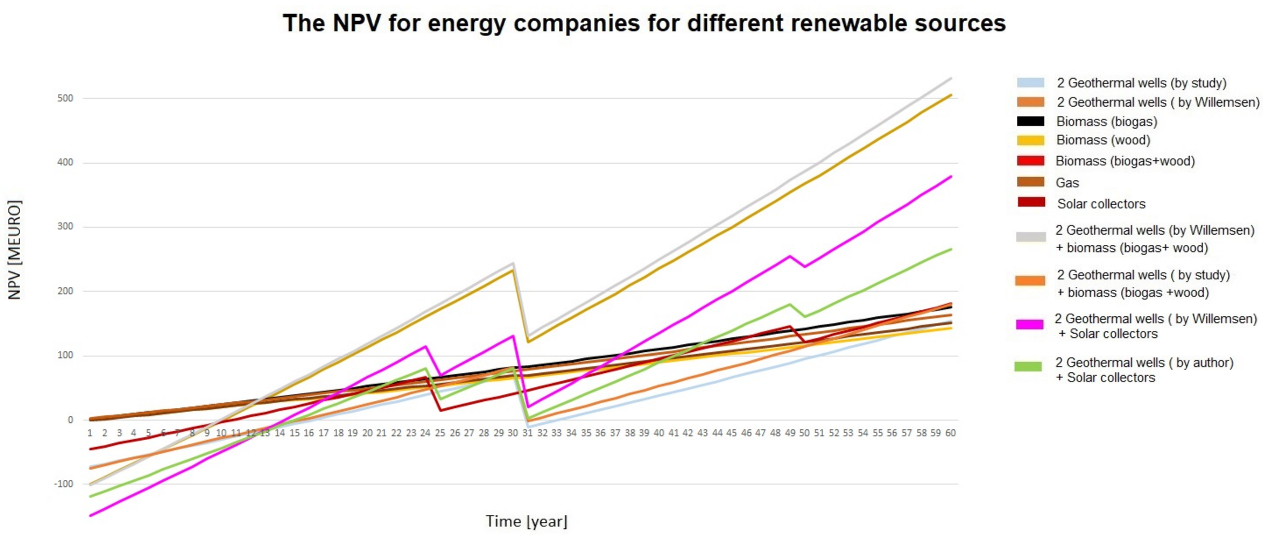
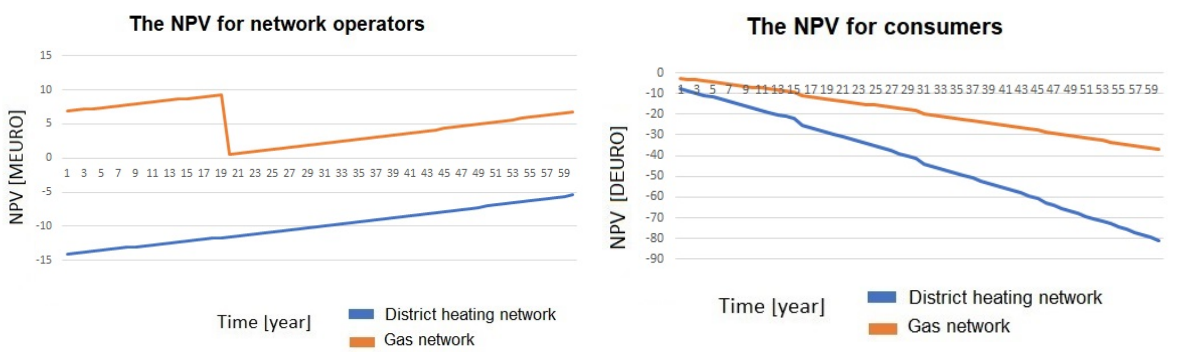


Figure D.8: The NPV for energy companies for different renewable sources



(a) The NPV for energy companies for different renewable sources (by author)

(b) The NPV for energy companies for different renewable sources (by author)

Figure D.9: The NPV for network operators and consumers (by author)

D.3.3. CO2 emissions

Table D.3: Detailed outcome of CO_2 emissions of the third scenario (by author)

Situation	Amount buildings linked	Total electricity consumption [GWh]	Total gas consumption [TJ]	Renewable heat consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission due gas [*10^6 kg]	CO2 emission due renewable source [*10^6 kg]	Total CO2 emissions for heating [*10^6 kg]	Total CO2 emissions (heat + Electricity) [*10^6 kg]
No district heating	8719	25	396	0	16	14	0	14	30
Two geothermal wells with potential according to study of Willemsen									
Buildings connected to district	8719	53.6	44	187	35	2	5	6	41
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	44	187	35	2	5	6	41
Two geothermal wells with potential according to author									
Buildings connected to district	8719	53.6	136	88	35	5	2.2	7	42
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	136	88	35	5	2.2	7	42
Biomass (biogas)									
Buildings connected to district	8719	53.6	212	4	35	8	0.1	8	43
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	212	4	35	8	0.1	8	43
Biomass (wood)									
Buildings connected to district	8719	53.6	212	4	35	8	0.1	8	43
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	212	4	35	8	0.1	8	43
Solar heat									
Buildings connected to district	8719	53.6	208	9	35	7	0	7	42
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	208	9	35	7	0	7	42
Biomass (wood + biogas)									
Buildings connected to district	8719	53.6	209	8	35	8	0.4	8	43
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	209	8	35	8	0.4	8	43
Two geothermal wells (Willemsen) + biomass (wood + biogas)									
Buildings connected to district	8719	53.6	42	190	35	0.9	4.8	6	41
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	42	190	35	0.9	4.8	6	41
Two geothermal wells (author) + biomass (wood+ biogas)									
Buildings connected to district	8719	53.6	131	93	35	5	2.4	7	42
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	131	93	35	5	2.4	7	42
Two geothermal wells (Willemsen) + Solar heat									
Buildings connected to district	8719	53.6	43	189	35	2	4.7	6	41
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	43	189	35	2	4.7	6	41
Two geothermal wells (author) + Solar heat									
Buildings connected to district	8719	53.6	131	93	35	5	2.3	7	42
Buildings not connected to district	0	0	0	0	0	0	0	0	0
Total	8719	53.6	131	93	35	5	2.3	7	42

D.4. Detailed outcome scenario 4

Postal code	Linked houses	Electricity demand [kWh]	Current gas system [m^3]	GSHP		ASHP		Elec. resistance		Infrared panels		Hybrid HP			High Eff. elec. boiler			District heating with elec. boiler		
				No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	No PV [kWh]	With PV [kWh]	Gas [m^3]	No PV [kWh]	With PV [kWh]	Gas [m^3]	No PV [kWh]	With PV [kWh]	Gas [m^3]
2591GG	22	4576	2698	5645	4522	8151	6652	25974	23381	21551	18974	3792	3365	1079	4601	19332	3242	3856	1691	2264
2591XB	21	2151	1035	2267	1493	3326	2243	9085	7144	8039	6101	896	786	414	1088	7340	1164	3856	1969	535
2591XC	16	3759	1058	2312	1527	3390	2292	9312	7330	8221	6242	935	819	423	1135	7888	1192	3856	1938	558
2591XG	30	3442	1075	2346	1831	3439	2773	9483	8522	8357	7397	965	922	430	1170	2282	1213	3856	2896	576
2591XH	39	3474	964	2122	1342	3119	2022	8360	6362	7459	5466	772	668	386	937	7940	1075	3856	1924	461
2592XV	35	4445	2189	4611	3730	6675	5482	20806	18717	17416	15331	2906	2675	876	3526	11460	2606	3856	1877	1735
2592HC	37	2770	1133	2465	1669	3609	2496	10078	8072	8833	6831	1066	938	453	1294	8325	1286	3856	1922	637
2592TE	19	1690	1393	2994	2109	4364	3131	12718	10455	10946	8693	1519	1329	557	1843	12931	1611	3856	1767	907
2592TG	23	1265	1442	3092	2239	4505	3322	13213	11081	11341	9216	1604	1425	577	1946	10658	1672	3856	1844	958
2592HB	19	8399	1829	3878	3041	5628	4485	17143	15138	14486	12483	2278	2086	731	2764	9649	2155	3856	1930	1360
2591AH	13	3121	1923	4070	3471	5901	5109	18098	16855	15250	14006	2441	2366	769	2962	4744	2273	3856	2613	1458
2591AJ	14	2612	1534	3279	2710	4772	4024	14147	13003	12089	10945	1764	1702	613	2141	3652	1787	3856	2712	1053
2591AK	16	4686	1671	3559	2913	5171	4306	15545	14136	13207	11799	2004	1913	669	2431	4794	1959	3856	2450	1196
2591CA	14	2911	1662	3540	2948	5145	4363	15452	14230	13133	11911	1988	1918	665	2412	4131	1947	3856	2634	1187
2591CB	12	2702	1671	3558	2965	5170	4387	15541	14315	13204	11978	2003	1932	668	2430	4160	1958	3856	2631	1196
2591DA	40	8331	1519	3249	2788	4729	4150	13997	13227	11969	11199	1738	1701	608	2109	2922	1768	3856	3087	1038
2591DB	42	5737	1930	4086	3433	5924	5051	18178	16757	15314	13892	2455	2356	772	2979	5392	2283	3856	2438	1466
2591GT	18	1984	1832	3886	3171	5638	4673	17178	15554	14514	12890	2284	2159	733	2771	6247	2160	3856	2244	1364
2591GV	18	2681	1645	3505	2881	5094	4262	15274	13939	12991	11656	1957	1876	658	2375	4453	1926	3856	2523	1169
2591GW	18	2712	1713	3643	3003	5292	4436	15966	14579	13544	12157	2076	1987	685	2519	4794	2011	3856	2471	1240
2591GX	15	2774	1629	3473	2827	5049	4183	15117	13706	12865	11454	1930	1841	652	2342	4714	1906	3856	2448	1153
2591GZ	24	2617	1675	3566	3087	5181	4574	15580	14749	13235	12405	2010	1969	670	2438	3337	1963	3856	3026	1200
2591JA	14	4441	2570	5386	4734	7782	6929	24681	23328	20516	19163	3570	3413	1028	4332	6464	3083	3856	2508	2132
2591JB	16	4151	2330	4897	4231	7083	6209	22237	20840	18561	17164	3151	2990	932	3823	6117	2782	3856	2466	1881
2591JC	10	4917	2746	5743	5048	8291	7360	26464	24917	21942	20395	3876	3750	1098	4702	7725	3302	3856	2317	2314
2591JD	14	2984	2640	5528	4860	7985	7110	25391	23995	21084	19688	3692	3524	1056	4479	6773	3170	3856	2467	2204
2591RX	16	4021	2291	4818	4143	6970	6083	21841	20419	18244	16822	3083	2917	916	3741	6138	2733	3856	2442	1841
2591VM	10	3539	1559	3331	3154	4846	4668	14407	14229	12297	12119	1809	1800	624	2195	2373	1819	3856	3678	1080
2591XE	36	3332	529	1237	573	1854	923	3935	2309	3919	2293	13	11	211	16	3575	530	3856	2232	8
2591XS	23	3305	1242	2687	2254	3925	3391	11183	10508	9718	9043	1256	1224	497	1524	2218	1422	3856	3181	750
2591XT	16	3496	1399	3005	2508	4380	3743	12776	11882	10992	10098	1529	1485	559	1855	2852	1618	3856	2963	913
2592AV	20	2289	1507	3225	2404	4695	3564	13876	11875	11872	9874	1718	1551	603	2084	8962	1754	3856	1931	1026
2592AW	21	1953	1396	3000	2178	4373	3235	12750	10721	10971	8946	1525	1364	558	1850	9103	1615	3856	1910	910
2592AX	19	1930	1558	3329	2468	4843	3655	14397	12269	12289	10166	1807	1616	623	2192	10821	1818	3856	1847	1079
2592CN	27	4030	2196	4624	3909	6694	5729	20873	19254	17469	15851	2917	2785	878	3539	6978	2614	3856	2249	1742
2592CP	16	2483	1489	3188	2357	4642	3495	13691	11652	11724	9688	1686	1515	596	2046	9424	1731	3856	1904	1007
2592CR	16	3442	1529	3269	2439	4758	3613	14097	12067	12049	10022	1756	1583	612	2130	9383	1781	3856	1910	1048
2592EV	19	3998	1430	3068	2123	4470	3148	13092	10604	11245	8780	1583	1362	572	1921	18270	1657	3856	1666	945
2592GJ	17	3512	1647	3510	2641	5102	3906	15303	13168	13013	10884	1962	1762	659	2381	11076	1929	3856	1845	1172
2592GK	15	3243	3484	7243	6073	10435	8882	33966	31301	27944	25296	5162	4692	1394	6263	24429	4225	3856	1642	3082
2594BG	18	4526	2257	4750	4078	6873	5972	21500	20016	17971	16487	3025	2915	903	3670	6370	2692	3856	2377	1806
2594BH	21	6605	3149	6562	5878	9462	8547	30562	29052	25221	23711	4578	4456	1260	5555	8385	3806	3856	2352	2734
2594BK	16	8972	3495	7264	6502	10464	9442	34070	32341	28027	26299	5179	5006	1398	6284	10468	4238	3856	2151	3093
2594BL	11	4128	2288	4813	4157	6962	6085	21813	20381	18222	16790	3078	2976	915	3735	6196	2730	3856	2427	1838
2594CB	21	7927	2311	4859	4100	7029	6003	22046	20299	18408	16662	3118	2959	924	3783	8104	2759	3856	2136	1862
2594CD	17	5798	2615	5477	4778	7911	6973	25135	23573	20879	19318	3648	3520	1046	4426	7528	3139	3856	2303	2178
2594CE	13	6575	3213	6693	5960	9648	8666	31214	29563	25742	24092	4690	4538	1285	5690	9329	3887	3856	2221	2800
2594CN	48	4548	2489	5220	4590	7545	6707	23852	22505	19853	18506	3428	3336	996	4159	6282	2981	3856	2510	2047
2594CP	27	3185	1998	4222	3321	6119	4892	18861	16691	15860	13696	2572	2337	799	3121	12260	2367	3856	1827	1536
2594CR	10	4491	1961	4148	3486	6013	5126	18491	17036	15564	14109	2509	2407	785	3044	5611	2321	3856	2404	1498
2594CS	15	4014	1788	3796	2880	5510	4251	16731	14473	14156	11906	2207	1973	715	2678	13370	2105	3856	1778	1318
2594CT	15	4876	2537	5319	4587	7685	6701	24344	22685	20247	18588	3512	3367	1015	4261	7957	3041	3856	2213	2097
2594CW	18	6118	2801	5855	5084	8452	7413	27028	25259	22394	20625	3972	3799	1121	4820	9315	3372	3856	2116	2372
2591X_G	12	2500	1075	2346	1503	3439	2253	9483	7269	8357	6155	965	822	430	1170	11550	1213	3856	1787	576
2594BT	7	17500	3251	6769	5896	9757	8589	31595	29585	26047	24039	4755	4505	1300	5770	12643	3933	3856	1931	2839
2594CL	10	25000	2375	4989	4289	7215	6274	22697	21129	18929	17361	3230	3104	950	3919	7058	2839	3856	2297	1928
2594CM	8	2500	2375	4989	4278	7215	6259	22697	21097	18929	17329	3230	3099	950	3919	7240	2839	3856	2267	1928
2594BV	6	2500	3334	6937	6079	9997	8849	32436	30463	26720	24748	4899	4659	1333	5944	12390	4037	3856	1957	2925
2594BW	8	2500	3251	6769	6045	9757	8786	31595	29968	26047	24421	4755	4608	1300	5770	9255	3933	3856	2242	2839
2594CK	5	2500	2375	4989	4352	7215	6366	22697	21325	18929	17557	3230	3135	950	3919	6132	2839	3856	2487	1928
2594CX	4	2500	4072	8437	7457	12140	10848	39934	37722	32718	30509	6185	5844	1629	7504	17039	4959	3856	1813	3693
2594CZ	4	2500	4072	8437	7647	12140	11082	39934	38138	32718	30923	6185	5988	1629	7504	12209	4959	3856	2094	3693
2591AT	4	2500	1146	2491	1632	3646	2440	10206	7962	8936	6704	1089	932	458	1321	12200	1302	3856	1772	650

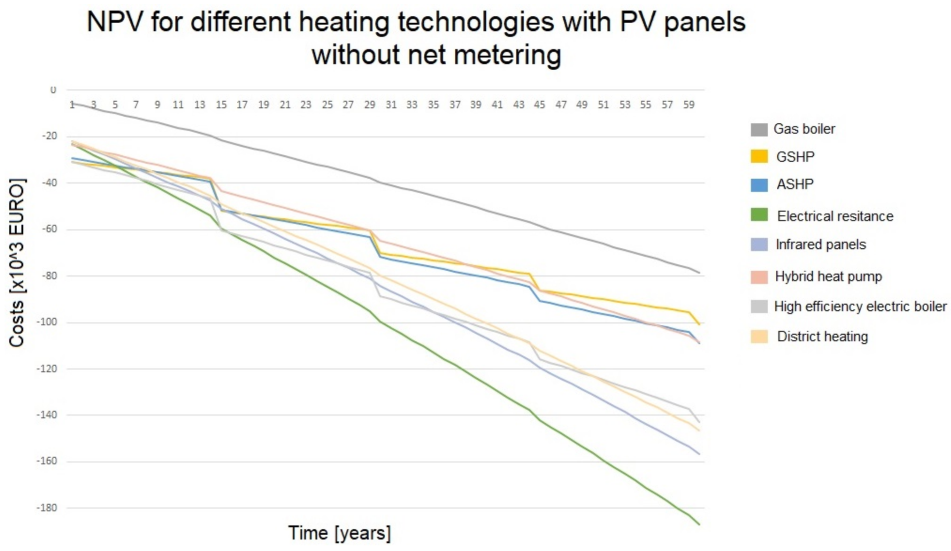


Figure D.10: NPV for decentralized heating systems with PV panels but no net metering (by author)

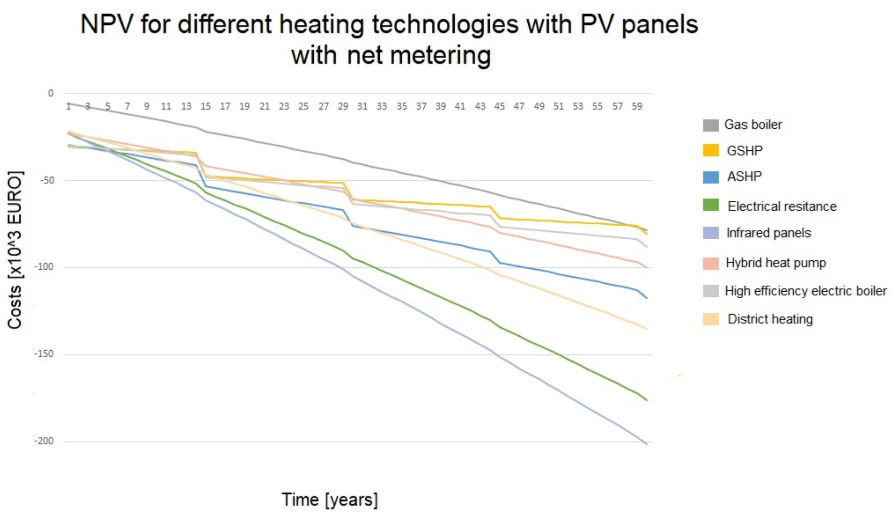


Figure D.11: NPV for decentralized heating systems with PV panels with net metering (by author)

Table D.4: CO2 reduction for the whole neighborhood when decentralized systems are applied and when no PV panels are used (by author)

Situation	Amount of linked buildings	Total elecitricity demand (for appliances) [GWh]	Total electricity demand for heating [GWh}	Total Gas consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission duel gas [*10^6 kg]	Total CO2 emissions [*10^6 kg]	CO2 reduction due electricity	CO2 reduction due gas	Co2 reduction total	CO2 reduction if elec. sustainable
No renewable heating	8719	25	0	396	16	14	30	0	0	0	0
GSHP	1007	5	5	0	6	0	6	119%	80%	100%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	5	315	19	11	30				
ASHP	1007	5	7	0	7	0	7	127%	80%	105%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	7	315	20	11	32				
elec resistance	1007	5	20	0	16	0	16	182%	80%	134%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	20	315	29	11	41				
infrared panels	1007	5	17	0	14	0	14	169%	80%	127%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	17	315	27	11	39				
hybrid HP	1007	5	3	30	5	1	6	111%	87%	100%	41%
rest	7712	20	0	315	13	11	24				
total	8719	25	3	346	18	12	30				
high efficiency elec boiler	1007	5	0	90	3	3	6	100%	102%	101%	48%
rest	7712	20	0	315	13	11	24				
total	8719	25	0	405	16	14	31				

Table D.5: CO2 reduction for the whole neighborhood when decentralized systems are applied with PV panels (by author)

Situation	Amount of linked buildings	Total elecitricity demand (for appliances) [GWh]	Total electricity demand for heating [GWh}	Total Gas consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission duel gas [*10^6 kg]	Total CO2 emissions [*10^6 kg]	CO2 reduction due electricity	CO2 reduction due gas	Co2 reduction total	CO2 reduction if elec. sustainable
No renewable heating	8719	25	0	396	16	14	30	0	0	0	0
GSHP	1007	5	4	0	5	0	5	115%	80%	98%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	4	315	18	11	30				
ASHP	1007	5	6	0	7	0	7	122%	80%	102%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	6	315	20	11	31				
elec resistance	1007	5	18	0	15	0	15	175%	80%	130%	37%
rest	7712	20	0	315	13	11	24				
total	8719,0	24,7	18,5	315,2	28,0	11,3	39				
infrared panels	1007	5	15	0	13	0	13	162%	80%	123%	37%
rest	7712	20	0	315	13	11	24				
total	8719	25	15	315	26	11	37				
hybrid HP	1007	5	3	30	5	1	6	110%	87%	100%	41%
rest	7712	20	0	315	13	11	24				
total	8719	25	3	346	18	12	30				
high efficiency elec boiler	1007	5	0	90	3	3	6	100%	102%	101%	48%
rest	7712	20	0	315	13	11	24				
total	8719	25	0	405	16	15	31				

E

Calculation model

In this section a short explanation will be given of the built calculation model.

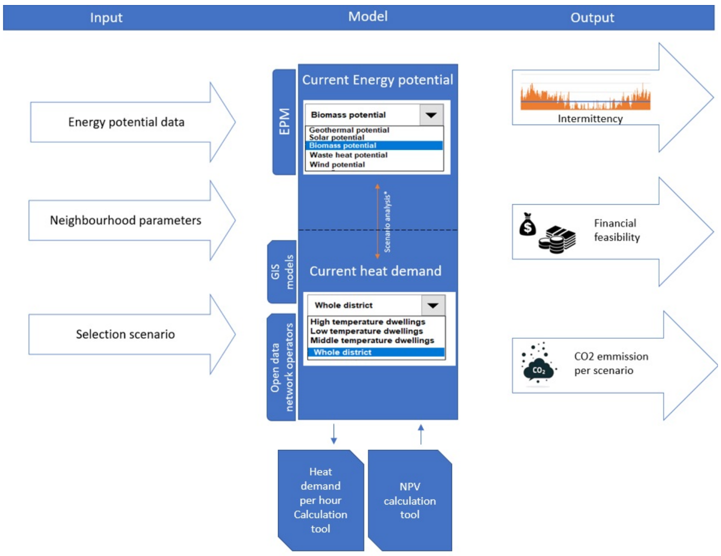


Figure E.1: The calculation model that create insight(By author)

The calculation model consist of four .CSV files. One file contains all the calculations for a decentralizes heating system including the calculation for heating potential, heating demand, financial potential and emission rates. Then three files are built for the centralized heating system. In this appendix first the files for the centralized heating system will be elaborated, followed by the file for decentralized heating system. The design and layout of the calculation model need to be improved when the calculation model is used in further research.

E.1. Centralized heating system

The calculation files for centralized heating system contains of one main file that calculate the technical, financial and emissions rate and two supporting files to calculate the hourly heating demand and specified financial costs. These supporting files are connected to the main file.

E.1.1. Main file

The main file consist of different tabs (see figure E.2):

1. Overview: Shows the framework for centralized heating system. In this way the user of the model can see which technical sources can be used for a high, middle or low temperature network (see figure E.2) .

2. Input parameter: Shows the parameters that determine the heating potential of different renewable energy sources. Here the user can change the input parameters dependent on the neighborhood that is considered. (figure E.3)

3. Input heat: Here all the important information of the buildings in the neighborhood is collected

4. Scenario centralized buildings: Here the outcome of the hourly heating demand of the buildings are collected (implementing data from the supporting file to calculate hourly demand)

5. Scenario centralized sources: (Here the hourly potential of all the variate heating sources are presented)

6. Technical feasibility: Here the user can select the alternative heating source and the size of the network. The outcome of the intermittency and financial feasibility are given here.

7. CO_2 calculation: Here the amount of CO_2 emissions are calculated.

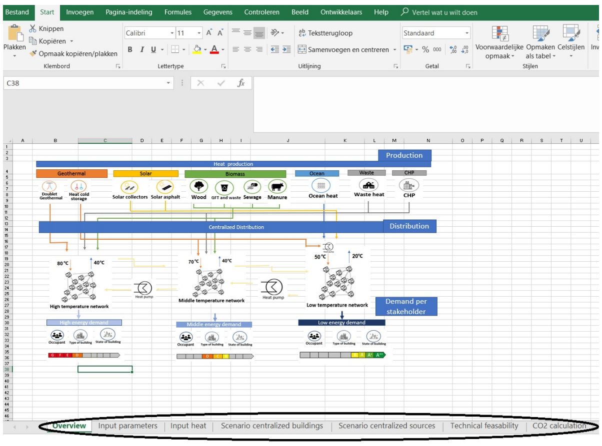


Figure E.2: Graphical presentation of centralized file (By author)

In the input parameter tab (figure E.3) the decision maker can change the parameters in yellow. These parameters differ per neighbourhood.

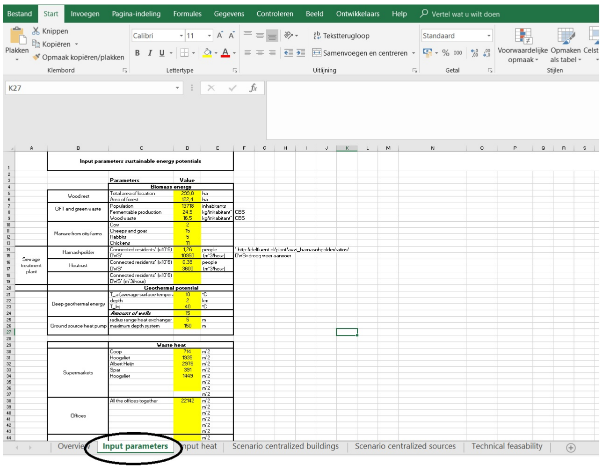


Figure E.3: Graphical presentation of input parameter tab (By author)

In the calculation model the collected data for determine the heating demand is structured in the input heat tab (figure E.4). This input tab looks overwhelming, but there is a structure behind it.

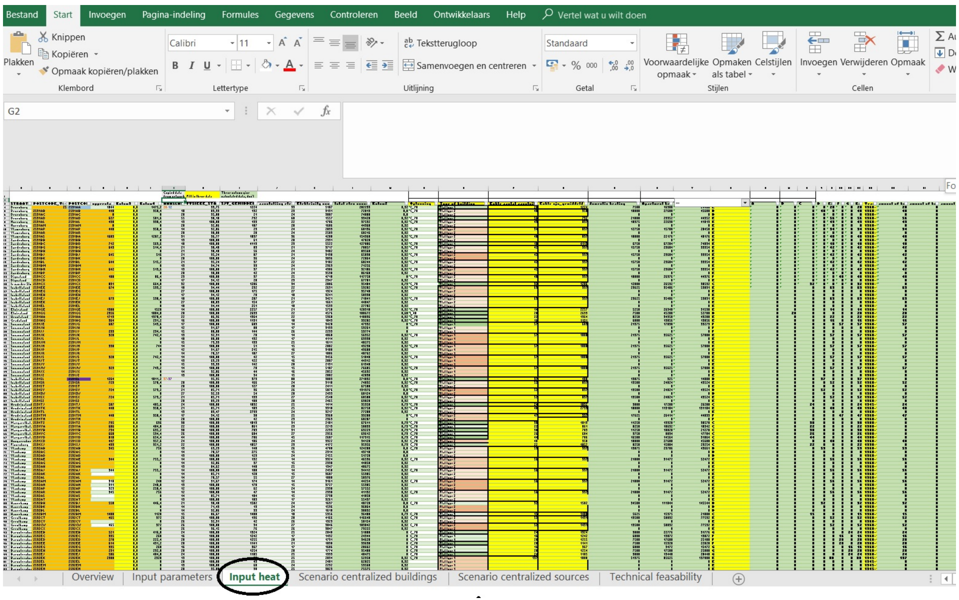


Figure E.4: Graphical presentation of input heat tab (By author)

The gray part present data copied from the data from the network operator (figure E.4) . In the green parts calculations are done. In the yellow part the user has to implement parameters that is collected by following the steps described in chapter 6. When all the data are collected and organized this tab is also used as input data for the supporting file to calculate the hourly heating demand.

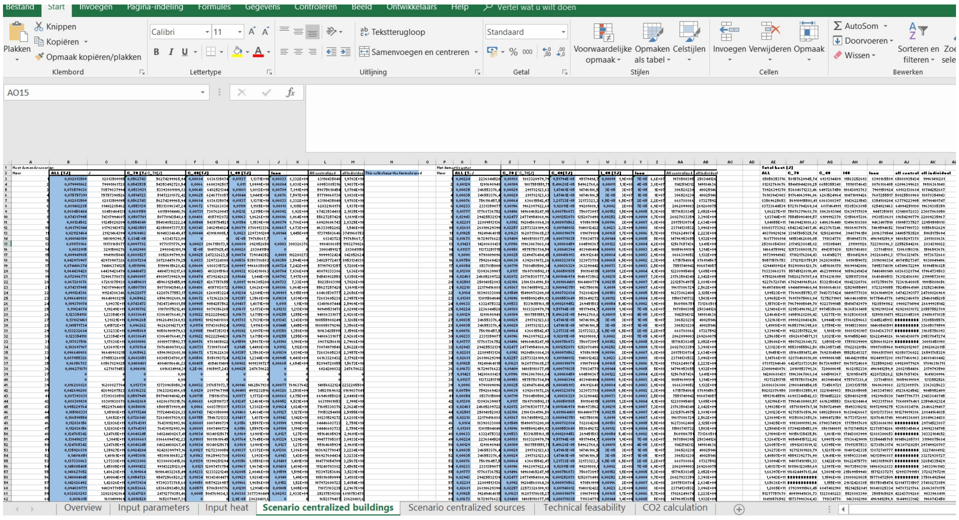


Figure E.5: Graphical presentation of scenario centralized buildings tab (By author)

In this tab; overview of scenario centralized buildings (figure E.5) the hourly heating demand of the buildings are calculated. It uses the supporting file that calculates for each building the hourly heating for space heating and DHW heating.

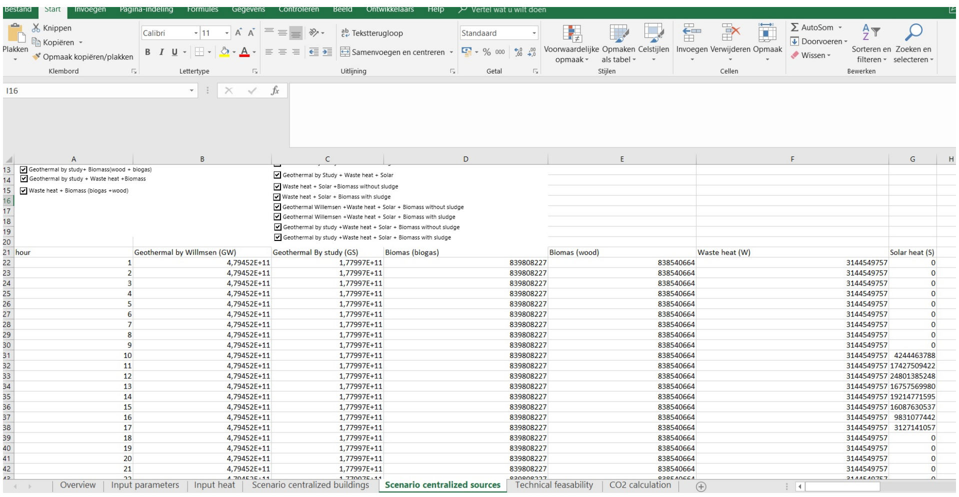


Figure E.6: Graphical presentation of scenario centralized sources tab (By author)

In the scenario centralizes sources tab (figure E.6) the hourly heating potentials of each alternative sustainable source is calculated. These tabs presented the input parameters for the calculation model. The outcome of all the calculation can be found in the Technical feasibility tab (figure E.7).

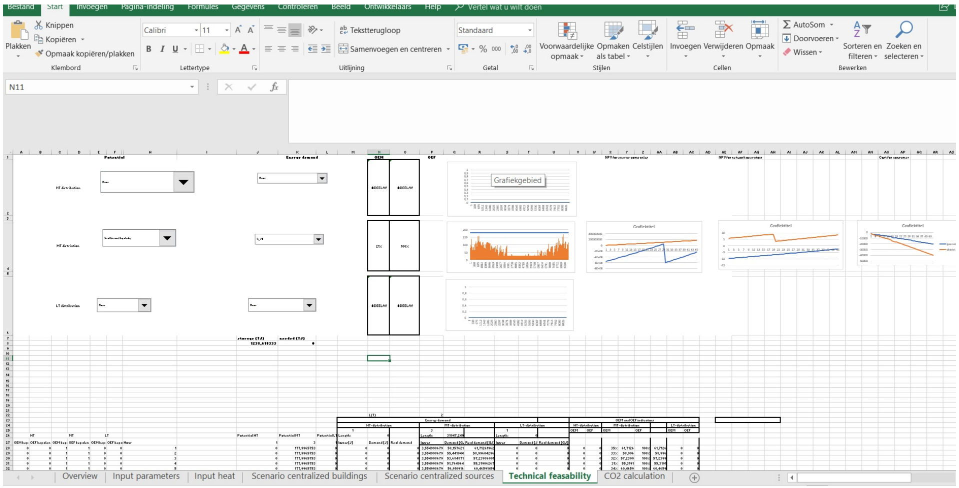
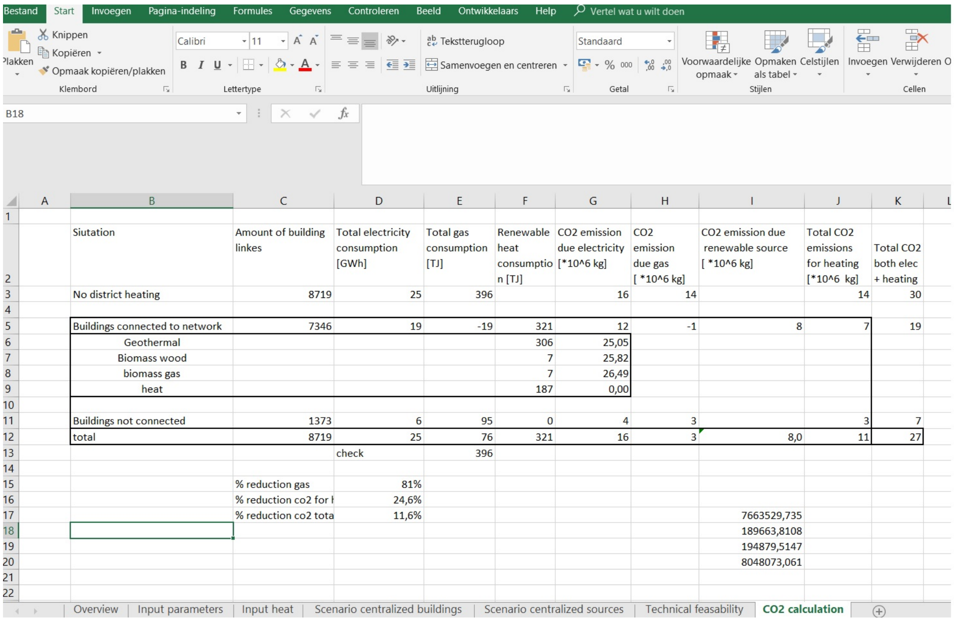


Figure E.7: Graphical presentation of the technical feasibility tab (By author)

In this tab the user can select if it wants to calculate heating alternatives for high energy temperature networks, middle temperature networks or low temperature networks. The OEM, OEF, intermittency and NPV for energy companies, network operators and residents are presented in this tab.
The final tab: CO_2 calculation present the amount of emitted CO_2 emissions depending on the consumed gas and electricity (figure E.8)



	A	B	C	D	E	F	G	H	I	J	K
2		Siutation	Amount of building linkes	Total electricity consumption [GWh]	Total gas consumption [TJ]	Renewable heat consumptio n [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission due gas [*10^6 kg]	CO2 emission due renewable source [*10^6 kg]	Total CO2 emissions for heating [*10^6 kg]	Total CO2 both elec + heating
3		No district heating	8719	25	396		16	14		14	30
5		Buildings connected to network	7346	19	-19	321	12	-1	8	7	19
6		Geothermal				306	25,05				
7		Biomass wood				7	25,82				
8		biomass gas				7	26,49				
9		heat				187	0,00				
11		Buildings not connected	1373	6	95	0	4	3		3	7
12		total	8719	25	76	321	16	3	8,0	11	27
13				check	396						
15			% reduction gas	81%							
16			% reduction co2 for h	24,6%							
17			% reduction co2 tota	11,6%					7663529,735		
18									189663,8108		
19									194879,5147		
20									8048073,061		

Figure E.8: Graphical presentation of CO_2 emissions tab (By author)

E.1.2. Supporting file to calculate the hourly heating demand

The supporting file to calculate the hourly heating demand consist of three tabs. The first tab is the same as the input heat tab of the main file. This is copied from the main tab. The second tab calculates for each building in the neighbourhood the hourly heating demand, depending on the year of construction and type of the building (figure E.9

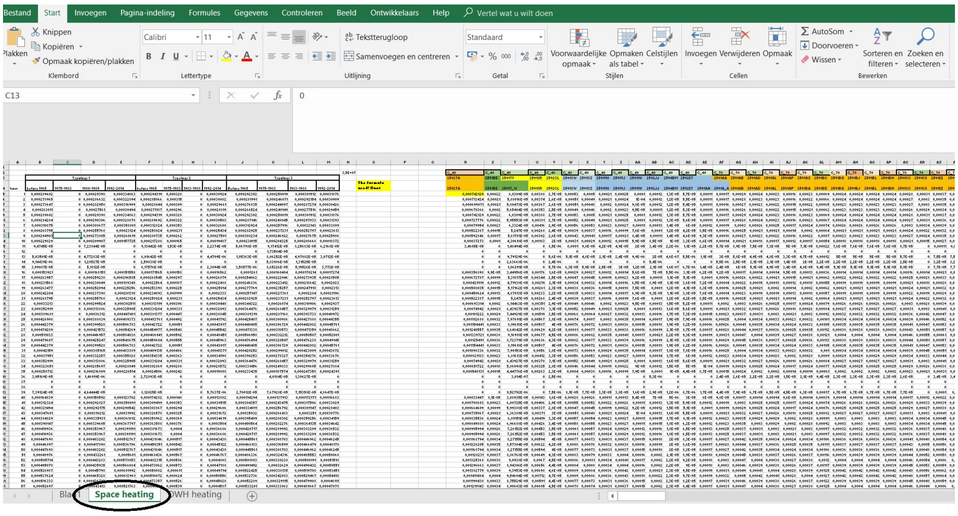


Figure E.9: Graphical presentation of calculating hourly space heating tab (By author)

Furthermore, the hourly heating demand for the DHW are calculated in the third tab (figure E.10).

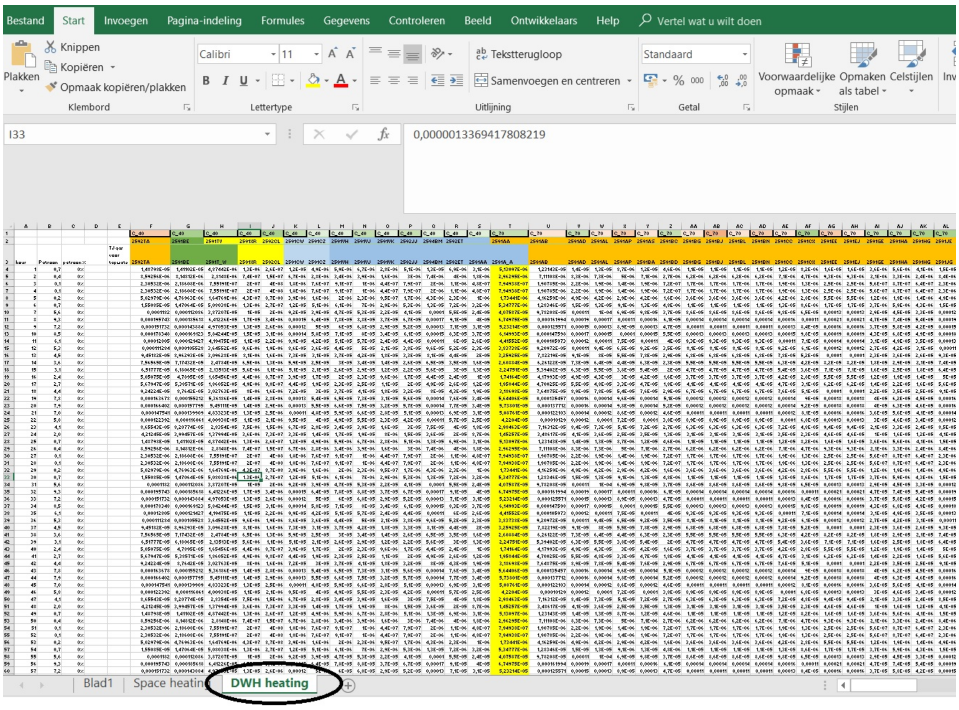


Figure E.10: Graphical presentation of calculating hourly DHW tab (By author)

E.1.3. Supporting file to calculate financial feasibility

The supporting file that calculates the financial feasibility consist of four tabs: input parameter tab, energy company tab, network operator tab and consumer tab.

In the input parameter tab (figure E.11 the user can change the values for investment costs and maintenance costs and the price of electricity and gas (if it should change over time). The green colored segments consist calculation, so these values cannot be change.

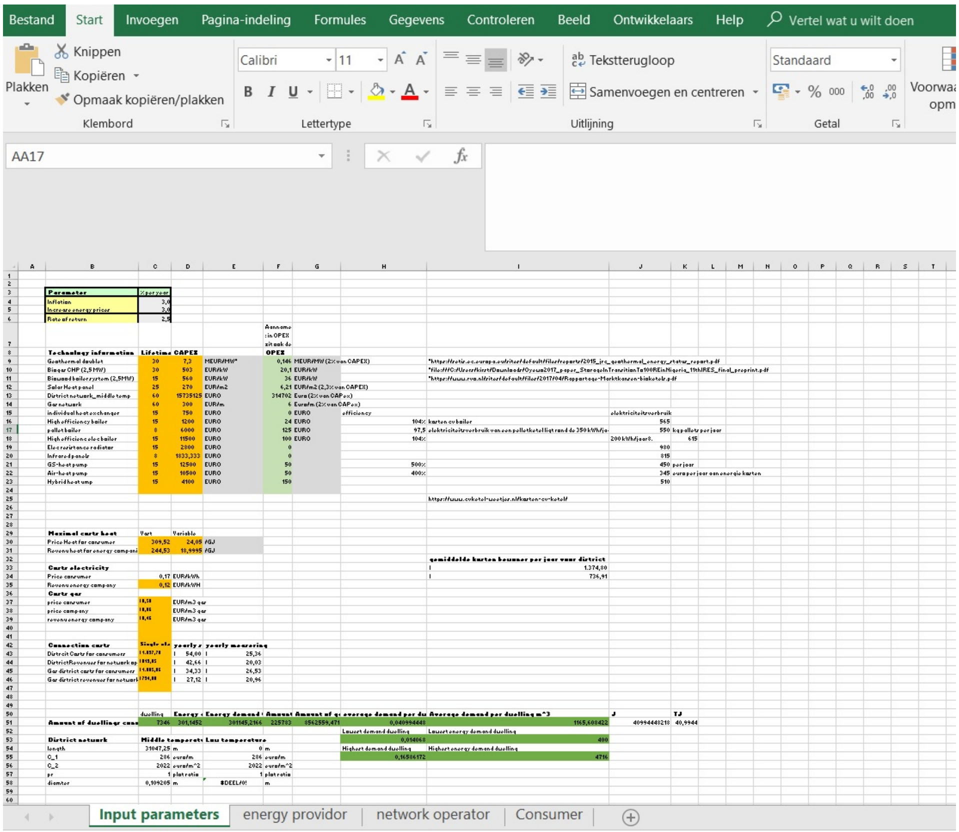


Figure E.11: Graphical presentation of input parameter tab (By author)

In the tab energy companies (see figure E.12) the NPV for energy companies are calculated. The same kind of calculations are done for the network operators (see figure E.13) and consumers (see figure E.14).

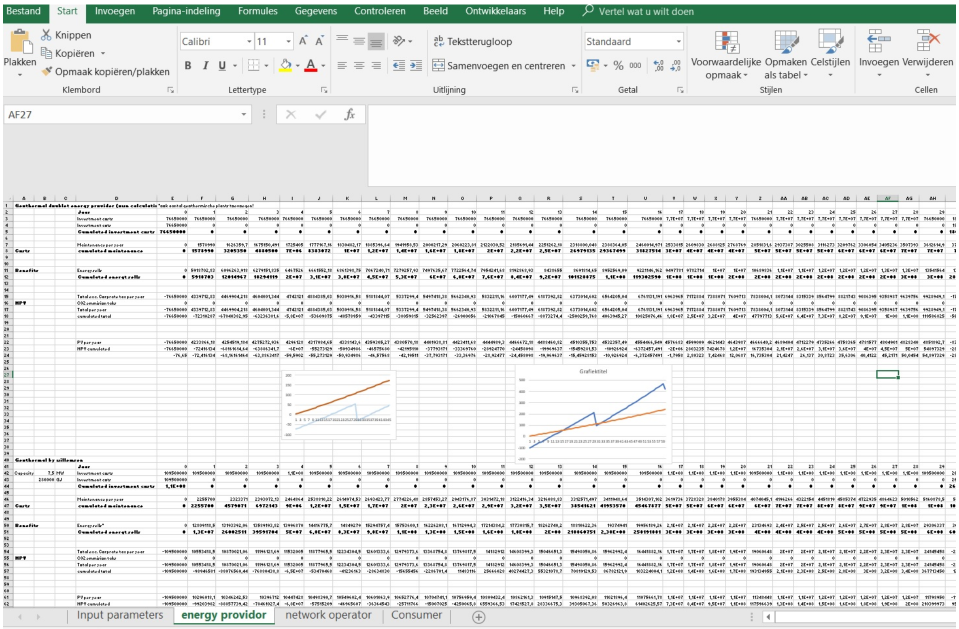


Figure E.12: Graphical presentation of the NPV of energy companies tab (By author)

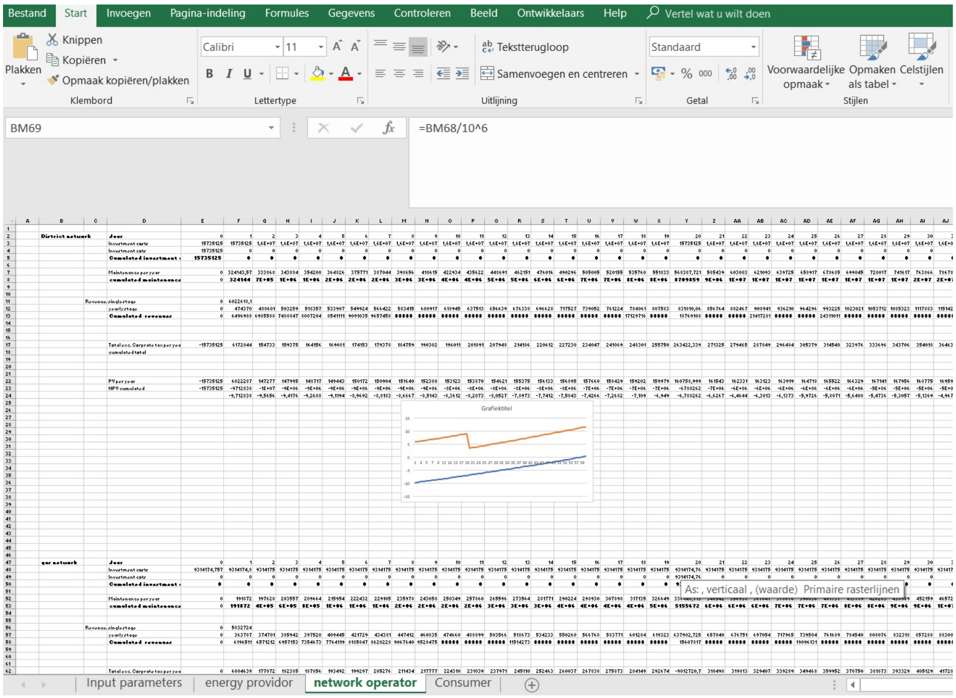


Figure E.13: Graphical presentation of the NPV of network operators tab (By author)

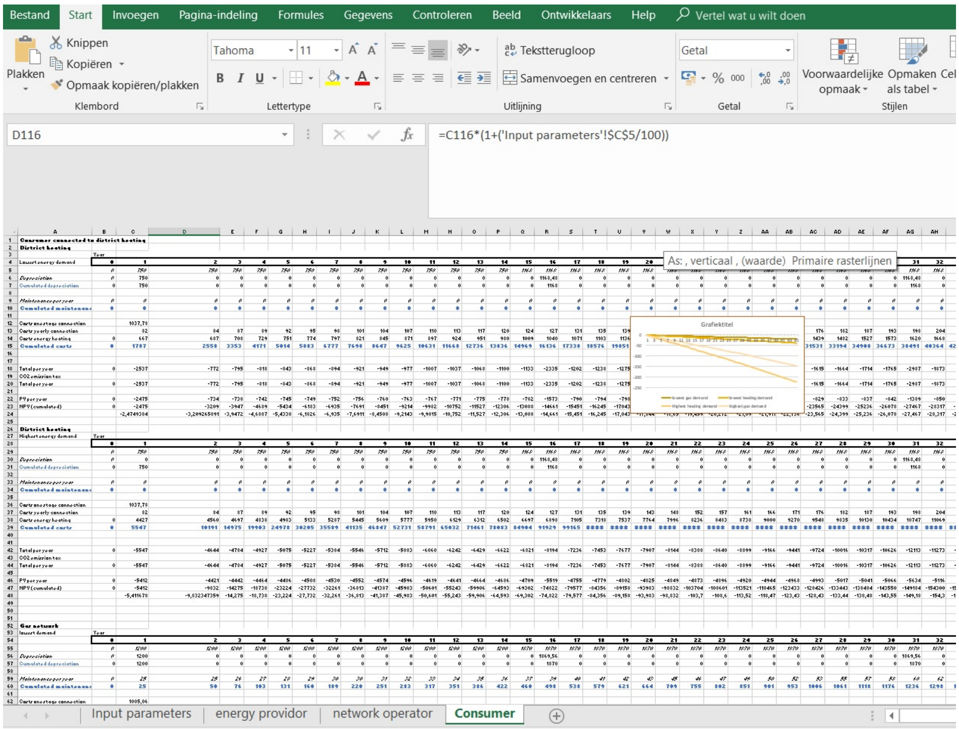


Figure E.14: Graphical presentation of the NPV of consumers tab (By author)

E.2. Decentralized heating system

To calculate alternative heating systems for decentralized system a special file is developed. This file consist of six tabs. The first tab is an overview of the framework of a decentralizes heating system (figure E.15).

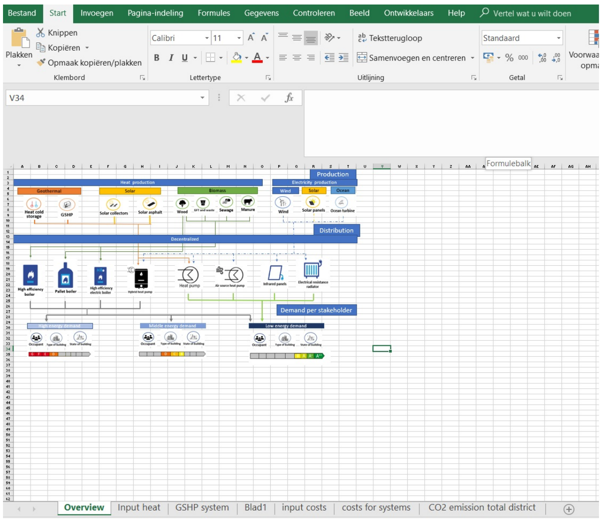


Figure E.15: Graphical presentation of the framework of decentralized heating system (By author)

The second tab consist the input heat tab of the main file (figure E.4). In the third tab the user can select specific postal code of individual buildings. For the buildings having these postal code all the energy consumption for all alternative energy heating technologies are calculated (see figure E.16).

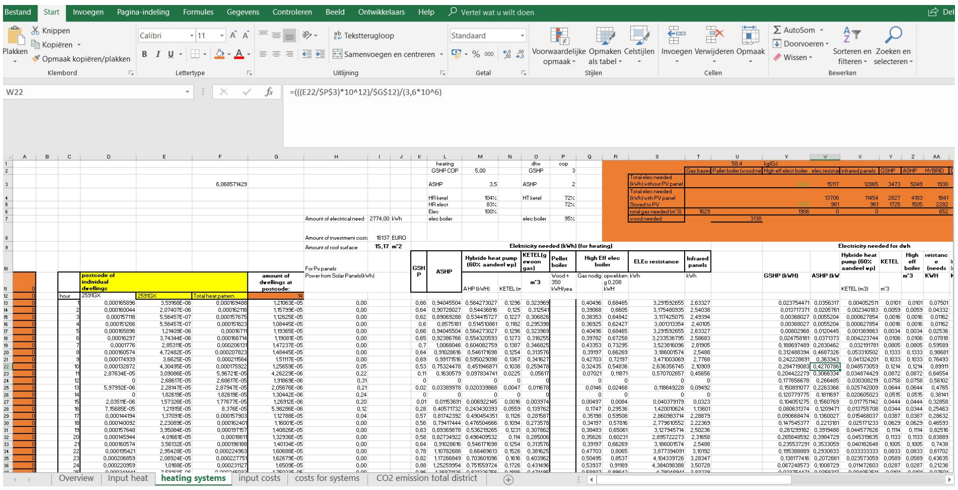


Figure E.16: Graphical presentation of the heating technologies tab (By author)

In the input costs tab the user can implement the investment and maintenance costs for the alternative heating technologies (figure E.17. This can be altered when these are changed over time.

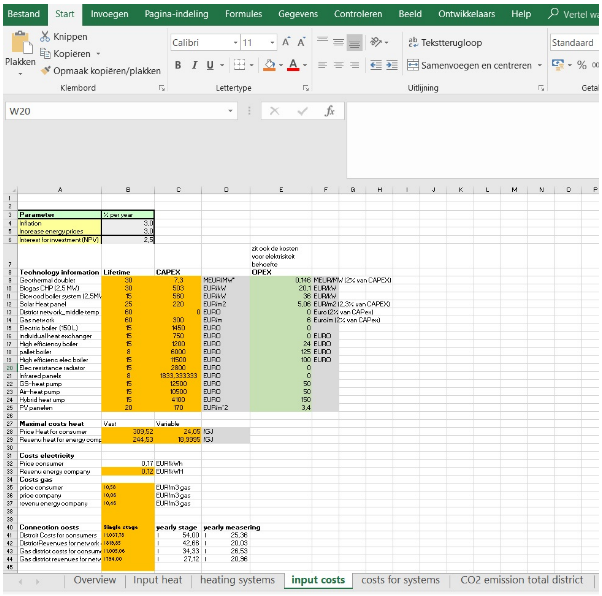


Figure E.17: Graphical presentation of the input costs tab (By author)

The costs are calculated in the costs for systems tab (see figure E.18)

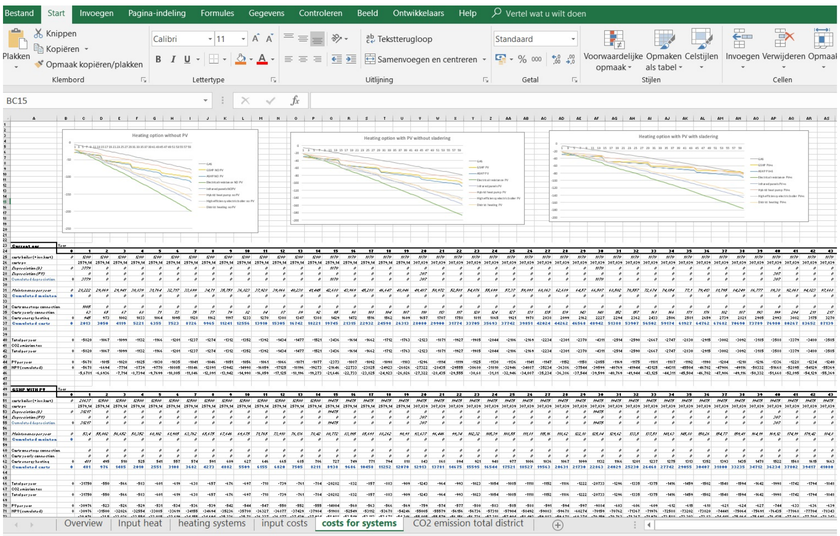
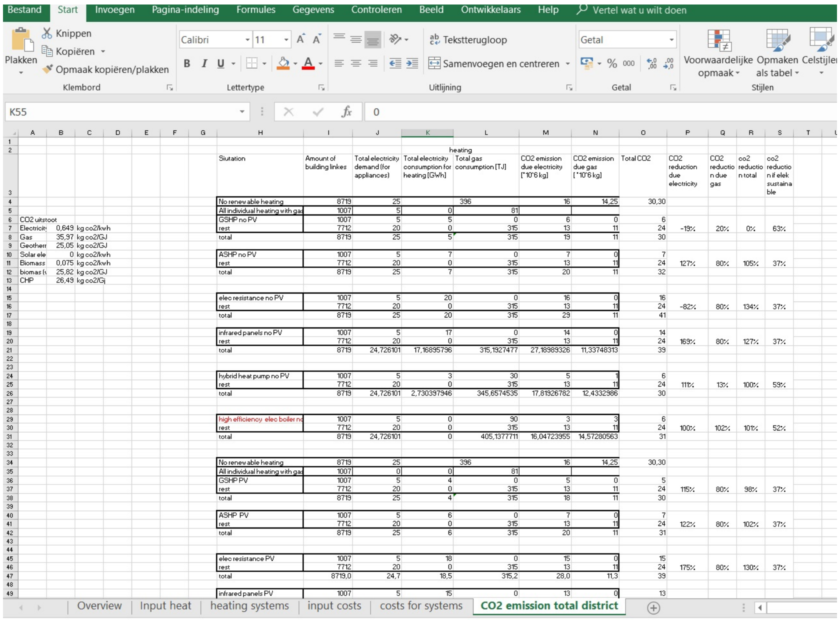


Figure E.18: Graphical presentation of the costs for systems tab (By author)

Finally the amount of CO_2 emissions per alternative heating technologies per building is calculated in the tab CO_2 emissions total district tab (figure E.19)



	A	B	C	H	I	J	K	L	M	N	O	P	Q	R	S
2							heating								
3				Siutation	Amount of building linkes	Total electricity demand (for appliances)	Total electricity consumption for heating [GWh]	Total gas consumption [TJ]	CO2 emission due electricity [*10^6 kg]	CO2 emission due gas [*10^6 kg]	Total CO2	CO2 reduction due electricity	CO2 reduction due gas	co2 reduction total	co2 reduction if elek sustainable
4				No renewable heating	8719	25		396	16	14,25	30,30				
5				All individual heating with gas	1007	5	0	81							
6	CO2 uitstoot			GSHP no PV	1007	5	5	0	6	0	6				
7	Electricity	0,649	kg co2/kwh	rest	7712	20	0	315	13	11	24	-19%	20%	0%	63%
8	Gas	35,97	kg co2/GJ	total	8719	25	5	315	19	11	30				
9	Geotherm	25,05	kg co2/GJ												
10	Solar ele	0	kg co2/kwh	ASHP no PV	1007	5	7	0	7	0	7				
11	Biomass	0,075	kg co2/kwh	rest	7712	20	0	315	13	11	24	127%	80%	105%	37%
12	biomas (v	25,82	kg co2/GJ	total	8719	25	7	315	20	11	32				
13	CHP	26,49	kg co2/Gj												
15				elec resistance no PV	1007	5	20	0	16	0	16				
16				rest	7712	20	0	315	13	11	24	-82%	80%	134%	37%
17				total	8719	25	20	315	29	11	41				
19				infrared panels no PV	1007	5	17	0	14	0	14				
20				rest	7712	20	0	315	13	11	24	169%	80%	127%	37%
21				total	8719	24,726101	17,16895796	315,1927477	27,18989326	11,33748313	39				
24				hybrid heat pump no PV	1007	5	3	30	5	1	6				
25				rest	7712	20	0	315	13	11	24	111%	13%	100%	59%
26				total	8719	24,726101	2,730397946	345,6574535	17,81926782	12,4332986	30				
29				high efficiency elec boiler no	1007	5	0	90	3	3	6				
30				rest	7712	20	0	315	13	11	24	100%	102%	101%	52%
31				total	8719	24,726101	0	405,1377711	16,04723955	14,57280563	31				
34				No renewable heating	8719	25		396	16	14,25	30,30				
35				All individual heating with gas	1007	0	0	81							
36				GSHP PV	1007	5	4	0	5	0	5				
37				rest	7712	20	0	315	13	11	24	115%	80%	98%	37%
38				total	8719	25	4	315	18	11	30				
40				ASHP PV	1007	5	6	0	7	0	7				
41				rest	7712	20	0	315	13	11	24	122%	80%	102%	37%
42				total	8719	25	6	315	20	11	31				
45				elec resistance PV	1007	5	18	0	15	0	15				
46				rest	7712	20	0	315	13	11	24	175%	80%	130%	37%
47				total	8719,0	24,7	18,5	315,2	28,0	11,3	39				
49				infrared panels PV	1007	5	15	0	13	0	13				

Figure E.19: Graphical presentation of the CO_2 emissions per heating system tab (By author)

F

Interviews

Here the interviews with civil servants are showed. Four people were interviewed, the interviews were in Dutch.

F.1. Interview with Mark Bal

Respondent: Mark Bal
Interviewer: Kirsten
Datum: 16-1-2018
Locatie: Spui Den Haag
Voor mijn afstuderen wil ik een ondersteunende tool creëren die inzicht geeft in de aanvoer van duurzame warmte en elektriciteit op wijkniveau. De inzicht die hiermee gecreëerd wordt moet helpen om de energie transitie te versnellen.

Wat zouden de behoeftes zijn van een begeleidende model bij energie transitie? Wellicht is het een idee om een model te ontwikkelen waaruit de verschillende mogelijke duurzame scenario's met de bijbehorende businessmodellen (kosten/baten overzicht) en overzicht van de voor en nadelen vergeleken worden met het huidige gas systeem. De haalbaarheid van de scenario's moeten hieruit naar voren komen. Het zou mooi zijn als er daarnaast zoiets als een regulierknop toegevoegd kan worden waarmee de hoeveelheid energiebelasting op een gas of extra externe kosten toegevoegd kan worden. Hoe verandert hierdoor de haalbaarheid van de verschillende scenario's? Een soort van quickscan model. Ook goed om de bron en het net gespreid te houden. Er zijn nog niet veel duurzame bronnen, het net zou zo gebouwd moeten worden zodat verschillende duurzame bronnen erop aangesloten kunnen worden. Net als het huidige elektriciteitsnet op dit moment.

Welke informatie mist u tijdens het plannen van de energietransitie in wijken? De haalbaarheid van de verschillende opties. it de modellen komen nu mogelijke opties naar voren, maar niet hoe haalbaar dit proces is vergeleken met huidige systeem. Duurzame energie zal altijd duurder zijn, maar hoeveel duurder moeten we het gas maken zodat duurzame warmte competitief wordt? Kan het break-even point van gas/duurzame warmte getoond worden. En hoe verandert dit door verandering in het gassysteem.

F.2. Interview with Johan Noordhoek

Respondent: Johan Noordhoek
Interviewer: Kirsten
Datum: 23-01-2018
Locatie: Spui, 6de etage

Algemene vragen

Wat is u taak in de energie transitie?

Senior beleidsmedewerker, ik probeer energietransitie-beleid te maken voor de hele stad Den Haag. Niet op projecten gericht maar strategie en de bestuurlijke kant. Gaan marktpartijen de energietransitie aanvoeren of is het de gemeente die de touwtrekker in het geheel moet worden en welk beleid hoort daar dan bij.

Waar heeft u behoefte aan en waar loopt u tegen aan tijdens u werk voor de energietransitie?

Heel in het algemeen, we moeten aan de slag. Het is heel duidelijk dat we duizenden woningen in Den Haag van het gas af moeten halen, de backcasting studie in 2012 heeft dit al inzichtelijk gemaakt dus dit weten we al heel lang, maar er wordt nu alleen maar papier geproduceerd en het lijkt dat de afgelopen jaren beetje verspeeld zijn. Niet dat er niks gebeurd, de CO2 uitstoot blijft constant, terwijl het aantal bewoners groeit en er worden meer zonnepanelen gebruikt in de stad. Maar je woning echt van het gas af halen, gebeurt nog niet terwijl dit wel een paar duizend woningen per jaar hoort te zijn. Het besef, dat er echt actie gevoerd moet worden, begint steeds meer duidelijker te worden dus grote kans dat dit in de toekomst snel zal veranderen. Een woning van het gas afbrengen is voor de markt op dit moment nog niet interessant, want er is niet genoeg geld te verdienen. Men zou er wel in kunnen investeren, maar het geld komt nog niet terug. Er is behoefte aan meer geld. Iets van geld blijkt nu te komen (9 miljoen van het Rijk , maar de energierekening van Den Haag is jaarlijks alleen al 900 miljoen. De investering die nodig is, is 6 miljard) In 2023/2025 zou Den Haag van het gas af moeten zijn, dit betekend dat je 10 van de totaal aantal woningen in Den Haag per jaar aanpakt en onafhankelijk van gas maakt. De formele doelstelling is dat in 2040 Nederland van het gas af moet zijn. Wanneer men 2040 aanhoudt, moet je nog steeds 5 van de totaal aantal woningen in Den Haag per jaar van het gas afhalen. Dit betekend niet alleen warmtenet aansluiten, maar ook individuele warmtepompen aanleggen.

Toelichting mijn doel

Voor mijn afstuderen wil ik een ondersteunende tool creëren die inzicht geeft in de aanvoer van duurzame warmte en elektriciteit op wijkniveau. De inzicht die hiermee gecreëerd wordt moet helpen om de energie transitie te versnellen. Het idee is dat de gebruiker bepaalde parameters typisch voor die wijk invoert in het model. Het model/ of de tool/ berekent en toont alle mogelijke duurzame warmte en elektriciteit toevoer voor een wijk(vooral bronnen). Doordat er dan een overzicht gecreëerd wordt, kan de gebruiker kiezen in welke optie hij zou moeten kiezen en in zou kunnen investeren.

Zou u interesse hebben in zo een soort tool? (Waarom wel/niet)

Ja, ik weet alleen niet helemaal zeker of die al ontwikkeld wordt of is. Het is een belangrijke tool. Het is nodig om meer inzichtelijkheid te creëren. Het lijkt mij erg waardevol als de gebouweigenaar ook gebruik kan maken van het model. Op gebouwniveau bestaat er al een model die ontzettend veel inzichtelijk maakt.

Welke behoefte zou u willen vervullen met een model?

Er bestaan opzicht al meerdere modellen op wijk niveau (warmte, koude-kaart, energieatlas) wat die modellen doen is inzicht geven in welk gebied het beste een warmtenet neergezet kan worden en welke huizen meer beschikbaar zijn voor individuele woningen (elektrisch). Wat ik hier zelf nog aan toe zou willen voegen is inzicht in de retourwarmte, wat zijn de mogelijkheden daarmee. Wil je retourwarmte gebruiken betekend dit wel dat er een hoge temperatuurwarmte ingevoerd moet worden. Het model van Overmorgen bekijkt vanuit de energiebehoefte en mogelijkheden van woningen en CE Delft bekijkt hoeveel energie er beschikbaar is in de omgeving. CE Delft begint met het aantal mogelijke warmtebronnen, bijvoorbeeld in Den Haag is er ruimte voor 10-14 geothermie bronnen. Daarna rekent het model van CE Delft per wijk uit hoeveel het zou kosten om een warmtenet te implementeren en hoeveel het kost om alle huizen elektrisch te verwarmen. Deze kosten vergelijken ze met elkaar en daar waar het kostenverschil het hoogst is zegt het model dat het beste een warmtenet aangelegd kan worden. Daar wordt dan de geothermiebronnen voor gebruikt. De 10-14 bronnen worden dan over de stad verdeeld op basis van de berekende kosten. Zo krijg je een duidelijk overzicht van de stad in welke wijken het beste warmtenet met hoge temperaturen toegepast kan worden en in welke wijken elektrisch verwarmd moet worden. Zonnewarmte is weinig bekeken, heet wel een technisch hoog vermogen, maar financieel moeilijk. Over de elektriciteit die jezelf opwekt hoef je geen belasting te betalen, maar warmte zit per hoeveelheid energie veel meer in de belasting. Het gebruik van zelfopgewekte warmte wordt daardoor duurder. Daarnaast is zonnewarmte een onregelmatige bron die opslag nodig heeft. Geothermie kan veel energie produceren en het is stabieler. Biomassa is niet altijd duurzaam (hout uit Canada).

Verdiepende vragen
Tool uitleg van Mark Bal
model ontwikkelen en hieruit komt verschillende scenario's met business model (kosten/ baten overzicht) en overzicht van voordeel en nadeel allemaal vergeleken met huidige gas systeem. Haalbaarheid van scenario's moeten hieruit naar voren komen. Daarnaast fijn als iets van een regulierknop bij zit die hoeveelheid energiebelasting op gas of extra externe kosten toegevoegd kan veranderen waardoor de haalbaarheid van de scenario waarschijnlijk ook verandert. Een soort van quickscan model. Garantie subsidies

Wat zou u hiervan vinden?
Dat is heel aantrekkelijk, misschien waardevol om te praten met QUINTEL, die heeft ook al een groot model die bekijkt naar wat er gebeurt als bijvoorbeeld de olieprijzen veranderen of niet. QUINTEL heeft wel een nadeel in dat het een commerciële club is. Den Haag moet ervoor betalen.
Heeft u andere ideeën daarbij of aanpassingen aan het doel?
Ik denk dat het een meerwaarde heeft als je gaat kijken naar de partijen die bij de energietafel aanwezig zijn en het energieakkoord gaan besluiten. Om te gaan kijken vanuit het gezichtspunt van die partijen. Dit zijn woningcorporaties (die moet een besluit nemen over hoeveel geld zij wanneer gaan stoppen in welk gebouw. Innoveren plannen en renovatie plannen hun doel is bewoners zo goedkoop kunnen laten wonen en financieel zelfstandig kunnen blijven doorgaan) bewoners van een flat (VVE, 70 moet instemmen met grote ingrepen) en energiebedrijven (partij besluit een warmtenet aan te leggen of warmtepompen worden aangelegd en het elektriciteitsnet moet worden bezwaard). Het warmtenet aanleggen moet je gezamenlijk doen op een bepaald moment, terwijl een huis elektrisch verwarmen opzicht elk moment kan (heeft wel voordeel om meerdere op een bepaald moment te doen, maar het is niet zo'n harde eis als warmtenet). Wanneer gaan deze partijen nu een beslissing nemen en wat zijn de doelen van de verschillende partijen (met eventueel interviews hier achter komen). Op een rijtje zetten wat er gebeurt met de verhouding onderling, bijvoorbeeld wanneer een minister gas extra gaat belasten of wat als iemand besluit niet mee te willen betalen. Er bestaat al een Exel business model, die wellicht zou kunnen dienen als tussenmodel. Dit bestand laat de businessmodellen van alle betrokken partijen zien. Wie pak de rol op van energieleverancier zou uit het model naar voren kunnen komen. Dit zijn nu de commerciële partijen (in Den Haag vooral Eneco).

Stel, verschillende scenario's worden met elkaar vergeleken in het model, welke criteria 's vind u belangrijk? (Kosten, C02 uitstoot GHG, volwassenheid van de technologie, lokaal mogelijk, etc)?
CO2 uitstoot is een hele belangrijke. Kosten-verdeling, de combinatie van kosten en wie gaat het betalen. Inzichtelijk maken van kosten en opbrengsten verdeling. Wat zijn de maatschappelijke kosten van de verschillende betrokkende partijen. Waarschijnlijk in het model vooral focussen op de buitenschil, niet teveel in de kosten duiken.

F.3. Interview with Bastiaan de Jong

Respondent: Bastiaan de Jong
Interviewer: Kirsten Neels
Datum: 23-1-2018
Locatie: Spui, 11de etage
Algemene vragen
Wat is u taak in de energie transitie?
Ik ben wijkmanager in de Mariahoeve. Mariahoeve is aangewezen als een van de eerste prioriteitswijken die van het gas af moet. Dus waar de energietransitie ook daadwerkelijk vorm moet krijgen. Als wijkmanager ben ik verantwoordelijk voor de integrale programma's die nu in de wijk plaatsvinden. De energietransitie wordt nu een van de grootste projecten die daar gaat plaatsvinden.

Waar heeft u behoefte aan en waar loopt u tegen aan tijdens u werk voor de energietransitie?
Er spelen een aantal zaken. Het is nog nooit gebeurd, dus niemand weet waar we aan beginnen. Eigenlijk hebben we behoefte aan alles: een plan van aanpak, structuur, geld en mensen. Wanneer we focussen op het aankomend jaar, aan het eind van dit jaar moeten we een concreet plan hebben van hoe je nu die energietransitie in de Mariahoeve kan vormgeven. Daarbij moet je weten wat voor warmtebron je moet kiezen, wat voor leidingnetwerk leg je, wat wordt je planning, hoe gaan we dat betalen, welke partijen heb je daarbij nodig en gaan die partijen zelf ook nog geld inleggen, welke rol hebben die partijen. Welke rol heb je als gemeente. Ik zou blij zijn als we aan het einde van dit jaar een preferensional scenario hebben voor de Mariahoeve, waarin staat hoe we het financieel en technisch gaan aanpakken en hoe we de bewoners meenemen.

Toelichting mijn doel Voor mijn afstuderen wil ik een ondersteunende tool creëren die inzicht geeft in de aanvoer van duurzame warmte en elektriciteit op wijkniveau. De inzicht die hiermee gecreëerd wordt moet helpen om de energie transitie te versnellen.
Tool uitleg van Mark Bal
model ontwikkelen en hieruit komt verschillende scenario's met business model (kosten/baten overzicht) en overzicht van voordeel en nadeel allemaal vergeleken met huidige gas systeem. Haalbaarheid van scenario's moeten hieruit naar voren komen. Daarnaast fijn als iets van een regulierknop bij zit die hoeveelheid energiebelasting op gas of extra externe kosten toegevoegd kan veranderen waardoor de haalbaarheid van de scenario waarschijnlijk ook verandert. Een soort van quickscan model.
Johan Noordhoek: Alle partijen in beeld brengen, hoe ziet de kostenverhouding van alle partijen eruit onderling en wat gebeurt er als bepaalde partijen uitvallen, of wanneer er bijvoorbeeld extra belasting wordt gevraagd voor gas?

Wat zou u hier van vinden?
Ik vind het idee van Johan Noordhoek leuk, maar ook erg ambitieus. Het idee van Mark Bal vind ik ook erg nuttig in deze fase van het project. De mogelijkheid om van elke scenario de business case te zien en kan zien waar de onrendabele top zit en wat er kan gebeuren als je aan bepaalde schuiven gaat zitten. Wat heeft bijvoorbeeld het belasten van gas voor invloed op de businesscases die wij nu hebben. Wat ik versta onder een business model is inzicht in de kosten (hoeveel kost een warmtenet, welke investeringen moeten gedaan worden in de huizen, hoe worden de kosten verdeeld over de verschillende partijen, hoeveel kosten gaan er naar de bewoners). Vanuit wijkperspectief is het belangrijk om te realiseren dat wanneer de bewoners nee zeggen en in de weerstand schieten er niks gaat gebeuren. Zou met wetregelgeving afgedwongen worden, maar die weg wil je niet inslaan. Stel je hebt straks scenario's die je technisch-financieel gaat beoordelen dan zou ik ook graag willen zien hoe de bewoners in de transitie staan. Goed om in de achterhoofd te houden: wat zijn de implicaties van de scenario's voor de bewoners. We hebben de bewoners nodig om alles mogelijk te maken.

Heeft u andere ideeën daarbij of aanpassingen aan het doel?

Nee, vind dat Mark en Johan al goede ideeën hebben gegeven, als je dit kan verwezenlijken is het al super.

Stel, verschillende scenario's worden met elkaar vergeleken in het model, welke criteria 's vind u belangrijk? (Kosten, GHG emissions, volwassenheid van de technologie, lokaal mogelijk, etc)?
Vanuit mijn perspectief zou ik er graag een willen toevoegen en dat is de impact op draagvlak van de bewoners van de wijk. Bewoners zouden graag zou min mogelijk last ervan hebben en zo min mogelijk ervoor hoeven te betalen.

F.4. Interview with Henry Terlouw

Respondent: Henry Terlouw
Interviewer: Kirsten Neels
Datum: 25-01-2018
Locatie: Spui, 6de etage
Algemene vragen
Wat is u taak in de energie transitie?
Ik coördineer het beleidsteam, vooral verantwoordelijk voor de strategie in grote lijnen. Het coördineren houdt in dat alle puzzelstukjes goed vallen, maar ook de koppeling met de uitvoering en de koppeling met communicatie.

Waar heeft u behoefte aan en waar loopt u tegen aan tijdens u werk voor de energietransitie?
Het lastige waar we nu tegenaan lopen is dat we van het plannen samen naar de uitvoering willen. En dan niet op pilotniveau, maar echt hele wijken nu willen aanpakken. Verder is het lastig dat er nog vragen zijn rondom de regelgeving, financiën, wie pakt welke rol, hoe gaan we het organiseren, wel of niet aanbesteden, mogen marktpartijen zomaar dingen doen. Het is wel echt een uitdaging om deze vragen met elkaar te beantwoorden. Er liggen heel veel antwoorden nog niet klaar. Hoe zorgen we ervoor dat we mensen die geen interesse hebben in het verduurzamen van hun huis toch motiveren om hun huis te verduurzamen.

Toelichting mijn doel
Voor mijn afstuderen wil ik een ondersteunende tool creëren die inzicht geeft in de aanvoer van duurzame warmte en elektriciteit op wijkniveau. De inzicht die hiermee gecreëerd wordt moet helpen om de energie transitie te versnellen.
Zou u interesse hebben in zo een soort tool? (Waarom wel/niet)
Ja, want ik heb wel het idee dat het helpt om keuzes te maken. Er bestaan wel al veel modellen die zich verdiepen in dit onderwerp, dus ben wel benieuwd hoe het implementeren van lokale duurzame bronnen in het model zit (in Den Haag is het bijvoorbeeld onmogelijk om alleen maar lokaal elektrische energie te produceren, voor de vraag moeten we elektriciteit van buiten Den Haag gebruiken). Met de modellen van Overmorgen en CE Delft ook echt gezien wat voor meerwaarde het gebruik van modellen kan hebben in het inzichtelijk maken.

Welke behoefte zou u willen vervullen met een model?
Het is altijd een uitdaging om zo een model te vertalen naar de werkelijkheid. Het is heel makkelijk om het als blauwdruk te willen zien, maar dat is het vaak niet. Het is een uitdaging om in de praktijk nu ook echt met de uitkomsten van een model te gaan werken. Het is een uitdaging om het model zo dicht mogelijk bij de werkelijkheid te maken. Wat ik nu merk is dat de modellen wel helpen om het startpunt te bepalen. Modellen zijn vaak ook heel rationeel, de omslagpunten in een model kunnen liggen op een euro of een bepaald bouwjaar, terwijl dit in de werkelijkheid veel gevoeliger ligt en niet zo zwart wit is.

Verdiepende vragen
Tool uitleg van Mark Bal
model ontwikkelen en hieruit komt verschillende scenario's met business model (kosten/baten overzicht) en overzicht van voordeel en nadeel allemaal vergeleken met huidige gas systeem. Haalbaarheid van scenario's moeten hieruit naar voren komen. Daarnaast fijn als iets van een regulierknop bij zit die hoeveelheid energiebelasting op gas of extra externe kosten toegevoegd kan veranderen waardoor de haalbaarheid van de scenario waarschijnlijk ook verandert. Een soort van quickscan model.
Johan Noordhoek: Alle partijen in beeld brengen, hoe ziet de kostenverhouding van alle partijen eruit onderling en wat gebeurt er als bepaalde partijen uitvallen, of wanneer er bijvoorbeeld extra belasting wordt gevraagd voor gas?

Wat zou u hier van vinden?
Leuk om met dat soort knoppen te spelen, ik denk dat het wel een toevoeging kan zijn als dit

makkelijk te verwezenlijken is. Ik denk wel dat je moet opletten dat je je maar op een paar parameters gaat focussen, niet teveel opties geven om te kunnen variëren. En een kanttekening, als je teveel ruimte in het spelen met je variabelen geeft kan het model mislukken. Ik heb het idee dat we doorgaans wel inzicht hebben in de betrokkenen partijen, wat voor energieketens of partijen een rol spelen. Als je de kosten gaat verdelen over de partijen gaat het wel wat meerwaarde bieden, aan de andere kant weet ik ook niet of die altijd relevant zijn. Het laat wel zien waar de pijn straks zit. Ligt het merendeel bij de warmteleverancier of bij een bewoner, dat soort beelden helpen absoluut, vooral omdat die ook echt extreem uit elkaar lopen. Uit het model van CE Delft kwam ook naar voren wat de investering voor een eigenaar kan zijn, en je ziet dat bijvoorbeeld de investering tussen de scenario's die je in je eigen woning moet doen harder oploopt en verschilt voor een bewoner dan de maatschappelijke kosten van zo een scenario. We kunnen eigenlijk niet meer de scenario's met een nul-scenario vergelijken, want de nul-scenario zal niet meer bestaan. Eigenlijk zou je de nul-scenario moeten 'weggooien' en kijken wat moeten we doen wanneer we van het gas afgaan, wanneer gas geen optie meer is, en die opties met elkaar vergelijken.

Heeft u andere ideeën daarbij of aanpassingen aan het doel?
Wat ik nog wel een uitdaging vind, is of je ook met zo een model kan spelen met de verschillende oplossing in de wijk. Wat er nu gebeurt is dat je een begrensd gebied pakt, bijvoorbeeld een wijk, en je doet daar een uitspraak over. Maar wat gebeurt er nu als 15 % van de bewoners in een wijk die eigenlijk op een collectief warmtenet zou moeten toch besluiten voor een individuele oplossing te gaan? Wat doet dat met de rest van de wijk? Want het gaat waarschijnlijk gebeuren dat er mensen zullen zijn die niet eens zijn met het plan en hun eigen plan trekken. Wat doet dat met de businesscase voor de rest van de wijk? Wat gebeurt er met de maatschappelijke kosten en baten?

Stel, verschillende scenario's worden met elkaar vergeleken in het model, welke criteria 's vind u belangrijk? (Kosten, GHG emissions, volwassenheid van de technologie, lokaal mogelijk, etc)?
Denk inderdaad dat de combinatie van dat soort factoren belangrijke criteria 's zijn. Ik denk dat het wel belangrijk is om inzichtelijk maken hoe je tot de afweging komt om die factoren met elkaar te vergelijken. Je kan bijvoorbeeld een model maken die alleen maar op basis van kosten gefundeerd is, maar die factoren die niks met kosten te maken hebben zijn ook belangrijk om erbij te betrekken. De weegfactor moet daarbij wel helder zijn.