COMPARING THE BUSINESS CASES OF DIFFERENT VARIANTS OF ALTERNATIVE HEAT SUPPLY IN A NEIGHBOURHOOD THAT WILL BECOME NATURAL GAS-FREE

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Preface

This thesis handles the assignment to study four alternative variants of heat supply to natural gas in a selected neighbourhood in Vlissingen. The assignment was commissioned by Stedin, the regional electricity grid operator for Zeeland, among others. From February 2022 up until and including June 2022 I worked on this assignment and writing this thesis.

I wrote this thesis as my graduation project for my study program Industrial Engineering & Management. The assignment really spoke to me because of its relation to sustainability and the energy transition, which are very interesting topics to me. I have always profiled myself with these topics during my study career whenever I got the chance, and I definitely wanted to involve it in my thesis.

During this thesis project, there were quite some challenges. In the personal sense, I had a covid infection and was ill another time as well. Professionally speaking, it proved very hard to get the right data for the study. Some data that I wanted to use was non-existent, which caused me to get stuck a couple of times. The biggest challenge was to admit when I was stuck and things were not going smoothly. In the end, I overcame these challenges and this thesis is the result.

This assignment was an initiative of Wil Zweemer, who guided me throughout the duration of the thesis. Ramon Bené and Wouter de Jonge guided me as well. We had weekly meetings with the four of us, and this really helped me during the project. They spent a lot of time helping me and discussing my ideas. For that I want to thank them. Their input and feedback is visible throughout the report.

I also want to thank my family and girlfriend for their continued support of my thesis and the process that I have gone through. They have motivated me and were always willing to talk about difficulties I encountered.

Luc Helmendach

Goes, 12th of June 2022

1. Executive summary

In Vlissingen, the municipality wants to make a selected neighbourhood natural gas-free. In order to support this, they have been granted a subsidy. There are many important stakeholders in this project such as the housing corporation l'Escaut which owns most of the houses in the neighbourhood. All of these stakeholders have their own agenda, but Stedin has took it upon itself to investigate what form of alternative heat supply is most feasible, resulting in the following main research question: 'Which of the four defined variants on heat supply as an alternative to natural gas is most feasible for the selected neighbourhood in Vlissingen and has the lowest total costs of ownership?' The four defined variants in question can be found in chapter 4.

In order to answer the main research question, three sub questions were designed of which the answers support the main research question. During the study, desk research was performed in the form of literature and case studies, and interviews were conducted with experts as well.

A rough scan of the vicinity within a radius of 1 kilometre of the neighbourhood was done for potential heat sources for a heat network. The scan showed that aqua thermal energy, solar thermal energy and residual heat from supermarkets were potential sources for a collective heat network solution. These are all low temperature sources, so the high temperature variant was eliminated from the study. This was also the case for the biomass solution, since this is not deemed as sustainable or renewable and is not perceived as such in society. The other remaining option was individual heat pumps.

A simulation showed that both solutions would impact the electricity grid in such a way that both solutions would require adjustments to the electricity grid. The individual heat pump solution mainly affects the low voltage electricity grid and the collective heat network solution mainly affects the middle voltage electricity grid. Either way, Stedin will have to make adjustments.

Generic business cases were made for both solutions, showing the key financial numbers. Based on these, the conclusion is that the collective heat network solution has the lowest yearly total cost of ownership, whereas the individual heat pump solution is financially more attractive for the residents of the neighbourhood. On top of that, it is also deemed most feasible based on complexities and dependencies.

It is recommended that both the heat sources and the technical systems are studied further. The exact potential of the heat sources has to be determined, as well as their availability. The technical systems should still be engineered to detail, based on which more accurate business cases can be made.

Contents

2. The host organization

Stedin is a regional grid operator for both electricity and gas. Their service area covers a big part of Zuid-Holland, the province of Utrecht and since January 2022 the province of Zeeland as well. In 2017, Enduris (the previous grid operator of Zeeland) became part of the Stedin Group. For several years, Enduris remained a separate company withing the Stedin Group, but as of 2022, Enduris became Stedin. All employees of Enduris were taken in by Stedin and have been integrated into the new organisation. (Stedin, 2022)

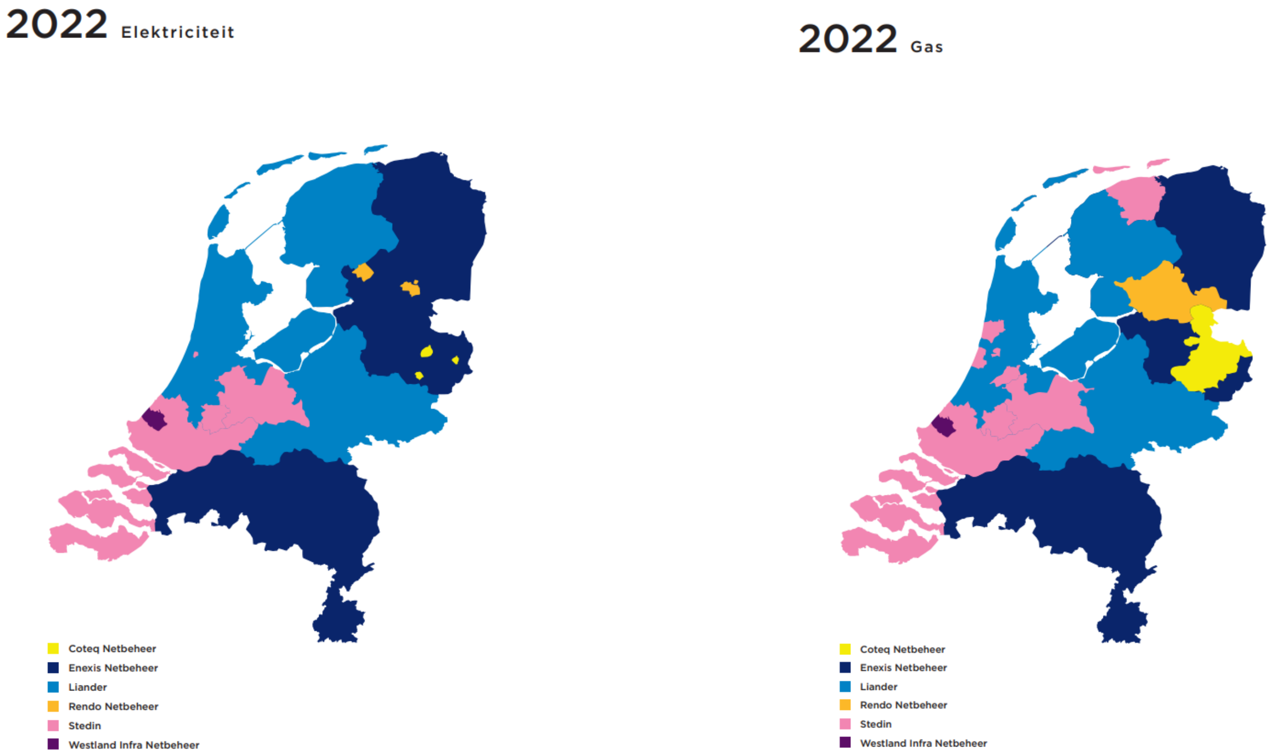

Figure 1: On the left side the regional grid operators for electricity in the Netherlands, on the right side the regional gas grid operators (Netbeheer Nederland, 2022)

Along with the national and other regional grid operators, Stedin is responsible for the infrastructure of electricity and gas from source to household/company connection within their service area, as well as the placement and monitoring of measurement equipment. They do not deliver or produce the electricity and gas itself, but ensure the transport of these energy mediums works well.
At the moment, Stedin is facing a big challenge in the form of the energy transition. In the long term, companies and households are supposed to become CO2-neutral. The alternative for gas is often electricity. If everybody switches from gas to electricity, the grid capacity has to increase. This is the responsibility of Stedin, along with the other grid operators in the Netherlands. At the moment, they are expanding the grid in several places. (Stedin, 2022)

3. Research context

3.1. The project

The municipality of Vlissingen has been granted a subsidy to disconnect a neighbourhood from the natural gas grid. Compensation package ‘Wind in de Zeilen’ offered Vlissingen the chance to submit an application as part of the ‘Programma Aardgasvrije Wijken’ of the ministry of Internal Affairs and Kingdom relations. This application can be found in Appendix 1. An impression of the neighbourhood through some photos taken in the neighbourhood can be found in Appendix 5.

Most houses (in this document, ‘houses’ will stand for all residential buildings, e.g. including flats) in Vlissingen are still connected to the regional natural gas grid. When these houses are disconnected from the regional natural gas grid, costs will be made in the neighbourhood and the houses. In the Netherlands, politicians have stated that the transition to an alternative energy source should be realistic and affordable for everyone. The technical and financial consequences will be covered in this study, both for a potential heat grid operator and the house-owners/tenants.

This assignment is done in cooperation with the municipality of Vlissingen and housing corporation l’Escaut. In this neighbourhood, there are a lot of old houses with bad insulation and, as a result of that, with an energy label of D or worse. Residents in this neighbourhood have higher energy bills than residents of houses with a better energy label elsewhere. Proper insulation of these houses improves multiple factors. The level of comfort rises and the energy bill goes down. Also taken into consideration are the other neighbourhoods which the housing corporation is already investigating. l’Escaut is planning to renovate these houses and make them more sustainable from 2022 to 2030. This means that this is a multidisciplinary project, combining insulation and sustainable heat supply. l’Escaut has gained a lot of experience in making houses more sustainable over the past years, and will bring this experience into this project.

3.2. Study stakeholder analysis

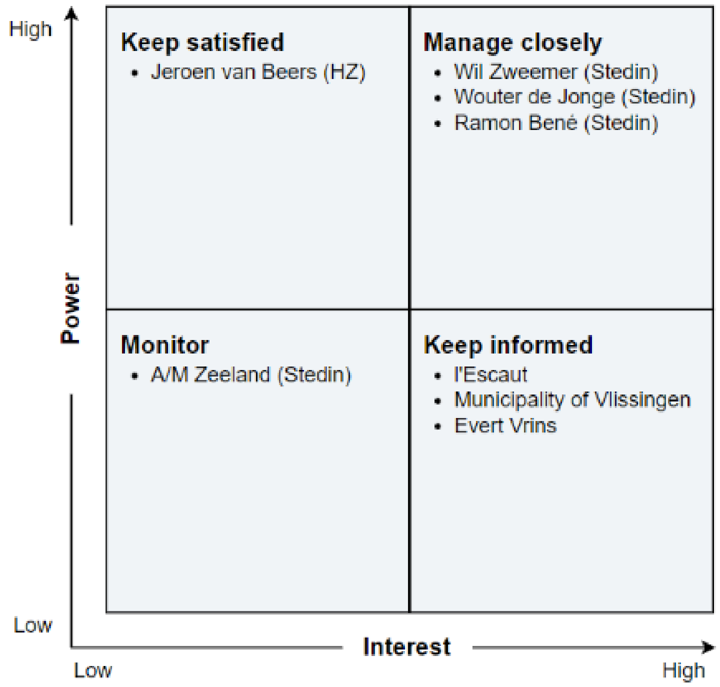

Figure 2: Stakeholder analysis

4. The research

4.1. Problem definition

The 'problem' of the research is that the houses in question are still (like most others) using natural gas to fulfil the need for heating, hot water and cooking appliances. The Dutch government has set the goal of being CO2-neutral by 2050, which is in line with the Paris Agreement. This includes disconnecting all houses and buildings from natural gas, and having them use another source for heat.

As an intermediary objective, the government has agreed to make 1.5 million houses more sustainable by 2030. The challenge is not only finding an alternative source of heat supply, it is also about reducing the heat demand. This is done through the improvement of energy labels of houses, for example with better insulation.

The municipality of Vlissingen, in collaboration with housing corporation l'Escaut, was granted a subsidy in the program 'Aardgasvrije Wijken' (natural gas-free neighbourhoods). The subsidy they applied for is part of a testing ground program. In this program, municipalities can apply for subsidies which they can use to test out techniques for alternative heat sources in one of their neighbourhoods. By doing this, they are testing methods and techniques on their feasibility. If the results are good, this concept can be applied in other parts of the Netherlands as well. If it does not turn out well, the same concept will not be applied elsewhere, and any financial losses will be limited because of the subsidy that was used. (Rijksoverheid, n.d.)

The project that this subsidy was given for entails many aspects. It involves, but is not limited to the following:

- Insulation of the houses
- Research of the best technical solutions
- Designing a final solution
- Participation of the residents
- The social impact of the project on the neighbourhood and its residents

In consultation with the client (Stedin) and other important stakeholders, the decision was made to focus on the research of the technical solutions in this study.

4.2. Objective

The specific objective of this study is to develop an advice based on the (economic) feasibility of alternative methods to heat houses in the neighbourhood of Vlissingen that will be used as testing ground for 'Programma Aardgasvrije Wijken'. In addition, an implementation plan will be made. While the third round of the subsidy for testing grounds already has a predilection towards a certain method, this study will incorporate all four methods of heating that have been identified in the assignment. The reason for this is that the insight gained while studying the different variants can be of use for future projects.

4.3. Research questions

Based on the research problem and the objective which derived from the assignment and the clients' wishes, several research questions were developed. The main research question, which this study aims to answer, is as following:

Which of the four defined variants on heat supply as an alternative to natural gas is most feasible for the selected neighbourhood in Vlissingen and has the lowest total costs of ownership?

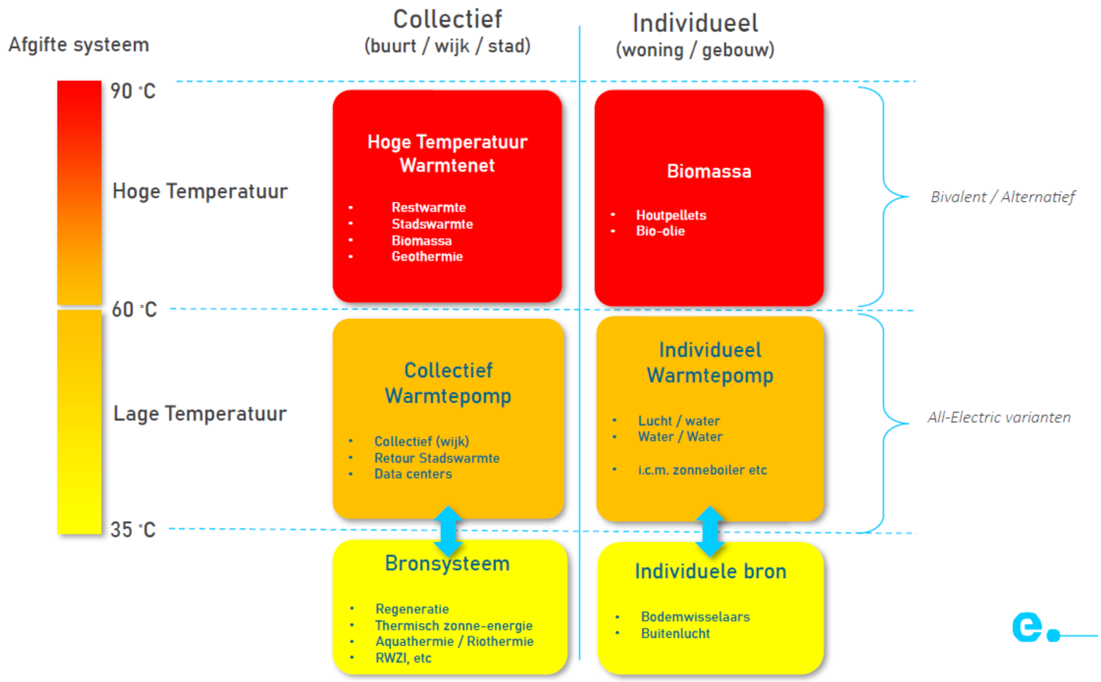

Figure 3: The four variants of alternative heat supply (Stedin, 2021)

In order to support the main research question, a set of sub-questions was developed as well:

- What is the future heat demand of the neighbourhood?
- What are the possible heat sources in the vicinity of the neighbourhood?
- How does each possible solution impact the low voltage electricity grid in the neighbourhood?

4.4. Scope

The following depicts the scope of the study. All elements named in this part will be included in the study and can be seen as the parameters. The scope was developed with and verified by the main client and stakeholders.

- The making of business cases for all possible variants on alternative heat supply
- The four different heat delivery systems from source to destination
- Taking into account input from the municipality and l'Escaut
- Delivering an answer on the main research question
- The geographical location in Vlissingen as shown in figure 4
- Making a rough simulation of the impact on the low voltage electricity grid for each possible solution

In welke buurten gaat Vlissingen aan de slag met aardgasvrij?
Het gaat om 632 woningen in het Middengebied (zie kaart):

A. 76 huurwoningen en 20 koopwoningen (bouwjaar 1948) in de Albert Cuyplaan, Beatrixlaan, Jan van Goylenlaan;
B. 296 huurappartementen (met bouwjaar 1958) in de Hercules Segherslaan, deel Bloemenlaan, Vincent van Goghlaan;
C. 22 huurwoningen en 38 koopwoningen (bouwjaar 1948) in de Breitnerlaan, Tooroplaan;
D. 45 koopwoningen (bouwjaar 1995) in het Mondriaanplantsoen, Breugelplantsoen, klein deel Van der Helstlaan;
E. 111 huurwoningen en een wijkcentrum (bouwjaar 1948) in de Mesdaglaan, Jacob Marislaan, Willem Roelofszlaan, deel Jozef Israelslaan;
F. 24 huurwoningen (bouwjaar 2015) in de President Rooseveltlaan, Willem Witsenlaan, Adriaen van Ostadelaan.

Figure 4: The neighborhood that the study focusses on

The following elements will not be included in the study. These include factors that the client, stakeholders or outsiders could expect to be in the study, but together with the client the choice was made to leave them out.

- The current natural gas infrastructure in the neighbourhood
- Hydrogen as a primary fuel source for heating
- In-depth technical calculations of the impact on the electricity grid
- Any adjustments to improve the insulation level of the houses in the area and corresponding costs
- Participation of the residents and their cooperation
- The engineering and/or the precise design of the solutions

5. Theoretical framework

5.1. Relevant concepts

5.1.1 Four variants of alternative heat supply

As shown in figure 3, the municipality of Vlissingen has identified four variants as possible alternative heat supplies to natural gas. They are combinations of four factors in two categories. On one hand the temperature of the heat delivery system, low or high temperature. On the other hand whether the system is individual or collective. Combining these factors, four variants were defined. In the upcoming sections, these four variants will be explained.

High Temperature Heat Network

The high temperature heat network is a combination between a high temperature heat delivery system and a collective solution. A collective solution would serve a neighbourhood or even an entire town, whereas an individual solution would serve a single house or building (e.g. a flat). In order to realise such a system, a source of heat is required. The possible sources as identified in figure 3 are as follows:

- Residual heat (e.g. from industrial processes)
- Biomass
- Geothermal energy

If the source of the heat is close to its destination, further upgrading of the heat is not necessary. In order to transport the heat from the source to destination, a heat network has to be constructed. This consists of (insulated) pipelines filled with water. Two pipelines have to be built, one that transports heated water from the source and one that transports the cool water back from its destination. The heat from the source is transferred to the water in the pipelines. The heat is then brought to the houses or buildings that are connected to the heat network.

In the case of biomass, materials of organic or animal origin are used to generate energy centrally through burning, gasification or fermentation. It is said to be sustainable because the materials take in CO2 during their life. During the energy generation process, however, this CO2 is released again. If enough organic material is put back into nature, such as through planting trees, this CO2 will be compensated for. This will, however take decades. It is seen as a means to reach climate goals on a short term, but not deemed sustainable enough for the long term. (Milieu Centraal, n.d.)

Geothermal energy is heat withdrawn from the sub-surface of the earth, which can be used for the heating of houses or industries. The deeper energy is withdrawn from, the higher the temperature. This can only be done in places where the ground is suitable, which means it is not always an option for a project. Ground investigation is always required to determine whether or not geothermal energy can be used in an area.

The working principle of geothermal energy is as follows: water from the ground is pumped up to the surface, where it goes through a heat exchanger. The heat of the water is extracted, and the water is pumped back into the ground. It uses two wells at an equal depth. One is used to pump up water, and one to return it. A sufficient distance between these two wells is required so the water can slowly heat up again after being returned to the ground. In figure 5 as displayed on the next page, the working principle is shown, as well as the temperature levels for the different depths. (Geothermie Nederland, n.d.)

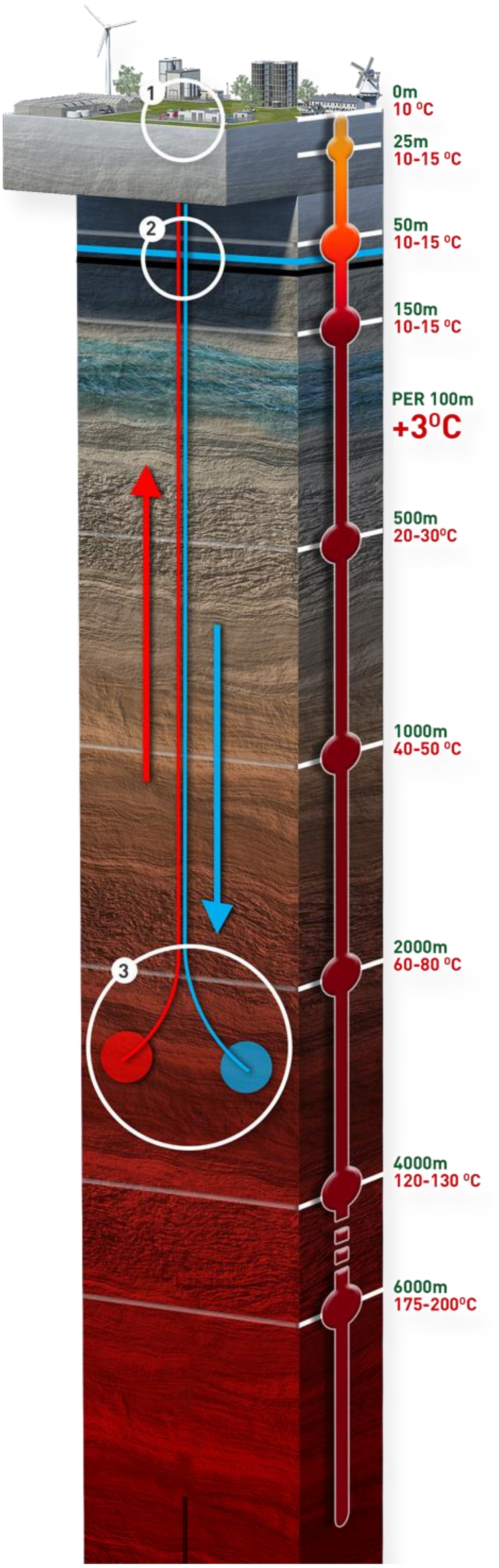

Figure 5: Working principle geothermal energy (Geothermie Nederland, n.d.)

Individual biomass system
In this instance, an individual system relates to a single house or building. In figure 3, for an individual biomass system, two variants have been defined. The two variants as defined are the usage of wooden pellets and bio-oil.

In the case of wooden pellets, house-owners can choose to heat their house with a wood pellet stove, which is comparable to a fireplace. These do need to be refilled regularly, depending on which stove is picked. Some have to be refilled daily, others weekly. This can be an impractical job, because the weight of the bagged pellets is quite high due to it being compressed (US Department of Energy, n.d.). The pellet stoves serve as an alternative to a central heating boiler. They distribute clean heated air with which rooms can be heated. They are often used as an addition to a current heating system, for example for when natural gas prices are high. (Houtpellet-kachel.nl, n.d.)

Bio-oils can be a number of products. Examples of bio-oils are natural oils such as rapeseed oil, natural fatty acids and used frying oil. These can be used to fuel central heating boilers. Some bio-oils are oils retrieved from natural products such as rapeseed. Others are made through a process called pyrolysis. This process is used to produce oils from solid biomass such as wood. It heats organic material without oxygen at a temperature of at least 500 °C. This causes the bio-polymers to deconstruct. Since there is no oxygen, combustion does not occur, but the biomass decomposes into combustible gases and char, which can be condensed into a combustible liquid. A schematic of the pyrolysis process is displayed in figure 6 below. (Agricultural Research Service, 2021)

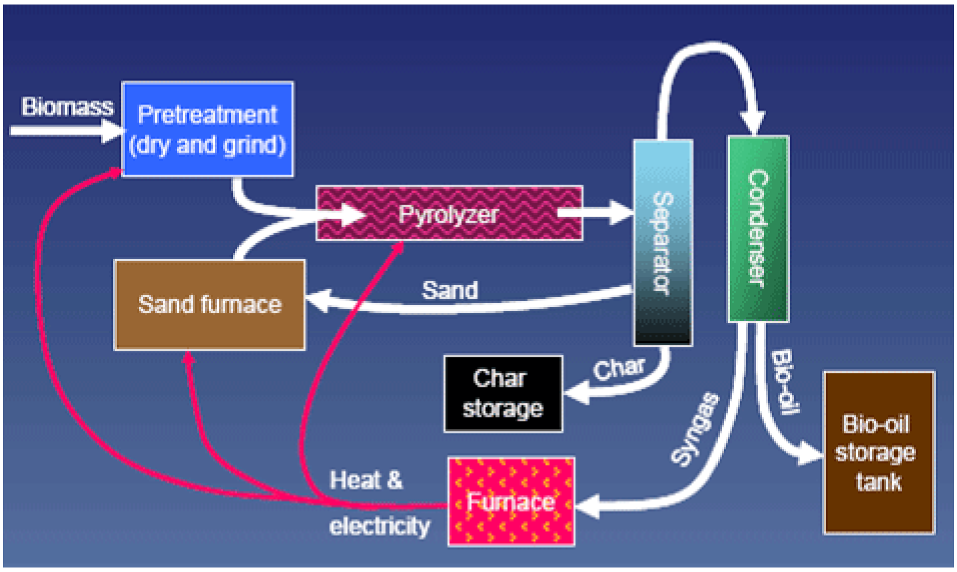

Figure 6: Schematic of the pyrolysis process (Agricultural Research Service, 2021)

Collective heat pump systems
This variant makes use of a low-temperature heat network in combination with a collective heat pump, supplying heat to a complete neighbourhood or town. In order for this system to function, a nearby source of heat with a low temperature is required. In this case, low temperature is anything lower than 65 °C. Examples of such sources are:

- Data centres
- Supermarkets
- Aqua thermal energy
  - Surface water
  - Sewer water
  - Sewage treatment water
- Thermal solar energy
- Residual heat of industrial installations

The heat captured from most of these sources is at such a low temperature that even well-isolated houses (with a high peel label) cannot use it for space- and tap water heating. For that reason, the heat has to be upgraded to a higher temperature level with a heat pump. In this variant, this is done centrally, instead of houses having an individual heat pump.

Depending on the temperature of the source, either a booster heat pump is needed or a heat pump with a higher capacity. If the heat source has a temperature of approximately 50 °C, this is enough for space heating (provided the house/building is isolated well enough). In this case, a heat pump with a relatively small capacity (and thus cheaper) is needed just to 'boost' the heat so its eligible for tap water heating. If the heat source has a temperature of 10 to 30 °C, a heat pump with a higher capacity is needed, as the heat is neither enough for space heating or tap water. (Expertise Centrum Warmte, 2020)

In figure 7 below, an example of a low-temperature heat network which uses an aqua thermal energy source in combination with a heat and cold storage is displayed. Heat networks which use other low-temperature sources look generally the same, apart from the source.

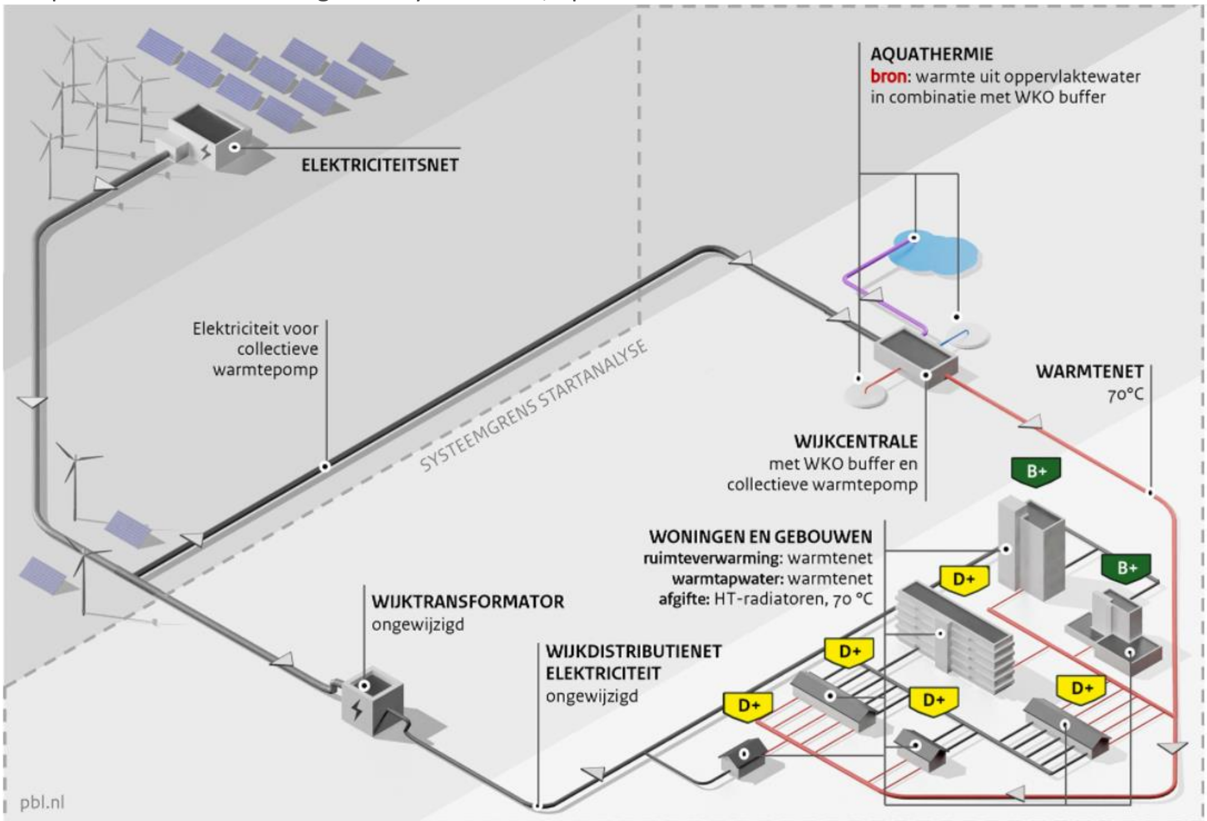

Figure 7: Low-temperature heat network example with an aqua thermal source (Planbureau voor de Leefomgeving, 2020)

Individual heat pump systems

The last defined variant makes use of individual heat pumps per house or building. They are called 'all-electric' variants. Two ways to realize this are an air to water heat pump and a water to water heat pump. Heat pumps are becoming more popular, especially since the adjustment of the gas law in the Netherlands. The change meant that all new housing built after the 1st of July 2018 can no longer get a connection to the gas grid. (Ministry of Economics and Climate, 2018) This means that new housing has to be heated in another way. Heat pumps are often a chosen alternative.

A big advantage of heat pumps is that they are almost always a possibility, especially air to water heat pumps. They do not depend on a lot of external factors where other heat sources may be very dependent. The only thing that may be affected by external factors is the electricity usage if the temperature changes.

Listed below are the other advantages and the disadvantages of heat pumps.

Advantages

- No direct use of fossil fuels
- More efficient than central heating on natural gas
- In summer they can be used for cooling
- Low maintenance
- Eligible for subsidies

Disadvantages

- High investment costs
- Surface area of heat delivery system must be bigger due to low temperature
- Requires good insulation
- Some installations need a permit
- Lower efficiency in cold weather
- Outside unit can be noisy (in the case of an air to water heat pump)

(Warmtepompenadvies, n.d.)

An air to water heat pump extracts heat from the air outside, upgrades the temperature through a compressor and transfers the heat to the water used for space heating and tap water. The working principle is displayed in figure 8 below. These heat pumps operate on electricity. An air to water heat pump is relatively the cheapest variant of heat pumps. Such a heat pump, including installation, costs approximately between €7000 and €10.000 in the Netherlands. (Vaillant, n.d.)

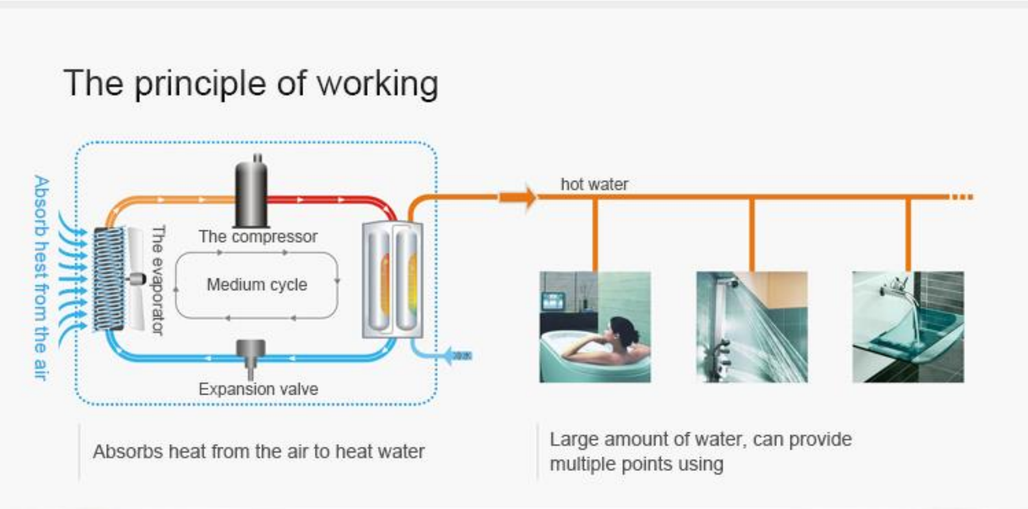

Figure 8: Working principle air to water heat pump (Nulite, n.d.)

A water to water heat pump extracts heat from water in the ground or surface water. Pipes are submerged in a body of water, containing a working fluid which absorbs the heat of the surrounding water. This is then upgraded in the same way as the air to water heat pump does it. The advantage a water source heat pump has over other sources is that it is more efficient since heat transfers best in water. Additionally, average water temperatures are higher and more stable throughout the year as opposed to air and ground temperature. One disadvantage to this technique is that it is more costly than other kinds of heat pumps, since it requires a bigger installation. (Energy Saving Trust, 2021)

The working principle of a water to water heat pump is displayed in figure 9 below.

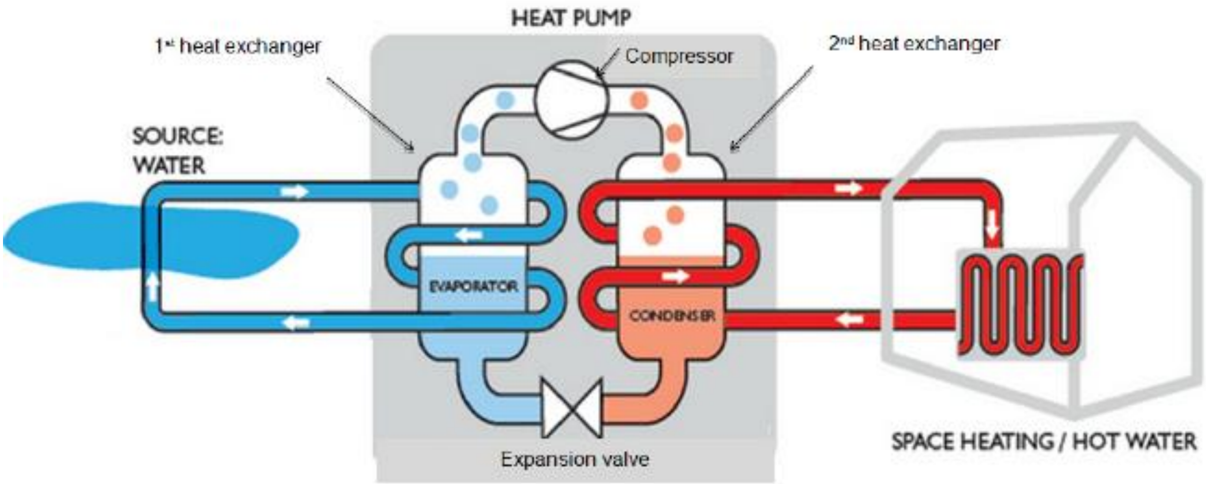

Figure 9: Working principle water to water heat pump (Emmanuel, 2014)

5.1.2 Thermal energy storage

Thermal energy storages are used to store heat for later use. It can solve the issue of seasonality which is fairly common for various sustainable heat/energy sources. One example of such a heat source is aqua thermal energy. If a system makes use of a water body as heat source, seasonality is often an issue. The temperature of the water body is highest in the summer, when the sun shines the most and outdoor temperatures are the highest. Therefore, a lot of heat can be extracted of the water body during the summer. The problem is that most residential houses/buildings have a low heat demand in the summer. With a thermal energy storage, this heat can be stored so that it can be used when the heat demand is the highest; in the winter.

There are multiple ways thermal energy is usually stored. It depends on for example the temperature of the heat and the size of the system (one house vs one neighbourhood). The most common storage method is storage in water. This can be done above the ground or in the ground, with open and closed systems and using big barrels or the ground itself.

Another appliance/advantage of thermal energy storages is that they can aid in stabilising the renewable energy production peaks. Since the energy transition has become more relevant, more and more appliances have switched from fossil fuels to electricity, since electricity can be generated in a sustainable way. This has increased the demand for electricity, and thus the supply of electricity has also increased. This has caused the electricity grid in the Netherlands to become more strained. In some parts of the Netherlands, the grid capacity is almost reached. One reason for this is the production of renewable energy. Some of these sources are weather-dependent, so when the weather is favourable for these sources, their supply can peak. These peaks can be very straining on the electricity grid. In order to flatten these peaks, thermal energy storages can serve as buffers. If heat pumps are connected to the thermal energy storage, they can be turned on during these peaks, even if no heat is needed at that moment. The heat can then be stored in the ground or barrels (depending on the form of storage) and used at a moment where the electricity is more scarce. (Expertise Centrum Warmte, 2020)

5.1.3 Proeftuinen

The proeftuinen, or testing grounds in English, are the initiative of the 'Programma Aardgasvrije Wijken' or program of natural gas-free neighbourhoods, as named in the next section of relevant sources. This program aims to support municipalities and other parties involved in the transition to natural gas-free neighbourhoods. It consists of a knowledge and learning program and the testing grounds.

The testing grounds aim to gain experience in the neighbourhood-oriented approach of the transition to natural gas-free. Through multiple rounds of subsidies, municipalities could apply neighbourhoods in their area to become a testing ground. Each round of subsidy has a set of criteria, so all testing grounds of that round gain experience with a certain range of techniques (e.g. low or high temperature heat networks, different kinds of sources). In the application, municipalities can ask for a grant in order to finance this process. The municipality of Vlissingen has applied the neighbourhood that concerns this study to be one of the testing grounds. (Programma Aardgasvrije Wijken, n.d.)

5.2. Relevant sources

5.2.1 ECW

The ECW stands for Expertise Centrum Warmte, which translates to Expertise Centre Heat. It is a knowledge centre for municipalities in the Netherlands. It aims to support municipalities with the technical, economical and sustainable aspects of the heat transition of buildings and houses in their respective areas. ECW offers factsheets, analyses and other products that support government officials in making for example the regional energy strategy. The ECW is an initiative of the Dutch Climate Agreement.
The centre is organised through a steering group and an advisory group. In these groups, there are representatives of various stakeholders and experts such as the association of Dutch municipalities, union of water authorities, various ministries, grid operators, energy suppliers, applied scientific research centre and so on. (Expertise Centrum Warmte, n.d.)

5.2.2 Regionale Structuur Warmte

The Regionale Structuur Warmte Zeeland, which translates to Regional Structure Heat (RSH) Zeeland, is an initiative of the Regional Energy Structure (RES) Zeeland. The RES has identified an approach for the transition to sustainable heating of the built environment. The RSH is an analysis of the possibilities for this transition on a regional level. It contains several maps with for example the heat demand density and the available sources for different kinds of alternative heating in Zeeland. This contains very useful information for the assessment of the different variants of alternative heating, and whether they can be realized in the area. (Zeeuws Energieakkoord, n.d.)

5.2.3 Programma Aardgasvrije Wijken

The program of natural gas-free neighbourhoods is an initiative of the ministry of internal affairs, ministry of economics and climate, provinces, union of water authorities and the association of municipalities. The initiative aims to support municipalities and other involved parties in their goal to become natural gas-free. The initiative has two elements, a knowledge and learning program and the testing grounds as explained in the relevant concepts. The goal is to gain as much knowledge and experience with natural gas-free neighbourhoods as possible. This knowledge can then be used by other municipalities. In the end, all municipalities and neighbourhoods will have to transition to natural gas-free. The themes the knowledge program focusses on are as follows:

- Supervision and organisation
- Costs and financing
- Technical solutions
- Juridical elements
- Participation and communication
- Connecting problems

The website of Programma Aardgasvrije Wijken contains a lot of data, cases, infographics and much more. Since the neighbourhood in question for this study will also become a testing ground, the information provided on the website will be very useful to the study. (Programma Aardgasvrije Wijken, n.d.)

5.2.4 Testing ground application (PAW3)

In order to become testing a ground and receive a subsidy, the municipality of Vlissingen had to submit an application. This application had to fulfil the requirements of the third round of testing grounds, which focussed on a low-temperature heat network. The goal of these different rounds of testing grounds is to ensure that all kinds of defined sustainable heat supplies will be tested. This way, knowledge and experience of all these variants is gathered, which can be used by all municipalities across the country. The application that the municipality did was written by a third party, Evert Vrins Energieadvies. This is a freelance energy consultant, who has a lot of experience with such projects. The application contains a rough plan of the testing ground project, how the municipality is planning to handle it and what kind of solutions are intended. On the 10th of March 2022, the subsidy was granted to the municipality of Vlissingen. This means the project will be executed. The information in the application will be very useful for this study.

5.2.5 Standards and target values existing housing report

One of the starting grounds of this study is the future heat demand of the houses in the selected neighbourhood. This is to be calculated based on the insulation levels that the houses will reach as a part of the project of the municipality of Vlissingen and l'Escaut. Knowing the types of houses and their building years, only the acreages of the houses and some key numbers are required.

The acreages of the houses can be retrieved from the BAG (Basisregistratie Adressen en Gebouwen) maps which Stedin has access to. These contain a lot of information about addresses and buildings, including the acreages of the houses. All municipalities across the country are the sources for this database. (Kadaster, n.d.)

The last data required to calculate the future heat demand is the heat demand per square metre of acreage of the different types of houses that are in the neighbourhood. The initial goal was to use key numbers of average heat demand based on the peel label of the houses per house type. In reality, however, it proved very difficult to find this data, perhaps because it does not seem to exist (yet) or has not been used in that way yet.

The aspect that makes this data difficult to find is its abnormality relative to the most used terms. As explained before, the peel label of a house is exclusively about the level of insulation of a house. This term, however, is not used widely. Mostly energy labels are used, which also include eventual solar panels on a house and thus include more than just insulation levels. This makes it unreliable as a starting point for the calculation of the heat demand.

Instead, a report written on standards and target values of heat demand in existing housing will be used. This report was written by an engineering firm (Nieman) commissioned by the RVO (Rijksdienst voor Ondernemend Nederland). This is a government service which creates the policies for the business climate in the Netherlands. It informs and supports business but also enforces laws and legislations. (RVO, 2021)

The report focusses on the heat demand of existing housing, in order to create standards and target values as agreed in the Dutch Climate Agreement. It identifies different types of houses and different levels of insulation. The levels of insulation will be explained below, as this will be used for this study:

- Level 0: The current level. In this research, this means it handles the insulation levels of the houses included in the research in 2018.
- Level 1: The original level. This level contains the levels of insulation based on how they were when the houses were built.

- Level 2: The lower limit of common measures. These houses have standard insulation with limited thickness and quality. Their cavity wall insulation is outdated and has unknown or poor quality.
- Level 3: The higher limit of common measures. These houses have applied common measures, but have high quality insulation with maximum thickness. Their cavity walls are completely filled with high quality insulation. The existing constructions/structures have been used optimally.
- Level 4: These houses have technically advanced measures. These are measures such as a completely new roof, exterior wall insulation or applying a centrally balanced ventilation system with heat recovery.

For each level of insulation and house type, there is a matrix that shows its corresponding (average) heat demand per square metre. These matrices will be used in the calculation of the heat demand as starting points. (Nieman Raadgevende Ingenieurs BV, 2021)

6. Research method

In order to make sure this study is as reliable as possible and to ensure it could be re-done and have the same outcome, a structured and specific research method will be outlined. This method explains how the study will be performed, what kind of data will be used and how it will be collected. All of these elements contribute to answering the main research question:

Which of the four defined variants on heat supply as an alternative to natural gas is most feasible for the selected neighbourhood in Vlissingen and has the lowest total costs of ownership?

6.1. Action plan

In this study, the different variants of alternative heat supply will be researched, and the most feasible ones will be compared based on their business cases. In order to do so, the first step is to determine the heat demand of the neighbourhood in the new situation. This means taking into account the insulation measures that the housing corporation will take and the level of insulation the municipality aims to achieve for house-owners.

Subsequently, a preliminary selection of the four defined variants will be made on a high level. For this comparison, the variants will be judged on multiple aspects, such as geographic availability and distance from source to destination. Based on these aspects, a preliminary selection will be done. One or more of the variants could already be excluded from the further study based on this. In that case, business cases will not be developed for them and they will be left out of the further comparison.

After a preliminary selection has been made, the remaining variants will be studied in detail. The possibilities of their appliance will be researched, and data will be gathered which is needed to develop business cases for all of them. For the development of the business case for heat networks, a model of Expertise Centrum Warmte will be used. This model is very extensive/detailed, and contains all aspects required for this study. After developing the business cases for all remaining variants, a selection will be made and a recommendation will be given.

The most important elements this business case model contains are as follows:

- Risks
- Subsidies
- Taxes
- Heat losses
- Income
- CAPEX
- OPEX
- Indexation
- Number of connections
- Phasing

In consultation with the client, this model was chosen as it was deemed most detailed and has a reliable source. The client knows Expertise Centrum Warmte as a useful and reliable source, as it is a government initiative. The model also contains more than enough details to satisfy the wishes of the client. The model is based on experience figures from realised heat networks. (Expertise Centrum Warmte, n.d.)

In order to maintain a good planning and ensure all deadlines will be met, a milestone planning has been designed using a Gantt chart. This planning can be found in Appendix 2.

6.2. Research question and method relevance matrix

A research question and method relevance matrix was made in order to show how each sub-question will be answered and what it entails. The results are shown in table 1.

Sub-question	Relevant business parameters	Theoretical framework	Research deliverable	Type of research	Research method	Data source	Quality/validity/ ethical aspects
1	Heat demand	Standards and target values existing housing report	Total heat demand of neighbourhood	Quantitative	Calculation/desk research	Heat demand key numbers	Limited data
2	Sources in vicinity	Regional structure heat	Potential heat sources in vicinity	Qualitative	Desk research/ observations	Regional structure heat	Prone to error
3	Electrical aspect	The different systems	Electrical impact of solutions	Qualitative	Simulation	Literature	Based on assumptions

Table 1: Research question and method relevance matrix

6.3. Data types

The type of data that is needed for the study and to execute the action plan will determine how data collection will be done. The following choices have been made for the types of data that will be used:

Both quantitative and qualitative data will be used

In order to get a good understanding of the different kinds of heating systems and the approach to the transition from natural gas to natural gas-free heating, qualitative data is needed. This should be data explaining how to handle the transition to alternatives and explaining the working methods of different kinds of heating systems. On the other hand, qualitative data will also be required for aspects such as the business cases of the variants and the impact of each variant on the electricity grid.

Mostly secondary data will be used

This study does not handle something so innovative that it has not been done before. There are already examples of testing grounds of neighbourhoods transitioning to natural gas-free heating. The techniques are relatively new, but have been used before. No experiments will be performed for the development of a solution of alternative heating solution, so data which is collected and used for this purpose will already exist.

Both descriptive and experimental data will be used

Descriptive data will be used to research and understand the different variants of alternative heat supply and construct the business cases. Experimental data will be used to determine/calculate the impact of each variant on the electricity grid. This impact will be determined using simulations, by entering variables and factors which influence/impact the electricity grid.

6.4. Data collection

The data types described will be collected in different ways. The following data collection methods will be used in this study:

1. **Literature study/desk research**
   In order to understand elements such as concepts, techniques, rules and regulations, subsidies, laws etc., literature study/desk research will be done. A lot of this will be done online. Preferably, reliable sources such as government agencies will be used. The topic of this study is a very relevant one to them too, and they provide a lot of information on it.
2. **Interviews**
   A lot of knowledge can be gained through interviewing the right people. The expertise of others will be of great value to this study. This will be retrieved through interviews. These will be well prepared, and notes will be taken of the contents discussed during the interviews. For significant interviews, reports will be written. This way, the data retrieved can be used in the study.
3. **Case study**
   Since the topic of this study has become extremely relevant over the last couple of years, there are quite some similar cases to the one handled in this study. Of the other testing grounds alone, there are multiple cases of which lessons can be learnt. Similar cases will be analysed for the purpose of this study. Both the good and bad aspects of them will be taken into account when performing this study.

(Scribbr, n.d.)

6.5. Validity, reliability and ethics

The validity in this study is maintained through the methods that were used throughout the study and its value according to the stakeholders. The methods that were used for this research have been checked with and validated by the main stakeholders of the study. The scope of the study was set very sharply in consultation with the client and stakeholders and the right kind of sources were used.

This study is reliable because of the consistency of the methods that were used and the kind of sources that were used. The study maintains a similar approach throughout the process and the sources that have been used have been checked prior to use. They were evaluated on their nature and reliability.

Ethics were not a big issue for this study. There were ethical aspects in just a few topics during the study. For example the subsidy application containing a lot of valuable information for the study was shared by the municipality of Vlissingen before it was made public. This meant that the contents of this application had to be kept secret until the application was made public. Another ethical aspect was the biomass alternative. This was mainly eliminated from the study because the municipality of Vlissingen did not deem it to be sustainable or renewable. Society shares this perception. As they are the ones that will have to execute the project, their opinion is valued. Biomass requires organic matter in order to produce a fuel, which makes it an ethical dilemma to use it. Therefore, it was excluded.

7. Results

7.1. Sub-question 1: The heat demand

Before a preliminary selection of alternative heat sources can be made, the heat demand of the neighbourhood in the new situation has to be calculated. By ‘the new situation’ is meant the situation after insulation of the houses. The reason for this is that the insulation of the houses is included in the project for the municipality of Vlissingen and housing corporation l’Escaut. Since one of the criteria of the subsidy is that the heat network solution will make use of a low temperature heat source, insulation of the houses is crucial. The better the insulation, the less heat is required.

7.1.1 Housing distribution

In the application for the subsidy, the municipality of Vlissingen has divided the neighbourhood into six parts. These parts have different structures, housing ages, owners and insulation levels. The divisions are shown in figure 10.

Figure 10: The six sub-areas of the neighbourhood (Evert Vrins Energieadvies, n.d.)

- Sub-areas A and C
  These parts consist of in total 156 houses which were all owned by l’Escaut. 59 of them have been sold to private owners. These houses were built shortly after 1945. In part A of the neighbourhood, the houses have already been post-insulated. For all other houses, this is not the case. l’Escaut will insulate the houses to make them ‘natural gas-free ready’ before they sell anymore.

- Sub-areas B and E
  Sub-areas B and E consist of 509 houses in total. The reason this contains so many houses is because they are mostly flats. All of these are owned by l'Escaut. These were also built shortly after 1945 and are known to have a low level of insulation. l'Escaut intends to renovate these flats thoroughly and focus on improving the energetic quality. The residents of these houses will not get an increase in housing costs because of it.
- Sub-areas D and F
  The houses in sub-areas D and F were built more recently than the houses in the rest of the neighbourhood. The total of 76 houses have construction years ranging from 1995 to 2015. Most of these are private-owned (52), the rest is owned by l'Escaut. The private home-owners will receive a favourable financial proposal in order to make their house natural gas-free ready. The municipality of Vlissingen is thinking about supporting the private home-owners in doing so. The houses owned by l'Escaut will also be made natural gas-free ready, without the residents getting an increase in housing costs.
  (Evert Vrins Energieadvies, n.d.)

7.1.2 Assumptions
For the calculation of the total heat demand of the neighbourhood, a number of assumptions have been done. They are listed and explained below:

- During this study, the peel label will be used, as opposed to the energy label. The peel label of a house focuses solely on the level of insulation. The energy label of houses and buildings are used widely, nowadays. To determine the heat demand, however, this is not deemed accurate enough for the study. The main reason for this is that the amount of renewable energy used (such as through solar panels) has influence on the energy label, and they are not always up to date (Milieu Centraal, n.d.). Whether or not there are solar panels on a house, however, does not influence the heat demand of the house. Therefore, the peel label of the houses will be used to calculate the total heat demand.
- In order to calculate the total heat demand, an assumption has to be made on the future insulation levels. During talks with the municipality of Vlissingen and their consultant, they made it known that the general aim is for the peel labels of all houses to become label B. As explained in the theoretical framework, however, the peel label has proven to be unusable as data for this calculation. There are no key numbers available of the heat demand based on peel labels. Instead, insulation levels will be used from the report 'Rapport standaard en streefwaardes bestaande woningbouw'. For this calculation, insulation level 3 was picked together with the client. This was deemed to correspond with peel label B; very good insulation, top of the line for existing measures, but no ground-breaking technologies. (Nieman Raadgevende Ingenieurs BV, 2021)

7.1.3 House types
The report about standards and target values for existing housing identifies four different types of housing and building year ranges. These will also be applied for the calculation of the total heat demand of the neighbourhood. The different categories are displayed below:

Housing types
- Mid-terraced houses
- Corner/semidetached houses
- Detached houses
- Staircase entrance flats

Building year categories

- Building years until 1945
- Building years from 1945 until 1975
- Building years from 1975 until 1995
- Building years from 1995

(Nieman Raadgevende Ingenieurs BV, 2021)

Housing surfaces

Using the BAG maps, the acreages of the houses in the selected neighbourhood can be retrieved. This will be done per housing type and building year category. Based on this separated data, the total heat demand can be calculated. The total acreages in square metres (m^2) for all houses in the selected neighbourhood within a category are displayed in table 1 below.

	Mid-terraced houses	Corner/semidetached houses	Detached houses	Staircase entrance flats
<1945	0	0	0	0
1945-1975	14930	9985	346	19361
1975-1995	3963	1515	0	0
>1995	2383	1128	0	0

Table 2: Total acreages per housing type and building year category

7.1.4 Calculation

For every housing type that is relevant for the selected neighbourhood, a figure will be displayed showing the average heat demands for every insulation level. There is also a distinction between the different building year categories. Based on these averages, the approximate future heat demand for the selected neighbourhood is calculated.

Mid-terraced houses

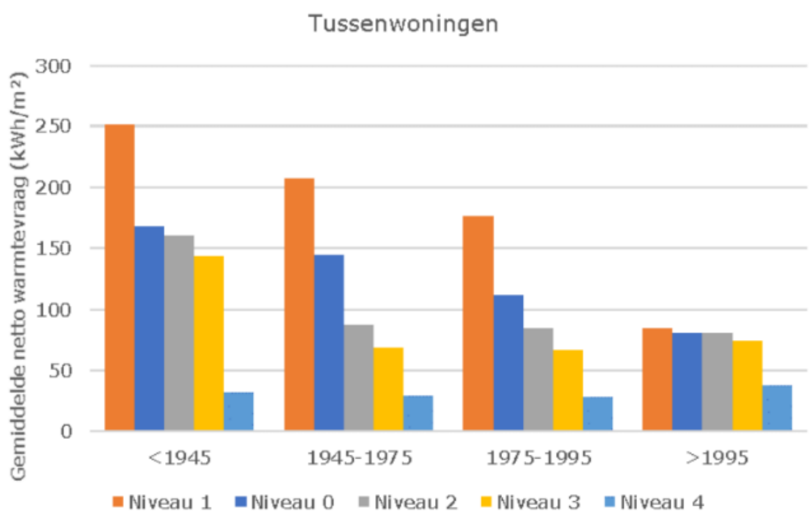

Figure 11: Average heat demand of mid-terraced houses for all defined building year categories (Nieman Raadgevende Ingenieurs BV, 2021)

The yellow colour in figure 11 represents the total future heat demand for mid-terraced houses with insulation level 3. Based on these averages, the heat demand is calculated in kWh, as shown in table 2.

	<1945	1945-1975	1975-1995	>1995	Total
Mid-terraced house	0	1.045.100	277.410	178.725	1.501.235

Table 3: Total future heat demand for all mid-terraced houses in the selected neighbourhood

Corner/semidetached houses

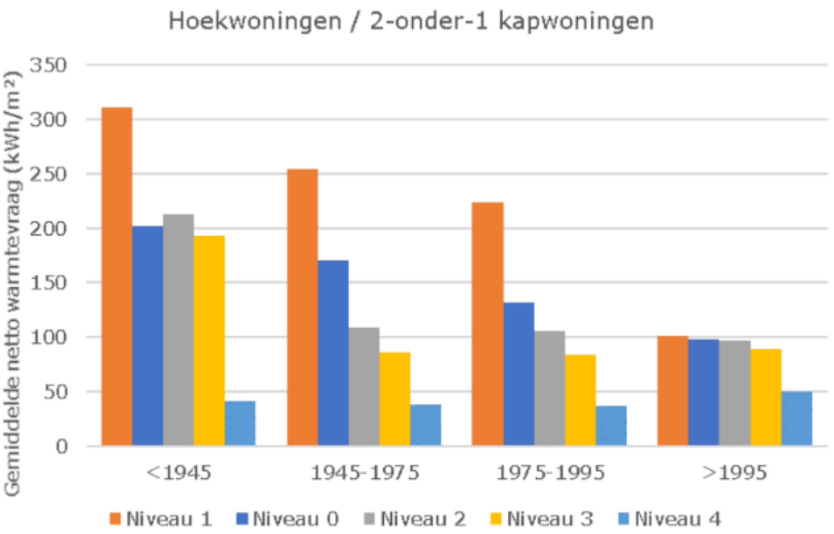

Figure 12: Average heat demand of corner/semidetached houses for all defined building year categories (Nieman Raadgevende Ingenieurs BV, 2021)

The yellow colour in figure 12 represents insulation level 3. Based on this, the total future heat demand for all corner/semidetached houses in the selected neighbourhood is calculated in kWh as shown in table 3.

	<1945	1945-1975	1975-1995	>1995	Total
Corner/semidetached houses	0	848.725	121.200	101.520	1.071.445

Table 4: Total future heat demand for all corner/semidetached houses in the selected neighbourhood

Detached houses

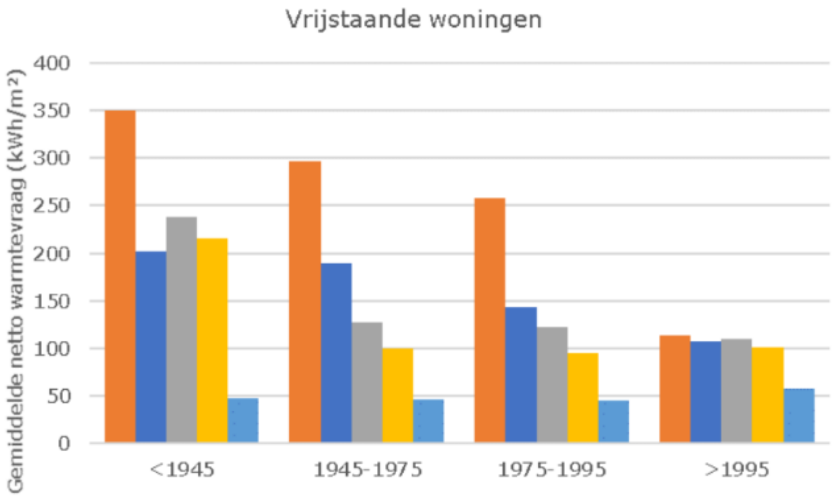

Figure 13: Average heat demand of detached houses for all defined building year categories (Nieman Raadgevende Ingenieurs BV, 2021)

The yellow colour in figure 13 represents insulation level 3. Based on this figure, the total future heat demand for all detached houses in the selected neighbourhood is calculated in kWh as shown in table 4.

	<1945	1945-1975	1975-1995	>1995	Total
Detached houses	0	34.600	0	0	34.600

Table 5: Total future heat demand for all detached houses in the selected neighbourhood

Stair entrance flats

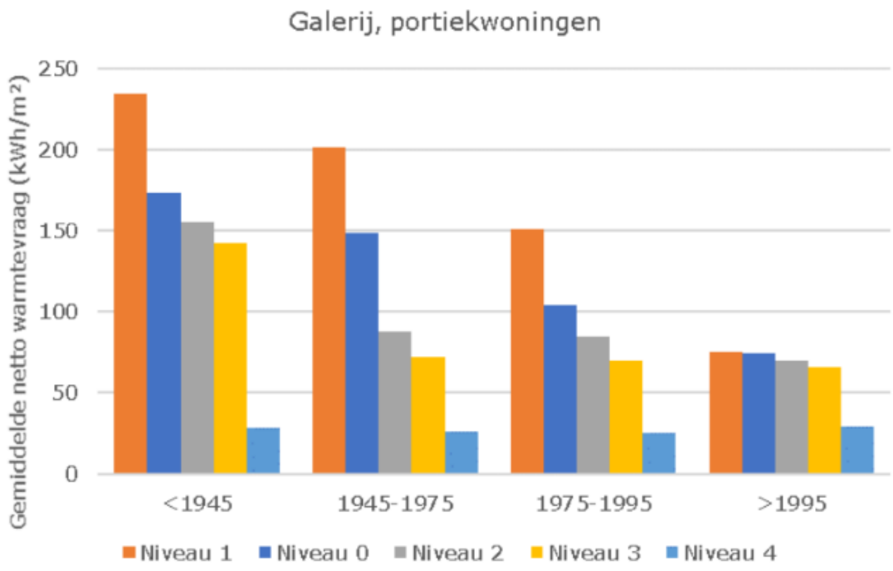

Figure 14: Average heat demand of stair entrance flats for all defined building year categories (Nieman Raadgevende Ingenieurs BV, 2021)

The yellow colour in figure 14 represents insulation level 3. Based on this, the total future heat demand for all stair entrance flats in the selected neighbourhood is calculated in kWh as shown in table 5.

	<1945	1945-1975	1975-1995	>1995	Total
Stair entrance flats	0	2.807.345	0	0	2.807.345

Table 6: Total future heat demand for all stair entrance flats in the selected neighbourhood

Total

The sum of the total future heat demands of all four housing types adds up to 5.414.625 kWh, which converts to 19492,65 Gigajoules (ConvertLive, 2022). This would require approximately 541.463 m³ of gas per year. Completely getting rid of this gas would save approximately 1023 tonnes of CO_2 each year (provided that the alternative source does not emit any CO_2 whatsoever).

7.2. Sub-question 2: Possible heat sources in the vicinity

Before determining specific heat systems, a rough scan will be done to identify the possible heat sources in the vicinity of the selected neighbourhood. In order to do so, the Regional Structure Heat (RSH) will be used. As explained in the theoretical framework, this is part of the Regional Energy Strategy of Zeeland. It contains a lot of information about the heating challenge in Zeeland. For this rough scan, mainly the various interactive maps about the different kinds of heat sources in the area will be used.
Important to note is that the scan will only include potential heat sources within a range of 1 kilometre of the neighbourhood, as shown in figure 15. This is seen as the maximum distance for a heat distance to be from its destination. If it is more than a kilometre away, the scale of the project must be immense in order to compensate for the investment costs in the infrastructure which ensures the transport of heat from source to destination. (DWA, 2020)

Figure 15: A circle with a radius of 1 kilometre around the neighbourhood

7.2.1 Residual heat

The first interactive map of the RSH contains heat sources in the form of residual heat. Companies that generate heat in their process or building are identified and the potential heat is quantified. While zooming in on the selected neighbourhood for this study, there is one potential heat source within one kilometre of the neighbourhood (or in the whole of Vlissingen) according to the map. This potential source is the Albert Heijn XL, a big supermarket located on Gildeweg 6. According to the information of the map, the Albert Heijn XL has residual heat at a low temperature in the form of condensation. The information states that the approximate potential heat is 18 Terajoules.

After discussing this with the consultant of the municipality, it became clear that the residual heat of the Albert Heijn XL is a result of the cooling installations that are present in the building. Supermarkets use cooling and freezers for their products. What these installations do is basically withdrawing heat in order to cool. This heat is currently transferred and let into free air.
One potential disadvantage of this source is that the cooling/freezing installations of the supermarket have to 'work' harder during the summer months, and therefore generate most heat during the summer. This clashes with the heat demand for houses, as they require most heat during the winter months. If this source would be used, heat storage would probably be required in order to make it work.

While considering supermarkets as a potential heat source for the neighbourhood, even though they are not on the map of the RSH, more supermarkets appear to be within a radius of 1 kilometre of the neighbourhood. The Lidl, for example, is just across the street from the Albert Heijn XL, on Mercuriusweg 16. Next to it is the Jumbo on Hermesweg 25. If the desired heat source would be a supermarket and the heat withdrawn from one of them would not be enough to heat the selected neighbourhood, one or two supermarkets could add to that heat. The question is then if multiple sources will impact the investment costs of the infrastructure negatively, and by how much.

7.2.2 Aqua thermal energy

For aqua thermal energy, there is one possible and obvious source of heat for the selected neighbourhood. At a distance of a bit less than a kilometre is the channel that runs from the Veerse Meer to the Westerschelde (see figure 15), which flows out to the North Sea. This means that the channel has a direct connection to the sea, which means it is salt water.

According to the RSH, the channel has a potential heat for between 100-200 houses per hectare of water. Based on this claim, this would mean that in order to provide enough heat for the selected neighbourhood, the heat of at least 3 to 4 hectares of water of the channel has to be captured/withdrawn.

7.2.3 Bio-energy

With bio-energy is meant biogas and biomass. Generally, there is not much potential for biomass in the province of Zeeland. This is partly due to the fact that there are few forests in the area. The potential for biogas is supposedly higher, mainly due to the waste streams of agricultural activities, of which there is a lot in the area.

After speaking with the municipality and their consultant, however, it became clear that bio-energy is not an option for this project. Their motivation for the exclusion of this option has two reasons:

1. There is a lot of social resistance towards bio-mass. The reason for this is that it is not seen as renewable/sustainable. In order to use wood, for example, forests must be chopped. This is seen as bad for the environment.
2. Biogas has much better applications which are already available as opposed to heating. For example in heavy industries and mobility it can be used and requires a much higher temperature.

(Vrins, 2022)

In addition to the motivation of the municipality of Vlissingen, the Regional Energy Strategy Zeeland has explicitly cast off biomass, as it is not deemed sustainable. Since the Regional Energy Strategy Zeeland has been developed in collaboration with all municipalities of Zeeland, this stance also applies to the municipality of Vlissingen. (Zeeuws Energieakkoord, 2020)

7.2.4 Solar thermal energy

Another possible source that is explored in this first scan of the vicinity is solar thermal energy through the use of thermal solar panels or pvt panels. The RSH states that these panels can be put on roofs in order to generate heat, but would benefit from a scale advantage in case of field setups with large amounts of panels. The RSH has identified the areas where field setups of solar thermal energy would be possible.

Figure 16: The suitable areas for solar thermal energy (Zeeuws Energieakkoord, n.d.)

As shown in figure 16, there are quite some areas around the selected neighbourhood that can be used for field setups of solar thermal energy. Solar thermal energy would have to be combined with thermal energy storage, since it is not a constant heat source all year round.

7.2.5 Geothermal energy

As explained in the theoretical framework, geothermal energy can be a good source of heat for houses/buildings, even though it is costly. The scale of the project would be a big factor in whether it would be profitable or not. Besides that, geothermal energy is not possible everywhere. The ground has to be suitable in order to make the extraction of geothermal energy possible.

A water-bearing layer underground is required for geothermal energy. This layer should have a sufficiently high temperature, which is permeable for water so that it can be pumped up to the surface.

The reason that geothermal energy is not applied widely is because of the related costs. It is, for example, only possible to determine the heat potential after having performed expensive drilling to the water-bearing layer. Without having to drill deep into the ground, it is possible to estimate the heat potential of the ground in places and whether or not a location has suitable ground for geothermal energy at all. The RSH has done this for the province of Zeeland. This analysis is shown in figure 17.

In figure 17, all (light)blue-coloured parts are areas that are suitable for geothermal energy based on their ground. The darker the colour, the more suitable the area is for geothermal energy and the more heat potential there is. Looking at the selected neighbourhood and Vlissingen as a whole, there are no areas suitable for geothermal energy anywhere near. The whole of Walcheren seems to be unfit for geothermal energy.

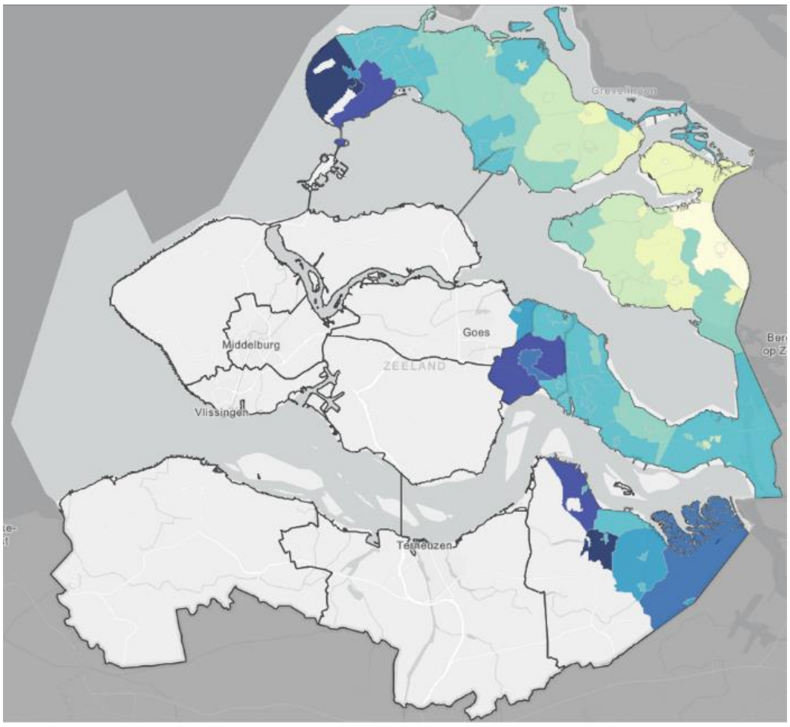

Figure 17: Geothermal energy potential in Zeeland (Zeeuws Energieakkoord, n.d.)

7.2.6 Data centres

Another option that could serve as a heat source for the neighbourhood is a (big) data centre. This would be a viable source for a low temperature heat network in combination with collective heat pumps.

In Vlissingen, however, there are currently no (big) datacentres. There are plans to build a very big datacentre, the so-called Green Bay. It is supposed to become one of the biggest datacentres in Europe, running on green energy. This does not seem to be a viable source, however. Firstly, the datacentre has not been built yet and recently lost one of its biggest clients (Huawei), which means the project has suffered a severe delay. Secondly, the location of the datacentre would be in Vlissingen-Oost, which is well without the 1 km radius that was determined. Therefore, it does not seem to be a viable option. (Omroep Zeeland, 2019)

7.2.7 Conclusion

Based on the scan of the vicinity of the neighbourhood, some variants can already be excluded from the study. Bio-energy will partly be excluded from the study based on the availability in the area, but mainly because of the attitude that the municipality of Vlissingen has towards it. It is not deemed renewable, has a certain stigma and is therefore not an option.

Besides bio-energy, geothermal energy will also be excluded from the study. This is completely because of the availability in the area. There are some parts of Zeeland where the ground is suitable for geothermal energy, but nowhere near the selected neighbourhood in Vlissingen. Because of this, geothermal energy is not an option.

Looking at figure 18, there are a few options that remain for this project. The full top row of the figure has been eliminated from the study, which contains all high-temperature systems, both for individual and collective solutions. The collective high-temperature solution should be in the form of residual heat, district heating, biomass or geothermal energy. Out of these options, only residual heat is an option in the form of supermarkets. This heat is at a low temperature, however, so the high-temperature heat network will not be an option.

As explained before, biomass is not an option for the stakeholders in this project. It is not deemed as renewable and partly due to its perception in society it will not be used as source. Therefore, the biomass option (top right of figure 18) is also excluded.

The full lower row of figure 18 remains an option for the project. The lower left corner of the figure shows the option of a collective heat pump using sources such as aquathermal energy, low temperature residual heat, solar thermal energy and data centres. The option of datacentres will also be excluded from the study based on its availability. At the moment there are no datacentres in Vlissingen at all, and The Green Bay will be built well outside the 1 km radius set for potential sources.

The lower right corner of the figure also remains an option. This contains the solution of individual heat pumps. This is definitely an option and does not require any specific circumstances.

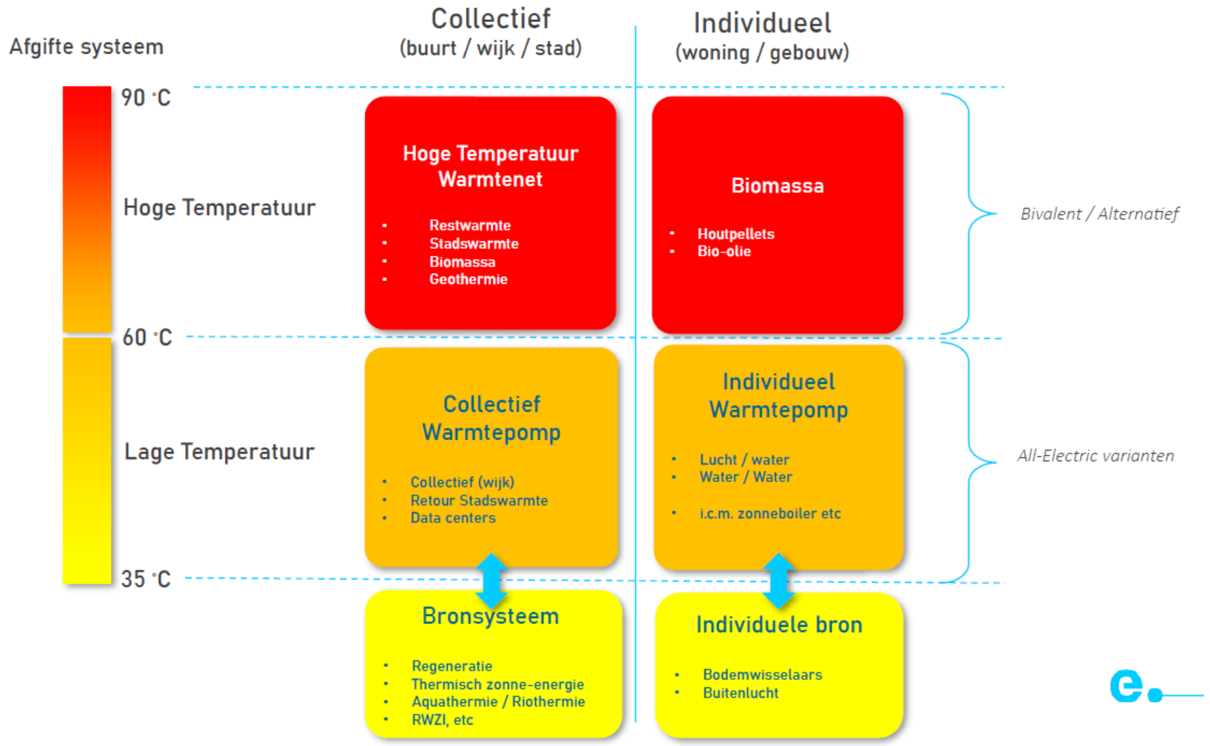

Figure 18: The four defined variants of alternative heat supply

Based on the remaining options according to figure 18, a collective heat pump solution with a low-temperature source and an individual heat pump solution are possible in the neighbourhood. For these two remaining options, the impact on the low voltage electricity grid will be simulated and a business case will be made for each of them.

7.3. Sub-question 3: Impact on electricity grid

In order to check whether or not the possible solutions require an adjustment to the local electricity grid, an analysis was done of the low voltage electricity grid in the neighbourhood. The outcome of this will show whether or not Stedin would have to invest in adjusting the electricity grid In order to make a proposed solution possible. This could also imply a solution would have to be postponed, since adjusting an electricity grid can take a lot of time.

First, the current situation of the low voltage grid is shown and analysed. Then, the scenarios of the two remaining solutions are analysed. All scenarios will be analysed on their impact on both the load on the grid and the voltage variation.

7.3.1 Current situation

In figure 19 below, the low voltage grid in the area of the neighbourhood can be seen. The red dots show all the connections of the houses and flats that belong to the selected neighbourhood of this study. The impact on the low voltage grid only handles impact related to these connections.

Figure 19: The low voltage electricity grid

In the current situation, the low voltage electricity grid in the area of the neighbourhood is not overloaded and the voltage variations are within the design specifications of Enduris. The load and voltage variation chart can be found in Appendix 3. These design specifications are still used now because the grid was built before Enduris became Stedin. The design specification prescribes a maximum of 5% of voltage variation in a low voltage electricity grid. (Enduris BV, 2021)

7.3.2 Individual heat pump scenario

In this scenario, individual heat pumps were added to the houses in the selected neighbourhood in a simulation/calculation program. For the stair case entrance flats, heat pumps with a capacity of 4 KW each were added. For all land-bound houses, heat pumps with a capacity of 7 KW were added. The charts that followed are shown in Appendix 3. Looking at the grid load, there are suddenly a lot of orange, red and even purple sections of the low voltage electricity grid. That means the capacity of the grid would not suffice, since there would be little to no room for other expansions such as solar panels or loading stations. The voltage variation will also be a problem in the case of individual heat pumps. There are a lot of blue dots on the chart for voltage variation, meaning the maximum of 5% cannot be achieved.

7.3.3 Collective heat network scenario

For the collective heat network scenario, there is no impact on the low voltage electricity grid. This solution would require one or multiple very big, industrial sized heat pumps. These kind of heat pumps cannot be connected to the low voltage grid. They would require their own central connection to the middle voltage electricity grid. Therefore the impact on the low voltage electricity grid is nothing. It would also require adjustments, however. A central connection to the middle voltage electricity grid would have to be constructed specifically for the connections of the collective heat pumps. It does not have to cause a delay for the construction of the collective heat network, but it is something to take into account.

7.3.4 Conclusion

In conclusion, the individual heat pump solution would have quite a high impact on the low voltage electricity grid and require adjustments of it. The collective heat network scenario would not impact the low voltage electricity grid at all, but would require a new central connection to the middle voltage electricity grid. This means that, whichever solution is chosen by the municipality of Vlissingen, Stedin would always have to make adjustments to their electricity infrastructure in order to be able to facilitate chosen solution. It should be noted that the analysis performed focused purely on the impact of the heat solutions. Any other elements that are likely to become relevant in the future such as loading stations for electric cars and solar panels have not been included in this analysis and should be taken into account in a future analysis if needed.

8. Business cases

After having done extensive research and narrowing down the alternatives to two solutions, business cases have been made for each of them. They show which of the solutions would be the best financially for an operator of the heat network or the heat pumps. Some highlights of the business case will be discussed and they will be compared as well. The justification and explanation of the input numbers used for both business cases can be found in Appendix 4.

8.1. Collective heat network solution

For this business case, a model was used from Expertise Centre Heat (ECW), as explained in the action plan in chapter 7. This model is very extensive and contains a lot of detailed information and phasing, but some highlights will be listed. The full, filled in business case model will be added as an appendix in a separate Excel file called 'Collective low-temperature heat network business case'. All numbers are excluding VAT.

- Total lifetime of the project is 30 years
- Total net initial investment is roughly €10 million
- Total net initial investment per connection is roughly €13.000
- Total income per connection over the full lifetime of the network is roughly €63.000
- Average yearly income per connection is roughly €2100
- Total cost of ownership is roughly €32 million
- Yearly total cost of ownership is roughly €1,1 million
- The payback period of the investment is roughly 16 years

Based on the numbers that have been used for this business case, a profitable project can actually be done. This business case used many key numbers, however, so the exact outcome should be calculated more precisely when the system is engineered in detail.

8.2. Individual heat pump solution

The business case for the individual heat pump solution was a lot less complex than the one for a collective low-temperature heat network. This solution only involves the installation of heat pumps for every house individually. In order to make a generic business case for this solution, some calculations were done. These can also be found in a separate Excel file called 'Heat pump business case'. The highlights of the business case are shown below. Again, all numbers are excluding VAT.

- Total lifetime of these heat pumps is 15 years
- Total initial investment is roughly €5,5 million
- Total initial investment per connection is roughly €8000 for land-bound houses and roughly €6000 for stair case entrance flats
- Total income per connection over the full lifetime of the network is roughly €30.000 for land-bound houses and roughly €21.000
- Average yearly income per connection for land-bound houses is roughly €2000 and for stair case entrance flats roughly €1400
- Total cost of ownership is roughly €20 million
- Yearly total cost of ownership is roughly €1,3 million
- The payback period of the investment is roughly 8 years

This solution also proves to be profitable based on the numbers used. The same goes for the other solution, however. This business case was made using key numbers, so the exact outcome should be calculated more precisely prior to executing the project.

8.3. Conclusion

Both business cases prove to pay themselves back and even make profit if done by an operator. The main differences are the height of the investment upfront, the total of the income per connection and the payback period. While the total income over the full lifetime of the project is way higher for the collective heat network solution, the payback period is much shorter for the individual heat pump solution, mainly because of the lower investment costs. For the residents, the heat pump solution is the better option. Their monthly costs would be the lowest, especially for the residents living in stair case entrance flats. For a heat network operator, the collective heat network solution would be most profitable, but it would require a far higher investments upfront, and take longer to pay back. Since the two solutions have different lifetimes, they cannot be compared on the total cost of ownership, but rather on the yearly total cost of ownership. These are very similar, but the yearly total cost of ownership is slightly lower for the collective heat network solution. The total cost of ownership contains the investment costs upfront and the operating costs during the lifetime of the project, all for the operator of either the collective heat network or the heat pumps.

9. Conclusion

This study focused on the research question: ‘Which of the four defined variants on heat supply as an alternative to natural gas is most feasible for the selected neighbourhood in Vlissingen and has the lowest total costs of ownership?’ In order to answer this research question, both qualitative and quantitative research was carried out, using multiple sub questions.

After having researched the future heat demand of the neighbourhood based on the new insulation levels after renovation (peel label B), the total heat demand of the neighbourhood turned out to be approximately 19,5 Gigajoules. This means that over a thousand tonnes of CO_2 could be saved if the new solution does not emit any CO_2.

The vicinity of the neighbourhood was studied in order to find all possible sustainable heat sources. Only sources within one kilometre from the neighbourhood were eligible. Possible sources within this radius are residual heat from supermarkets, solar thermal energy and aqua thermal energy, as well as individual heat pumps. This meant only a low temperature collective heat network solution and an individual heat pump solution still remained.

A simulation of the individual heat pump solution showed that the low voltage electricity grid would have insufficient capacity if this solution was chosen. The collective heat network solution would, however, also require adjustments to the grid of Stedin, but to its middle voltage grid. For both possible solutions, Stedin would have to make adjustments to their electricity grid.

The business cases showed that the collective heat network solution would have the highest upfront investment, highest income but also the longest payback period. The yearly total cost of ownership, however, were lower for this solution. For the residents, on the other hand, the individual heat pump solution would be the cheapest.

The most feasible variant for alternative heat supply would be the individual heat pump solution. This solution has the lowest complexity and less dependencies than the collective heat network system.

This study has shown that the individual heat pump solution is most feasible, whereas the collective heat network solution has the lowest total cost of ownership for the neighbourhood in Vlissingen.

10. Discussion

For this study, a lot of desk research was done through literature studies and case studies, and also a lot of interviews were conducted. If the study were to be repeated, the results would likely be the same, provided the same steps and research method were used. The sources used to get important information for this project are deemed reliable sources, a lot of them are government initiatives and knowledge bases. The business case model for the collective heat network is a model based on realised heat networks, making it reliable. Based on this, the results of this study are deemed to be valid.

This study has shown that the only two possible variants of alternative heat supply are a low temperature heat network and individual heat pumps. This was expected from the start. In the theoretical framework, it was already explained that the biomass solution is not deemed fully sustainable, and might not be perceived as such in society. The high temperature heat network solution was also quickly eliminated as a possible solution, since there are no high temperature sources in the vicinity of the neighbourhood. This also matched the expectations, as there were no known high temperature heat sources near.

With these results, I have shown that there are multiple possible options for alternative heat supply in the neighbourhood in Vlissingen. Besides that, I have shown that the project that the municipality of Vlissingen wants to do with the subsidy is a valid choice if the total cost of ownership is an important criteria. If the subsidy would be used for the business case, it could become more profitable.

During this study, there were quite some challenges. The availability of the right data, for example. No key numbers were found for the average heat demand based on peel labels, so this was solved in another way. It was also hard to rely on prior studies and cases, since it is a relatively new concept. Heat networks already exist, but not that many and they are different for every situation.

As foreseen, another thing that could impact the results is the fact that the proposed solutions have not been engineered to detail. This was not part of the scope. In order to provide a more reliable outcome, this should be done in the future.

The current business cases have been made based on the current electricity price, but it is very likely that this price will change in the future, definitely considering the lifetimes of the solutions. As a result of that, the business cases may turn out to be more or less profitable.

This study shows a general research on the possible alternatives for heat supply in the selected neighbourhood in Vlissingen and includes generic business cases. In a next step of the project, the considered solutions should be researched further and engineered to detail.

11. Recommendations

In order to use the results of this study, further research is recommended on several topics. Firstly, the proposed heat sources. As possible heat sources for the collective heat network solution, aqua thermal energy, residual heat from supermarkets and solar thermal energy were found within a radius of 1 kilometre of the neighbourhood. To ensure these sources could actually be used for the solution, they should be researched further. It is important to determine their exact heat potential and whether or not the owner of the heat source would be willing to supply heat and whether or not they want a fee. They should also be critically assessed on whether or not the residual heat is generated through the use of fossil fuels. The results of this research could impact the viability of the source and its business case.

Once the sources have been studied further, the technical system of the solution should be engineered to detail. This has not been done in this study, as it was out of scope. The engineering of the system should be done by an expert. Once engineered and with all technical details, the business case can be specified more. The business case of this study is based on key numbers and some assumptions. With the full details, it could be made more specific and thus more reliable.

It is also recommended that the choice of the alternative heat supply is communicated with all stakeholders, especially with housing corporation l'Escaut. For the most part, they are responsible for the renovation of the houses and getting them to peel label B. There are multiple ways to achieve peel label B, however. It is important that they take into account the chosen alternative heat supply. The form of alternative heat supply will impact the heat delivery system in the houses, and these have to be compatible.

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13. Appendices

13.1. Appendix 1: Subsidy application

Panoramabuurt: "Vlissingen op weg naar aardgasvrij"

Vlissingen staat, net als alle Nederlandse gemeenten, voor de grote maatschappelijke opgave alle woningen in de stad en naastgelegen dorpen Oost-Souburg en Ritthem aardgasvrij te maken voor 2050. De Transitievisie Warmte (TVW) is in concept gereed. Om ervaring op te doen met aardgasvrij maken van gebieden heeft Vlissingen een aanvraag ingediend voor een subsidie voor een concreet uitvoeringsproject binnen het Programma Aardgasvrije Wijken (PAW3) van het ministerie van Binnenlandse Zaken. Het projectgebied noemen we de Panoramabuurt. Deze buurt is in de Transitievisie Warmte (TVW) aangewezen als "warmtegebied". Conform de landelijke afspraken uit het Klimaatakkoord (2019) zijn inmiddels ook eerste stappen op weg naar een zogeheten Wijk Uitvoeringplan (WUP) voor de Panoramabuurt zijn gezet.

De Panoramabuurt in Vlissingen ligt in het Middengebied van Vlissingen in de CBS-wijken Hercules Segherslaan en Bloemenbuurt Oost. De contouren van dit PAW3-selectiegebied zijn gegeven in onderstaande afbeelding.

Figure 20: Panoramabuurt in Vlissingen.

Er is in Zeeland nog weinig ervaring met het aardgasvrij maken van buurten. Vlissingen wil de ervaringen die bij de aanpak in deze buurt worden opgedaan gebruiken als voorbeeld om in de toekomst ook de overige wijken in de gemeente aardgasvrij te maken. Samen met de provincie Zeeland worden die ervaringen ook met andere Zeeuwse gemeenten in het kader van het Zeeuws Energieakkoord gedeeld, en uiteraard ook binnen de community van het Programma Aardgasvrije wijken van het ministerie van Binnenlandse Zaken.

Kenmerken van de Panoramabuurt

Het PAW selectiegebied valt binnen een tweetal CBS-buurten: 'Hercules Segherslaan e.o.' en 'Bloemenlaan e.o.', valt binnen het nog grotere 'Middengebied' en wordt door ons in dit kader daarom aangeduid als “Panoramabuurt”. Het gebied is net na de Tweede Wereldoorlog gebouwd. De meeste woningen zijn uit de periode 1945 – 1960. Enkele complexen zijn recent gebouwd in de periode 1995 – 2015.

Gemeente en woningcorporatie woonservice l'escaut hebben in het kader van de uitvoering van het participatieplan voordeurgesprekken gevoerd waar bij alle woningen in het gebied is aangebeld en waaruit 144 korte interviewgesprekken volgenden. Daarin is de Panoramabuurt als volgt getypeerd:

Veel mensen wonen hun hele leven in deze buurt en vaak ook in hetzelfde huis. Hun woning is hun thuis. Ze worden er geboren en gaan er ook weer dood. Verandering is een grote uitdaging voor deze mensen die zo ontzettend gehecht zijn aan de situatie hoe het nu is. De uitdaging zit hem dan in een stukje organisatorisch vermogen, intellect, financieel, mentaal of vanwege een taalbarrière. Bij meerdere personen gaat dit gecombineerd met een fysieke beperking.

De woningen met de laagste huurprijzen zijn veelal hoogbouw. In deze woningen wonen meer dan gemiddeld mensen met druggerelateerde problemen of hebben anderszins mentale problemen. Anderen wonen er als overbrugging of als (op)start. Ook wonen hier meer anderstaligen dan elders in de wijk.

In het aangewezen gebied voor de proeftuin aardgasvrije wijk zitten grote verschillen in de belangstelling die mensen daarin hebben. Sommigen zijn oprecht geïnteresseerd, en zijn daarbij nieuwsgierig naar het vervolg in het traject. Er is ook een behoorlijke groep die er niets mee te maken wil hebben. Dat zijn over het algemeen de bewoners van de koophuizen. Ze maken zich zorgen over de financiën.

In de wijk wonen zorgmijders en mensen die onder bewindvoering staan. Zij zien vaak hun eigen problemen niet. Snappen het systeem niet en mogelijk komen ze uit niet al te sterk netwerk. De meeste mensen uit die groepen wonen in de goedkoopste huurwoningen of op een kamer bij een private verhuurder. Idealiter kan hulp ingezet worden bij uitverhuizing, waar anders nooit iemand achter de voordeur zou zijn gekomen.

Anderstaligen in grondgebonden woningen zowel in koopwoningen als huurders van l'escaut vormden een uitdaging. Deze hadden verschillende komaf en niet altijd duidelijk waar ze vandaan kwamen en spraken vaak geen Nederlands of Engels. In een enkel geval vermoeden van illegale kamerverhuur met redelijk schrijnend situatie. Hier liggen kansen voor het sociaal domein. Mensen die uitkeringen missen, maar wellicht ook in de preventie. Eenzaamheid en daarmee gezondheidsproblemen zijn hier verstopt achter voordeuren.

Indachtig bijgaand citaat van Diederik Samsom, oud-voorzitter van de Sectortafel Gebouwde Omgeving, tijdens de presentatie van het Klimaatakkoord op 28 juni 2019, is de aanpak naar een aardgasvrije Panoramabuurt is daarom een aanpak waarbij meerdere disciplines samenkomen om bewoners te helpen bij de dagelijkse mentale, fysieke en financiële problematiek. Als we dat niet aanreiken zullen veel mensen de overstap naar een aardgasvrije woning niet maken. Betrokken afdelingen binnen de gemeentelijke organisatie werken daarin intensief samen met woningcorporatie l'escaut.

> *"We staan aan de vooravond van een grote verbouwing. (…) Dit kunnen we uitvoeren, als we het gestructureerd aanpakken en alle randvoorwaarden verbeteren. (…)*
>
> *Maar vooral als we ons realiseren dat de grootste uitdaging van deze verbouwing geen technische, financiële of bestuurlijke opgave is, maar een sociale opgave. Dit gaat over mensen."*

De aanpak naar een aardgasvrije wijk wordt ook gecombineerd met de aanpak van de openbare ruimte. Door de gelijktijdige aanpak van de openbare ruimte is er een goede ingang om het gesprek ook over een aardgasvrij te voeren. Gelijktijdige herstructurering van de openbare ruimte en het warmtenet geeft synergie en kostenreductie.

Binnen het gebied onderscheiden we 6 deelgebieden. Elk deelgebied heeft een andere structuur. Eigendom van de woningen, leeftijd van de woningen en isolatiegraad verschillen per deelgebied. Zie De deelgebieden hebben een eigen karakter. Zie ook onderstaande afbeelding.

Figure 21: Zes PAW3-deelgebieden.

De verschillen zijn als volgt:

- Deelgebieden A en C.
  Deze deelgebieden bestaan uit totaal 156 woningen van l'escaut. Een deel van de woningen (59) is verkocht. De woningen zijn gebouwd kort na 1945. In deelgebied A zijn de woningen van l'escaut al nageïsoleerd. Voor alle overige woningen is dat nog niet het geval. Voor dit deelgebied geldt dat de woningen aardgasvrij ready worden gemaakt. Voorafgaand aan de verkoop van de woningen past l'escaut de woningen aan zodat ze meteen aardgasvrij ready zijn bij verkoop. De overige woningen zijn in particulier bezit. Particulieren worden benaderd met een financieel aantrekkelijk aanbod de woningen aardgasvrij ready te maken.
- Deelgebieden B en E
  Beide deelgebieden bestaan uit 509 woningen. Een groot deel gestapeld. Volledig eigendom van de woningcorporatie l'escaut. De woningen zijn kort na 1945 gebouwd en slecht geïsoleerd. De aanpak bestaat deels uit hoog niveau renovatie met aanpak van de energetische kwaliteit. Alle woningen in deze gebieden worden woonlastenneutraal aangesloten op het nieuw aan te leggen warmtenet.
- Deelgebieden D en F
  Deze deelgebieden (totaal 76 woningen) zijn van recenter datum (1995 tot 2015). De woningen zijn deels van l'escaut (24 woningen). Deze woningen worden woonlastenneutraal aardgasvrij gemaakt. De overige 52 particuliere woningen krijgen een financieel aantrekkelijk aanbod om de woning aardgasvrij ready te maken.

Per deelgebied wordt een aanpak op maat ontwikkeld. Voor de corporatiewoningen is dat het reguliere proces bij renovatie van woningen. Voor de particuliere woningen wordt een aanpak op maat ontwikkeld. In die aanpak wordt het aanbod uitgewerkt in samenspraak met de particuliere eigenaren, via zogeheten Buurttafels per deelgebied.

Het beoogd alternatief voor aardgas in de buurt is een duurzaam lokaal warmtenet. Het streven is er op gericht om een coöperatief warmtebedrijf tot stand te brengen. De warmtevoorziening is gebaseerd op duurzame bronnen zoals aquathermie, riothermie en restwarmte bij koeling van supermarkten. De warmte wordt deels opgeslagen in lokale bodembronnen. Met centraal opgestelde warmtepompen wordt de duurzame energie opgewerkt naar bruikbare temperaturen voor verwarming en warm tapwater en geleverd aan de woningen.

Voor het warmtenet is een eerste globale business case opgesteld. De voorlopige conclusie is dat het warmtenet rendabel geëxploiteerd kan worden. De business case wordt de komende maanden verder uitgewerkt.

Het aanbod voor aardgasvrij ready- en aardgasvrije woningen dat in concept is uitgedacht en verder wordt ontwikkeld in de Buurttafels zal leiden tot een verbetering van de woonkosten voor alle bewoners in het gebied. De integrale PAW3-business case wijst uit dat dit mogelijk is. Met de betrokken samenwerkingspartners en bewoners gaan we daarover verder in gesprek.

Het communicatie en participatietraject is al tijdens het opstellen van de PAW3-subsidieaanvraag gestart en loopt door in de tussenfase tot de toekenning van de subsidie (naar verwachting uiterlijk eind maart 2022). Daarna wordt het concrete uitvoeringstraject gedurende de hele projectperiode tot en met 2030 voortgezet. Per deelgebied wordt een afzonderlijke aanpak ontwikkeld die afhankelijk is van de sociaal-maatschappelijke en technisch-inhoudelijke karakteristieken van het betreffende deelgebied en de integraal afgestemde plannen in de openbare ruimte.

Gemeente Vlissingen en l’escaut trekken gedurende de gehele projectperiode intensief samen op in de communicatie en participatie. De gemeente is hierbij overkoepelend coördinator van de gezamenlijke communicatie-, participatie- en renovatieactiviteiten. Ook ondersteunt zij de betrokken partijen bij hun individuele bijdragen en borgt dat partijen gezamenlijk en tijdig tot de beoogde resultaten komen.

Op weg naar een aardgasvrij selectiegebied is met woningcorporatie l’escaut een gezamenlijk projectteam gevormd onder leiding van een gemeentelijk projectleider. Ook gaat speciale aandacht uit naar de gezamenlijke communicatie en participatiewerkgroep. Als artikel 12 gemeente Vlissingen is inmiddels veel kennis opgedaan over een integrale aanpak gericht op toekomstbestendige wijken. Meekoppelkansen worden verankerd via bijvoorbeeld de digitale projectenkaart van het Afstemmingsoverleg Zeeuwse Overheden & Nutsbedrijven (AZON) en de geïmplementeerde lessen vanuit het VNG-ondersteuningsprogramma voor klimaatadaptatie.

Er is bovendien periodiek strategisch bestuurlijk afstemmingsoverleg tussen de bestuurlijk opdrachtgever en de directeur-bestuurder van l’escaut. Ook de stuurgroep Wind in de Zeilen informeren we periodiek over de voortgang.

De bewoners (zowel huur als koop) hebben inmiddels ook al zitting genomen in het overkoepelende Buurtpanel. Hierbij worden, met behulp van een onafhankelijk voorzitter, kansrijke thematische meekoppelkansen geïdentificeerd en operationeel verbonden op weg naar een aardgasvrije Panoramabuurt. Tijdens de uitvoeringsfase worden zij via de diverse Buurttafels betrokken bij de duurzame woningrenovatie in hun deel van het selectiegebied.

13.2. Appendix 2: Milestone planning

To ensure all deadlines of this study will be met and progress can be tracked, a milestone planning has been made. This has been done using a Gantt chart, which is displayed in figure 22 below. For each deliverable/milestone, a start and end date has been defined. If this planning is maintained, no delays should occur.

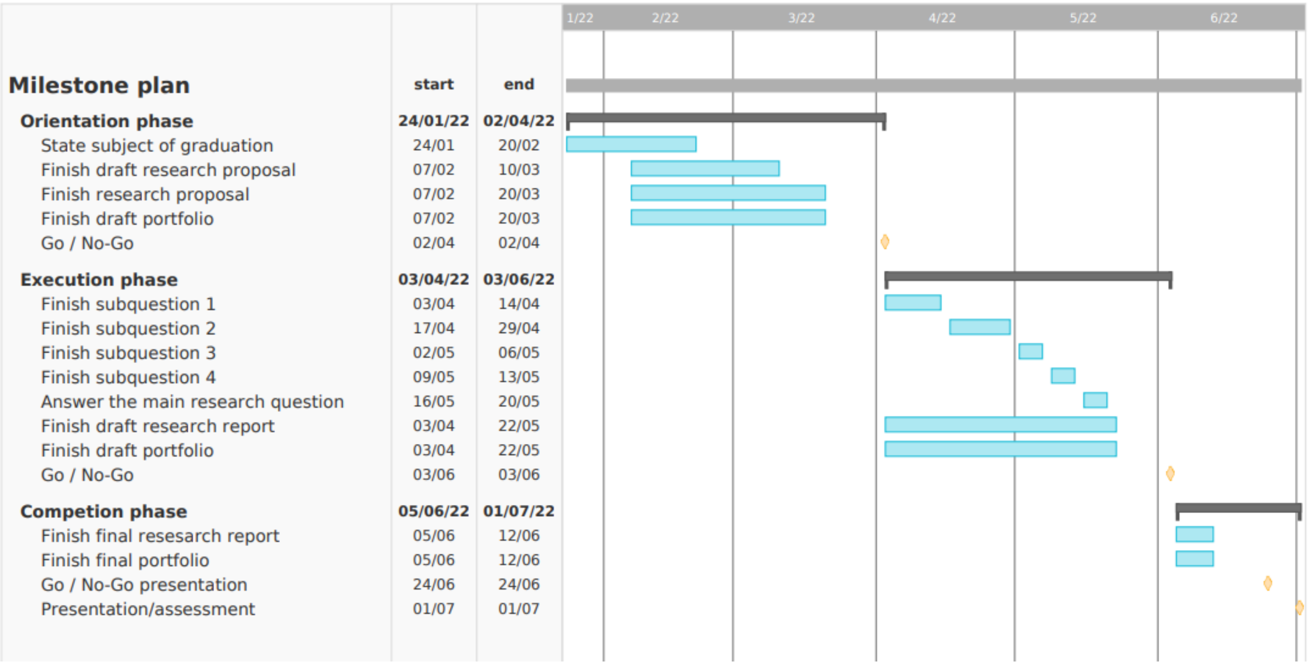

Figure 22: Milestone planning

13.3. Appendix 3: Low voltage grid impact analysis

13.3.1 Current situation

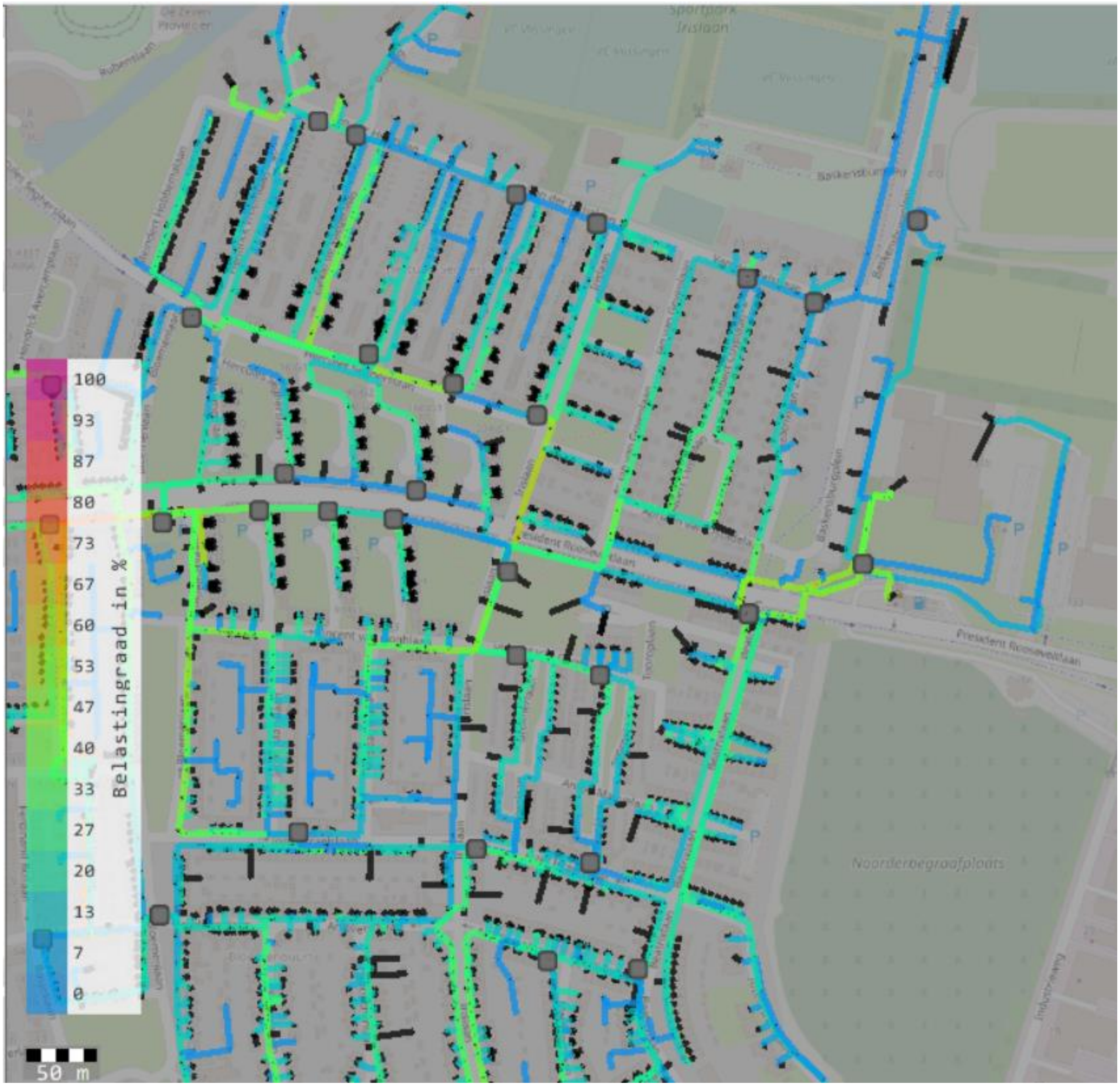

Figure 23: Current grid load

Figure 24: Current grid voltage variation

13.3.2 Individual heat pump scenario

Figure 25: Grid load with individual heat pumps

Figure 26: Voltage variation with individual heat pumps

13.4. Appendix 4: Business case input justification

13.4.1 Collective heat network solution

A lot of the numbers and percentages used in the model of the business case were already there and are key numbers provided by the Expertise Centre Heat. In the columns to the right of the input columns, these standard/key numbers are shown, including their source. A lot of these key numbers were used, but the input numbers that were changed are listed below.

- Calculating with the EIA (Energie Investerings Aftrek). Input: no.
  The decision was made not to calculate with the subsidy for investments in sustainable practices. It is not sure whether or not this project would be eligible for that, since it already has a subsidy.
- The lengths of the network. Input: 0,65 km main distribution tracing, 0,25 km primary net, 5 km secondary net.
  These distances were measured using Google Maps and otherwise calculated based on the rules of thumbs which are shown in the columns next to the input columns.
- Calculating with a project return. Input: yes, 6%.
  The decision was made to calculate with a project return, as this is normal for projects like this. Operators want to earn money as well. The return of 6% was retrieved from Marcel Brand from NetVerder.
- The kostendekkingsbijdrage (cost recovery contribution).
  This is the amount that participating residents have to pay in order to get connected to the network. This amount is calculated by the model based on my input so far.
- The number of sub stations. Input: 1 and 3.
  This number was retrieved from Marcel Brand from NetVerder.
- Costs of heat meters for all kinds of houses. Input: €300 and €1000.
  These numbers were retrieved from Marcel Brand from NetVerder.
- Costs for building of heat storage. Input: €800.000.
  This number was retrieved from Duratherm. Based on the amount of houses, this would be the rough estimate for the costs for a heat storage (closed system).
- Buying prices for heat. Input: €12 and €16.
  These numbers were retrieved from a case study with a similar heat network. (Warming Up, 2021)
- Connection capacities of ground-bound and stair case entrance houses. Input: 7 kW and 4 kW
  These numbers were calculated based on the acreages of the houses and a table. (Warmtepompinfo, n.d.)
- (Now moving to tab 'Aantallen & Fasering) Timing, the starting year and lifetime. Input: 2030 and 30 years.
  The starting year was retrieved from a conversation with the municipality of Vlissingen and the lifetime of 30 years was retrieved from Marcel Brand from NetVerder.
- The numbers of connections. Input: 111, 332 and 298.
  These numbers were retrieved from the subsidy application, see Appendix 1.

Together with an expert in the form of Marcel Brand from NetVerder, the key numbers that were already in the business case model were checked and validated. They matched with his experience.

13.4.2 Individual heat pump solution

A lot of the numbers used for this calculation are similar to those of the collective heat network business case, but of course other numbers were used. The input numbers used are listed below.

- Capex
  This is the investment cost of a heat pump, 7 kW for a ground-bound house and 4 kW for a stair case entrance flats. The capacities were calculated using a table. (Warmtepompinfo, n.d.) The capex was taken from the website of Saman, which is a supplier and installer of heat pumps in the area. The capex is the price including installation excluding VAT. (Saman Groep, n.d.)
- Depreciation term
  The depreciation term of 15 years is how long heat pumps usually last. (Daikin, n.d.)
- Return
  For the return, the same percentage of 6% was used as for the business case of the collective heat network, to keep it fair. This number can turn out to be lower, however. The reason for this is that the risk for the investor/operator is way lower for this solution due to its lesser complexity and dependencies.
- KW (thermic)
  The capacity required for the 2 house types in this business case was calculated for the capex as well.
- kWh/m2 (thermic)
  This is the average heat required per square metre, taken from the report that I used for the total heat demand calculation as well. (Nieman Raadgevende Ingenieurs BV, 2021)
- Maintenance
  A percentage from the capex of 5% was used as maintenance costs, similar to maintenance costs percentages from the business case model for the collective heat network.
- SCOP
  An average Seasonal Coefficient Of Performance of 3 was used. In practice, this seems to be a reasonable number in the Netherlands. This number was decided on in consultation with my supervisors.
- Acreage
  For this, an average acreage for the house types were taken from the BAG maps.
- Yearly use in kWh
  These are the yearly costs for running the heat pump based on acreage, heat required per square metre and the current electricity price.
- Number of houses
  This number was retrieved from the subsidy application, see Appendix 1.
- Electricity price
  This is the current average electricity price excluding VAT. (Overstappen, 2022)

13.5. Appendix 5: Neighbourhood impression

Figure 27: Flats in the neighbourhood

Figure 28: Mid-terraced houses with solar panels in the neighbourhood

Figure 29: Mid-terraced houses in the neighbourhood