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Phasing Out Natural Gas

“Comparing cost-effective sustainable heating alternatives for both urban and rural areas in the Netherlands.”

Finding out which technologies are feasible in rural areas and which options are better suitable for densely populated cities

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Preface

In a world that is constantly moving and thriving, adaptations have to be made. Adaptations to the way we live, transport and also how we make use of fossil fuels. Environments are changing and the way we cooperate with it as well. This document represents the master thesis for the Master of Environmental Energy Management (MEEM) at the university of Twente. This research aims to give an insight in cost-effective sustainable residential heating concepts for urban and rural parts of the Netherlands.

Before you lies the thesis “Phasing out natural gas – comparing cost-effective sustainable heating alternatives for both urban and rural parts of the Netherlands.”

This thesis has been written to fulfil the graduation requirements of the master’s program Environmental Energy Management at the university of Twente. I was engaged in writing this thesis from May till August 2020, in the academic year 2019-2020.

I myself came up with the research subject and formulated my research questions in accordance with my thesis supervisor, M.J. Arentsen. I would like to thank supervisors and professors at the university of Twente for their willingness to dissertate about topics and discuss different viewpoints. To my fellow students, I would like to thank you all for your cooperation and willingness to give a helping hand when needed.

I hope you enjoy reading this master thesis.

Ivo ter Avest

Enschede, August 21, 2020

Abstract

By the year 2050 around 6 million houses must be transformed to sustainable housing (natural gas free), starting with 100.000 homes before 2022. After 2022, annually 100.000 homes must be disconnected from the gas infrastructure. This research aims to cover the most cost-effective sustainable residential heating alternatives for residents living in urban and rural parts of the Netherlands. Specifically, it focusses on the suitability of sustainable residential heating under specific characteristics of the area. In this context, cost-effective sustainable residential heating is defined as a system which has the ability to provide the requested amount of heat without the usage of fossil fuels and at a fair rate (comparable to using natural gas).

To find out what sustainable heating alternatives are viable under certain area specific circumstances, a literature study was carried out. First the necessity for sustainable residential heating in the Netherlands was researched. Here it was found that residential heating plays a major role in phasing out the usage of natural gas. Over 38% of all the natural gas used in the Netherlands is used for heating, making sustainable heating an important factor in becoming a sustainable country.

The characteristics of rural and urban areas, and how they affect the suitability of a heating system, were mapped using the information from the municipality of Achtkarspelen and Amsterdam. In order to calculate the costs, charged prices (Dutch companies) were used. The costs of the different heating systems were then brought in relation to the area characteristics and their feasibility.

This research has shown that the heat demand, house density, size of residential buildings and the availability of geothermal heat have a great effect on the price and suitability of a system in rural and urban areas. It shows that if geothermal heat is available, that heat networks are viable in urban areas, but less suitable for rural areas. The research shows that besides a heat network biogas, infra-red panels and hydrogen are the most cost-effective alternatives to natural gas. It is found that these systems demand the least upfront costs, and function with a lower annual cost as compared to other alternatives.

Abbreviation list

GHG	Greenhouse Gasses
NECP	National Energy Climate Policy
COP21	Climate Conference 2021
SER	Economic and Social Council
NGO	Non-Governmental Organisation
CBS	Central Plan Bureau of the Netherlands (statistics about the Netherlands)
Mton	Megatons (1000 million kilogrammes)
kWh	Kilowatt-hour (1 kilowatt per hour)
Pj	Petajoule (10^{15} joule)
NAM	The Dutch oil company
Bcm	Billion cubic metres
AD	Anaerobic Digestion
TES	Thermal Energy Storage
DHW	Domestic Hot Water
CHPDH	Combined heat and power heating district
SWH	Solar Water Heating

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CHAPTER 1. THE INTRODUCTION

1.1. Background

Upcoming decades almost everybody will have to make adaptations to their homes in order to adhere to the rules as agreed upon. The Netherlands is currently busy with a national energy transition, which means that the Netherlands wants to switch from non-renewable to renewable sources.

This national goal will also affect residents, this because currently over six million houses are still connected to the gas infrastructure in the Netherlands. This research focusses on the feasibility and cost-effectiveness of sustainable heating (eliminating fossil fuels) for both rural and urbanized areas in the Netherlands. In paragraph 1.1.1, the energy transition on a national level is explained, focussing on measures which affect residential heating. Secondly, the energy transition on a community level in the Netherlands is discussed in paragraph 1.1.2. In paragraph 1.1.3 the differences between rural and urbanized areas in relation to phasing out natural gas are stated. In chapter 1.1.4 the knowledge gap, covered in this thesis, is outlined.

1.1.1. Transition on a national level - residential heating

The climate is changing globally, this is also the case in the Netherlands. Average temperatures have risen in the last decade and the intensity and the amount of rain has increased. Summers are becoming warmer and winters less cold. Overall, the weather has become more unpredictable and extreme (National Institute for Public Health, 2020).

In order to prevent further global warming, together with the negative side effects that come with it, the climate agreements of Paris were called into life in 2015. In order to adhere to these set rules, the Netherlands must shift from fossil fuels to renewable energy sources. These sustainable energy sources (renewables) consist of for instance solar and geothermal energy. The draft climate agreement covers all the measures and rules which were agreed upon by the European Union's member states. The end goal of this agreement (Paris agreement 2015) is to reduce the emission of greenhouse gasses (GHG) with 49% by the year 2030, and to further reduce it with 95-100% by the year 2050 (as compared to 1990) (National Institute for Public Health, 2020).

The measures which are introduced are there to reduce the emissions of greenhouse gasses, these reductions at their turn result in better health, safety and preservation of nature (National Institute for Public Health, 2020).

In order to reach the set goals a lot must change in the Netherlands, in almost any sector adaptations must be made. Table 1.1 shows the goals, focussing on buildings & heat.

Sector	Goals	Measures
Buildings & Heat	*The built environment must be completely Co2 neutral by 2050.* *Improve the environment inside buildings.* *Improving health by improving the overall living environment.*	*6.6 million homes must be converted to become Co2 neutral* ▪ *Eliminating gas use* ▪ *Sustainable heating* ▪ *Sustainable electricity* ▪ *Increase geothermal* ▪ *Eliminate woodstoves* ▪ *Electrification*

Ch. 1, Table 1.1: Measures to achieve national goals (National Institute for Public Health, 2020)

As stated, this research focusses on buildings and heat, in particular on phasing out the use of natural gas. The Dutch government feels the need to phase out the use of natural gas in order to adhere to the transition agreements, and because of the need for an early foreclosure of the gas fields in the Groningen. The two reasons for the Dutch government to phase out the use of natural gas is further explained in chapter two, necessity for a change.

Switching from natural gas to sustainable residential heating alternatives has a positive impact on the emission of greenhouse gasses (GHG). If one household switches from natural gas to sustainable alternatives, the emission of five tonnes of Co2 is prevented annually. Five tonnes of Co2 is the equivalent of what 250 trees need annually to grow (absorption of Co2) (Scitech Europe, 2019).

1.1.2. Heating without natural gas, rural vs. urban

The Netherlands is phasing out the use of natural gas step by step, in practise it will probably take several decades before the Netherlands is completely transitioned to renewable sources (van het Hof, 2018). Currently the Dutch are in the first phase of the transition, this means that natural gas is still widely used for heating, hot water and cooking, but they are at the start of converting to alternatives (Enexis, 2020).

Getting rid of natural gas is not something that is done alone, usually the municipality comes into play when collective plans have to be made. Municipalities research sustainable alternatives for certain neighbourhoods and start the transition by implementing the best option. However, for people that live in less densely populated areas, this is not always the case (Enexis, 2020).

In urban areas there are numerous collective options when it comes to renewable gas alternatives. An example in this case is district heating, this system uses geothermal heat to provide heating to multiple houses. When it comes to switching from gas to a renewable source, the decision for people that live in urban areas seems simple, join the collective option. However, a significant amount of households will not be able to connect to these so called collectively arranged gas alternatives, for them individual renewable sources are the better option (Pols, 2019).

When it comes to individual options a lot of different technologies are available, more remote households could in this case for instance choose for a heat pump. This system uses heat from the air, the ground surface, or a pond. The heat pump system is quite a popular alternative, but it not yet widely adopted (Pols, 2019).

1.1.3. Knowledge gap

As stated in the preceding paragraphs, multiple options for both residents living in rural and urban areas are available, but which option is the best under what conditions? Different areas ask for different approaches, more individual approaches. This research seeks to find out what option, or what combination of options, is most suitable in the Netherlands in the rural areas and the urban areas. Focussing on the ability of systems to sustainably provide an adequate amount of heat, at a fair rate, for different circumstances.

1.2. Problem statement

In order to achieve the 49% greenhouse gas emission reduction by the year 2030 an average of two to three billion Euros per year is needed in the Netherlands alone (Planbureau voor leefomgeving, 2018). Citizens have a big share in the ability to achieve the goal of a 49% greenhouse gas reduction as well. An example of the above is that for every house that becomes gasless, five tonnes of Co2 reduction is realised (Scitech Europe, 2019).

In the trend of developing residential heating without natural gas, the Dutch citizens participate in a moderate way, this has to improve (CBS, de Wit, & Schmeets, 2018). Since 2018 new buildings and housing are no longer connected to the gas network, in the upcoming years 30 to 50.000 buildings a year must become free of natural gas. For a fact it is known that 30% of the total greenhouse gas emissions in the Netherlands comes from buildings, hence why this is one of the main focal points of this report (National Institute for Public Health, 2020).

By the year 2050 around 6 million houses must be transformed to sustainable housing (natural gas free), starting with 100.000 homes before 2022. After 2022, annually 100.000 homes must be disconnected from the gas infrastructure, this is a humongous and cost intensive task (CObouw, 2019).

What the costs are, and what options households in the Netherlands have, is quite uncertain. Hence why this research focusses on the options for residential heating alternatives for Dutch residents, making a clear distinction between rural and urban areas.

Sustainable heating alternatives for residential heating are numerous, but which one is suitable in what environment? The list below, shown in table 1.2, states the current available technologies for residential heating in the Netherlands.

1. Heat pump
2. Heat networks
3. Biogas
4. Geothermal heating
5. Thermal energy storage
6. Pellet stove
7. Electrical boiler
8. Infrared panels
9. Solar boilers
10. Hydrogen

Ch. 1. Table 1.2: List of sustainable heating alternatives (CObouw, 2019)

1.3. Research objective & goal

The objective of this research is to analyse the feasibility of different sustainable alternatives for natural gas in residential heating in rural and urban areas in the Netherlands. Which sustainable heating alternatives have the biggest impact on greenhouse gas (GHG) emissions reduction in a cost-effective way and in what environment are they most suitable? This research seeks to find suitable alternatives for natural gas in rural and urbanized areas in the Netherlands and seeks to give an insight in which sustainable concept is the best in terms of cost and GHG emissions reduction without doing concessions in heat capacity.

This research describes the impact on the micro level and their influence in achieving political and environmental goals in a cost-effective manner. This to give a recommendation to Dutch residents, on a household level, to steadily contribute to the energy transition. This research will contribute to the knowledge on cost-effective alternatives for households to sustain their residential heat needs in urban and rural areas in the Netherlands.

Research questions

In this paragraph, the research questions and sub-questions of this research are stated. The main research question and the sub-questions are stated below.

"What are currently (2020) cost-effective and sustainable natural gas-free residential heating alternatives for households in urban and rural parts of the Netherlands?"

Sub-questions

What are sustainable alternatives for natural gas based residential heating?

How do the sustainable alternatives match the specific circumstances/conditions in rural and urban environments?

Which of the sustainable alternatives is most cost effective for individual households and urban environments?

1.4. Research Method

This thesis relies on one research methods, namely a literature review. The literature review research method is in the first case chosen in order to find out what has and has not yet been investigated in the past. Doing so resulted in the finding that very little is written about the distinction between rural and urban environments in relation to phasing out natural gas for residential heating in the Netherlands.

Besides the ability to see what has and has not yet been investigated literature reviewing makes it possible to identify data sources that researchers in the past have used for studies that have interfaces with this study. The literature review method is further used to define key concepts and to put this research in perspective. In terms of reliability and validation, literature review provides the opportunity to critically evaluate findings and can provide evidence to support own findings (University of North Carolina, n.d.).

In this thesis two example municipalities are used in order to compare densely populated areas of the Netherlands with less densely populated areas. Making this distinction, using information from the Municipality of Achtkarspelen (sparsely populated area) and the municipality of Amsterdam (densely populated), insights for this research were provided. The municipality of Achtkarspelen was chosen because of the low address density (427/km2), as compared to 6057/km2 in the municipality of Amsterdam. Other reasons to compare the two municipalities are that buildings in both municipalities are mainly built well before the year 2000 (Achtkarspelen 90% and Amsterdam 85%), and that Achtkarspelen has a large percentage of single-family homes as compared to Amsterdam (88% vs. 12%) (Municipality of Achtkarspelen, 2011) (National Bureau of Statistics, 2006). Information from these two municipalities made it possible to make variations in terms approaches. It allows for both quantitative and qualitative analysis of the data. Besides, the information from these two municipalities make it possible to explore and describe data in real-life environments. See appendices A1 & A2.

1.5. Reading guide

This thesis is structured as follows. In chapter one the problem in introduced, together with some background information, the problem statement, research objective, research questions and the used strategy, design, and methodology. In chapter two the two main reasons to phase out natural gas in the Netherlands are discussed. Namely, the Dutch energy transition, and the foreclosure of the onshore gas fields in Groningen. In chapter three the available sustainable alternatives for natural gas based residential heating are explored and briefly described. In chapter four the sustainable residential heating alternatives are matched with the specific circumstances and conditions in rural and urban environment. In chapter five a financial analysis of the sustainable residential heating alternatives on an individual household level can be found. In the last chapter, chapter six, the most cost-effective sustainable residential heating alternatives for rural and urban environments in the Netherlands are recommended.

CHAPTER 2. NECESSITY FOR CHANGE

Chapter two, necessity for a change, gives an insight in the two main reasons why phasing out the use of natural gas for residential heating is considered necessary in the Netherlands. The most important, decisions, agreements and documents which relate to these two reasons are stated.

This chapter particularly focusses on the impact of sustainable residential heating and the use of natural gas. Paragraph 2.1 highlights the necessity for change in terms of the energy transition and the corresponding agreements. Paragraph 2.2 focusses on phasing out the use of natural gas in relation to the foreclosure of the onshore gas fields in Groningen.

2.1. The energy transition in relation to sustainable residential heating

In chapter one, the introduction, the general energy transition in the Netherlands is briefly described. Below, in paragraph 2.1.1 the current status of the energy transition, in relation to sustainable residential heating is described. In paragraph 2.1.2 the energy transition and the most important documents/agreements and their relation to residential heating are explained.

2.1.1. Current status energy transition and the use of natural gas for heating

The Dutch government constantly seeks for affordable and feasible measures in order to reduce carbon emissions. These measures contribute to a cost-efficient transition and try to limit the financial impact on households as much as possible (Ministry of Economic Affairs and Climate Policy, 2019).

An example of this step by step approach is that since the first of July 2018 new buildings are prohibited to be connected to the natural gas network. Sine 2018 approximately 30 to 50.000 existing homes must be disconnected from the natural gas infrastructure. The government demands alternative sources for heating and cooking in these new and existing homes (CObouw, 2019).

However, natural gas is still one of the biggest energy users, approximately 38% of the energy used goes to heating, cooling accounts for approximately 2.4% of the energy use. (National Service for Entrepreneurial Netherlands, 2016).

Earlier it was stated that 38% of the energy is used for heating purposes. In the Netherlands annually 3493 PJ of energy, coming from oil, is used for the production of electricity, heat, plastics or is used as fuel for transportation. The grand total of 1324 PJ, 38% of the total, is used for heating alone, making it the biggest use of energy in the Netherlands. From the grand total of 1324 PJ, 388 PJ is annually used in domestic buildings for heating alone, making it a significant gas user (National Service for Entrepreneurial Netherlands, 2016).

2.1.2. The Paris agreement of 2015 – Residential heating

The Paris agreement of 2015 was one of the causes that set motion to the energy transition. For the Netherlands this means transitioning the energy systems from fossil fuelled to sustainable systems and it incentivised the Dutch government to form a national energy and climate plan (NECP) (Netherlands Environmental Assessment Agency, 2020).

Following the agreement in limiting GHG reduction, the Netherlands has started to decarbonise home heating. One of the agreements made is that the tax on natural gas will rise by the end of 2020, and that the tax on electricity will lower by the end of 2021. Besides tax reduction the Paris agreements discusses subsidies. These subsidies are called into life to for instance insulate building which are built before 1995, or provide the option to switch to an alternate heating source (The Dutch Cabinet - Ministry of Economic Affairs and Climate, 2019).

In line with the subsidies a heat fund was agreed upon, this fund is introduced to help finance residents which are unable to make investments in sustainable heating alternatives. The fund resembles a loan with a low interest rate and a long duration. This fund gives residents the ability to invest in sustainable heating, and even makes it possible to pass the fund on to future residents after selling the premise (The Dutch Cabinet - Ministry of Economic Affairs and Climate, 2019).

The Paris agreement covers residential heating in the Netherlands as well, it states that to achieve the climate goals the Netherlands must disconnect 50.000 existing domestic buildings from the natural gas infrastructure annually by 2021. By the year 2030 over 200.000 buildings must be disconnected from natural gas annually. The goal is to reduce carbon emissions with 3.4 Mton by the year 2030 (compared to the reference year 1990) (The Dutch Cabinet - Ministry of Economic Affairs and Climate, 2019).

2.1.3. National Energy & Climate agreement – Residential heating

Until the year 2013 the role of natural gas in Dutch energy systems was rarely questioned in neither political nor climate energy debates. The availability of gas, the gas infrastructure and the large Dutch gas sector was long seen as a blessing. However, critics pointed out that this way of thinking could also be the cause of the rather slowly increasing share of renewable energy.

Critics claimed that the existence of a large gas infrastructure and gas sector resulted in the fact that the Dutch, as compared to for instance Germany, still have a small share in renewable resources. Typical for this way of thinking was the first energy accord, as presented in September 2013. This accord was presented by the Social and Economic Council of the Netherlands (SER) (The Oxford institute for energy studies, 2019).

The accord took a total of nine months of negotiations between approximately 40 NGOs, authorities, business representatives and the energy industry. These were asked by the Dutch government to show how the Netherlands could increase renewable energy shares and how they could accomplish energy savings. Although the Dutch energy accord was one of the key policy documents, which still functions as the basis of the Dutch energy policy regime for renewable energy, it had very little to say about natural gas (The Oxford institute for energy studies, 2019).

By 2017, the way of thinking in terms of the Dutch gas sector had changed drastically. In 2017 a four-party coalition was formed, which presented a coalition agreement, that outlined government policies. This agreement contained targets and ambitions considering climate, especially devoting attention to natural gas as well. In this agreement the GHG reduction target of 49% was first announced. It also announced that the government will initiate the creation of a national Climate and Energy Accord. This amount was divided over the different sectors, the coalition agreement does not spell out the implications for natural gas of the emission reduction targets, but it does specify a number of measures that will be taken to reduce gas consumption and production (The Oxford institute for energy studies, 2019).

The final energy agreement followed the original Energy Agreement that was realised in 2013. This energy agreement was called into life to work towards a climate-neutral society with a safe, reliable affordable and low-carbon energy supply by the year 2050 (Ministry of Economic Affairs and Climate, 2019).

The NECP agreements are sector specific. In this thesis the covered sector is the built environment of the Netherlands (domestic). In these agreements it is claimed that 7 million homes, which are connected to the natural gas infrastructure, have to be disconnected from natural gas by 2050. Residential heating, using a natural gas alternative, is principally precipitated by climate change. However, another reason is that the Dutch government wants to cease the extraction of natural gas in Groningen and want to provide a more comfortable home to their residents (Ministry of Economic Affairs and Climate Policy, 2019).

When it comes to financing and funding the sustainability improvements in residential homes it is agreed upon to offer prospects accessible and responsible funding options. A part of the costs can potentially be recouped through lower energy bills. In addition, the Dutch government will draw up a provision which makes it possible for residential homeowners to transfer funding through building related financing (Ministry of Economic Affairs and Climate Policy, 2019).

2.2. The foreclosure of onshore gas fields – Residential heating

Production of natural gas has resulted in earthquakes since 1991. These earthquakes have over the last couple of years increased in magnitude and number. In 2012, near Huizinge, the largest earthquake thus far was measured. This earthquake had a magnitude of 3.6 (Richter scale) and was a turning point for the Dutch public. Groningen is encountering an increase in resistance from the public. People, who live in the area, have great difficulty with receiving compensation for damages caused by the onshore gas production. Households, located in the affected areas, received widespread sympathy from residents in the Netherlands. Not long-ago policymakers started to acknowledge that safety and environmental aspects outweigh the financial and economic aspects (The Oxford institute for energy studies, 2019).

Together with safety concerns, concerns over the climate change induced earthquakes in Groningen changed drastically between 2012-2018 as well. Both factors lead to a shift in policy focus. Shifting from economic and financial to environmental and safety concerns. As stated, the newly elected coalition adopted GHG reduction targets, implying that natural gas extraction must cease by 2050. In March 2018, the Dutch government announced that the biggest gas production field in Groningen will be phased out as quickly as possible. For over 50 years this gas field was the mainstay of gas production in the Netherlands, but it is promised to be phased out by 2030 (The Oxford institute for energy studies, 2019).

In June 2018, a new mining law was published, this law gives the Dutch government the ability to have unilateral control over the gas production in Groningen. Before this law, the Dutch government had to consult the NAM about the to be taken measures (The Oxford institute for energy studies, 2019).

The minister of economic affairs of the Netherlands, Eric Wiebes informed the parliament on the 3rd of December in 2018 that the gas phase-out in Groningen was proceeding as planned. The expectations are that the gas production in Groningen will be less than five Bcm by the year 2023. However, it should be noted that a shift from production to import is visible since the measures were implemented. Showing the trend of switching from Groningen gas to imported Russian gas, rather than decreasing the gas consumption (The Oxford institute for energy studies, 2019).

2.3. Conclusion necessity for a change

Phasing out natural gas for residential heating is considered necessary because of two reasons. Namely, the political agreements upon the foreclosure of the onshore gas fields in Groningen and the global energy transition which also affects the Netherlands.

Residential heating plays a substantial role in the usage of natural gas in the Netherlands. Approximately 38% of all the natural gas used in the Netherlands is used for residential heating. Since 2018 approximately 30-50000 residential buildings are disconnected from the natural gas infrastructure in order to make a start in phasing out the usage of natural gas (National Service for Entrepreneurial Netherlands, 2016).

In 2015 the Paris agreements was introduced, recently the Dutch government agreed upon the goals stated in this agreement as well. The Dutch government, together with the contributions of the citizens in the Netherlands, want to reduce the GHG emissions. The target is set to a reduction of 3.4 Mton by the year 2030 (as compared to 1990 values) (The Dutch Cabinet - Ministry of Economic Affairs and Climate, 2019).

In order to adhere to the goals of the energy agreements in the Netherlands and the Paris agreements it is necessary that the way the Dutch citizens heat their homes changes. In order to adhere and achieve these goals it is necessary that residential heating in the Netherlands must gradually become sustainable (fossil fuel free). This means that the usage of natural gas for residential heating must be lessened and gradually phased out in the upcoming years.

In the Netherlands, the availability and usage of natural gas was long seen as a blessing. However, by the year 2017 this vision changed. The Dutch cabinet, the four-party coalition and approximately 40 NGO's worked together on a plan to reduce GHG emissions by lessening the usage of natural gas in the Netherlands. The realisation that the usage of natural gas in the Netherlands for heating and cooking should be lessened gained even more momentum among Dutch citizens because of regional earthquake problems in Groningen. Production of natural gas has resulted in earthquakes since 1991. These earthquakes have over the last couple of years increased in magnitude and number. Together with safety concerns, concerns over the climate change induced earthquakes in Groningen changed drastically. Both factors lead to a shift in policy focus. Shifting from economic and financial to environmental and safety concerns (The Oxford institute for energy studies, 2019).

In the last energy agreement, the Dutch government agreed upon the fact that they, as a nation, want to become a climate-neutral society by the year 2050. The aim to become climate-neutral mainly includes a change in the usage of fossil fuels. Implementing sustainable natural gas free residential heating alternatives in the homes of Dutch citizens can be a contributing factor in this case (Ministry of Economic Affairs and Climate, 2019).

By completely changing residential heating from natural gas-based heating to sustainable natural gas free residential heating alternatives, it is possible to annually eliminate 388 PJ of energy (produced using gas). This because in the Netherlands 1324 PJ, 38% of the total, is used for heating alone, making it the biggest use of energy in the Netherlands. From the grand total of 1324 PJ, 388 PJ is annually used in domestic buildings for heating alone (National Service for Entrepreneurial Netherlands, 2016).

CHAPTER 3. SUSTAINABLE ALTERNATIVES FOR NATURAL GAS BASED RESIDENTIAL HEATING

Chapter three, sustainable alternatives for natural gas based residential heating, gives an insight in the currently available heating alternatives. In this chapter, paragraph 3.1, a distinction is made between collective and individual alternative residential heating concepts. This distinction is particularly of interest because it serves as a starting point for what is suitable for rural and urban environments. In paragraph 3.2 and 3.3, the working mechanisms of the sustainable heating alternatives are structurally described, explaining the different techniques, energy sources and energy carriers.

Chapter three answers the first sub-question of this research, which is as follows:

“What are sustainable alternatives for natural gas based residential heating?”

3.1. Distinction collective and individual sustainable heating concepts

When it comes to sustainable residential heating without the use of natural gas there are practically two options, collective or individual solutions. Individual systems are systems which use individual heat sources per building. An example of an individual system is a heat pump, which can in this case be installed as a heat source for one singe house. Collective systems rely on a heat source which provides heat to more than one building, this heat source is located elsewhere outside the property of the residents. Most of the time collective heating systems are implemented in apartment blocks. However, it is also possible to connect multiple detached or semi-detached houses to a collective heat system (Andrews, 2009).

For collective heating there are two possibilities, block heating and district heating. Collective heating systems can in some cases save energy. Whether this happens depends on the energetic properties of the source, the produced temperature, and the quality/length of the distribution network. Another advantage of a collective system is that connected households use a lower capacity as compared to individual systems. Individual systems use approximately 10 to 20 Kw (regular boiler) whereas collective system users only need a capacity between 3 to 6 Kw. This because of the inconsistency in the use of a collective system. This means that during peak hours the peak demand can be smeared out over multiple households (Andrews, 2009).

According to the Dutch central bureau of statistics (CBS), approximately 6.6% of the houses in the Netherlands are connected to a form of district heating in 2016. Numbers used by the CBS rely on the data of buildings without a gas connection. The total amount of houses in the Netherlands in 2016 was approximately 7.7 million, which means that currently around 420 thousand homes are connected to some form of collective heating (Segers, van den Oever, Nissink, & Menkveld, 2019).

For rural parts of the Netherlands, with a low house density, individual options seem to be the more logical route to go. For urban areas, the collective options are the more logical choice. In chapter four the classifications for rural and urban environments is explained.

3.2. Sustainable energy sources & energy carriers

The systems used for sustainable residential heating rely on the energy provided by sustainable energy carriers and sustainable energy sources. Sustainable energy carriers are phenomenon or fuels which contain energy that has the ability to be converted (ISO13600, n.d.). In this thesis the focus lies on the ability of an energy carrier to be converted into heat.

Sustainable sources are renewable, this means that it has the characteristic that it does not run out or is not endless. Sustainable sources are often referred to as alternative energy, alternative energy serves as an alternative to the most commonly used non-sustainable energy sources. Examples of sustainable and non-sustainable sources are the sun and coal (U.S. Energy Information Administration, 2019).

In terms of residential heating there are several renewable sources available. Below the most common available alternative sources are stated (Wright, 2018).

Solar Energy   Geothermal Energy   Biomass Energy

Other sustainable sources which can be used to produce heat, as described in literature, are wind energy, tidal energy and wood (Wright, 2018).

When it comes to sustainable energy carriers it is important that the fuel has the ability to store, transport and distribute energy which comes from a renewable source. Instances of renewable energy carriers are hydrogen, liquid air, nitrogen, and water (Yongliang, Huisheng, & Xinjing, 2010).

The distinction between energy sources and energy carriers is of importance because in paragraph 3.3 and 3.4 the collective and individual systems are described. The working mechanisms, energy sources and energy carriers per sustainable heating alternative are described.

3.3. Collective sustainable residential heating alternatives

Collective systems are characterised as systems that provide heat to multiple buildings (two or more), coming from a shared source. Examples of sustainable collective heat sources for block heating and district heating are biomass, residual heat, and geothermal heat (Andrews, 2009).

Below the available collective residential heating alternatives, potentially suitable for urban environments are described.

Heat network

Heat networks, also called district heating, is a system which distributes heat generated in a centralized location through a system of insulated pipes. The system is mostly used for residential and commercial heating requirements such as water an space heating.

The heat is often obtained from a cogeneration plant, that burns fossil fuels or biomass. Besides burning fossil fuel heat-only boiler stations, geothermal heating, heat pumps and central solar heating are also used. In the Netherlands residual heat from power plants/large production facilities is sometimes also used for residential heating.

Centralized heating locations, that provide heat to districts, can provide higher efficiency rates and better pollution control than localized residential boilers. The near future of heat networks seems bright, this in particular for district heating with combined heat and power (CHPDH). Short term this is allegedly the cheapest method of cutting carbon emissions and has one of the lowest carbon footprints of all fossil generation plants. However, CHPDH is not a sustainable source, but heat networks relying on for instance geothermal heat are.

Geothermal heating systems have become more popular over years, this because people look for more efficient and environmentally friendly ways of residential heating. Geothermal heating is essentially a ground source heat pump, these solutions harness renewable energy to provide heat to homes through heated water from a geothermal source (Viessmann, 2020).

Geothermal systems use the heat from the ground as a main energy source. These systems then transfer this heat to the radiators and other climate control systems in a home. Geothermal heat can also be used to provide hot water, just like a gas boiler system. As stated in the paragraph which covers heat pumps, many of these systems can also be used in reverse to provide cooling and cold water. The geothermal system takes advantage of the given fact that the layer underneath the earth surface remains at a fairly constant temperature throughout the whole year (Viessmann, 2020).

The functioning of a ground source heat systems is exactly the same as that of a heat pump. Both work by pumping water containing antifreeze (called glycol) around a ground loop pipe which can be buried in a garden. The length of the loop that is required will depend on the size of the property and the level of heat needed to provide a comfortable temperature (Viessmann, 2020).

Thermal energy storage

Thermal energy storage (TES) is a technology that has the ability to stock thermal energy by heating or cooling a storage medium. This with the idea that the stored energy can be used at a later time. The stored energy can then be used for either heating and cooling applications or even power generation (Sarbu & Sebarchievici, A Comprehensive Review of Thermal Energy Storage, 2017).

Thermal energy storage (TES), can be achieved with numerous different technologies. Depending on the specific technology, it is possible for excess thermal energy to be stored and then used later on. The thermal energy can be stored for hours, days, months, at scales ranging from the individual process to whole neighbourhoods or districts (Sarbu & Sebarchievici, A Comprehensive Review of Thermal Energy Storage, 2017).

As stated, different TES technologies are available, the same goes for the media used. The storage media include for instance water or ice-slush, the earth's surface, or bedrock. Heat and cold from bedrock and the earth's surface are accessed with heat exchangers by means of boreholes. Other media are for instance deep aquifers, which are essentially impermeable strata like shallow pits filled with gravel and water which are insulated at the top.

Other possibilities of TES media are eutectic solutions and phase-change materials (Sarbu & Sebarchievici, A Comprehensive Review of Thermal Energy Storage, 2017).

Pellet stove

Stoves are used for residential heating for decades; however, these conventional stoves burn blocks of wood. Pellet stoves burn compacted pellets, which consist mostly of wood. Pellets used in pellet stoves can also be derived from other organic materials. Examples are nutshells, kernels of corn and saw dust (U.S. Department of Energy, 2020).

The higher burning efficiency has as a consequence that pellet appliances produce very little air pollution. In fact, pellet stoves are the cleanest solid fuel for residential heating appliances currently available to the public.

Pellet stoves, certified by the environmental protection agency, are likely to achieve an efficiency rate of approximately 70 to 83%. Pellet fuelled appliances have heating capacities that can range between 8,000 and 90,000 Btu per hour. These systems can be fitted in homes but can also be used for apartment complexes (U.S. Department of Energy, 2020).

3.4. Individual sustainable residential heating alternatives

In this paragraph, paragraph 3.4, the individual sustainable heating alternatives are described in terms of working mechanism, energy source and energy carrier. The described individual sustainable residential heating are selected for the rural environments in the Netherlands.

Heat pump
The heat pump can be used as an alternative to the gas-powered boiler. Normally a heat pump is used for heating tap water and residential heating. In essence it does exactly the same as a gas-powered boiler, but in a sustainable manner without burning fossil fuel.

Heat pumps transfer heat by circulating a refrigerant through a cycle of evaporation and condensation. The compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant evaporates at low pressure and absorbs heat from the surrounding of the coil. The refrigerant is then compressed and transferred to the other coil, where the refrigerant condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle (NRCAN, 2017).

In essence the heat pump cycle is fully reversible, this means that heat pumps can provide year-round climate control for your home. Providing heat in winter and cooling and dehumidifying in summer, which is a big advantage of this system. Since the ground and air outside always contains a certain level of heat, a heat pump can supply heat to a house even in the coldest winter days. In fact, air at –18°C still contains approximately 85% of the heat it contained at 21°C (NRCAN, 2017).

An air-source heat pump absorbs heat from the air outdoors in winter and transfers heat out into the outdoor air during summer. The air-source heat pump is the most common type of heat pump found in residential Dutch homes at this time. However, ground-source (also called earth-energy, geothermal) heat pumps, which draw heat from the ground or ground water, are becoming more widely used (NRCAN, 2017).

Biogas
Biogas is a product which is produced by anaerobic digestion (AD). AD is a process in which various types of anaerobic bacteria ferment/decompose complex organic matter (biomass). The bacteria break down the biomass into smaller compounds, this all in the absence of oxygen (Rutz, 2015).

Residential heating, using biogas, works essentially exactly the same as with natural gas, the only difference is that biogas is won from a sustainable source (biomass). Biogas usually originates from the fermentation process of manure, organic waste, or a combination of the two. This gas can be harnessed as a source of sustainable energy (Rutz, 2015).

Biogas could be particularly interesting for the Netherlands, this because of the presence of the profound natural gas infrastructure in the Netherlands. The presence of the gas network, which covers almost all land are of the Netherlands, makes it an interesting natural gas alternative (Gawalo, 2019).

Electrical boiler
An electric boiler uses electricity rather than gas to heat hot water. Just like a gas boiler, it will heat up the water that warms your radiators, and the tap water used in residential buildings. Electrical boilers come in various shapes and sizes, but in all electric boilers, you will see water running through the system to be heated by a heating element – similar to the way a kettle works (Occupational Safety and Health Branch Labour Department, 2016).

Electrical boilers are in essence not sustainable, this because in the Netherlands electricity is still produced using fossil fuels. Sustainable sources for renewable electricity could be solar, wind or tidal energy. If an electrical boiler is used, using renewable energy as a source, electrical boilers can be classified as sustainable alternatives for natural gas based residential heating systems (Occupational Safety and Health Branch Labour Department, 2016).

Infrared boiler
Infrared has been around for quite some time, but as a source of heating is a fairly recent addition to the domestic and commercial heating scene. Infra-red is emitted from the panel, which then travels until it hits an object. These objects have the ability to absorb the infra-red radiation, causing molecules vibrate, which therefore produce heat (The Greenage, 2019).

This penetration of heat provides a feeling of heat, but even if an object is not directly in front of the emitting source, any solid body will vibrate when the waves hit them. These waves then reflects off of the solid body, causing them to radiate heat back towards the person (The Greenage, 2019).

Just like electric boilers, infrared boilers are in essence not sustainable. Once infrared panels use sustainable energy sources they can be classified as sustainable residential heating alternatives.

Solar boilers
Solar water heating systems take advantage of the heat which is supplied by the sun to warm domestic hot water (DHW). These solutions provide DHW throughout the whole year and they can, if needed, be supported by immersion heaters or boilers to ensure constant availability of DHW (Viessmann, 2019).

Solar water heating, with the abbreviation SWH, is the conversion of heat provided by the sun in the form of sun light into heat for water heating. This can be done using a solar thermal collector unit. As stated, a variety of solar-boiler configurations are available, also varying in cost. The wide range of configurations are needed to provide solutions in different climates and at different latitudes. SWHs are widely used for residential and industrial applications (Chiaro, 2007).

The working mechanism of a solar-boiler is a sun-facing collector, which heats a working fluid that passes into a storage system for later use. SWH system can be both active and passive. Active systems need a pump to function, where passive systems are convection driven. SWH system can use two working fluid, most of the time consisting of water, or both water and a working fluid. The sun-facing collectors can be heated directly by the sun or via light-concentrating mirrors. The latter is more often used in larger scale solar-boiler systems. The collectors can operate as an independent heating system or as a hybrid with electric or gas heaters (Chiaro, 2007).

Hydrogen
Of all the chemical elements, hydrogen is the one which is most plentiful available in the universe. Hydrogen is a component of water and organic compounds, just like for instance natural gas and oil (Viessmann, 2019).

Hydrogen has, in relation to its mass, the highest energy density. In fact, hydrogen has an energy density of 33.33 kWh per kilogram, which is the highest of all fuels. By way of comparison, methane has a mass-related energy density of 13.9 kWh per kilogram and petrol has an energy density of 12 kWh per kilogram (Viessmann, 2019).

When conventional boilers burn fuels, carbon is released into the atmosphere. Hydrogen has an advantage over other fuels, because when it is burned, it produces only water and heat without any carbon (Dodds, Staffel, & Hawkes, 2015).

3.3. Conclusion sustainable residential heating alternatives

In this chapter, chapter 3.3, the first sub-question of this research is answered. It namely explains what the current available sustainable alternatives for natural gas based residential heating are in the Netherlands and what classifies them as sustainable.

When it comes to sustainable residential heating, two divisions are made. A distinction between collective and individual sustainable natural gas free residential heating alternatives was made in this thesis.

The individual solutions, using individual heat sources per household or per residential building are most suitable for the rural parts in the Netherlands with a low residential building density. Whereas collective sustainable residential heating alternatives are more suitable for densely populated areas of the Netherlands (Segers, van den Oever, Nissink, & Menkveld, 2019).

For collective sustainable residential heating alternatives there are basically two options. Namely, block heating systems and district heating. As by the year 2016, approximately 6.6% of the residential buildings in the Netherlands are connected to a collective heat system (Segers, van den Oever, Nissink, & Menkveld, 2019).

In order for a heating system to be sustainable, the energy provide for sustainable heating must come from renewable or sustainable sources. Currently in the Netherlands the most commonly used renewable sources of energy for sustainable residential heating are geothermal energy and biomass energy (U.S. Energy Information Administration, 2019).

In order for a residential heating system to be sustainable, the used fuel must have the characteristic that it does not run out or is endless. Looking at the energy carriers in sustainable residential heating systems, it is important that they have the ability to transport, store and distribute energy in a sustainable manner (U.S. Energy Information Administration, 2019).

The sustainable residential heating alternatives, as described in paragraph 3.3. and 3.4. are classified as sustainable. The collective systems in this paragraph rely on geothermal heat or sustainable heat storage media. Besides geothermal and TES systems, wood is also a popular gas fuel alternative. However, pellets (wood) still emit pollutants into the air and it releases small harmful particles during combustion (small particle dust emissions).

The individual sustainable residential heating alternatives have a wide range of energy sources. A division can be made between geothermal, biomass and electric residential heating solutions. It is important to notice that only electricity coming from or produced with renewable sources is suitable for sustainable residential heating systems (U.S. Energy Information Administration, 2019).

CHAPTER 4. MATCHING SUSTAINABLE HEATING ALTERNATIVES WITH URBAN/RURAL CONDITIONS

In this chapter, chapter four, the differences between rural and urban environments are stated. This chapter aims to clarify what distinctions there are between rural environments and urban environments in terms of opportunities and limitations. In paragraph 4.1 the heat demand of the municipality of Amsterdam (densely populated) is compared to the sparsely populated municipality of Achtkarspelen. In paragraph 4.2 the characteristics of these urban and rural environments are explained in their relation to heat supply. Here limitations in terms of location, house density, type of building and infrastructure are stated.

The characteristics from the two municipalities (two examples) are used as an input for the scoring card. This scoring card in paragraph 4.3 analyses individual and collective sustainable residential heating alternatives using characteristics of the rural and urban characteristics of the municipality of Achtkarspelen and Amsterdam. The scores from the scorecard are profoundly explained in paragraph 4.4 and 4.5.

Chapter four answers the second sub-question of this research, which is as follows:

"How do the sustainable alternatives match the specific circumstances/conditions in rural and urban environments?"

4.1. Heat demand rural vs. urban

In order to fully understand the potential of natural gas free residential heating alternatives it is important to identify the existing demand of heating for residential buildings (domestic) in the Netherlands in a rural and urban environment. This paragraph is used to analyse the current situation in the Netherlands. This information is used in order to test the ability of sustainable residential heating alternatives to provide a sufficient amount of heat for different circumstances.

The definition of heat demand, as used in this thesis, is as follows:

The amount of active heating input required to heat a building usually expressed in kWh/m2/yr. (European Commission, 2018).

As the definition of heat demand describes, the heating input for domestic buildings is normally expressed in kWh/m2/yr. To calculate the heat demand for Dutch citizens the gas usage is used. On average households in the Netherlands use 1.269 m3 of gas. However, this is and average and does not tell much. In order to give an indication of the heat demand the building itself is of greater importance (size and age) (Statistics Netherlands, 2020).

To give an indication the gas usage of houses with two residents is used. The table below, table 4.1, shows the differences per house for the year 2018.

Type of building	Gas usage 2018
Small old apartment	1090 m3
Small new apartment	870 m3
Small old house (semidetached)	1330 m3
Medium size old house (corner)	1510 m3
Medium size new house (corner)	1170 m3
Big old house (corner)	2100 m3
Big old house (detached)	2630 m3
Big new house (detached)	1450 m3

Ch. 4. Table 4.1: Gas usage domestic buildings in the Netherlands (Statistics Netherlands, 2020)

In table 4.1, old buildings are built before 1992 and new buildings after 1992. Small buildings are no more than 100 m2, medium size houses are between 100-150 m2 and big houses are larger than 150 m2. The data comes from CBS and is temperature corrected (Statistics Netherlands, 2020).

Approximately 80% of the gas used in domestic buildings is used for space heating, the other 20% is used for heating of water and a small portion of that 20% is used for cooking. In the Netherlands one cubic metre of natural gas delivers approximately 10,7 kWh (Gasunie, 2020).

Using the CBS data and the size of the buildings the average heat demand is calculated below in table 4.2.

Type of building	Gas usage	Size (m2)	Average size (m2)	kWh/m2/yr.
Small old apartment	1090 m3	< 100	49	238
Small new apartment	870 m3	<100	80	116
Small old house (semidetached)	1330 m3	<100	70	203
Medium size old house (corner)	1510 m3	>100, 150<	120	134
Medium size new house (corner)	1170 m3	>100, 150<	120	103
Big old house (corner)	2100 m3	>150	160	141
Big old house (detached)	2630 m3	>150	170	166
Big new house (detached)	1750 m3	>150	170	110

Ch. 4. Table 4.2: Sizes of domestic buildings and their heat demand (Statistics Netherlands, 2020)

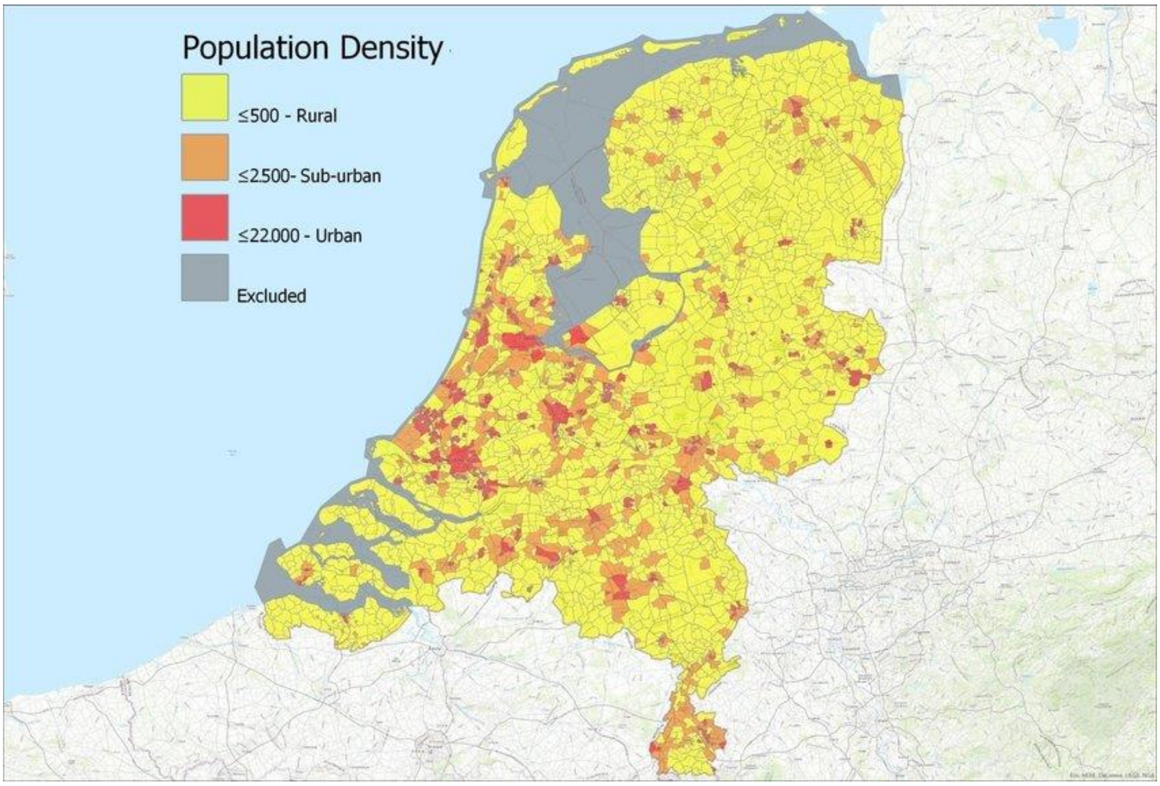
The average size of the different residential buildings come from CBS, average living space in the Netherlands (Statistics Netherlands, 2018).

When it comes to heat demand the biggest variable factor is the size of the domestic building. Larger buildings have a higher heat demand, this since a larger area has to be heated. Besides the size of a building the type of building has a great effect on the heat demand as well. An example is that for instance Flevoland, which is a relatively new province with a large amount of newer domestic buildings, has a significantly lower heat demand than other provinces. According to CBS, the heat demand in cities is lower than in rural parts of the Netherlands. This because buildings in rural parts of the Netherlands are larger, more remote, and most likely detached. Other causes that make for a higher heat demand in rural parts of the Netherlands is that in those areas old large farm houses are located (Statistics Netherlands, 2020).

In order to make a distinction between rural and urban areas in the Netherlands it is important to set examples. In order to do so it is important to know what the geographical characteristics of the Netherlands are.

Approximately 80% of the land area of the Netherlands consists of rural area. The Netherlands has a total area of over 41.000 km^2, 18% of this area consists of water. Around 6% of the Dutch residents live in rural areas, which account for a grand total of 925.000 people (Netherlands Bureau of Economic Policy Analysis, 2000).

Figure 4.1 shows the population density in the Netherlands in the year 2006, showing the distinction between urban and rural environments in the Netherlands.



Ch. 4. Figure 4.2: Population density in the Netherlands in 2006 (National Bureau of Statistics, 2006)

In this research the information from two municipalities are used. The municipality of Amsterdam is chosen as a densely populated municipality and the municipality of Achtkarspelen as a sparsely populated are. In table 4.3 the characteristics of both municipalities are stated.

Characteristic	Municipality of Achtkarspelen	Municipality of Amsterdam
Households per km2	427	6.057
Population density factor	7 times smaller than Amsterdam	7 times larger than Achtkarspelen
Size in hectares	10.398	21.949
Gas usage in m3	1630	870
Electricity usage in kWh	2660	2090
Gas used for heating in m3	1304	696

Ch. 4 Table 4.3: Characteristics of the municipality of Amsterdam and Achtkarspelen (Statistics Netherlands, 2020) (Statistics Netherlands, 2018) (National Bureau of Statistics, 2006)

Using Amsterdam and Achtkarspelen as practical examples of densely and sparsely (urban/rural) populated areas of the Netherlands the differences in heat demand and heat density is mapped.

On average households in the municipality of Amsterdam used 870 m3 of gas and 2090 kWh of electricity in the year 2018. In Achtkarspelen the average gas usage in 2018 was 1630 m3, and they used on average 2660 kWh of electricity. Keeping in mind that 80% of the gas is used for heating purposes, means that on average households in Achtkarspelen have a heat demand which is twice as high as that of households in Amsterdam (696 m3 vs. 1304 m3) (Statistics Netherlands, 2020).

4.2. Characteristics rural & urban environments in the Netherlands

Larger detached buildings of age have a higher heat demand per square metre, which rules out certain sustainable heating concepts with a low heat output.

Besides differences in size and age of buildings the area plays a large role as well. Certain sustainable heating concepts rely on geothermal heat, which asks for geotechnical or hydrogeological assessments. The decision if a concept, which relies on geothermal energy, produces enough, or overproduces heat, depends on the area in which this system should potentially be implemented. This means that for instance a certain heat density per region is needed in order for certain heat network systems to be viable (Information Resources Management Association (USA), 2013).

Using the average heat demand per domestic building and the geographical characteristics of the municipality of Amsterdam and Achtkarspelen the heat density differences between an urban environment and a rural environment are mapped (table 4.4).

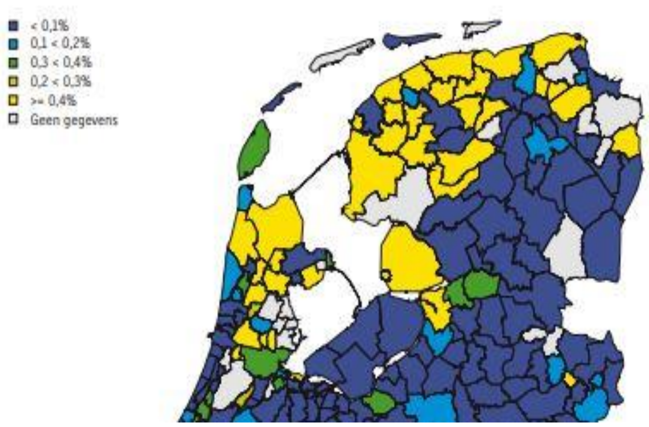
Municipality	Area km^2	Heat demand kWh	Households km^2	Heat density W/m^2
Amsterdam	219	7.500 per household	6.057	398
Achtkarspelen	104	14.000 per household	427	52

Ch. 4. Table 4.4: Heat density difference between rural and urban (National Bureau of Statistics, 2006)

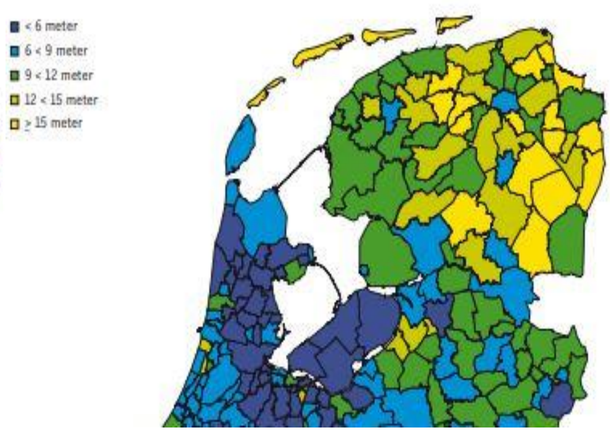
This paragraph explains the characteristics and limitations of different locations in the Netherlands using data from RioNed and the European Geothermal Congress and the National Bureau of Statistics.

Other burdens in relation to heat demand and sustainable heating alternatives is the available space. Some sustainable heating concepts only meet capacity requirements when enough surface area is available, ruling out densely populated areas (Information Resources Management Association (USA), 2013).

Data from sewer connections is used to make a distinction between rural and urban environments. In the Netherlands approximately 99.7% of the buildings are connected to the sewer network, however there are differences. Around 95% of the buildings are connected to the gravity-flow line sewage system, which is present in urban environments (RioNed, 2013).



Ch. 4. Figure 4.2: Percentage of buildings not connected to the sewage system (RioNed, 2013)



Ch. 4. Figure 4.3: Average length of sewer pipe needed (RioNed, 2013)

For domestic buildings in a rural environment sometimes mechanical sewage systems are needed, this since the location of the gravity-flow line sewage is too far from the hereditary border of the domestic building.

Approximately 4% of the buildings in the Netherlands have a mechanical sewage system and 0,3% make use of individual sewer waste treatment systems and 0,3% are not yet connected to the sewage system (RioNed, 2013).

As seen in figure 4.2, more than 0.4% of the buildings in Achtkarspelen are still not connected to the gravity-flow line sewage system. Other interesting rural characteristics Achtkarspelen are mapped using the average length of sewer pipe needed to connect a residential building to the sewage network. In the municipality of Achtkarspelen (rural), the average length of pipe needed to connect to the sewage system is >15 metres. Whereas in the municipality of Amsterdam less than six metres is needed. The needed sewer pipe length is shown in figure 4.3.

The length of the sewage pipe needed highlights how remotely the buildings in the municipality of Achtkarspelen are as compared to the municipality of Amsterdam. This fact is also a limitation when it comes to sustainable residential heating. The location, together with the low household density, the larger buildings and the buildings of age make it hard for the municipality of Achtkarspelen to implement collective residential heating systems on a large scale. This, together with the fact that the people in Achtkarspelen mainly live in detached single household houses (National Bureau of Statistics, 2006).

House density, location, building type, and characteristics of the area are of greatest importance when it comes to sustainable residential heating. The availability of geothermal heat on a location is a key factor which decides whether collective heating networks even belong to the available options. In figure 4.4, the available heat fields in the Netherlands are shown.

Ch. 4. Figure 4.4: Permits for geothermal heat in the Netherlands (Ministry of Economic Affairs and Climate Policy, n.d.)

Geothermal heat is often too expensive in the Netherlands, or geothermal heat fields are insufficient for the use of residential heating on a collective scale. Geothermal heat networks pay off on a collective scale if the house density is high, this so the heat loss through transportation is the lowest. Since 2018, 20 geothermal projects were completed. Of the total of 20 geothermal projects, 18 projects are currently operational. Around 7 projects are still under construction and 13 projects are working on a financial closure. All operational projects produce heat for the horticultural sector, but the interest is increasing for geothermal heat in the built environment as well. But currently there are still political, social, and financial barriers that prevent these projects from development (Provoost, Laurien, & Godschalk, 2019).

4.3. Analysing collective and individual residential heating concepts

In This paragraph the information of house density, spacing, infrastructure, available heat sources and urban/rural characteristics of the two regions are matched to the available natural gas free sustainable residential heating alternatives.

The collective systems which are matched to the urban and rural conditions consist in this case of heat networks, thermal energy storage and pallet stoves. Pellet stoves belong in this case to both collective and individual solutions, this because pellet stoves can be implemented both in larger blocks and individual homes.

The figure below, figure 4.5, visualises the suitability of the sustainable residential heating alternatives in both collective systems and individual systems for characteristics of rural and urban environments. On the vertical axis the different sustainable heating alternatives are shown, on the horizontal axis the characteristics of urban and rural environments are shown. Using a scoring from zero to five, it is visualised how the environmental characteristics affect the suitability of a sustainable residential heating system. Being zero the least/no effect and five the highest negative effects. In the scorecard a score of zero is accredited if an environmental (urban/rural) characteristic is not affecting the sustainable residential heating alternative. Using this scoring method, the lowest scores for both an urban situation and a rural situation give insight in the most suitable sustainable heating concept when it comes to characteristics of rural and urban environments. The scores accredited in this scorecard are further explained per sustainable residential heat alternative in paragraph 4.4 and 4.5, again making a distinction between rural and urban environments.

Characteristics urban/rural environment

		High House Density	Low house density	Short lenght of needed infrastructe	Long length of needed infrastructre	Availability of geothermal heat	Absence of geothermal heat	Large surface available	Small/no surface available	Small number of detached buildings	Large number of detached buildings	Buildings mainly built before 1995	Buildings mainly built after 1995	Average heat demand below 7.500 kWh annually	Average heat demand above 17.000 kWh annually
Collective Residential Heating	Heat network	1	5	1	5	1	5	2	3	3	2	3	2	3	3
	Thermal energy storage	2	2	1	5	2	3	2	3	2	3	3	2	2	4
	Pellet stove	0	0	0	0	0	0	1	4	2	2	5	4	1	5
Individual Residential Heating	Heat pump	0	0	0	0	1	5	1	4	0	0	4	3	1	4
	Biogas	0	0	0	0	0	0	0	3	0	0	4	2	1	2
	Electrical boiler	0	0	0	0	0	0	1	4	2	3	5	4	2	5
	Infrared panels	0	0	0	0	0	0	1	0	0	0	5	4	2	5
	Solar boilers	0	0	0	0	0	0	1	4	4	1	5	4	2	5
	Hydrogen	0	0	1	3	0	0	0	3	0	0	4	2	1	2

Ch. 4. Figure 4.5: Scorecard sustainable residential heating alternatives in rural and urban conditions (PBL Netherlands Environmental Assessment Agency, 2016)

The scores, as seen in figure 4.5, are summed up in table 4.5 & 4.6. In these tables it becomes clear what heat concepts suit rural and urban conditions best. The lower the score, the least negative impact a sustainable heating concept experiences from a rural or urban condition.

Concept	Urban
Biogas	6
Infrared panels	6
hydrogen	6
Heat pump	9 (14)
Pellet stove	11
Electrical boiler	12
Thermal Energy storage	12
Solar boilers	14
Heat Network	13 (18)

Ch. 4. Table 4.5: Sum of the impact of area conditions on sustainable residential heating alternatives

Concept	Rural
Biogas	6
hydrogen	9
Infrared panels	11
Heat pump	9 (14)
Solar boilers	12
Pellet stove	13
Electrical boiler	14
Thermal Energy storage	19
Heat Network	20 (25)

Ch. 4. Table 4.6: Sum of the impact of area conditions on sustainable residential heating alternatives

Looking solely at the characteristics of the area, together with the available sustainable residential heating alternatives, it is evidently visible that biogas is favourable when it comes to residential heating in a collective heat system. This because it shares a lot of characteristics with the currently used natural gas. It is not dependent on ground bound characteristics like availability of geothermal heat, and it does not require large ground areas in order to provide the required heat demand.

For some sustainable residential heating alternatives availability of geothermal heat is crucial. This is both the case for heat networks and heat pumps in collective and individual systems, hence the high secondary score. If a pallet stove, as compared to a heat network and thermal energy storage system is really favourable is discussed in paragraph 4.4.

Looking at the characteristics of rural environments and the suitability of sustainable residential heating alternatives the following can be said: For individual heating systems biogas and hydrogen fuelled systems clearly are favourable over the other options, this mainly has to do with the fact that little adaptations to the current available infrastructure are needed (Netherland's Grid Management, 2018).

If hydrogen and biogas are commercially available, with sufficient quantity, without drastic adaptations to homes is urban and rural environments is further explained in paragraph 4.4.

4.4. Conclusion matching sustainable residential heating systems

In this paragraph, paragraph 4.4, the second sub-question of this thesis is answered. Here it is explained how the sustainable alternatives match the specific circumstances/conditions in rural and urban environments of the Netherlands.

In the Netherlands there are large differences identifiable when it comes to house density and population density. In this thesis the information from the municipality of Achtkarspelen and Amsterdam are used to map the differences in heat demand, available space, size of residential buildings, gas usage and necessary length of infrastructure.

When it comes to heat demand the biggest variable factor is the size of the domestic building. In rural areas, where ground prices are lower, bigger domestic buildings are present in multiples. Besides the size, the type of building has a great effect on the heat demand as well. According to data from CBS, the heat demand in cities is significantly lower than in rural parts of the Netherlands, this because the buildings in rural areas are not only bigger, but also often detached and of age (older than 1995).

Approximately 80% of the Netherlands consists of rural areas, around 925.000 Dutch citizens live in such areas, making it a significant group which should not be neglected when it comes to residential heating alternatives. In the Netherlands areas with less than 500 people per km^2 are labelled as rural areas. In these areas collective residential heating alternatives are harder to implement, this because it is often not financially or technically feasible.

In order for a collective heating system to be feasible, it is important that prices for residential heating stay somewhat the same as compared to heating using natural gas. It is also of great importance to have an insight in the geothermal characteristics of the area. The availability of geothermal and the level of heat density per region is needed in order for certain heat network systems to be viable.

Comparing data from Achtkarspelen and Amsterdam, it is visible that Achtkarspelen has a heat density of 52 W/m^2, whereas the municipality of Amsterdam has a heat density of 398 W/m^2. Given this information it is in most rural areas not viable to build a collective geothermal heat system for residential heating only. This since the production side and the demand side are not in balance. The other way around it works the same. Some sustainable heating alternatives need large ground surfaces in order to provide enough heat to meet the heat requirements in densely populated areas.

In the figure 4.5, a distinction was made between collective and individual sustainable residential heating alternatives. On the horizontal axis the characteristics of urban and rural environments are shown. This scorecard shows how the sustainable residential heating alternatives are positively or negatively affected by the characteristics of urban and rural areas in the Netherlands. The outcome of this scorecard is shown in table 4.5 and 4.6, here it is visible which sustainable residential heating alternative is most suitable in what conditions.

Below is concluded why the most suitable sustainable residential heating alternatives suit the urban and rural characteristics best. It is also explained what characteristics cause limitations or make certain heating systems less viable under certain conditions.

4.4.1 Using biogas for sustainable residential heating

Advantages of biogas are that only a limited amount of adaptations in residential homes have to be made in order to be able to use biogas for heating. Typically, radiators, gas-boilers and cooking appliances are already suitable for the use of biogas. Other advantages of biogas are that the infrastructure is already there and that it is not dependable on geothermal heat. Downsides are that biogas is still scarce and expensive for residential heating purposes (Jorna, 2018).

Biogas could be an ideal alternative for both rural and urban environments, this since the least adaptations have to be made. Besides, biogas suffers the least from alterations in environmental characteristics (Jorna, 2018).

4.4.2 Using hydrogen for sustainable residential heating

Heating using hydrogen would be an ideal alternative for natural gas when it comes to the suitability in both rural and urban environments. Hydrogen is not dependent on the availability of geothermal heat, nor is it affected by the length of pipe needed. The natural gas pipe infrastructure can with little adaptations be used for the transportation of hydrogen. In order for the current infrastructure to be sufficient for the transportation of hydrogen the compressors must be enlarged, and the infrastructure must be cleaned (KIWA, 2018).

Using hydrogen for residential heating has other advantages. Because of the high caloric value hydrogen has the ability to produce heat in large quantity, making is sufficient for even the largest and oldest buildings in the Netherlands (Stedin, 2018).

Hydrogen is currently used in Rotterdam for residential heating (pilot). Hydrogen can together with biogas, all-electric and heat networks contribute to phasing out the use of natural gas in the Netherlands. Hydrogen is particularly interesting for buildings in the built environment which are hard to insulate, or where heat networks and all-electric solutions are not available (Stedin, 2018).

4.4.3 Using infrared panels for sustainable residential heating

Advantages of electrical systems are that they are not depending on geothermal heat, nor on a pipeline infrastructure. These facts make them suitable in every environment. However, capacity is often insufficient in larger buildings of age, making them less favourable in rural areas than urban areas.

For heating with electric boilers or infra-red panels in larger detached buildings, the available amount of sustainably produced electricity is often too low. This means that electricity has to be used coming from the net, which often still is produced using fossil fuels. Infrared panels are in this case more efficient, this because there is a narrower focal point. Using infrared panels, it is possible to heat specific areas (The independent HVAC agency, n.d).

According to network operators Enexis, Liander and Stendin phasing out natural gas will particularly have a negative impact on old and less well insulated homes, this because heat pumps and electric heating are insufficient in this case. Even with as much as 15cm of insulation around a building, households with an old house will still suffer from low inside temperature in winter (Enexis, Liander, Stendin, 2020).

4.4.4 Using heat pumps for sustainable residential heating

Heat pumps rely heavily on the availability of geothermal heat in the surrounding areas, making it not suitable/feasible for a large portion of the Netherlands. For urban and rural environments there are advantages and disadvantages when it comes to geothermal heat using heat pumps. For heat pumps typically larger systems must be installed in the premise, costly size which is most of the time not available in urban residential buildings. Besides the available size, the size of the premise plays a role as well. For heat pumps, shallow depth, larger ground areas must be available in order to produce sufficient amounts of heat.

Heat pumps are not affected by the house density or the heat density in the area. The needed length of pipe is also not affecting the viability of heat pumps. What does affect the efficiency of a heat pump are the characteristics of the building. In order to efficiently use a heat pump, the building in which the system is situated, should be adequately adapted.

For smaller buildings with small ground surface areas, mostly situated in urban environments, ground surface heat pumps are mostly not suitable because of the above. Heat pumps are more favourable in rural environments, this since premises are larger, and more ground surface is available.

4.4.5 Using a pellet stove for sustainable residential heating

Pellet stoves can be used both as individual systems in houses, and as collective systems in block heating. Pellet stoves have advantages over heat networks and thermal energy storage systems, this because they are not dependant on geothermal heat, nor on an adequate pipe infrastructure. Other advantages for both rural and urban conditions are that they can be fitted in densely populated areas and sparsely populated areas. However, pellet stoves do need available floor space to install the system and to store pellets.

In order for pellet stoves to render it is important that the size of the system is adequate for the level of insulation and the size of the residential building. Pellet stoves also provide the ability to function in conjunction with for instance heat networks. Pellet stoves can be fitted in almost every building, this because the presence of a chimney is not necessary (exhaust outlet of 8cm is sufficient). Pellet stoves in residential buildings (one household) typically have a capacity of 35 thermal kilowatts per hour (Yong, 2011).

Pellet stoves are available in all sizes, typically pellet stoves with a British thermal unit of 60.000 are sufficient for a building as large as 190m^2. Given this fact makes it possible to heat almost any building in the Netherlands. However, the relation between cost and heat is not included here. A downside of the pellet stove is that the pellet stove still needs electricity to run, and that they still emit pollutants into the air (U.S. Department of Energy, 2020).

Besides the necessity for electricity there is another downside which causes that pellet stoves are not favourable in densely populated areas. Pellet stove namely emit fine dust particles, which could cause strong air pollution if large amounts of people would install them (Yong, 2011). Even in areas with a low house density the pellet stove could cause air pollution, which takes away a part of the success formula of sustainable residential heating.

4.4.6 Using a heat network for sustainable residential heating

Areas with low heat density have the problem that high investment costs and high heat losses are apparent. Heat networks, or district heating, have great advantages as a collective system, this because of the environmental and financial benefits. However, a heat network is only viable if there is a return of investment strategy available. For the planning and financing of a heat network system it is of great importance that there is high density housing. The availability of reliable pipe networks make up for the biggest financial investment. For a heat network there is a general rule of thumb when it comes to feasibility. The general rule of thumb here is that a heat density in a region must be at least 50-200 W/m^2 for systems larger than 50mW. Besides the house density the biggest other factor for heat networks to be viable in a certain region is the nature of the terrain and the consumers (MacKenzie-Kennedy, 2014).

4.4.7 Favourable solutions which suit the rural and urban areas the best

Looking at the characteristics of the areas, the availability of geothermal heat, the available infrastructure, the size of the buildings, the house density and the heat demand, there are a couple of sustainable residential heating systems favourable. In both the urban and rural areas, the best solutions are biogas, hydrogen, and infrared panels. In urban areas where geothermal heat is available, heat networks could be a viable option as well. The information from this chapter, matching the characteristics of the area with different sustainable residential heating solutions, is used to make a cost analysis for these four options (in both urban and rural areas).

CHAPTER 5. FINANCIAL ANALYSIS OF SUSTAINABLE HEATING ALTERNATIVES IN URBAN/RURAL CONDITIONS

In this chapter, chapter five, a financial analysis for the four best suitable sustainable heating alternatives in urban and rural conditions is carried out. This financial analysis focusses on the cost on an individual level (household).

Chapter five answers the third sub-question of this research, which is as follows:

"Which of the sustainable alternatives is most cost effective for individual (rural) households and urban environments?"

5.1. Cost analysis

In this paragraph, paragraph 5.1, a cost analysis is carried out for the collective heat network and for the best suitable three sustainable residential heating alternatives in both rural and urban environments. This analysis is a systematic approach, which helps to map the weaknesses and strengths of the sustainable residential heating alternatives. It helps determining which options provide the best approach for households in urban and rural environments to achieve benefits. This cost-benefit analysis helps to estimate the value of a residential heating concept against the costs of the concept.

5.1.1 Cost heat transition urban

If in an urban area geothermal heat is sufficiently available, it is possible that a municipality opts for a collective heat network. On a household level the total transitioning costs consist of a connection to the grid, standing charges, annual costs for measuring devices and annual costs for the delivery set. In table 5.1, the costs for a collective heat network connection are stated.

Connection to existing grid <25 metres	€1.037,78
Additional costs per metre	€33,70
Fixed costs (standing charge)	€309,52
Annual costs measuring device	€25,36
Annual costs of the delivery set	€181,09
Price per kWh	€0,0866

Ch. 5. Table 5.1: Costs heat network (Authority of the consumer market, 2018)

The cost of a connection to an existing heat network in the Netherlands are currently fixed. The maximum in 2019 was €1.037,78, but the authority of the consumer market notified Dutch resident that the costs of a connection will increase to as much as €4.510,00. If an existing heat network connection is not possible, then the costs for a new connection pipe are divided over the users of the heat network. Currently there is not a maximum price for the installation of a new connection pipe (Authority of the consumer market, 2018).

For a comparison with the costs of gas in an urban area, the gas usage information of the municipality of Amsterdam is used (table 5.2). As seen in chapter 4, table 4.3, the average gas usage in this urban area is 870 m^3. If gas is used this would cost approximately €1.194. An average cost of €1.200 is used for the gas boiler, this boiler depreciates approximately €80, -, annually. In terms of maintenance the annual cost of an all-in maintenance contract is used (€168, -). The fixed price for a gas connection is set to approximately €260, -. The price for 870 m^3 of natural gas is set to €686, - (Vattenfall, 2020).

Natural gas usage urban	870 m^3
Average cost of boiler	€1.200
Annual depreciation boiler	€80, -
All in maintenance contract annually	€168, -
Fixed price for gas connection annually	€260, -
Price per m^3 of gas	€0,78, -

Ch. 5. Table 5.2: Costs of using gas for residential heating in urban environment (Amsterdam) (Vattenfall, 2020)

For the cost of a boiler the average price of a boiler is used as stated on the website of the consumer agency of the Netherlands, the installation costs are included in this price. The average boiler has a life span of approximately 15 years, this is how the annual depreciation was calculated (Dutch Consumer Agency, 2019). The price of an annual maintenance contract at Feenstra, which is a reputable business, is set at the same price for regular boilers (Feenstra, 2020). The price of a connection to the gas grid is nationally set to a price of approximately €260,- (Liander, 2020). The used gas price in this calculation is €0,78, which is an average price per m^3 (Vattenfall, 2020).

If a transition to a heat network was made this would cost approximately €1.174, -. If a heat network is used for sustainable residential heating a boiler is no longer needed. For a building with a gas usage of 870m^3 27GJ is needed. Below in the table, table 5.3, the costs for using a heat network for sustainable residential heating are shown.

Gas usage (natural gas)	870m^3
GJ needed for heat demand	27GJ
Value of one GJ in m^3 gas	32,68m^3
Price of one GJ	€25,90
Fixed costs annually heat network	€475, -

Ch. 5. Table 5.3: Costs of using a heat network for sustainable residential heating in an urban environment (Vattenfall, 2020)

If an existing heat network is available in an urban area the usage of geothermal heat, provided by a heat network, is favourable. In case there is no heat network available the prices can increase drastically, this because the price for the development of the grid will mainly be divided under the users of the system (Authority of the consumer market, 2018).

Opting for biogas as a heating alternative is also an option, below the costs for this heat transition are calculated and compared to the usage of natural gas (table 5.4). If biogas is used as a sustainable residential heating alternative this would cost approximately €1.342,30.

Gas usage (natural gas)	870m^3
Average price of gas boiler	€1.200, -
Annual depreciation boiler	€80, -
Annual maintenance contract boiler	€168, -
Costs of biogas per m3	€0,89
Fixed costs including tax annually	€60, -
Infrastructure costs annually	€260, -

Ch. 5. Table 5.4: Costs of using biogas for sustainable residential heating in an urban environment (Essent, n.d.)

According to the matches made in chapter 4, hydrogen could also be a viable option for sustainable heating. Below, the heat transition costs are stated when a switch is made from natural gas to hydrogen. Unlike as with biogas, using hydrogen for residential heating demands a new hydrogen specific boiler. The other appliances in the house are most likely already able to work with hydrogen. Even the piping in the residential building can stay the same. In the table below, table 5.5, the transition to hydrogen is calculated.

Gas usage (natural gas)	870m^3
Price hydrogen boiler	€13.874
Annual depreciation	€1.387,50
Annual maintenance contract boiler	€168, -
Cost of 1 kg of hydrogen	€15, - (Mulder, 2019)
Annual cost hydrogen for heating house	€3.337, -
Caloric value of 1 kg of hydrogen	120 MJ/kg (World Nuclear, 2018)
Caloric value of 1 kg of natural gas	42 MJ/kg (World Nuclear, 2018)
Expected future hydrogen price per kg	€2,17 (Mulder, 2019)
Annual cost hydrogen for heating house	€488,25
Fixed costs including tax annually	€60, -
Infrastructure costs annually	€260, -

Ch. 5. Table 5.5: Costs of using biogas for sustainable residential heating in urban environment (Viessmann, 2018)

To heat a house with an annual gas usage of 870m^3 of gas, approximately 27 GJ is needed. If the same house has to be heated using hydrogen this means that 225 kg of hydrogen is needed annually. The calculation used was that 1 kg of hydrogen provides 0,12GJ. In the table it is visible that the annual cost of hydrogen is calculated with both €15, - and €2,17. Annually hydrogen costs in an urban environment in this particular case €5.212, -. When the expected future price is used, it would annually cost approximately €2.363, -. The assumption was made that the annual maintenance, fixed costs including tax and the annual infrastructure costs stay the same as with gas. The hydrogen boiler depreciates over a time span of 10 years (Viessmann, 2018).

Another suitable alternative to heating with gas in urban environments are infra-red panels. In order to heat a residential building with an annual gas usage of 870m^3 (80-100m^2), the following transition costs are present (table 5.6).

Gas usage (natural gas)	870m^3
Average size corresponding with gas usage	80-100m^2 (PBL Netherlands Environmental Assessment Agency, 2016)
Price per kWh of green electricity	€0,20
Fixed costs including tax electricity	€40, - (Energy comparing agency, 2020)
Price infra-red panel 300W	€150, -
Panels needed for 3 room building	3
Depreciation 3 panels annually	€45, -
Hours activated annually	1.920 (Essent, 2019)
Annual cost of electricity for 1 panel	€1.267,20

Ch. 5. Table 5.6: Costs of using infra-red panels for sustainable residential heating in urban environments (Verwarmingshandel, 2020)

If infra-red panels are used, there is an immediate feeling if warmth, which has the advantage that only the panel in the area where people are located has to be enabled. Infra-red panels consume quite an amount of electricity. Annually an infra-red panel of 300W uses 6.336 kWh, this number is calculated using the information that the temperature in the Netherlands is below 15 degrees Celsius for eight months a year. In the Netherlands people normally use their central heating system when outside temperatures are below 15 degrees Celsius (Essent, 2019). In the calculation the number of hours a day in which an infra-red panel is active is set to 8 hours. Using these data, it is calculated that heating using infrared panels annually costs approximately €1.352, -. This is what it would cost if one panel is used at a time. If all three panels were used at the same time for the same duration it would cost €3.886, - annually.

In the table below, table 5.7, the annual costs of a heat transitions from gas to a sustainable residential heating alternative are stated. For hydrogen two calculations were made, one using the current price of one kilogram of hydrogen, and one using the expected future price of one kilogram of hydrogen. For heating with infra-red panels two calculations were made, in essence only the room in which people are located will have the panels enabled. This is stated in the table below as the one panel enabled scenario. If all rooms have the panels enabled (3 panels), then the costs for the used electricity triple.

Heating system	Annual cost	Difference with natural gas heating
Natural gas boiler	€1.194, -	-
Heat Network (geothermal)	€1.174, -	€-20, -
Biogas	€1.342, -	€+148, -
Hydrogen (current price)	€5.212, -	€+4.018, -
Hydrogen (expected future price)	€2.363, -	€+1.169, -
Infra-red panel using one panel	€1.267, -	€+73, -
Infra-red panel using 3 panels	€3.886, -	€+2.692, -

Ch. 5. Table 5.7: Annual costs per sustainable heating alternative (residential building in urban environment)

5.1.2 Cost heat transition rural

If in a rural area in the Netherlands geothermal heat is sufficiently available, it is in some cases possible that a municipality opts for a collective heat network. On a household level the total transitioning costs consist of a connection to the grid, which in rural areas is often more expensive than in urban areas. Other costs consist of the standing charges, annual costs for measuring devices and annual costs for the delivery set. In table 5.8, the costs for a collective heat network connection in a rural environment are stated. The costs of using this heat network are compared to what it would have cost if natural gas is used in the same situation. In order to make an estimation of the required length of pipe needed, the information from the municipality of Achtkarspelen is used (paragraph 4.1.).

Gas usage (natural gas)	1630m^3
Average length of extra pipe required	15m
Required GJ to substitute natural gas	50GJ
Price per GJ	€25,90
Annual price 50GJ	€1.295
Connection to existing grid <25 metres	€1.037,78
Additional costs per metre	€33,70
Fixed costs (standing charge)	€309,52
Annual costs measuring device	€25,36
Annual costs of the delivery set	€181,09
Price per kWh	€0,0866

Ch. 5. Table 5.8: Costs included in the heat transition from natural gas to a heat network (Vattenfall, 2020)

In rural areas the costs of a heat network are highly dependent on how remote the residential building is located. The initial costs can become extremely high and the feasibility of a heat network system decreases once the length of the pipeline increases. Comparing data from Achtkarspelen and Amsterdam, it is visible that Achtkarspelen has a heat density of 52 W/m^2, whereas the municipality of Amsterdam has a heat density of 398 W/m^2 (paragraph 4.1). Given this information it is in most rural areas not viable to build a collective geothermal heat system for residential heating only. If the data from table 5.8 is used, the upfront costs for a residential building in a rural environment would be higher, this because an average additional length of 15 meters of pipe is needed (€505,50). Annually it would cost approximately €1.760, - to heat a residential building in a rural area with a former natural gas usage of 1630m^3.

If natural gas is used to heat this same type of residential building in a rural area it would cost approximately €1.794, -. Below, in table 5.9, the data for the cost calculation is presented.

Natural gas usage urban	1630 m^3
Average cost of boiler	€1.400
Annual depreciation boiler	€93, -
All in maintenance contract annually	€168, -
Fixed price for gas connection annually	€260, -
Price per m^3 of gas	€0,78, -

Ch. 5. Table 5.9: Costs included if a residential building is heated using natural gas (annually) (Vattenfall, 2020)

Since residential buildings are often bigger in urban environments, a bigger natural gas boiler is required. The natural gas boiler depreciates over a time span of 15 years, costing annually approximately €93, -.

Opting for biogas as a heating alternative is also an option in rural areas, below the costs for this heat transition are calculated and compared to the usage of natural gas (table 5.9). If biogas is used as a sustainable residential heating alternative this would cost approximately €2.031, -.

Gas usage (natural gas)	1630m^3
Average price of gas boiler	€1.400, -
Annual depreciation boiler	€93, -
Annual maintenance contract boiler	€168, -
Costs of biogas per m3	€0,89
Fixed costs including tax annually	€60, -
Infrastructure costs annually	€260, -

Ch. 5. Table 5.10: Costs of using biogas for sustainable residential heating in a rural environment (Essent, n.d.)

Hydrogen could in the future also become a viable alternative residential heating alternative. Below the heat transition costs are stated.

Gas usage (natural gas)	1630m^3
Price hydrogen boiler	€13.874
Annual depreciation	€1.387,50
Annual maintenance contract boiler	€168, -
Cost of 1 kg of hydrogen	€15, - (Mulder, 2019)
Annual cost hydrogen for heating house	€6.225, -
Caloric value of 1 kg of hydrogen	120 MJ/kg (World Nuclear, 2018)
Caloric value of 1 kg of natural gas	42 MJ/kg (World Nuclear, 2018)
Expected future hydrogen price per kg	€2,17 (Mulder, 2019)
Annual cost hydrogen for heating house	€900, -
Fixed costs including tax annually	€60, -
Infrastructure costs annually	€260, -

Ch. 5. Table 5.11: Costs of using biogas for sustainable residential heating in a rural environment (Viessmann, 2018)

To heat a house with an annual gas usage of 1630m^3 of gas, approximately 50 GJ is needed. If the same house has to be heated using hydrogen this means that 415 kg of hydrogen is needed annually. Annually hydrogen costs in a rural environment in this particular case €8.100, -. When the expected future price is used, it would annually cost approximately €2.775, -. The assumption was made that the annual maintenance, fixed costs including tax and the annual infrastructure costs stay the same as with gas. The hydrogen boiler depreciates over a time span of 10 years (Viessmann, 2018).

Another suitable alternative to heating with gas in rural environments are infra-red panels.

Gas usage (natural gas)	$1630m^3$
Average size corresponding with gas usage	$150\text{-}170m^2$
Price per kWh of green electricity	€0,20
Fixed costs including tax electricity	€40, - (Energy comparing agency, 2020)
Price infra-red panel 300W	€150, -
Panels needed for 5 room building	5
Depreciation 5 panels annually	€75, -
Hours activated annually	1.920 (Essent, 2019)
Annual cost of electricity for 1 panel	€1.267,20

Ch. 5. Table 5.12: Costs of using infra-red panels for sustainable residential heating in a rural environment (Verwarmingshandel, 2020)

Using these data, it is calculated that heating using infrared panels annually costs approximately €1.352, -. This is what it would cost if one panel is used at a time. If all five panels were used at the same time for the same duration it would cost €6.450, - annually.

In the table below, table 5.13, the costs of the sustainable residential heating alternatives are compared to natural gas.

Heating system	Annual cost	Difference with natural gas heating
Natural gas boiler	€1.794, -	-
Heat Network (geothermal)	€1.760, -	€-34, -
Biogas	€2.031, -	€+237, -
Hydrogen (current price)	€8.100, -	€+6.306, -
Hydrogen (expected future price)	€2.775, -	€+981, -
Infra-red panel using one panel	€1.267, -	€-527, -
Infra-red panel using 5 panels	€6.450, -	€+4.656, -

Ch. 5. Table 5.13: Annual costs per sustainable heating alternative (residential building in rural environment)

5.2. Conclusion cost analysis

Looking at the costs annually and the upfront costs, large differences can be seen. If biogas was used, little to no upfront costs are required. The same goes for infra-red panels, but these should best be used in conjunction with solar or other renewable electricity sources. This so the initial investment can be partly recouped of a longer period of time.

Using a heat network or hydrogen requires high upfront costs, not only in rural environments. The connection costs can be as high as €4.510, -. Note that this is the standard price, within the range of 25 meters of an existing connection. Compared to biogas and infra-red panels a heat network is an expensive alternative which demands large investments.

When it comes to hydrogen the future seems bright. However, suitable boilers are currently still expensive and the price per kilogram of hydrogen is high. Once the lower price of €2,17 per kilogram is used, prices start to creep towards those of the usage of natural gas. If geothermal heat is available, and a connection is nearby, then a heat network is the best solution for urban areas. Looking at the costs only, then biogas and infra-red panels are the best suitable alternatives when geothermal heat is absent. Even in urban areas heat network connections demand higher upfront costs, making it a costly alternative. In rural environments with a low house/heat density, heat networks are less viable. In this case, looking at cost, infra-red panels and biogas are the most viable alternatives.

6. CONCLUSION & RECOMMENDATION

In this chapter, chapter six, the main research question from this thesis is answered. In paragraph 6.1, the findings from chapter two to five are stated. Paragraph 6.2 is used to give recommendations to homeowners living in rural and urban environments in relation to sustainable residential heating alternatives. In this paragraph the environmental characteristics, heat demand and the cost of the concepts are taken into account. Paragraph 6.3 discusses what limitations the researcher encountered, and what could be done in the future to improve a similar research.

The main research question is as follows:

"What are currently (2020) cost-effective and sustainable natural gas-free residential heating alternatives for households in urban and rural parts of the Netherlands?"

6.1. Conclusion

This research aimed to find cost-effective and sustainable alternatives for residential heating in rural and urban areas in the Netherlands. Multiple options for both residents living in rural and urban areas are available, but which option is the best under what conditions? Different areas ask for different approaches, more individual approaches. This research aimed to find out what option, or what combination of options, is most suitable in the Netherlands in the rural areas and the urban areas. Focussing on the ability of systems to sustainably provide an adequate amount of heat, at a fair rate (compared to natural gas), for different circumstances.

This research gives an insight in the possibilities Dutch citizens have in order to adhere to the goals of the energy agreements in the Netherlands and the Paris agreements. It can be concluded that it is necessary that the way the Dutch citizens heat their homes will change in the upcoming years. In order to adhere and achieve these goals it is necessary that residential heating in the Netherlands must gradually become sustainable (fossil fuel free). This means that the usage of natural gas for residential heating must be lessened and gradually phased out in the upcoming years.

The options to heat residential buildings in a sustainable manner are numerous. In this thesis two divisions were made. It can be concluded that the individual solutions, using individual heat sources per household or per residential building, are most suitable for the rural parts in the Netherlands with a low residential building density. Whereas collective sustainable residential heating alternatives are more suitable for densely populated areas of the Netherlands, but only if an adequate heat source is located nearby. For collective sustainable residential heating alternatives there are basically two options. Namely, block heating systems and district heating. As by the year 2016, approximately 6.6% of the residential buildings in the Netherlands are connected to a collective heat system. If this amount will greatly expand cannot yet be said, this because of the conclusion that the upfront costs are high for both citizens living in rural and urban areas.

Based on literature review and example data from the municipalities of Amsterdam (urban) and Achtkarspelen (rural) it can be concluded that the characteristics of an area in which a residential building is located greatly influences the suitability of a natural gas-free residential heating alternative. In chapter four the characteristics per area were matched with the different sustainable residential heating alternatives. The results indicate that factors like house density, heat demand and availability of geothermal heat have the biggest impact when it comes to choosing a sustainable residential heating alternative.

Bases on the characteristics of rural and urban environments, it can be concluded that the best matches for rural environments are biogas, hydrogen, and infra-red panels. Looking at urban environments, it can be concluded that heat networks (if geothermal energy is available), biogas, hydrogen and infra-red panels are the most promising sustainable heat alternatives.

Looking at the costs annually and the upfront costs, it can be concluded that large differences can be seen. When it comes to price an adaption to urban and rural environments, biogas needs little to no upfront investment in order to be adaptable. The same can be concluded for infra-red panels, but these should best be used in conjunction with solar or other renewable electricity sources. Looking at the costs of a heat network or hydrogen it can be concluded that these systems requires high upfront costs and not only in rural environments. The connection costs are an important burden and can be as high as €4.510, -. The high upfront costs and the difficulty to connect to buildings which are located more remote, make it a less favourable option for rural than for urban environments.

When it comes to hydrogen it can be concluded that the future seems bright. However, suitable boilers are currently still expensive. If geothermal heat is available, and a connection is nearby, then a heat network is the best solution for urban areas. Looking at the costs only, then biogas and infra-red panels are the best suitable alternatives when geothermal heat is absent. In rural environments, with a low house/heat density, heat networks are less viable. In this case the costs for a connection increase rather rapidly, this because an additional €33,70 per meter of extra pipe is charged. Another conclusion that can be drawn is that in rural areas where the heat demand is around or less than $50W/m^2$ a collective heat system for residential heating alone is not feasible.

Based on the necessity for a change, the available sustainable residential heating, the best match between area characteristics and cost the following can be concluded:

For rural areas in the Netherlands, the best alternative for natural gas-based residential heating are biogas and infra-red panels. This because of the low upfront costs, and the acceptable annual running costs. For urban parts of the Netherlands heat networks are preferred, but since geothermal heat is not readily available and a connection demands high upfront costs, the usage of biogas and infra-red panels is preferable.

The problem stated in this thesis may seem far away, but I would like to notify you about the fact that the Netherlands wants to phase out natural gas by the year 2050, this means that residential heating will change rather quickly over the upcoming years!

6.2. Recommendations

In the introduction it is stated that that this research tries to provide a clearer view into the possibilities for sustainable residential heating in the Netherlands. This research is based on information found in literature. During this research, the researcher found out that a lot of information regarding this topic is still absent. Ideally the characteristics per region in the Netherlands should be researched, this to narrow down the suitable residential heating alternatives.

Besides the above, the researcher would like to motivate the reader to further investigate how profound the plans of the Dutch government are when it comes to switching to sustainable sources for residential heating. By the looks of it there is still no clear answer to the question what percentage of the Netherlands could be connected to a collective sustainable heating system, or what it would cost the Dutch citizens.

References

Andrews, D. (2009, January 7). *"Carbon footprints of various sources of heat – biomass combustion and CHPDH comes out lowest " – William Orchard.* Retrieved from Claverton-energy: https://claverton-energy.com/carbon-footprints-of-various-sources-of-heat-chpdh-comes-out-lowest.html

Authority of the consumer market. (2018, 31 July). *Energiebesparen*. Retrieved from Heat network or heat pump: https://www.samenenergiebesparen.nl/nieuws/stadsverwarming-of-een-warmtepomp-alle-kosten-baten-voor-en-nadelen-op-een-rij/

Ayodeji, O. (2015, February 10). *Research framework*. Retrieved from Sciencedirect: https://www.sciencedirect.com/topics/computer-science/research-framework

Baarda, B. (2012). *Basisboek methoden en technieken.* Groningen en Houten: Noordhoff uitgevers.

Baarda, B. (2014). *Dit is onderzoek!* Groningen/ Houten: Noordhoff Uitgevers.

Bryan, E. (2019). *Three storied apartment buildings constructed using lightweight eps concrete panels .* Jayasinghe M.T.R.

CBS, de Wit, S., & Schmeets, H. (2018). *Milieu en duurzame - Opvatting en gedrag.* The Hague: CBS.

CCS. (2019, October 24). *Duurzame warmte*. Retrieved from CCS Energy: https://www.ccsenergieadvies.nl/duurzame-warmte/

Chiaro, B. D. (2007). *Solar Water Heating.* Wilshire: Environment California Research & Policy Center.

CObouw. (2019, January 15). *Gasloos bouwen, de stand van zaken*. Retrieved from CObouw: https://www.cobouw.nl/bouwbreed/nieuws/2019/01/gasloos-bouwen-de-stand-van-zaken-101268653?vakmedianet-approve-cookies=1&_ga=2.151876857.151279781.1586774228-606078326.1566556931

Davor. (2015, October 12). *Geothermal heating – Advantages and disadvantages*. Retrieved from Our-energy: https://www.our-energy.com/geothermal_heating_advantages_and_disadvantages.html

Dodds, P., Staffel, L., & Hawkes, A. (2015). Hydrogen and fuel cell technologies for heating: A review. *International Journal of Hydrogen Energy*, 2065-2083.

Dutch Consumer Agency. (2019, September 26). *Buying a new gas boiler*. Retrieved from Consumer agency of the Netherlands: https://www.consumentenbond.nl/cv-ketel/beste?gclid=CjwKCAjwm_P5BRAhEiwAwRzSO3pHDNQOsac9GTCMiDkltVYMgSZZofURgR74Wpq8Rub2HrOAKBg3CxoC3NMQAvD_BwE&cid=sea_google_lidw_CV-Ketels_wvjg_do&ef_id=CjwKCAjwm_P5BRAhEiwAwRzSO3pHDNQOsac9GTCMiDkltVYMgSZZofURgR74Wpq8Rub

ECN. (2018, March 21). *Energietransitie kan nadelige gevolgen hebben voor burgers en bedrijven*. Retrieved from ECN: https://www.ecn.nl/nl/nieuws/item/energietransitie-kan-nadelige-gevolgen-hebben-voor-burgers-en-bedrijven/

Energy comparing agency. (2020, February 12). *Fixed costs*. Retrieved from Energievergelijken: https://www.energievergelijken.nl/energieprijzen/energierekening/vastrecht

Energyguide. (2020, April 12). *Benefits and disadvantages of the pellet stove*. Retrieved from Energy guide Brussels: https://www.energuide.be/en/questions-answers/what-are-the-benefits-and-disadvantages-of-a-pellet-stove/357/

Enexis. (2020, April 13). *Van het gas af in de praktijk*. Retrieved from Enexis: https://www.enexis.nl/consument/aansluiting-en-meter/aansluiting/van-het-gas-af-in-de-praktijk

Enexis, Liander, Stendin. (2020, March 5). *Natural gas will still be needed for residential heating*. Retrieved from RTLnews: https://www.rtlnieuws.nl/nieuws/nederland/artikel/5049026/oudere-woningen-aardgas-onmisbaar-elektriciteit-waterstof

Essent. (2019, 9 7). *When is the heating system turned on?* Retrieved from Essent: https://www.essent.nl/content/particulier/essenties/praktische-tips/wanneer-verwarming-aan.html

Essent. (n.d.). *Natural gas vs. biogas*. Retrieved from Essent: https://www.essent.nl/content/particulier/essenties/feit-of-fabel/groen-gas.html#

European Commission. (2018, 01 05). *Labelling and certification guide.* Retrieved from ec.europa.eu: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ilete_labelling_and_certification_guide_en.pdf

Feenstra. (2020, 4 22). *Maintenance contracts*. Retrieved from Feenstra: https://www.feenstra.com/nieuwe-cv-ketel-nodig/?gclid=CjwKCAjwm_P5BRAhEiwAwRzSO9JHoCQxBkMcYZwIaC-ozXfxwbjJGAjbQJIZzJ529JaNeaL1nFprMRoCXMEQAvD_BwE

Gasunie. (2020, June 10). *Gasunie unit converter*. Retrieved from Gasunie: https://unit-converter.gasunie.nl/

Gawalo. (2019, August 8). *Biogas as an alternative for natural gas* . Retrieved from Gawalo: https://www.gawalo.nl/energie/artikel/2019/08/biogas-als-alternatief-voor-aardgas-1017606?_ga=2.95950492.121845069.1594045794-606078326.1566556931

Greenpower. (2019, July 9). *ADVANTAGES AND DISADVANTAGES OF SOLAR WATER HEATING PANELS*. Retrieved from Greenpower: https://www.greenpower-technology.co.uk/news-and-advice/advantages-and-disadvantages-of-solar-water-heating-panels/

Helplink. (2020, April 2). *What is an electric boiler*. Retrieved from Helplink: https://www.help-link.co.uk/new-boilers-and-central-heating/electric-boilers/

Huber Technologies. (2019, July 28). *How To Heat And Cool Buildings With Wastewater*. Retrieved from Huber Technologies: https://www.huber.de/huber-report/ablage-berichte/energy-from-wastewater/how-to-heat-and-cool-buildings-with-wastewater.html

I&O Research. (2019, March 7). *Duurzaam denken is nog niet duurzaam doen*. Retrieved from ioresearch: https://www.ioresearch.nl/actueel/duurzaam-denken-is-nog-niet-duurzaam-doen/

ICAX. (2019, February 18). *Advantages and disadvantages of district heating*. Retrieved from ICAX: https://www.icax.co.uk/Advantages_District_Heating.html

Information Resources Management Association (USA). (2013). *Sustainable Practices: Concepts, Methodologies, Tools, and Applications.* Hershey: Information Science Reference IGI Global.

ISO13600. (n.d.). *ISO 13600 Technical Energy Systems.* Retrieved from ISO.org: https://www.iso.org/obp/ui/#iso:std:iso:13600:ed-1:v1:en

Jorna, J. (2018). *Why the Netherlands can not yet switch to biogas.* HIER.

Kaori. (2020, January 1). *Heat pump.* Retrieved from Kaori BPHE: https://www.kaori-bphe.com/uploads/editor/files/HeatPump_en.pdf

Keith, P. (2017, November 7). *Ethics of empirical research*. Retrieved from Online Library: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118901731.iecrm0086

Khayal, O. (2019). *ADVANTAGES AND LIMITATIONS OF BIOGAS TECHNOLOGIES.* Atbara Sudan: Department of Mechanical Engineering, Faculty of Engineering and Technology, Nile Valley University.

KIWA. (2018). *Future gas distribution.* Apeldoorn: Netherlands' network operator.

Liander. (2020, January 15). *Prices of a gas connection for private parties*. Retrieved from Liander: https://www.liander.nl/uwtarieven

MacKenzie-Kennedy, C. (2014). *District Heating - Thermal Generation and Distribution.* Pergamon.

Milieucentraal. (n.d.). *Pellet stove or biomass kettle*. Retrieved from Milieucentraal: https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/energiezuinig-verwarmen-en-warm-water/pelletkachel-of-biomassaketel/#:~:text=Voor%20een%20pelletkachel%2Dcv%20waarmee,installatie%20(zie%20bij%20biomassaketel).

Ministry of Economic Affairs and Climate. (2019, January 15). *Draft NECP of the Netherlands 2021-2030.* Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/documenten/jaarplannen/2018/11/06/draft-necp-of-the-netherlands-2021-2030

Ministry of Economic Affairs and Climate Policy. (2019, June 28). *Climate deal makes halving carbon emissions feasible and affordable*. Retrieved from Government: https://www.government.nl/latest/news/2019/06/28/climate-deal-makes-halving-carbon-emissions-feasible-and-affordable

Ministry of Economic Affairs and Climate Policy. (2019). *National energy climate agreement.* The Hague.

Ministry of Economic Affairs and Climate Policy. (n.d.). *Geothermal Permits in the Netherlands*. Retrieved from Government: https://www.government.nl/topics/renewable-energy/government-stimulates-geothermal-heat

Mulder, M. (2019). *Outlook for a dutch hydrogen market.* Groningen: CEER.

Municipality of Achtkarspelen. (2011). *Gemeente op maat Achtkarspelen.* Achtkarspelen: Municipality of Achtkarspelen. Retrieved from CBS.

Myers, P. (2005, 10 22). *Phase-Change Media for CSP Thermal Energy Storage*. Retrieved from Sensible TES: http://philipmyers.myweb.usf.edu/toppage1.htm

National Bureau of Statistics. (2006, January 1). *Bevolkingsdichtheid.* Retrieved from CBS: https://commons.wikimedia.org/wiki/File:BevolkinsdichtheidNederland.png

National Institute for Public Health. (2020, April 5). *Energietransitie*. Retrieved from RIVM: https://www.rivm.nl/onderwerpen/energietransitie

National Service for Entrepreneurial Netherlands. (2016, January 20). *Warmte en koude in Nederland.* Retrieved from RVO: https://www.rvo.nl/sites/default/files/Warmte%20en%20Koude%20NL%202NECW1202%20jan13.pdf

Netherlands Bureau of Economic Policy Analysis. (2000, May 29). *Nederland raakt zijn boeren kwijt*. Retrieved from CBS: https://www.cbs.nl/nl-nl/nieuws/2000/22/platteland-raakt-zijn-boeren-kwijt

Netherlands Environmental Assessment Agency. (2020, Jauary 22). *Energietransitie joulebak 2050*. Retrieved from PBL: https://themasites.pbl.nl/energietransitie/

Netherland's Grid Management. (2018). *Future proof gas infrastructures.* Apeldoorn: KIWA.

NRCAN. (2017, March 27). *What Is a Heat Pump and How Does It Work?* Retrieved from Natural resources Canada: https://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6827

Occupational Safety and Health Branch Labour Department. (2016). *Electrically heated boilers and their operation.* Hong Kong.

Office of Energy Efficiency & Renewable Energy. (n.d). *Solar heating*. Retrieved from Energy.gov: https://www.energy.gov/energysaver/home-heating-systems/active-solar-heating

PBL Netherlands Environmental Assessment Agency. (2016, 5 30). *Cities in the Netherlands*. Retrieved from PBL: https://www.pbl.nl/en/publications/cities-in-the-netherlands

Planbureau voor leefomgeving. (2018, April 4). *Kosten energietransitie tussen € 2 en ruim 3 miljard per jaar in 2030*. Retrieved from PBL.nl: https://www.pbl.nl/nieuws/2018/kosten-energietransitie-tussen-2-en-ruim-3-miljard-euro-per-jaar-in-2030#:~:text=Kosten%20energietransitie%20tussen%20%E2%82%AC%202%20en%20ruim%203%20miljard%20per%20jaar%20in%202030,-26%2D04%2D2018&text=De%20meerkosten%20va

Pols, D. (2019). *Routekaart eerlijk om naar gasloos wonen.* Amsterdam: Milieudefensie.

Provoost, M., Laurien, A., & Godschalk, B. (2019, June 14). *Geothermal Energy Use, Country updat for the Netherlands*. Retrieved from European Geothermal Congress: http://europeangeothermalcongress.eu/wp-content/uploads/2019/07/CUR-19-Netherlands.pdf

Rijksoverheid voor ondernemend Nederland. (2016, November 11). *Warmtepompen en warmte- en koudeopslag*. Retrieved from RVO: https://www.rvo.nl/subsidies-regelingen/regeling-groenprojecten/voorwaarden/projectcategorie%C3%ABn/energiebesparing/warmtekoudeopslag?utm_campaign=9249153042&utm_source=google&utm_medium=cpc&utm_content=416545095551&utm_term=hoe%20werkt%20een%20warmtepom

RioNed. (2013). *Sewer Benchmark.* Stichting RioNed.

Rutz, D. (2015). *Sustainable heat use of biogas plants.* Munich: WIP Renewable Energies, Munich, Germany. Retrieved from WIP-Munich.

Sarbu, I. (2018). *A Comprehensive Review of Thermal Energy Storage.* Timisoara: MDPI.

Sarbu, I., & Sebarchievici, C. (2017). *A Comprehensive Review of Thermal Energy Storage.* Timisoara: December.

Scitech Europe. (2019, August 15). *Tree's limitations of Co2 absorption*. Retrieved from Scitech Europe: https://www.scitecheuropa.eu/the-trees-limitations-of-co2-absorption/96594/

Segers, R., van den Oever, R., Nissink, R., & Menkveld, M. (2019). *Energie Balance.* CBS.

Solarprices. (2020, April 7). *Solar boiler prices*. Retrieved from Zonnepaneelprijzen: https://www.zonnepaneelprijzen.nl/zonneboiler/kosten/#:~:text=Installatiekosten%20van%20een%20zonneboiler,500%20en%20de%20%E2%82%AC1000).

Sonti, P. (2018, July 16). *Benefits thermal energy storage*. Retrieved from Nexant: https://www.nexant.com/resources/benefits-thermal-energy-storage

Statistics Netherlands. (2018, February 6). *Gemiddelde woonoppervlakte in Nederland*. Retrieved from CBS: https://www.cbs.nl/nl-nl/achtergrond/2018/22/woonoppervlakte-in-nederland

Statistics Netherlands. (2020, January 14). *Energieverbruik particuliere woningen; woningtype en regio's*. Retrieved from opendata.cbs: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81528NED/table?fromstatweb

Statistics Netherlands. (2020, January 14). *Gasverbruik particulier woningen*. Retrieved from opendata.cbs: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81528NED/table?fromstatweb

Stedin. (2018, 11 10). *First houses heated with hydrogen in the Netherlands*. Retrieved from Stedin: https://www.stedin.net/over-stedin/pers-en-media/persberichten/eerste-huizen-verwarmd-met-waterstof-komen-in-rotterdam-rozenburg

Straver, K., Kooger, R., & Hulshof, M. (2017, December 18). *Winnaars & Verliezers.* Retrieved from Tertium: https://www.tertium.nl/wp-content/uploads/2018/03/winnaarsenverliezers.pdf

Tegtmeier, J. (2019, August 23). *PELLET STOVES, CAN I HEAT MY WHOLE HOUSE WITH ONE?* Retrieved from Woodheatanswers: https://woodheatanswers.com/pellet-stoves-can-i-heat-my-whole-house-with-one/

The Dutch Cabinet - Ministry of Economic Affairs and Climate. (2019). *Paris Climate agreement 2015.* The Hague: Rijksoverheid.

The Greenage. (2019, March 15). *Infrared heating systems*. Retrieved from The greenage: https://www.thegreenage.co.uk/tech/infrared-heating-panels/

The independent HVAC agency. (n.d). *Electric heating or a heat pump?* Retrieved from Klimaatexpert: https://www.klimaatexpert.com/blog/elektrische-verwarming-of-warmtepomp

The Oxford institute for energy studies. (2019). *The great Dutch gas transition.* University of Oxford.

TNO. (2019, July 12). *Social aspects of the energy transition*. Retrieved from TNO: https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-broad-support-for-the-energy-transition/the-social-aspects-of-the-energy-transition/

Toffetti, L. (2016, March 9). *District heating.* Retrieved from Commons.wikimedia: https://commons.wikimedia.org/wiki/File:District_heating.gif

U.S. Department of Energy. (2020, April 12). *Wood and Pellet Heating*. Retrieved from Energy.gov: https://www.energy.gov/energysaver/heat-and-cool/home-heating-systems/wood-and-pellet-heating

U.S. Energy Information Administration. (2019, 7 12). *Renewable energy explained*. Retrieved from EIA: https://www.eia.gov/energyexplained/renewable-sources/

University of North Carolina. (n.d.). *Conducting a Literature Review*. Retrieved from UNC: https://library.unc.edu/support/tutorials/litreview/

Van der Hyde. (2020, April 10). *Certified Geothermal HVAC System Installer for Grand Rapids and the Surrounding Areas*. Retrieved from Vanderhyde: https://vanderhyde.com/geothermal-systems/

van het Hof, W. (2018, January 5). *Ministry of economic affairs - Energy transition in the Netherlands.* Retrieved from ec.europa: https://ec.europa.eu/energy/sites/ener/files/documents/01.b.02_mf31_presentation_nl-fuel_switch-vanthof.pdf

Vastelastenbond. (2017, April 16). *Heat pumps*. Retrieved from Vastelastenbond: https://www.vastelastenbond.nl/blog/warmtepomp-zonneboiler-of-pelletkachel-rendabel-of-niet/

Vattenfall. (2020, 8 2). *Heat network prices versus costs of natural gas*. Retrieved from Vattenfall: https://www.vattenfall.nl/producten/stadsverwarming/kosten-stadsverwarming/

Vekomy, A. T. (2020, March 27). *Heat Pumps: 7 Advantages and Disadvantages*. Retrieved from Greenmatch: https://www.greenmatch.co.uk/blog/2014/08/heat-pumps-7-advantages-and-disadvantages

Verwarmingshandel. (2020, June 13). *Costs of infrared heating*. Retrieved from Verwarmingshandel: https://www.verwarminghandel.nl/faq/infrarood-panelen/verbruik/

Verwarmingsinfo. (2020, July 2). *Costs of a electrical boilers*. Retrieved from Verwarmingsinfo: https://www.verwarminginfo.nl/elektrische-cv-ketel#:~:text=Hoeveel%20kost%20een%20elektrische%20cv,tussen%204.000%20en%206.000%20euro.

Viessmann. (2018, 8 8). *Vitovaltor*. Retrieved from Viessmann: https://www.elementalheating.com/ehl-blog/2018/8/8/viessmann-vitovalor-300-p-hydrogen-fuel-cell-combined-heat-and-power

Viessmann. (2019, June 5). *Hydrogen as an energy source*. Retrieved from Viessmann: https://www.viessmann.co.uk/products/combined-heat-and-power/fuel-cell/hydrogen-in-vitovalor

Viessmann. (2019, October 19). *Solar Hot Water & Thermal Heating Systems*. Retrieved from Viessmann: https://www.viessmann.co.uk/products/solar-thermal

Viessmann. (2020, April 12). *How does a geothermal system work*. Retrieved from Viessmann: https://www.viessmann.co.uk/heating-advice/how-does-geothermal-heating-work

Wettengel, J. (2018, October 25). *Citizens' participation in the Energiewende.* Retrieved from Cleanenergywire: https://www.cleanenergywire.org/factsheets/citizens-participation-energiewende

Wildschut, J. (2017). *Heat storage in thermal energy storage tanks.* Wageningen: Wageningen University & Research.

World Nuclear. (2018, August 1). *Heat Values of Various Fuels*. Retrieved from World-Nuclear: https://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx

Wright, C. (2018, 1 31). *What's The Most Sustainable Method Of Heating Your Home?* Retrieved from Resource Center: https://www.buschsystems.com/resource-center/page/whats-the-most-sustainable-method-of-heating-your-home#:~:text=Geothermal&text=Unlike%20ordinary%20heating%20and%20cooling,again%20and%20again%20and%20again!

Yong, W. L. (2011). *Assessment of wood pellet combustion in a domestic stove.* Springer.

Yongliang, L., Huisheng, C., & Xinjing, Z. (2010). Renewable energy carriers: Hydrogen or liquid air/nitrogen? *Elsevier*, 1985-1990. Retrieved from Elsevier.

Zahra, A. A. (2015, May 1). *Scheme of the evaluated gas boiler heating system combined with a solar thermal system.* Retrieved from Researchgate: https://www.researchgate.net/figure/Scheme-of-the-evaluated-gas-boiler-heating-system-combined-with-a-solar-thermal-system_fig1_279837983

APPENDICES

A1. Research Strategy

In order to answer the main research question mainly literature review methods, together with desk research are used. Case studies from applicable projects are used to be able to form conclusions based on practise.

A1.1. Data analysis

In this research both quantitative and qualitative methods are used to analyse data. The nature of the data correlates with the data analysis methods which are employed in this research.

The data coming from urban and rural parts of the Netherlands (in terms of chances and limitations) are used as input for a cost-effectiveness model. This to calculate the cost per scenario of the sustainable heating concepts, using qualitative input to form quantitative outcomes.

A1.2. Method of data analysis

Below, table A1.1, shows the method of analysis for the data/information gathered during this thesis.

Data/information	Method of analysis
Information on energy carriers	**Qualitative**, compare data of multiple energy carriers available in the Netherlands
Information on consumption values	**Quantitative**, as input for calculation on feasibility of sustainable heating concepts
Geographical data of the Netherlands	**Qualitative**, as input for the comparison of urban and rural areas of the Netherlands
Population density urban vs. rural (Municipality of Amsterdam and the municipality of Achtkarspelen)	**Qualitative**, as input for the comparison of urban and rural areas. As input to conclude support base for sustainable heating concepts
Criteria for sustainable sources	**Qualitative**, as input for the assessment of available heating concepts
Alternatives for gas boilers	**Qualitative**, as input for the assessment of sustainable heating alternatives
Feasibility of sustainable heating concepts	**Quantitative**, as input for the calculations in terms of feasibility per scenario
Information on cost-effectiveness of sustainable heating systems	**Quantitative**, as input for the cost-effectiveness calculations for both scenarios
Energetic performance of sustainable heating concepts	**Qualitative**, compare data of sustainable heating alternatives to draw conclusions in terms of performance

A1. Table A1.1: Methods of analysing data

A1.3. Validation of data analysis method

The focal point of this report, when it comes to validation, is that empirical data solely comes from reputable sources. During the research, documents are used which are similar in nature and goal, this to assure the possibility to make comparisons. When statements are made in report, these are checked in literature. To check statements, triangulation is used.

In the social sciences, triangulation is defined as the application and combination of several research methods. Multiple research methods are used while studying the same phenomenon, this to cover multiple views. Combining multiple observers, theories, methods, and empirical materials, it is impossible to limit intrinsic biases. Besides intrinsic biases the limitations of certain observations, methods and single-theory studies can be minimalised using triangulation (Baarda, Dit is onderzoek!, 2014).

Theories and methods used in the research come from reputable scientific sources. Gathering the information is done by accessing the University of Twente library, Google Scholar, and other reputable databases (as provided via the UT library).

Used references and data sources are scientific in nature and come from reports, journals, or scientific literature. Sources and references are added using APA-regulations (Baarda, Basisboek methoden en technieken, 2012).

In order to conduct valid research some measures are taken. The definition of validity is in this case to what extend a concept or conclusion is well-founded and accurately corresponding to the real world. External validity makes it possible to generalise data for people or situations. Internal validity says something about the level of minimization of systematic failures within the data (Baarda, 2014).

To assure the researched data and drawn conclusions are in line with the to be achieved goal of the research, regular meetings with supervisors are held. Involved parties, in this case the researcher and the thesis mentor, regularly discuss findings and assessed data.

By regularly meetings the researcher stays on the right track and will keep a clear end goal. Feedback from experts is regularly asked and was used during the research. Using this method, the quality of the research is assured.

A2. Research design

The research design functions as a strategy to answer the research question or to test the research hypothesis (Pollit et al, 2001). This chapter, chapter three, will describe the needed activities to find the answers for the research questions. These activities will result in a research that will contribute to the knowledge on cost-effective gas alternatives for residents in urbanized and rural areas in the Netherlands, this to sustain their residential heat needs.

A2.1. Research Framework

The research framework will be used for implementation of the steps taken throughout the research. The framework is normally used as a guideline, which provides focus in the scope of the research (Ayodeji, 2015).

Below the conceptual research framework for this study is presented.

Step 1: Characterizing briefly the objective of the research project

The objective of this research is to analyse what effect measures regarding residential heating, as put forward in the Paris agreement, the NECP or by the Dutch government, have on Dutch residents (making a distinction between residents living in urban and rural areas). Researching the different options Dutch residents, living in urban or rural areas, have when it comes to energetic and financially optimal heating.

Researching state of the art technologies, rating their performances and rating their applicability in urbanized and rural parts of the Netherlands. This to give a recommendation to Dutch residents, on a household level, to steadily contribute to the energy transition and the road to become a gasless country.

This research will contribute to the knowledge on energetic/financial optimal gas alternatives for households to sustain their residential heat needs in urbanized and rural parts of the Netherlands.

Step 2: Determining the research object

Residential heat supply in urbanized and rural areas in the Netherlands

Step 3: Establishing the nature of research perspective

The nature of this research will be evaluative using empirical data. This because it seeks to offer a perspective for Dutch residents living in urbanized or rural areas. It assesses the current state of the art gasless heating alternatives and seeks to inform residents on what kind of technology is best suitable, most cost-efficient and sustainable (energetically and financially).

This research provides information on cost/energetically effective technologies to comply with stringent emission standards set by the European union and the Dutch government.

Assessment criteria used: sustainability, efficiency, cost-effectiveness.

Thus, this research will be a mix of a design-oriented research and an intervention-oriented research. The research perspective are the energetic and financial optimal options for residential heating. Analysing what impact becoming a gasless country has on the residents.

Step 4: Determining the sources of the research perspective

The research uses academic literature, publicly available data and statistics to come up with cost-effective gas alternatives for households in terms of residential heat needs.

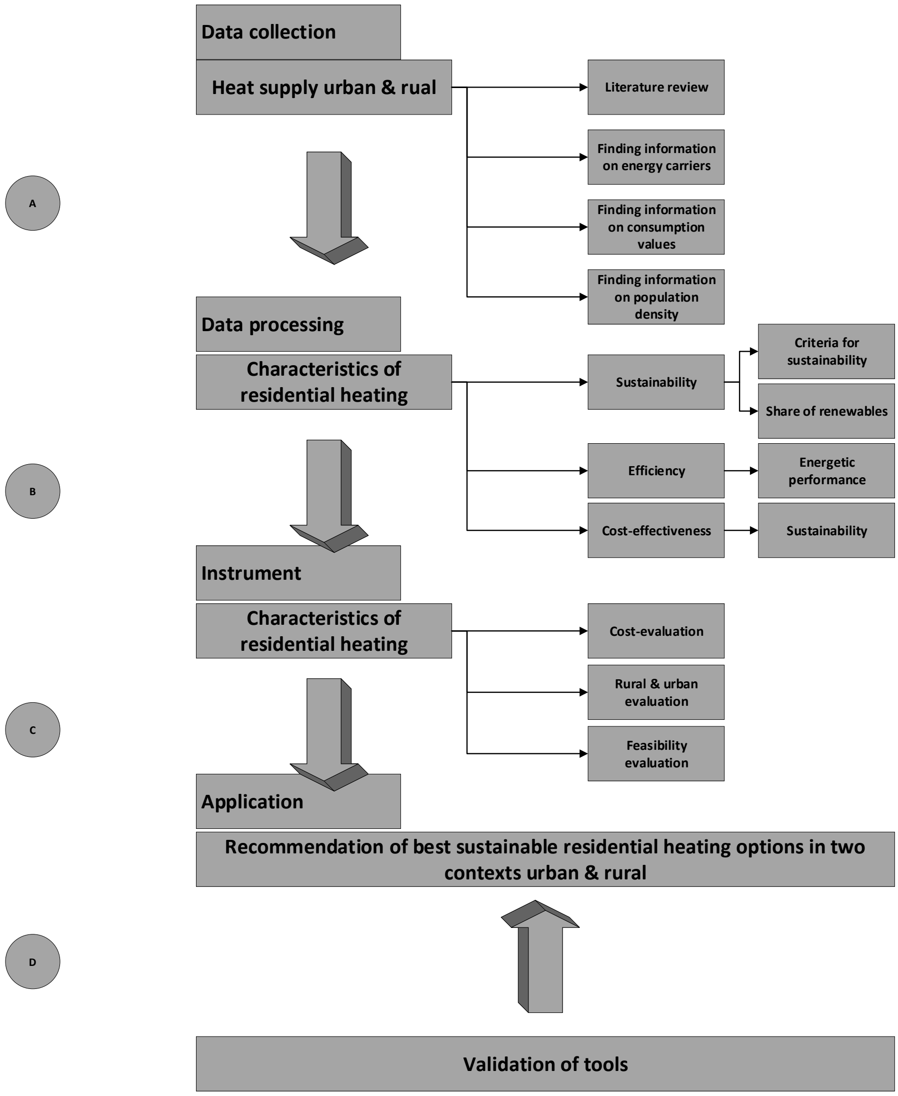
The table below, table A2.1, shows the key concepts of the research and clarifies which documentation and theories will be used.

Key concepts	Documentation & theories
▪ Heat demand of Dutch citizens ▪ Differences between rural and urbanized areas in the Netherlands ▪ Renewable heating concepts ▪ Energetically optimal heating ▪ Financially optimal heating	▪ Desk-research ▪ Preliminary research ▪ Cost-effectiveness analysis CEA ▪ Systematic case studies ▪ Matrix for comparison of technologies ▪ Meta-analysis ▪ Literature review ▪ Empirical research ▪ Scientific literature

A2. Table A2.1: Key concepts & Documentation/theories

Step 5: Making a schematic presentation of the research framework

Below, in figure A2.1, the schematic presentation of the research framework is shown.



A2. Figure A2.13: The research framework of this study

Step 6: Formulating the research framework in the form of arguments which are elaborated

- Introducing the problem, problem statement and the used methodology.
- Background and necessity of getting rid of natural gas in the Netherlands and to what extend could residents contribute with sustainable heating adaptations.
- Analysing the heat systems used in the Netherlands
- Analyse the differences between residential heat needs in rural and urbanized areas in the Netherlands.
- Analysing the renewable heating concepts (alternatives for gas)
- Comparing technological feasibility (energetically and financially)
- Combining the optimal option, energetically & financially for Dutch residents living in rural and urban areas.
- Forming conclusions and recommendations

A) Preliminary research, desk-research and empirical research on theories and information regarding the energy transition, heat and cold demand and opportunities and limitations of households located in rural and urbanized parts of the Netherlands.
B) Indicating the type of data gathered and familiarizing the reader with the empirical literature used. Indicating the information needed in order to answer the sub-questions of the research.
C) Indicating the nature of the data, which is in this case qualitative.
D) Analysing literature and give a measurable indication for the feasibility of different technologies in different geographical situations.
E) The results of the research, being able to give recommendations in terms of cost-effectiveness to household situated in both urbanized and rural areas.

Step 7: Checking whether the model requires any change

Inapplicable

A3. Advantages and disadvantages sustainable heating concepts

In this appendix some advantages and disadvantages of the currently available natural gas free sustainable heating alternatives are given.

Heat pump

Advantages	Disadvantages
Lower running costs as compared to gas	Increase in electricity use
Less maintenance than a gas boiler	High upfront cost
Safer than gas boilers	Harder to install than regular gas boiler
Lower carbon emissions than gas boilers	Questionable sustainability
Longer lifespan than gas boilers	Cold weather can damage the system
Ability to cool and heat	Not carbon neutral by itself, electricity is used

A3. Table 3.1: Advantages and disadvantages of the heat pump (Vekomy, 2020)

Heat networks

Advantages	Disadvantages
Heat, otherwise termed as waste, can be used for residential heating	Heat network sources are not always sustainable since the source can still be polluting
Increased availability and reliability because multiple sources can be included in the network	Substantial upfront capital is needed in order to establish a heat network system
Less maintenance and running costs as compared to individual systems	Large diameter piping needed, which makes extensive groundwork inevitable
Introduces opportunities for renewable sources which otherwise on a small scale would not be feasible	Heat losses to the ground, transferring heated media over longer distances
	Potential risk people do not want to commit to a long-term heat contract
	System can only be used to heat and not to cool

A3. Table 3.2: Advantages and disadvantages of heat networks (ICAX, 2019)

Biogas

Advantages	Disadvantages
Production of renewable power through combined heat and power cogeneration (CHP)	Inefficient systems, large scale facilities are not feasible as for now
Disposal of waste, using crop residues as a fuel	Biogas contains impurities, leading to higher maintenance and running costs
Useful by-products (fertilizer) come along with this heating concept	Greatly affected by the weather, optimal temperature is 37 degrees Celsius, acclimatisation needed for optimal fermentation
Avoidance of landfill gas escape, using crop residue to controllably generate biogas	Less suitable for densely populated areas, plant must be near the source
Simple in nature, low-cost technology	

A3. Table 3.3: Advantages and disadvantages of biogas (Khayal, 2019)

Geothermal heating

Advantages	Disadvantages
Long lifespan of the system	High installation costs
Low maintenance needed	Pre assessment needed, not all locations are suitable
Low running costs	Not sustainable by itself, this since it is an all-electric system
Flexible system, easy to scale up if the capacity of the source allows to do so	Dependent on the geothermal properties and available ground area
Cost savings as high as 80% as compared to fossil fuels	
Able to heat and cool	

A3. Table 3.4: Advantages and disadvantages of geothermal heating (Davor, 2015)

Thermal energy storage

Advantages	Disadvantages
Ability to store sustainable energy	Loses heat over time
Ability to store heat and cold	Expensive
Capacity to recoup up to 99% of energy	Needs large ground surface
	Still in developing stage

A3. Table 3.5: Advantages and disadvantages of thermal energy storage (Sonti, 2018)

Pellet stove

Advantages	Disadvantages
Efficiency as high as 90%	Higher maintenance than gas-boilers
Low installation costs	Emits small amounts of fine dust
Stable pellet prices	Needs electricity to operate
Neutral carbon balance	Louder than a gas-boiler

A3. Table 3.6: Advantages and disadvantages of the pellet stove (Energyguide, 2020)

Electrical boiler

Advantages	Disadvantages
Quiet	Small system, hard to scale up
Small and compact	Higher general running costs
Easy to install	Warm water is not always available since storage units are limited
Can be placed as long as electricity is available	
Efficient, little heat is lost in the process	

A3. Table 3.7: Advantages and disadvantages of the electrical boiler (Helplink, 2020)

Infrared panels

Advantages	Disadvantages
Compact system	More expensive than convection heating systems (radiator system)
Can be installed anywhere as long as electricity is available	Obstacles between a person and the panel block infrared radiation
Little to no maintenance	
Emission free	
More efficient than conventional systems, such as gas boilers	
Objects get heated rather than the air around the objects, making it possible to greatly improve efficiency	

A3. Table 3.8: Advantages and disadvantages of infrared panels (The Greenage, 2019)

Solar boilers

Advantages	Disadvantages
Solar energy as an input is free	Less flexible than electric boilers or solar panels
Solar boilers take up little space, placed outdoors	Annual maintenance needed
80% efficiency, use 80% of all sun radiant to heat water	Performance greatly dependent on the climate

A3. Table 3.9: Advantages and disadvantages of solar boilers (Greenpower, 2019)

Hydrogen

Advantages	Disadvantages
Only small adaptations needed in order to function with the current infrastructure	Not yet available to the public
Original equipment can most of the time still be used	Production of hydrogen is expensive
Burning hydrogen emits zero carbon emissions	If not captured, the production of hydrogen emits carbon

A3. Table 3.10: Advantages and disadvantages of hydrogen (Dodds, Staffel, & Hawkes, 2015)