

Master Thesis

The role of geothermal energy in the Dutch energy
transition

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TABLE OF CONTENTS

LIST OF FIGURES	3
LIST OF TABLES	3
ABSTRACT	4
ACKNOWLEDGEMENT	5
1. INTRODUCTION	6
1.2 RESEARCH BACKGROUND	6
1.2.1 <i>Energy Transition</i>	6
1.2 PROBLEM STATEMENT	8
1.3 READING GUIDE.....	10
2. RESEARCH DESIGN.....	11
2.1 RESEARCH OBJECTIVE.....	11
2.2 RESEARCH QUESTIONS	11
2.3 SCOPE AND LIMITATIONS	12
2.4 RESEARCH FRAMEWORK.....	13
RESEARCH MATERIAL AND ACCESSING METHOD.....	15
CHAPTER 3.....	1
3.1 GEOTHERMAL ENERGY.....	1
3.1.1 <i>Play-based portfolio approach</i>	3
3.1.2 <i>Geothermal cascading</i>	4
3.2 STATE-OF-THE-ART TECHNOLOGIES.....	5
3.2.1 <i>Geothermal Heat Pumps</i>	5
3.2.2 <i>Liquid Dominated Geothermal Plants</i>	6
3.2.3 <i>Binary cycle power plants</i>	6
3.2.4 <i>Enhanced Geothermal Systems (EGS)</i>	7
3.3 GEOTHERMAL ENERGY IN THE NETHERLANDS	8
3.3.1 <i>Subsurface properties</i>	8
3.3.2 <i>History</i>	9
3.3.3 <i>Ideas and future plans</i>	10
3.3.4 <i>Institutions</i>	14
3.4 INTERESTS AND BENEFITS	15
3.4.1 <i>Government</i>	15
3.4.2 <i>Customers/society</i>	16
3.4.3 <i>Investors/businesses</i>	17
3.5 CONCLUDING REMARKS.....	17
CHAPTER 4	19
4.1 GREEN DEAL	19
4.2 LEEUWARDEN PROJECT	20
4.2.1 <i>BGDD</i>	21
4.2.2 <i>RFC</i>	21
4.2.3 <i>Heat networks</i>	22

4.3 STAKEHOLDER ANALYSIS	23
4.3.1 Friesland Campina	23
4.3.2 Ennatuurlijk	24
4.3.3 Housing Corporations	25
4.3.4 Vermillion Energy	26
4.3.5 Province of Friesland	26
4.3.6 Municipality of Leeuwarden	27
4.3.7 Citizens of Leeuwarden	28
4.4 RISKS, BARRIERS, AND UNCERTAINTIES	28
4.4.1 Technical risks	28
4.4.2 Financial risks	29
4.4.3 Social risks	30
4.4.4 Political risks	30
4.4.5 Legal risks	30
4.5 CONCLUDING REMARKS	31
5. CONCLUSION	33
REFERENCES	36
APPENDICIES	41
APPENDIX 1 DRY STEAM POWER PLANTS	41
APPENDIX 2 ENNATUURLIJK INTERVIEW	42
APPENDIX 3 FRIESLANDCAMPINA INTERVIEW	43
APPENDIX 4 DAGO INTERVIEW	44

LIST OF FIGURES

Figure 1 Total primary energy supply in the Netherlands in 2016 (IEA, 2018)	8
Figure 2 The '3-i' framework (Gauvin, 2014)	14
Figure 3 Cross-sectional structure of the Netherlands (TNO)	3
Figure 4 Capacity curve (Opschaling aardwarmte in warmtenetten, 2018)	4
Figure 5 Enhanced geothermal energy system (Tester at al., 2006)	7
Figure 6 Ambition for geothermal energy in the greenhouse horticulture, urban environment, and industry (Masterplan, 2018)	11
Figure 7 Leeuwarden geothermal projects (Ennatuurlijk, 2019)	20
Figure 8 Existing heat networks in Leeuwarden (Warmteatlas, 2019)	22

LIST OF TABLES

Table 1 Accessing methods	2
Table 2 Renewable energy mix 2020 (Gemeente Leeuwarden, 2018)	27

ABSTRACT

The increasing global energy demands from society and the rapidly exhausting fossil fuel resources coupled with environmental obstacles require sustainable resource utilization. The transition from the fossil fuel-based to a green, sustainable or 'zero-carbon' energy sector is one of the greatest and most difficult task of the twenty-first century. Geothermal energy has the potential to become a key player in the decarbonization of the energy system. It can provide base-load energy as it offers a sustainable alternative for electricity generation, space heating, and industrial applications. The geothermal energy profile in the Netherlands has seen a rapid expansion in recent years. The Dutch government set a goal of reducing the country's CO₂ emissions with 49% by 2030 and targeting carbon-neutrality in 2050. The high geothermal potential of the Dutch subsurface would allow to upscale the role of geothermal energy in the energy mix, which could contribute to achieving the aforementioned national objective. However, several complicating factors must be taken into account, such as infrastructure requirements, investment costs, subsurface conditions, societal and governmental support. The potential locations and technologies of electricity generation and heat extraction are investigated as well as the barriers of implementation. The current condition of geothermal energy development is discussed including future prospects and action plans, with the question of whether the currently implemented policies and incentives are sufficient to further encourage the development of geothermal energy. A comprehensive review of a potential pilot case located in Leeuwarden is described, with project background information, financial and technological aspects, and stakeholder analysis.

Keywords: Geothermal Energy, socio-technical systems, transition management, Dutch energy transition

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1. Introduction

1.2 Research Background

At the 21st Conference of the Parties (COP) on 12 December 2015, an agreement was reached by more than a hundred countries aiming to combat climate change and limit global warming below 2 degrees Celsius compared to the pre-industrial level. Within the agreement, that is generally referred to as the Paris Agreement, the actions, and investments for a sustainable, carbon-neutral future were outlined (Rogelj et al., 2016). Combating climate change is a common cause, which requires all nations to act and adopt new, sustainable approaches as soon as possible. It also means that the fossil fuel-based global energy sector needs to change fundamentally over the coming decades. According to the goals, by 2050, electricity generation and heating supplies will be based on renewables, industries will adopt sustainable production processes, and the transportation sector will be almost completely electric (Fujimori et al., 2016). This transition requires a huge effort from the entire society, including the general public, businesses, and governments. Even though it was already an enormous accomplishment to have the agreement accepted, the more specific rules and procedures of the implementation are not necessarily clear or quite vague (Lesnikowski et al., 2017).

The Netherlands, like many other countries that have a fossil fuel-based energy system, is facing a complex task. However, unlike in many countries, the Dutch government shows a willingness and proactivity to adopt new practices and sees an opportunity in the transition. An opportunity to develop knowledge and skills, and to provide a sustainable future for the inhabitants of the densely populated country. The energy transition is a major social challenge, that will directly influence the everyday life and environment of people. Three key pillars must be achieved as the energy supply needs to remain safe, affordable and reliable (Energy Agenda, 2017).

1.2.1 Energy Transition

The energy transition is a widely discussed phenomena of today's world, however, it is not nearly a new concept. It can be described as a vital shift in the role of various fuels and energy conversion technologies at regional, national and global scales (Verbong and Geels, 2006). Historical transitions, such as from wood and water power to coal in the nineteenth century, or from coal to oil and gas in the twentieth century contributed significantly to developments,

such as industrialization, urbanization, or electrification of urban and rural areas. The current energy transition is described as a shift from fossil fuels towards a sustainable, low-carbon energy system that is characterized by the three pillars: accessibility, security, and reliability. However, carbon-neutrality is often described as an idealist approach, since energy availability, path dependency and lock-ins by the dominant regime could delay the decarbonization of the energy system (Geels, 2014).

The ways societies deal with energy has a major influence on their economic prosperity and international relations. Furthermore, human-induced climate change, that roots back to fossil fuel extraction, can not only influence weather patterns but can risk the future of mankind. Even though the implication of change and its target are clear (Paris Agreement or Sustainable Development Goals), there is no consensus on the ways of implementation. Some, mostly well-developed, western countries already incorporated the concept into their national energy policies, but these nations mostly gained wealth because they started fossil fuel exploitation earlier than others, which resulted in fast economic development. In other parts of the world, the energy transition might even increase carbon intensity, as the availability and affordability of energy services would significantly increase consumption. In Central Europe and the former Soviet Union, the transition is referred to as a liberalization of the sector, that can be seen in ownership changes and increasing competition (Bridge et al., 2013). The decarbonization process requires the reconfiguration of the current spatial models of both economic and social activity. Technological innovations and policy incentives are key aspects in the transition, however, the change in consumer behavior and societal acceptance are just as inevitable.

1.2 Problem Statement

The Netherlands, as a nation with a long history with fossil fuels, especially with natural gas extraction, is facing a major task. As Figure 1 illustrates, the energy mix of the country is heavily dependent on fossil fuels. Even though the efficient energy consumption of the nation is often highlighted, when it comes to the renewable share of the energy mix, the Netherlands

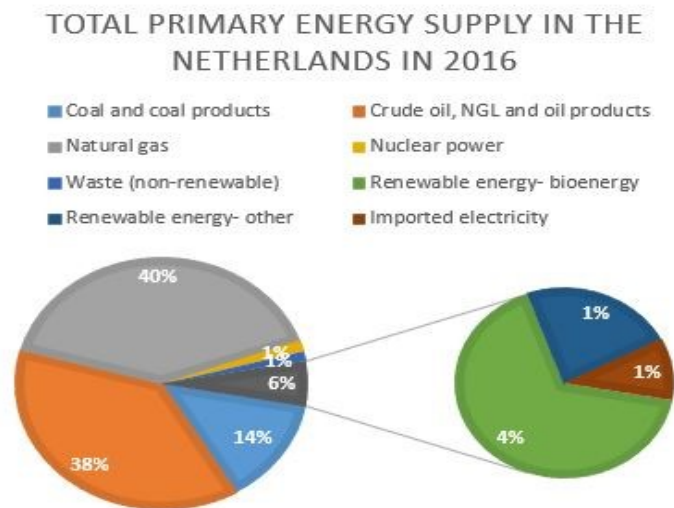


Figure 1 Total primary energy supply in the Netherlands in 2016 (IEA, 2018)

is on the second to last place among the European countries, with not even 10% (EEA 2018). The explanation for this is quite simple. In 1959, an enormous natural gas field was discovered in the province of Groningen, which at that time was ranked as the biggest on the world (now it is among the top ten). Oil and coal were replaced by natural gas, which counts as one of the cleanest fossil fuels, as it provides with the highest amount of energy with much lower (than other fossil fuels) CO₂ emissions. The natural gas exploitation began four years after the discovery, and within just a decade, 75% of all Dutch households were connected to the natural gas grid, which grew to almost 100% by now. Since then, smaller fields have also been discovered, the majority of them located offshore (North Sea). However, the intense exploitation caused several earthquakes in recent years near Groningen, which is why the government decided to stop the exploitation of the field by 2030 (Luginbuhl et al., 2017).

The country's natural gas reserves contribute to its wealth. The future oil price fluctuations and the depleting fossil fuel reserves could increase the monetary value of the fields. As a result, it would also increase the revenues of the government, as selling natural gas is an important source of income for the state. This income is highly uncertain, as the fluctuation of oil and gas prices can be drastic, furthermore, as it is not likely to find new fields and start production, this

income could cease on long-term (Luginbuhl et al., 2017). This financial uncertainty is an essential complicating factor for the government in the development of a long-term energy strategy.

In order to achieve the goals set in the Paris Agreement and also to comply with the national energy objectives, major improvements are required. Governmental officials need to make hard decisions, businesses must invest, and the general public also has to adjust to the changing circumstances, as the transition to a carbon-neutral, renewable energy-based system requires devotion from the whole society. The future plan is that in the following years, the role of natural gas will be decreased, if possible, drastically, as the increasing involvement of other sources (biogas, residual heat, geothermal energy) allow it (Energy Agenda, 2017). The increasing prices of fossil fuels could serve as a good base for entrepreneurs to invest in research and development, to find more efficient energy solutions or to apply already existing renewable and sustainable methods. However, the upscaling of the aforementioned resources is highly complex, and currently in an uncertain phase. Even though the government has chosen to act proactively and have novel ideas to increase the share of renewables in the energy mix, fast and drastic actions are required to reach the desired goals by 2050 (Masterplan, 2018).

Geothermal energy has been used as a source for base-load energy production around the world for more than a century, but when it comes to national energy supply plans, it is often ignored or at least neglected. It is often associated with low potential hydrothermal systems that can only be found at extremely specific locations. This prevailing perception has led to undervaluing the long term potential of geothermal energy while failing to develop methods for secure and sustainable heat extraction from the hot subsurface that is available anywhere on Earth. The qualities of geothermal energy, such as its small carbon footprint, widespread distribution, no storage requirement, and dispatchability make it an excellent source to reduce dependency on fossil fuels and contribute to the goals of carbon-neutrality (Akella et al., 2009).

Lately, the Netherlands has seen continued growth in the development of geothermal energy, but so far it was mainly used in the greenhouse horticulture. However, based on the improvements of the last couple of years, the possibilities for establishing heating and industrial applications are greatly investigated (Richter, 2019). Considering the developments, a common ambition and associated action plan are required in order to upscale the role of geothermal energy in the energy transition.

1.3 Reading Guide

The research attempts to give a comprehensive overview of the current status of geothermal energy and its future role in the energy transition in the Netherlands. The study is based on two pillars. The first major section includes the overview of geothermal energy, the state of the art technologies, while the second describes a potential pilot project in depth. As the ongoing geothermal project is ahead of most of the others in the country, the description of the Leeuwarden located geothermal plan aims to illustrate the potential of upgrading geothermal energy in the heating sector, based on technical, economic and stakeholder analysis.

The study is divided into four chapters. The first chapter outlines the broader research context and defines the problem that the thesis attempts to address. The following chapter explains the conceptual and technical design of the report, including the description of the research objective, framework, research questions, and the used materials. Chapter three will aim to cover the first major component of the study. It is divided into sub-sections, in order to have a clear understanding of each of the components regarding the topic. In chapter four, a detailed analysis can be read about a geothermal pilot project located in Leeuwarden, which is in its early (research) phase. The potential difficulties and possibilities will also be identified and discussed in the respective sections. The last chapter will summarize the findings in respect of the core and the sub-research questions and will end with the final conclusions.

2. Research Design

In order to successfully conduct the study, the researcher used triangulation as the main research strategy. As such, both qualitative and quantitative methodologies and a wide array of sources were used. The process of the research can be divided into three steps, namely literature review, general study about the Dutch geothermal situation and a detailed case study of one chosen location within the Netherlands. The primary and secondary sources are referenced in the discussion, however, in some cases, the enclosed information is a result of personal experience and observation. The theoretical framework, namely the 'three i' framework helped to guide the analysis and geared the research to answer the research questions.

2.1 Research objective

The objective of the research is three-fold. First, to give a comprehensive description of geothermal energy, including the general knowledge of geothermal energy, a geoscientific analysis of the Netherlands and the state of the art technologies. These are essential in order to have an understanding of the potential of geothermal energy in the Netherlands. Second, to see the opportunities and limitations of the current national energy policies and to have an understanding of the interest of different stakeholders. Lastly, to analyze the feasibility of a potential geothermal energy pilot, from a technical, economic and social perspective.

2.2 Research questions

The study involves desk research and primary research as well. The desk research entails a critical review of scientific literature, policy documents, and geological and geophysical surveys and maps, as well as data provided by various stakeholders. Below the primary research, discussions with stakeholders were contacted mostly through personal (direct) interviews or via email or Skype. Prior to conducting the meetings, a questionnaire was prepared and sent to the interviewees. Capturing information from past activities and policies, and also gathering insights about future prospects and plans serve as a base for the study. The criteria used in the study are based on five objectives, that are: social, political, environmental, economic and technical aspects. Throughout the analyses the following research questions are answered:

Could geothermal energy become a significant, affordable and sustainable energy resource for residential heating in the Netherlands and if yes, what would be the time perspective?

1. What is geothermal energy and what is the current state of the art, especially for residential heating in the Netherlands with respect to the subsurface properties of locations and energy production technologies?
2. What are the expectations of experts and the academic literature about the sustainability and the socio-economic feasibility of geothermal energy for residential heating and what is the assessment of a realistic time perspective for full exploitation of the geothermal potential in the Netherlands?
3. What is the current state of the art of the geothermal pilot in the city of Leeuwarden, who are the stakeholders, how are they involved in the pilot, and how do they perceive the potential of the geothermal energy as a sustainable and affordable heat resource for residential heating in Leeuwarden?
4. What are the risks and barriers that stakeholders involved in the pilot perceive with respect to the full-scale geothermal heat supply for residential heating in Leeuwarden?

2.3 Scope and limitations

The research focuses upon the geothermal situation in the Netherlands and involves all relevant stakeholders with reference to the pilot project in Leeuwarden. The findings of the research are based upon a comprehensive literature review, the data available on secondary sources and the data provided mainly by Ennatuurlijk and other stakeholders. However, the findings of the research are restricted by certain constraints which have arisen during the conduct of the study. These limitations are mentioned below.

- The data/literature for the geological review of the country, especially for the city of Leeuwarden was not /or not easily accessible, or mostly reported in Dutch, that increased the time for data interpretation.
- Even though several emails and phone calls were made, numerous stakeholders were not willing to provide information or answer my questions regarding the topic. The lack of cooperation made it difficult to have a comprehensive analysis of the projects and also to include all sorts of information and the opinion of experts.

- Throughout the interviews with relevant stakeholders related to the pilot project in Leeuwarden, the interviewees were not able to enclose several important details because of confidentiality reasons.
- The availability of financial data was rather limited and inadequate to conduct a detailed financial analysis. This is largely due to the fact that the geothermal project is at a relatively early stage, and somewhat due to the lack/uncertainty of information about investment capacity, prospective cash flows, breakeven and profitability for all the involved stakeholders. As a result, the report includes only general financial plans based on the few accessible figures.

2.4 Research framework

Given that the study incorporates the aforementioned two overlapping but still separate components, it was essential to have a framework that can be applied for both sections. Even though for geothermal energy projects, TNO has a performance assessment tool that would have been a good option as an analytical tool, considering that there is not enough data available about the projects, I choose the '3i' framework (TNO, 2019; Peters, 2002). The decision next to this framework is based on the uncertain status of the geothermal sector at the moment in the Netherlands, which does not enable to have an analysis based on a long history, existing patterns and habits in the sector. That is why the analysis of the ideas of different actors, the interests of these stakeholder groups and also the involved institutions serve as a good basis for the research (Gauvin, 2014). Currently, the geothermal situation in the Netherlands is under development. The regulatory background, that involves ownership, licenses, penalties, etc, are not established, or the currently applied system is not tailor-made for the geothermal sector. Until these are not established, and until the projects, wells, and drillings are permitted or started, all projects and plans are not more than ideas, which is one of the main components of the framework.

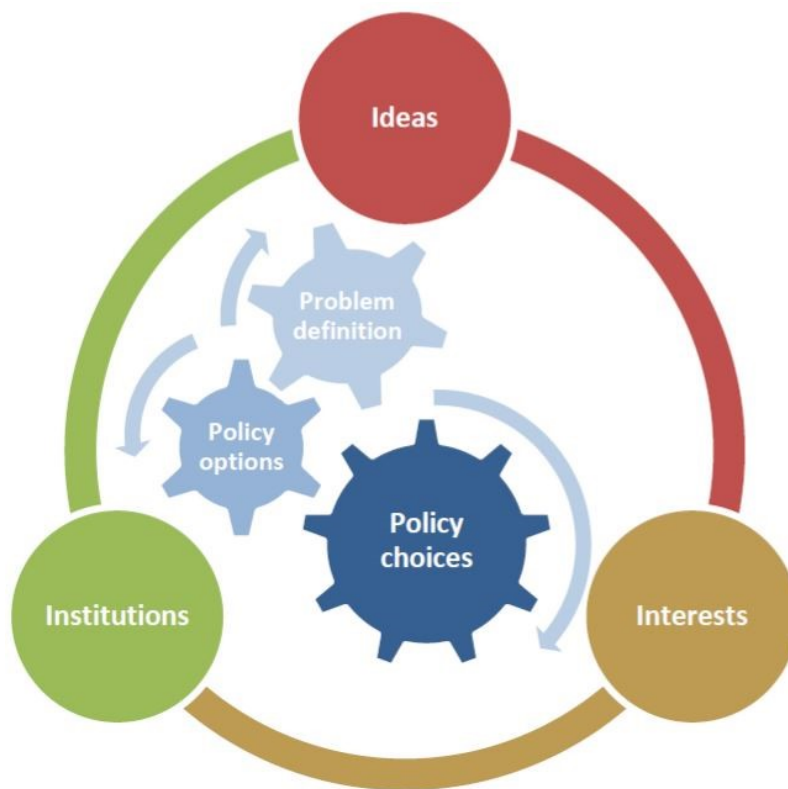


Figure 2 The '3-i' framework (Gauvin, 2014)

The “3 i” framework incorporates three major factors, that can be applied when analyzing the ongoing geothermal processes. These factors are interests, ideas, and institutions. The first factor, *interests*, refers to the influence of societal groups, governmental officials, and researchers. Each stakeholder groups have their own interests (political, financial, professional), and throughout the analysis of the relevant pillars, these and their role in project development are described. Furthermore, the costs and benefits of each stakeholder group will be investigated (Hall, 1997).

The second pillar within the 3-i framework is *ideas*. Ideas can be the beliefs, views, knowledge, values, empirical research-based information or experimental knowledge of the different actors involved. These can determine how players define problems, how they favor to solve them and also what policy options they would find acceptable and feasible (Bashir and Ungar, 2015).

The third factor is *institutions*, that are defined as rules, standards, and organizational structures which affect political behavior. Policy networks can also shape policy developments as these are necessary between public, private and non-profit organizations in order to address public problems. Lastly, a country’s constitution or its path dependency regarding policies can significantly influence how future policies are developed, which still belongs to the third pillar (Gauvin, 2014).

The framework can be applied for both of the national scale geothermal plans and also for the small scale project in Leeuwarden. The interests, ideas, and institutions can somewhat overlap in the two different cases, but there are significant differences as well.

Research material and accessing method

The aim of the research is to conduct a comprehensive analysis of the current state of geothermal energy in the Netherlands with a detailed description of an ongoing pilot project. In order to succeed, both primary and secondary data were collected and analyzed. In the following section, table 1 will be elaborated in detail, in the order of subquestions.

Gathering enough and adequate data, the analysis of the literature, documents, maps and media platforms of geothermal energy, both worldwide and on the country-level serves as the basis of the research. The geological description of geothermal energy is inevitable, just as the description of the state of the art technologies. This step is mainly based on secondary data, however, in order to understand the chosen technologies at specific locations in the Netherlands, primary data, as such interviews with involved parties was necessary.

For the second main component of the research, which is the socio-technical analysis of the Leeuwarden located geothermal pilot project, secondary data played the key role. As the project is ongoing, and the published data is limited, interviews with actors were inevitable and essential. The analysis of the stakeholder groups started only after the submission of the research proposal, in which the interviews with Ennatuurlijk, FrieslandCampina (as the potential owner of the ultra-deep well) and DAGO contributing the most. After personal/via email communication with the aforementioned stakeholders, a clear and comprehensive description can be elaborated about the project, from a social, environmental, technical and economic point of view.

Research Question	Information Required to Answer the Question	Sources of Data	Accessing
What are the current technologies in the field of geothermal energy and under what circumstances can these be applied?	Information about the available technologies and the geological requirements for each to be applied	<u>Secondary Data</u> Literature about the technologies applied in the world, and in the Netherlands	Content Analysis
		<u>Primary Data</u> Actors involved the ongoing and the planned projects in the Netherlands, in order to understand the chosen technologies	Questioning: Face to face individual interview, and/or questionnaire via email
What are the subsurface properties and the geothermal potential in the Netherlands like?	Detailed geological and geodynamic information about the subsurface properties of the Netherlands in the context of potential geothermal locations	<u>Secondary Data</u> Literature about the Dutch subsurface properties	Content analysis
What is geothermal energy? Is geothermal energy a sustainable renewable energy source?	Information about the footprint of geothermal energy Information about other renewable energy types	<u>Secondary Data</u> Literature about geothermal energy Comparative literature of all renewable energy types	Content analysis
What are the expectations of experts and the academic literature about the sustainability and the socio-economic feasibility of geothermal energy for residential heating and what is the assessment of a realistic time perspective for full exploitation of the geothermal potential in the Netherlands?	Information about all stakeholder groups Information about the roles of each actor Information about the interests, values of the actor groups	<u>Primary Data</u> People: project implementer, communities (leaders), Municipality, end-users, suppliers Media: websites, newspapers	Questioning: Face to face individual interview, and/or questionnaire via email
		<u>Secondary data</u> Literature about previously implemented projects	Content analysis

How could the city and its inhabitants of Leeuwarden benefit from the geothermal energy project?	Information about the costs and benefits of an ultra-deep geothermal project in general Information about the specificities of the Leeuwarden project	<u>Secondary Data</u> Literature about the costs and benefits of a similar project	Content analysis
		<u>Primary Data</u> Actors involved in the implementation, Municipality, Media: websites, newspapers	Questioning: Face to face individual interview, and/or questionnaire via email
What are the risks and barriers that stakeholders involved in the pilot perceive with respect to the full-scale geothermal heat supply for residential heating in Leeuwarden?	Risk analysis of geothermal projects, with specific emphasis on ultra-deep geothermal systems Stakeholder analysis Financial information Environmental analysis	<u>Secondary Data</u> Literature about the risks, financial details, environmental aspects	Content analysis
		<u>Primary Data</u> Actors involved in the implementation Media: websites, newspapers	Questioning: Face to face individual interview, and/or questionnaire via email

Table 1 Accessing methods

CHAPTER 3.

In the following chapter, a description of geothermal energy, the properties and the geothermal potential of the Dutch subsurface, moreover the state of the art technologies can be found. Furthermore, the history and the ideas and future plans for the upscaling of the geothermal sector are also elaborated, with the focus of goals and ambitions and the interests of major stakeholders. As a result, the chapter answers the first two sub-questions. The conclusions for these questions can be read at the end of the chapter.

3.1 Geothermal Energy

Geothermal energy is the energy in the form of heat that is originated from the Earth's interior. This huge, virtually inexhaustible quantity of heat is derived from two sources: the primordial energy generated throughout the creation of Earth; and the radioactive decay of long-lived isotopes within the upper crust (Stober and Bucher, 2013). The heat flows from the core to the direction of the surface where it dissipates. Analyzed from the opposite angle, with depth, the temperature increases, which deviation is measured by the geothermal gradient. The average temperature increase by kilometer is 30°C, however, there are certain geographical areas where the geothermal gradient of the Earth's crust is beyond than average. This occurs when magma bodies can be found near the surface (a few km deep) that are releasing heat, or if there is no magmatic activity, the heat accumulation is a result of the specific geological or geodynamic conditions (Barbier, 2002).

The extraction and utilization of the heat stored underground require a carrying medium to transfer this heat to the surface. This medium is the geothermal fluid, originally ocean or rainwater, that has penetrated into the crust and has been heated up by the surrounding hot rocks (Dickson and Fanelli, 2013). These specific areas where this water accumulates are called aquifers or reservoirs. The reservoirs can contain water in a gaseous or liquid phase or co-exist in both phases. These reservoirs are the fundamental components of most (except for hot dry rocks, see later in 3.2.4) geothermal fields. The liquid content of these reservoirs is in most cases cannot migrate to upper strata because they are covered with impermeable layers (Glassley, 2010). Geothermal fluids usually comprise additional chemicals, such as CO₂, HCL, H₂S, CH₄, H₂, NH₃, HF. After a geothermal well has been installed and the production began,

the excess gas content decreases, but throughout the exploitation, these can cause several issues, the most common one is the corrosion of pipes (Barbier, 2002).

From a geological perspective, geothermal reserves are steam or liquid water accumulations under high pressure and temperature conditions. From a technical and economic point of view, geothermal reservoirs are potential energy extracting locations, where apart from the geological properties (pressure and temperature conditions, depth, thickness, porosity, permeability and size of the reservoir), the cost-effective extraction depends on economic indicators (technology, cost, incentives, policies, etc) (Dickson and Fanelli, 2013).

The first step in the realization of the geothermal potential is the analysis of the available subsurface data. The strata need to be at least 50 m thick, have ideal porosity and permeability requirements (except for hot dry rock systems) to enable the flow of the fluids and have to be in a reachable depth (Huenges and Ledru, 2011). With applied 2D and 3D seismology methods, a clear picture can be obtained from the aquifer. After the seismic acquisition, test boreholes can be drilled, in order to take samples. The exploratory drillings can provide with all additional subsurface details that the seismic survey could not show, and the combination of the two processes should be enough to determine the further actions (Johnston et al., 2011). In order to extract the hot fluids, at least two wells have to be drilled: one for production and one for reinjection. The fluids are in continuous circulation. Depending on the temperature and the pressure circumstances of the reservoir, the fluids can be used for electricity generation (in case of high-temperature), for space heating or industrial uses (low-medium temperature) (Stober and Bucher, 2013).

According to the definition, renewable energy is energy from a resource that cannot be depleted when it is used (Shinn, 2018). Strictly speaking, geothermal energy can only be categorized as a renewable source if the extraction rate does not exceed the replenishment rate of the aquifer. However, with the frequently applied systems (especially used for heating), the exploitation of large volumes of water often leads to the reduction or total depletion of the geothermal resource in just a few decades, as such, those are not renewable energy systems. This phenomenon can be avoided by adequate reservoir management methods, such as optimal extraction and reinjection rates and reservoir monitoring (Dickson and Fanelli, 2013).

3.1.1 Play-based portfolio approach

In order to reduce risks and investment costs, a so-called ‘play-based portfolio approach’ can be applied. In essence, rock strata with approximately similar properties - such as age, depth, permeability, porosity, chemical composition, etc - can be categorized as a ‘plays’ from different geographical locations (Masterplan, 2018). Figure 5 shows the cross-sectional structure of the Netherlands, from Middleburg (A) to Groningen (B), where the colors represent the different formation ages of the strata. As can be observed, there are several plays within the country, that has the same properties, at different locations.

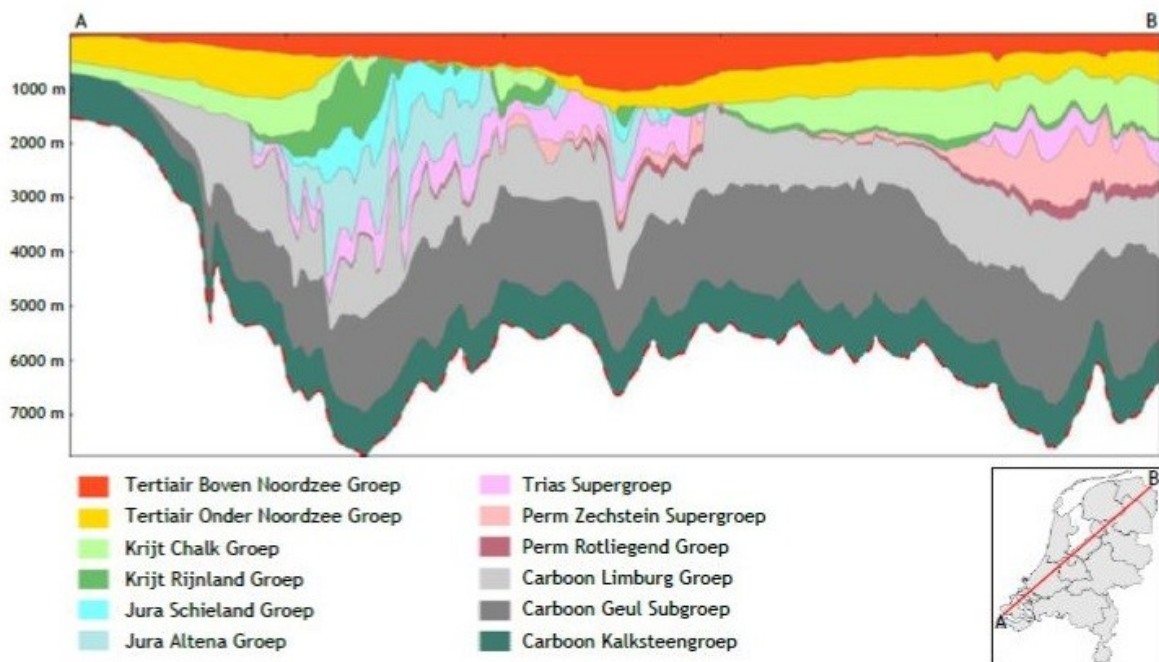


Figure 3 Cross-sectional structure of the Netherlands (TNO)

As a result, there is a high probability that throughout the geothermal energy exploitations, the capacity, costs, and risks would be greatly similar since the properties of the strata are relatively the same. For all locations within the play, the same technology could be applied, the same permits would be accepted, and the same process would be elaborated, which makes the upscaling significantly easier. In other words, economies of scale would reduce the costs, the risks and also the required time-frame for the projects, as processes within plays could be standardized. With this approach, the geological uncertainties can also be reduced, which is often demonstrated on the capacity curve (Stringer K.D, 2018). The expected, most favorable and most unfavorable capacities are presented with the P90 (90% probability) P50 (50% probability) and P10 (10% probability) values.

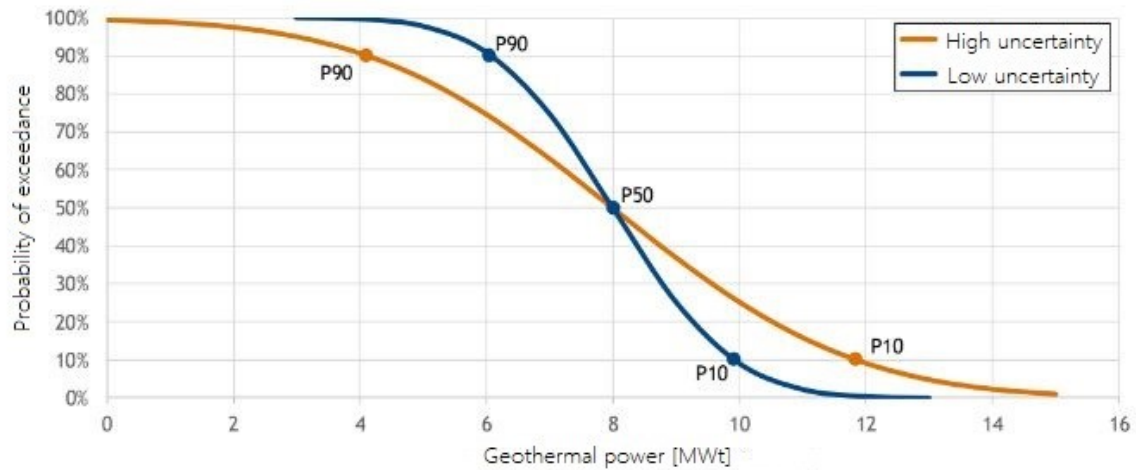


Figure 4 Capacity curve (Opschaling aardwarmte in warmtenetten, 2018)

The play-based portfolio approach would lead to an optimized capacity curve and reduce the difference between the high (P90) and low (P10) values. Of course, this approach does not mean that the currently available seismic or geological data is enough and no further investigation is needed (Opschaling aardwarmte in warmtenetten, 2018).

3.1.2 Geothermal cascading

A great option when it comes to the most economically advantageous utilization of geothermal energy is the cascading approach. The requirement for this method is high-temperature water, for which the most suitable locations would be the ultra-deep projects (see later in 3.2.4). In practice, after some amount of the stored heat is extracted from the water, its temperature decreases, however, it does not mean that the thermodynamic quality of the water is not sufficient for other, second or third temperature-level processes (Szanyi and Kovács, 2010). These lower temperature level processes include hot water supply, aquaculture, balneology, heating systems or low-to-medium temperature food production processes. There are two main types of cascades. In the first type, geothermal energy at its highest potential is used for electricity generation, followed by direct utilization for thermal uses, while the second type is only for thermal purposes (Rubio-Maya et al., 2015).

3.2 State-of-the-art technologies

There are numerous different geothermal systems available commercially, with tailored characteristics depending on locations. Within the following section, an overview of the most common technologies is included, with a specific emphasis on Enhanced Geothermal Systems, as there is a potential in the Netherlands for its' application, and also for a better understanding of the Leeuwarden located project presented in Chapter 4. Technologies that are not likely to be implemented in the Netherlands, (e.g. the dry steam-based technology) can be found in the Appendix.

3.2.1 Geothermal Heat Pumps

Geothermal heat pumps or geoexchangers have been used since the middle of the 20th century, as these are great alternatives for space heating or for industrial purposes that utilize much less energy to heat buildings than conventional heating systems. When selecting heating options, it is essential to compare the benefits of each ground heat pump alternatives, in terms of efficiency, emissions, and economics while keeping the subsurface and climate characteristics of the specific area in mind (Lund et al., 2014). Geothermal heat pumps use low-temperature geothermal resources that are abundant in most areas throughout the world. The technology is based on the steady temperature of the earth as an exchange medium rather than the outside temperature of the air. Even though there can be a significant air temperature difference between seasons, the temperature of the shallow subsurface remains almost constant. Depending on geographical locations, this temperature changes between 7°C and 21°C (Omer, 2008). Throughout the winter, the ground temperature is warmer than the air, while it changes to the opposite in summer. With the help of a heat exchanger, the heat pump uses this temperature difference by exchanging heat with the earth, and it can be used for either heating or cooling services. Heat extraction with heat pumps is relatively easy, as it is done from shallow depths. Heat pumps extract water (<30°C) and raise its temperature for a required level. Installation costs are relatively high, but with the low maintenance and additional cost and with the energy savings due to the heat pumps, the expenses are returned in 5-10 years (depending on climate and subsurface characteristics) (Omer, 2008). In the Netherlands, the Sustainable Energy Investment subsidy scheme is a governmental grant that can be obtained for geothermal heat pump installations, for both individual and business applicants if they meet all the technical criteria. (Netherlands Enterprise Agency, 2019)

3.2.2 Liquid Dominated Geothermal Plants

This technology uses hot liquid that is piped from the production wells to the plant. Since the electricity generation process requires steam to rotate the blades of the turbine, the water from the aquifer needs to be transformed into vapor. It is done by lowering the pressure of the water in a water-steam separator. The steam - after the power generation process - is condensed into liquid and injected back to the reservoir. Reservoirs storing hot liquid water are much more common than dry steam reservoirs, so the technology can be applied worldwide. These power plants operate using water reservoirs with temperatures around 180°C or higher. The aquifers are mainly located in rift zones, hot spots, and near subsurface magmatic bodies (“Different Types of Geothermal Energy,” 2019).

3.2.3 Binary cycle power plants

Binary cycle plants -just like liquid dominated plants - use warm water as a heat transferring medium, however, in this case, the temperature of the water is not high enough, therefore direct steam generation is not economically feasible. Instead, the low-temperature subsurface water (~110-160°C) is used to heat up another, secondary working liquid with a lower boiling point and high vapor pressure at that specific temperature (Franco and Villani, 2009). It is important to mention that the two fluids must be kept separate in the heat exchanger, as avoiding direct contact would eliminate the risk of contamination. One of the greatest advantages of this technology is that since the geothermal fluid does not have direct contact with mechanical components either, the life expectancy of the equipment is longer. To increase both the energy and exergy efficiency of the system, recovery cycles can be implemented for all geothermal fluid temperature and working fluid combinations. The process from this point is exactly the same as in the other, previously described electricity-generating power plants. These reservoirs are the most abundant among the three types used for electricity generation, and as a result, binary cycle power plants are a great alternative for green energy generation. In numerous fields, binary plants are the only economic technology for geothermal energy exploitation (DiPippo, 2012). The likelihood for this technology to be applied in the Netherlands is relatively high, as at several locations the geological properties of the areas do not allow other technologies since the temperature of the subsurface liquids is not that high.

3.2.4 Enhanced Geothermal Systems (EGS)

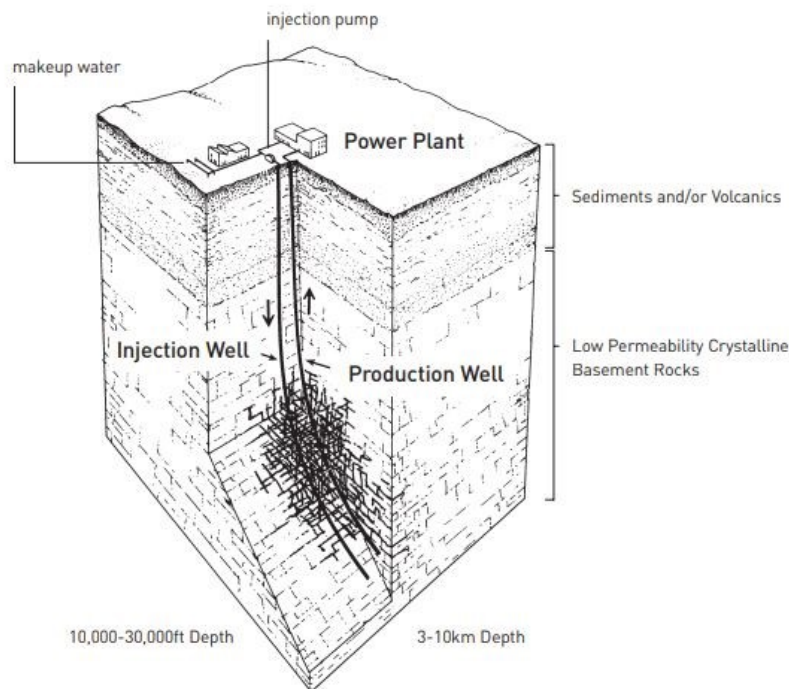


Figure 5 Enhanced geothermal energy system (Tester et al., 2006)

The previously described geothermal systems or conventional, commercially feasible systems have three major characteristics. First, the high-temperature geothermal formation is located near the surface (1-4 km), which makes the drilling and the extraction relatively simple. Second, the fragmentation and permeability of the targeted rock formation enable fluid-circulation. Third, the fluid content of the geothermal

reservoir is sufficient for extraction. Enhanced or Engineered Geothermal Systems does not have all three attributes to qualify as conventional systems naturally, but these are created artificially, for instance, by hydraulic stimulation (Sanyal and Butler, 2005). In other words, the missing criteria are engineered in order to extract geothermal energy of the deep underground strata. The permeability of the deep (<10km), high-temperature rock formations is low, as these basement rocks are mostly hard, crystallines, for instance, granite. If the rock formation does not have the required permeability (which is the most common in case of non-conventional geothermal resources) with the injection of high-pressure fluid, the existing fractures can be opened, or new fractures can be created. It is also possible that the permeability would be good, but there is no liquid. This is the so-called hot dry rock system, which can be turned into geothermal energy producing strata with the injection of liquids (water). Similarly to conventional systems, at least two wells need to be drilled, a producer and an injector (Tester et al., 2006).

The first Enhanced Geothermal systems project took place in the USA in the early 1970s'. At that time, the technology was called the Hot Dry Rock program, and it was only changed to EGS (which represents the technology more precisely) in the last decade (DiPippo, 2012).

First, the low-permeability hard rock is reached by a well. With the injection of high-pressure fluid, the existing fractures are opened and grown in order to sufficient fluid circulation. A second well is required which intersects the expanding cracks so connection within the wells is created. The fluid circulation between the wells must be monitored since, at this point, additional fracturing can be performed to moderate flow impedance. The extraction can begin as soon as the required flow rates are stabilized. After the stored heat is used for either electricity generation (with the conventional binary flash systems) or heating services, the cooled fluid is re-injected. As it is a closed circle system, the fluids will be reheated underground and used again (Olasolo et al., 2016). Several successful projects prove that this conceptual model works in practice as well. Boreholes can be drilled into hard, low permeability rock, the strata can be pressurized and the hydraulic conductivity can be achieved through the fractures among the boreholes. Fluid circulation in the enhanced geothermal systems is possible, which provides opportunities for energy extraction from reserves at great depth. Even though all steps of heat extraction are technically feasible, the development of EGS is yet at its early stage. Altogether it can be stated that all technical components are in place to extract the energy stored deep underground by the Engineered Geothermal Systems. With this technology, long-term, secure and cost-competitive capacity could be provided which would help to eliminate the energy-related economic risks (supply disruptions or the influence of fuel price fluctuation). However, there are still a lot of contingencies regarding subsurface characteristics, flow rates, engineering options, and economic uncertainties which determines the future competitiveness of EGS (Tester et al., 2006).

3.3 Geothermal energy in the Netherlands

3.3.1 Subsurface properties

The geological structure of the Netherlands provides great conditions for the planned extensive utilization of geothermal energy. Detailed information about the subsurface conditions, as the mineralogy of the reservoir, the composition of the stored fluids, and the temperature distribution is essential in order to find the best locations for exploitation. As the study does not focus on the specificities of all locations, only the most important details are enclosed. Generally, in the Netherlands, the sandstone strata have the best properties from the onshore subsurface layers. So far, the targeted reservoirs have been Tertiary or older, Jurassic, Cretaceous layers, with seven potentially suitable strata. Based on the currently available subsurface information, the estimated stored energy of the Rotliegend, Triassic, Cretaceous and

Jurassic layers is 370,000 PJ (Masterplan, 2018). This number is only an estimate, as the real geothermal potential for the majority of the subsurface remains unknown. However, EBN and TNO are commissioned by the Ministry of Economic Affairs and Climate Policy in order to conduct seismic surveys and test drillings to increase the accuracy of the estimations (Masterplan, 2018). As more big players get involved in geothermal research and utilization, the more detailed the subsurface information will become, and the better the business case will be. In 2019, Shell, Eneco, and Vermilion Energy, all wealthy, originally oil and gas companies that are nowadays simply called 'energy companies' announced that they will start working on the development of geothermal projects (DAGO, Personal communication, 31.07.2019). These multinational companies have the financial background and also the experience with underground drillings, which enables them to quickly become involved within the geothermal industry ("Eneco and Shell join forces to jointly develop geothermal heat in the Netherlands," 2019).

3.3.2 History

The history of geothermal energy only goes back to a few decades in the country, as the first well was drilled in the South, in Asten, in 1986. At that point, only one stratum (Breda Formation) was discovered with the required properties for geothermal exploitation, however, the drillings did not succeed and without the establishment of a doublet, and the project has not started again since (Lokhorst and Wong, 2007). Twenty years have passed between the first and the second deep geothermal exploration project, that occurred near Bleiswijk, in 2006, which showed a successful example and lead to the establishment of a couple of other doublets. By the beginning of 2018, fourteen doublets were operating, out of the drilled twenty. Each of the doublets produces water between 65-100°C without an artificial induction. Geothermal energy is mostly used in the greenhouse horticulture, however, based on the technological developments and the properties of the country, it's role could be expanded significantly, especially for residential heating. Even though the desired attributes are mainly given, there are unwanted circumstances, like the corrosion of pipes caused by the chemical composition of water. Generally, the salinity geothermal fluids are originated from dissolved salts, that is most commonly sodium chloride and other chemicals that can cause corrosion, which complicates the upscaling (ThermoGIS, 2017).

3.3.3 Ideas and future plans

The Dutch energy sector is facing a major shift, as the 2050 goal is to be as close to carbon neutrality as possible and cut the CO₂ emissions by 95%. Heat consumption in the country is responsible for approximately 40 % of the emissions (all, CO₂ equivalent), which means that in order to reach the set target, 36 megatonnes of emission needs to be reduced from the heating sector by 2050. New or currently not applied technologies and heat sources are needed to diversify the sector. According to forecasts, due to more efficient use of energy, improved insulation, and the stagnating population, the current heat demand will fall with around 10% (from 960 PJ to 870 PJ) in the following 30 years (Energy Agenda, 2017). When analyzing the current consumption and forecasting the future energy need, three categories can be separated: urban, industrial and agricultural sector. In the following, for each sector, the different, sector-specific technologies are also mentioned that can reduce the consumption and emissions, while improving efficiency. Currently, almost 50% of the country's demand originates from the urban setting. Individual solutions as numerous types of heat pumps, and also collective solutions as the establishment of district heating networks should be applied. The industrial sector consumes around 40% of the total demand, where new more efficient technologies, waste heat recovery, green fuels, and other options are available for reducing consumption. The agricultural sector consumes the remaining 10% of the total heat demand of the Netherlands, where all sorts of options are available, which are similar to the ones of the urban environments'. The reduction of heat demand on a small scale heavily depends on the properties of each unit, as the location, demand of heat, the temperature of heat, etc. In order to achieve the goals, all sorts of sustainable alternatives need to be considered and used, solar, wind biomass and geothermal energy (Opschaling aardwarmte in warmtenetten, 2018).

Geothermal energy could play an important role in the upscaling of sustainable heat in the energy mix and contribute to the heating sector by 200PJ and one-third of the required emission reduction in the year of 2050. This significant contribution comes from the fact that geothermal energy can not only be used in one sector but in horticulture, industry (<250°C) and also in the urban environment. Currently, it is mostly used in the greenhouse horticulture, as it supplies around 3 PJ of sustainable heat from medium depths (2000-3000m). In specific geographical areas, geothermal energy is the cheapest of the sustainable heat options as it is able to supply the required heat without seasonal fluctuations (perfect for baseload), it requires low maintenance and also, the CO₂ emissions are minimal (Masterplan, 2018). All of the ambitious geothermal plans are based on the following assumption: in the coming years, the more

accurate subsurface knowledge gain and the successful ultra-deep pilots will help in the upscaling, and the costs, uncertainties and technical risks will significantly be reduced by economies of scale. Additional long-term reductions are also possible through innovations and intense R&D. Compared to the total heat demand, the current and planned geothermal energy use per sector can be seen in Figure 6 in the year 2018, 2030 and 2050. It is important to realize that for the calculations, the reduction of the total future heat demand was already considered (Masterplan, 2018).

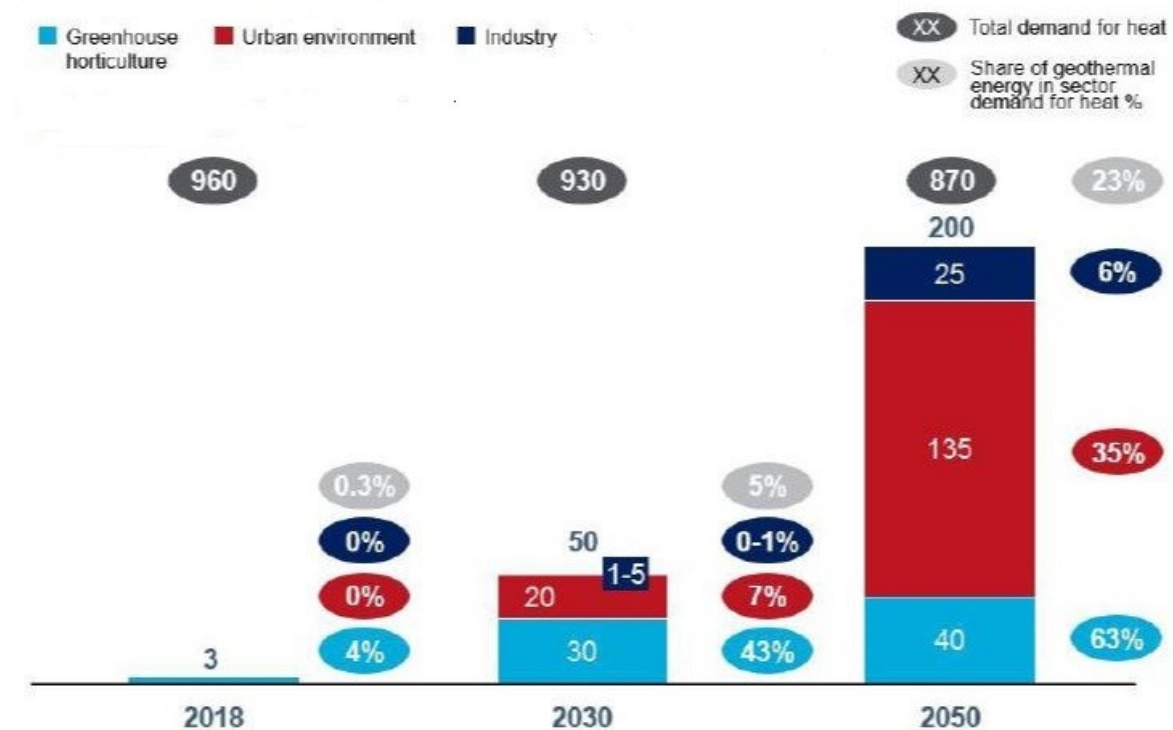


Figure 6 Ambition for geothermal energy in the greenhouse horticulture, urban environment, and industry (Masterplan, 2018)

The greenhouse horticulture is the only sector at the moment that uses geothermal heat, but the installed capacity is minor, only 3PJ which is 4% of the total demand. The idea is, that with the planned expansion, in 2030 it could increase to 30 PJ (43%) and by 2050, the amount could reach 40 PJ (63%). The play-based portfolio approach serves as a good opportunity for the upscaling in the horticulture, as most of the greenhouses require the same temperature, while this factor varies widely in the other sectors. Finding the suitable plays (subsurface strata) and exploiting it with the same parameters (same technology, risk, cost) would enable the fast extension. As the demand is concentrated and the number of full-load hours is large (6000 h/year) there is already a good business case for geothermal energy, meaning it is one of the best, most economical solutions for heating (Opschaling aardwarmte in warmtenetten, 2018).

In the urban environment geothermal energy could contribute by 20 PJ (7%) in 2030, and 135 PJ (35%) by 2050. For this sector, the establishment of the district heating networks and new grids were also already considered for the calculations (Masterplan, 2018). The most reasonable idea for upscaling geothermal energy in this sector is focusing on the existing heat networks and turning those into renewable ones (as most of them currently run on natural gas). A district heating network transports the heat that has been generated in a plant (that could be both based on fossil fuels or renewables) to consumers within a specific area (Opschaling aardwarmte in warmtenetten, 2018). A primary pipe network distributes the water from the plant to the network, while a secondary, more complex underground pipe network transports the water to the end-users. As in most cases, there are distribution losses involved in the process as the water has to be transported to extensive distances. Depending on the temperature value of the distributed water, the energy loss is relatively high and rises with 0.75% per every 10°C increase. The insulation of the pipes and the lower temperature values of the water can reduce the exergy losses, however, the lower temperatures would increase the costs of the pumping (Çomaklı et al, 2014). The following step should be the exploration of further options, as realizing pilots to test the technical and organizational requirements and gain experience with geothermal heat networks. The initial goal would be to reach the 200+ PJ / year within the urban environment, which would require about 3.3 million households to be connected to the new district heating networks (Opschaling aardwarmte in warmtenetten, 2018). Geothermal energy is the cheapest and most sustainable (after waste heat) heat source that could provide the baseload of a heat network, as it's availability does not show fluctuations, and the volume is not limited (compared to e.g. biogas).

Application of geothermal energy in the industrial sector would take the longest time, since in industry the temperature requirements are much higher (but still in the medium temperature zone), which would most likely require the operating ultra-deep geothermal plants. In those specific industrial areas where the required temperature is exceeding 250°C, geothermal energy cannot be used. Depending on the success of ultra-deep geothermal projects, in 2030, 1-5 PJ (0-1%) of capacity could be installed, that could be upscaled to 25 PJ (6%) by 2050, with a bandwidth of 1-60 PJ. The uncertainty originates from the lack of knowledge and experience (Opschaling aardwarmte in warmtenetten, 2018).

The aforementioned ideas and the serious upscaling plans require high upfront investments and the establishment of nearly 700 geothermal doublets. Based on personal conversations (see

Appendix), this number seems optimistic (not impossible) but greatly depends on the success or failure of the geothermal projects of the upcoming years. Currently, there are 17 active doublets, but this number is planned to grow to around 175 by 2030, and 700 by 2050. The most intense increase is forecasted to occur from 2025, with at least five simultaneous drillings yearly (Masterplan, 2018).

According to the Master plan, six goals need to be achieved in order to reach the main goals set by the government and the geothermal sector,

- First, with the development of competent business cases, profitable projects must be elaborated. This involves the reduction of costs and risks as much as possible while increasing the profits throughout the life cycle of the projects. Adequate tools for this step would be the SDE+ scheme and application of the play-based portfolio model.
- Second, the government has to provide the appropriate regulatory and policy background. This includes the development of industry standards, the implementation of the New Mining Act, the creation of new permit models, coordinating and cooperating with stakeholders.
- Third, providing safe and efficient operational activities while expanding and distributing information which would enable better decision making regarding investments and operational activities.
- As the fourth step, ensuring successful public participation with proper communication, knowledge sharing, and transparency. Each target groups must be contacted and informed about all the risks and costs which requires a national and local plan for information exchange and participation model.
- Fifth, throughout the given time period (until 2050) while the entire geothermal value chain will be under development and growth, new and innovative ideas must be involved and developed in order to further reduce costs and risks and to increase the pace of the upscaling.
- As the last factor, the establishment of district heating networks is required. With these new/already existing but geothermal energy based grids, more than 3 million households could be supplied by the year 2050. In order to achieve this, new partnerships between heat supplier companies and the government must be made, and pilot projects must start in the upcoming years.

3.3.4 Institutions

In order to achieve these plans in a safe, cost-effective and sustainable way, the sector has already started to work on all aspects of the upscaling. Stakeholders, such as heat suppliers, research institutions and the government are actively developing propositions for geothermal energy exploitation. As mentioned before, it is still in the first phase, however, in order to have the chance for upscaling, stakeholders must act now, and develop structural partnerships, business cases and start experimenting with pilots. The sector started to grow in the last decade, however, the base needs to be broadened, the entire value chain needs to grow. Several institutions are involved with different responsibilities in order to facilitate the objectives of the geothermal energy sector, with DAGO, SPG, Stichting Warmtenetwerk, EBN, Ministry of Economic Affairs and Climate Policy (EZK), Ministry of the Interior and Kingdom Relations (BZK) holding the most important roles. If the process develops according to the plans, new consumers, operators, and other market players will be involved with a heavily increasing number (Opschaling aardwarmte in warmtenetten, 2018). This requires a solid and detailed policy and regulatory background, which also needs to be developed. Industry standards will be prepared and implemented by DAGO (Dutch Association Geothermal Operators) which institution is also responsible for cooperation and coordination of policymakers and regulatory groups. Support from all stakeholder groups and most importantly from society is inevitable and needs to be in parallel with the development of the industry. For this aspect, cooperation, knowledge sharing, and transparency are at high importance. Stichting Platform Geothermie is the dedicated platform that provides general information about geothermal energy and represents both the demand and supply side. Furthermore, local and national forums are also planned to ensure adequate conversation within society. The development of successful public participation and support model is important, especially before the geothermal energy projects begin since not only the enrollment of the government and suppliers side but from the eventual consumers' side is required in order to reach the goals (Masterplan, 2018).

The sector is somewhat dependent on the government. Financial support needs to be provided for further research and investigation about the subsurface properties, and also for the implementation phase. The SDE+ subsidy scheme needs to be broadened in order to be more 'geothermal energy-friendly'. The SDE+ (Stimulerend Duurzame Energieproductie) scheme is a governmental grant created to support renewable energy generation. Energy production from renewable sources comes with higher costs for the producers than the market price, which price difference is called an unprofitable component. Applicants that are eligible for the grant can

get the unprofitable component back for a specific number of years, based on the used technology. The compensation is available for renewable gas, heat or electricity producers but the application is tight to explicit criteria (Netherlands Enterprise Agency, 2019). It is important to include all three sectors for geothermal energy use (urban, industry, horticulture) and also to provide sufficient capacity for the processing of permit applications adequately. Other than financial support, the government plays an essential role in regulatory aspects. Secure and sustainable energy policy has to be developed with specific commands, goals (e.g. CO₂ savings), and cost-models (e.g. specific cost reductions). Furthermore, the Mining Act needs to be amended accordingly, with the inclusion of geothermal permits, tendering, technical and safety requirements. Governmental authorities will have to make decisions on the local level as well, regarding the establishment of heat networks, identifying the districts, deciding on the ownership and to ensure low social costs (Masterplan, 2018).

3.4 Interests and benefits

Currently, the government, investors and the society are mostly uninformed of the benefits of geothermal energy, which results in a slow process of upscaling with a lot of uncertainties. This problem could be solved if all information related to geothermal energy would be public, which could easily raise awareness among society. In the following section, the interests of the three aforementioned major stakeholder groups will be discussed, simultaneously with the benefits, as these are in close relation.

3.4.1 Government

The government has to keep several things in mind. From one hand, actors of the state must operate in a way to serve the needs of society, however, they also have to follow international, and also national regulations. Energy security is one of the most important factors for the governments, as safe and reliable energy should be accessible for everyone in society. The issues at the Groningen natural gas site and also current and future regulations for reducing natural gas consumption require more renewable and sustainable sources of energy. If the operation of the Groningen site will be entirely closed by 2030, other alternative fuels will be necessary to be applied, which is an ideal case would not come from other countries (“Dutch to stop drilling for gas under Groningen by 2030 - DutchNews.nl,” 2018). Importing energy sources would heavily increase the Netherlands’ dependency on another country, which can cause several issues. For instance, Russia is the main exporter of crude oil and natural gas in

Europe, which means that countries that depend on the Russian supply must pay the price set by them, and also keep a good relationship with the country. Politics plays a key in this regard, as there are several examples from the past when the Russians decided to close the pipes because of political conflicts (Söderbergh et al., 2010). As geothermal energy is independent of seasonal fluctuations and serves a perfect source for baseload supply, its share in the energy mix should be increased. Complying with international and national regulations is also at high importance. Contributing to the Sustainable Development Goals of the United Nations, national carbon emission goals, and all sorts of green regulations that can be expected within the next decades are essential from an effective federal government. The increasing pressure from society for clean energy supply could also be served.

3.4.2 Customers/society

There are numerous benefits for society linked to geothermal energy usage. The usage of renewable clean energy can reduce the CO₂ emissions of a country that contributes to better, healthier living conditions. Furthermore, job creation is one of the main benefits society could gain through geothermal projects, whether direct (engineers, project managers) or indirect ways (suppliers, consultants). Most of the projects, especially the ultra-deep ones take years to establish and involves people with all sorts of expertise. The planning of the project, the financial and legislative matters, the scientific surveys that are required prior the drillings can give job opportunities to geologists, geophysicists, governmental officials, and other leaders of relevant stakeholder groups (Opschaling aardwarmte in warmtenetten, 2018). Operations, engineering, administration, and maintenance are common areas where labor is needed, once the plants/boreholes are operating. In 2018, only 240 people were working related to geothermal energy, 70 directly, and 170 indirectly. According to the Masterplan, by 2050 after a successful upscaling around 700 actively operating wells, the number of employees in the geothermal energy sector can reach 3400 (1000 direct, 2400 indirect) on a national level. This number is based on assumptions, indicates approximately 2.5 indirect jobs per direct job and also includes the needed labor for the heat network expansion (Masterplan, 2018). Another great benefit for consumers is that the price they pay for geothermal energy must cost 15% less than gas, which rule is set in the NMDA (not more than otherwise) principle in the Heat Act (Oei, 2016).

3.4.3 Investors/businesses

Even though with the NMDA principle the investors are in a disadvantageous position when it comes to selling geothermal heat, there are several other factors that are in favor of the investors. In those cases where the drilling and the operation of the geothermal wells were successful, and the infrastructure already exists (district heating network) for distribution, the payback time is relatively low. Geothermal plants do not require excessive maintenance is also beneficial for the investors, just as the fact that the plants can run for decades. The play-based portfolio approach could also be in favor of the investors as after one successful project, the follow-up projects within the portfolio have much smaller risks, both technically and financially. For businesses and in industry, using geothermal energy for the processes can increase the number of customers, that are environmentally conscious, and they want to support green businesses. Even though there are numerous factors that can serve the benefit of a business, the risk from the three aforementioned stakeholder groups is the largest in the case of investors (Opschaling aardwarmte in warmtenetten, 2018).

3.5 Concluding remarks

The third chapter identifies that geothermal energy offers great potential and could be applied extensively for residential heating purposes. At the moment, the heat demand in the housing sector is mainly fossil fuel-based and supplied by mainly natural gas, with only a diminutive fraction of renewables. Increasing renewable energy within the energy mix requires new policies, societal acceptance and high investments from businesses and the government. As a closure of the first major section of the study, in the following paragraphs, the first two sub-research questions are answered, namely:

What is geothermal energy and what is the current state of the art, especially for residential heating in the Netherlands with respect to the subsurface properties of locations and energy production technologies?

The Earth's interior heat, or geothermal energy can be found in the form of natural steam or hot water all around the world. For decades, it has been exploited for electricity generation, space heating, and industrial purposes. Depending on the location, the geological properties of the subsurface are different, which determines the type of technology that should be applied for the above-mentioned sectors. In the Netherlands, where the geothermal gradient of the subsurface is around the global average (30°C), most of the technologies could be applied,

except for those that require hot natural steam. Even though electricity generation is not a priority in the plans of the country, it does not mean that in the future, binary cycle plants or liquid dominant plants cannot be established (as the circumstances are adequate). Currently, the direct application of geothermal energy is dominant, via simple production and reinjection wells, and it is applied in the greenhouse horticulture. The plan of the actors within the sector to expand the application of geothermal energy to not only the industry but more importantly to the residential heating sector. Geothermal heat pumps are also applied, on a small scale, but since this technology is the easiest one to establish even on a household level, it is expected to be applied more commonly in the coming years. Lastly, ultra-deep geothermal energy has a high potential to be applied in the Netherlands, as there is an ongoing, intense research project to find the best locations for pilot testing. However, it is important to note that there are numerous uncertainties related to this technology, and also a lot of risks.

What are the expectations of experts and the academic literature about the sustainability and the socio-economic feasibility of geothermal energy for residential heating and what is the assessment of a realistic time perspective for full exploitation of the geothermal potential in the Netherlands?

Geothermal energy would be a great option to supply a large number of consumers with green, secure and safe energy, as it is independent of weather patterns, and has a substantial capacity. The current plans and ideas of actors within the sector indicate a significant increase in the number of doublets by the year 2050. At that point, it is expected to have more than 700 doublets established and operating in the country. Throughout the interviews, the interviewee's opinion was rather similar and stated that since this sector is new, and in development, there are too many uncertainties to decide whether the 700 doublets is an optimistic or realistic number. The regulatory background has a lot of white spots, and also, it is uncertain how society would react to the intense upscaling, which involves a lot of risks, especially when it comes to the drillings. Economically, at this point, geothermal energy is only competitive since the SDE+ subsidy covers renewable heat generation as well, and not only electricity generation (as in many other countries). However, the price of natural gas is expected to increase in the future (resource depletion, carbon tax) which could also make geothermal energy more attractive. Furthermore, a lot depends on the success or failure of the ultra-deep geothermal projects of the upcoming few years. In case the pilots are successful, the upscaling can happen even faster than planned, but if those fail, the upscaling of the geothermal sector can be significantly slower than stated in the Masterplan.

Chapter 4

The following section serves as the second major component of the study, which describes the geothermal energy plans of Leeuwarden. The information and data used for the section are mainly based on the documents released by relevant institutions, or provided by relevant stakeholders, particularly by the geothermal project leader of Ennatuurlijk. In the first subsection, the general context of the Dutch ultra-deep geothermal projects is introduced, and it is followed by a detailed analysis of the Leeuwarden project.

4.1 Green Deal

A significant milestone was reached on the annual presentation of the EBN-report in The Hague, 19 June 2017 when the Green Deal was signed. The Green Deal is a covenant in which the Ministry of Economic Affairs together with seven partners agreed to invest and explore the Dutch subsurface and the utilization possibilities of ultradeep geothermal energy (Heijnen et al., 2019). The signatory partners are categorized based on their geographical regions: Friesland (FrieslandCampina), Central Netherlands (Vermillion Energy, Geothermie Brabant, Parenco, GOUD), and the South of the Netherlands (Port of Rotterdam, Huisman B.V). The facilitation of the research is done by the Ministry of Economic Affairs in cooperation with the Energie Beeher Nederland B.V (EBN) and the Organisation of Applied Scientific Research (TNO). The outstanding significance of this agreement is that the signatories agreed on absolute transparency, meaning that the information and knowledge from the surveys and research they pursue in the upcoming years will be shared (“Green Deal Ultradiepe Geothermie getekend - EBN,” 2018). The transparency shows that in this case rather than profit and the interests of the parties, the reduction of technical risks, costs and the achievement of the common national targets are in main focus. The central goal of the project is to select the most suitable locations for the pilot-scale ultradeep geothermal energy exploitation, ideally in a well-distributed manner throughout the country. The first, still ongoing stage includes the analysis of the geological properties and seismic data of each of the chosen locations meanwhile exploring the utilization options and infrastructure requirements. The planned date of the decision making regarding the selection of the most promising pilot project locations will be the end of 2019/beginning of 2020, however, due to several uncertain circumstances, the date is not finalized. As a result, the first drillings will not be done before 2020 (EBN, 2019).

After the adequate conditions are found and the successful drilling operations are done, the first pilot project shall provide deep insight into the most promising approaches and would allow further development of ultradeep geothermal energy utilization in the country. The knowledge and information gained throughout the implementation of the first project could significantly reduce the costs and the risks of the follow-up projects (Personal communication, Ennatuurlijk, April 2, 2019).

4.2 Leeuwarden project

The geothermal energy project in Leeuwarden is based on three pillars: two geothermal wells (RFC and BGDD) and a heat network. As the map 1 presents, the location of the first well (BGDD) is on the west of the city, located nearby the World Trade Center while the second one (RFC) is on the FrieslandCampina site.



Figure 7 Leeuwarden geothermal projects (Ennatuurlijk, 2019)

Ennatuurlijk, as the company in charge of the planning, has developed a model which envisions constructing a district heating network through the entire city. This is demonstrated through the red lines on the map which represent the main infrastructure (pipes) for distributing the heat to the consumers. In case the project reaches the phase of establishment, the idea is to execute the plan in three phases. First, the infrastructure which connects BGDD to the south network of the city would be released. Second, the line from RFC to the power plant of Ennatuurlijk (Energiecentrale) would be constructed. Finally, the remaining infrastructure (mainly on the

North) would be connected to the already established heat networks. The proposed heat resources to supply this network are geothermal heat, biogas, and heat from FrieslandCampina. (Personal communication, Ennatuurlijk, April 2, 2019).

4.2.1 BGDD

A construction company, Dijkstra Draisma would be the first one to establish a geothermal heat plant in the city, as -according to the plans-, the drillings will start in 2019. The depth of the well is approximately 2700 meters, with the expected water temperature of 92 °C. At the current stage, the plan with the geothermal energy is to be used directly in the World Trade Center site and also for the heating of Cambuur Stadium. In the future, however, when the residential area is already connected to the existing southern heat network, the geothermal heat could be also used for heating households. This way 80% of the southern network's demand would be supplied by the geothermal source, heating approximately 750 households ("Leeuwarden de tweede stad met geothermie in de bebouwde kom? - Bouwgroep Dijkstra Draisma," 2018). As per the finances, the company in cooperation with Ennatuurlijk already received 72 million euros of a grant from the government. The upfront investment is approximately 30-40 million euros, however, 15 years after the operation starts, the plant has to become profitable, which requires the rest of the grant for financing the maintenance and other expenses. On the long-term, this plant could supply 15% of the energy demand of the Leeuwarden (Ennatuurlijk, 2019).

4.2.2 RFC

The second, RFC well is an ultradeep geothermal energy project. The plan is under development by FrieslandCampina in cooperation with Ennatuurlijk. The project is still in the research phase but based on the results so far, it seems promising (Personal communication, Ennatuurlijk, April 2, 2019). According to the plans, the wells would go further than 5km depth, with the expected water temperature of >150°C. However, based on the data collected already, there might be some complications, regarding the pressure. At this depth, the pressure can reach as high levels as 140 kbars, which complicates the process and requires more specific infrastructure. The exact implementation would not be done by either FrieslandCampina or Ennatuurlijk. A third party with more knowledge and experience in drilling would be responsible. It is reasonable, as the main focus of the dairy company is to produce milk powder and condensed milk, while Ennatuurlijk is an energy supplier company, but not in charge of drilling and other tasks. As such, none of the two parties have expertise with geothermal energy,

therefore the project has to be outsourced. Additionally, an exploration permit must be issued as pre-requirement by the Dutch Mining Act (Mijnbouwwet). In case the RFC is chosen by the Government for the pilot, and the third party is selected (possibly Vermilion Energy), the drilling process itself and the installation of the plant can be conducted. On the long-term, the third company (Vermilion Energy) would also maintain the plant. At the moment, the ownership of the well and the plant itself is uncertain, but most likely FrieslandCampina will have the biggest share. Consequently, FrieslandCampina would enter into two contracts with Vermilion Energy: one contract for the implementation of the geothermal plant and one contract for the consistent maintenance of the upcoming years (Personal communication, FrieslandCampina, March 21, 2019).

4.2.3 Heat networks

The already existing infrastructure of the district heating network can be seen on map 2.

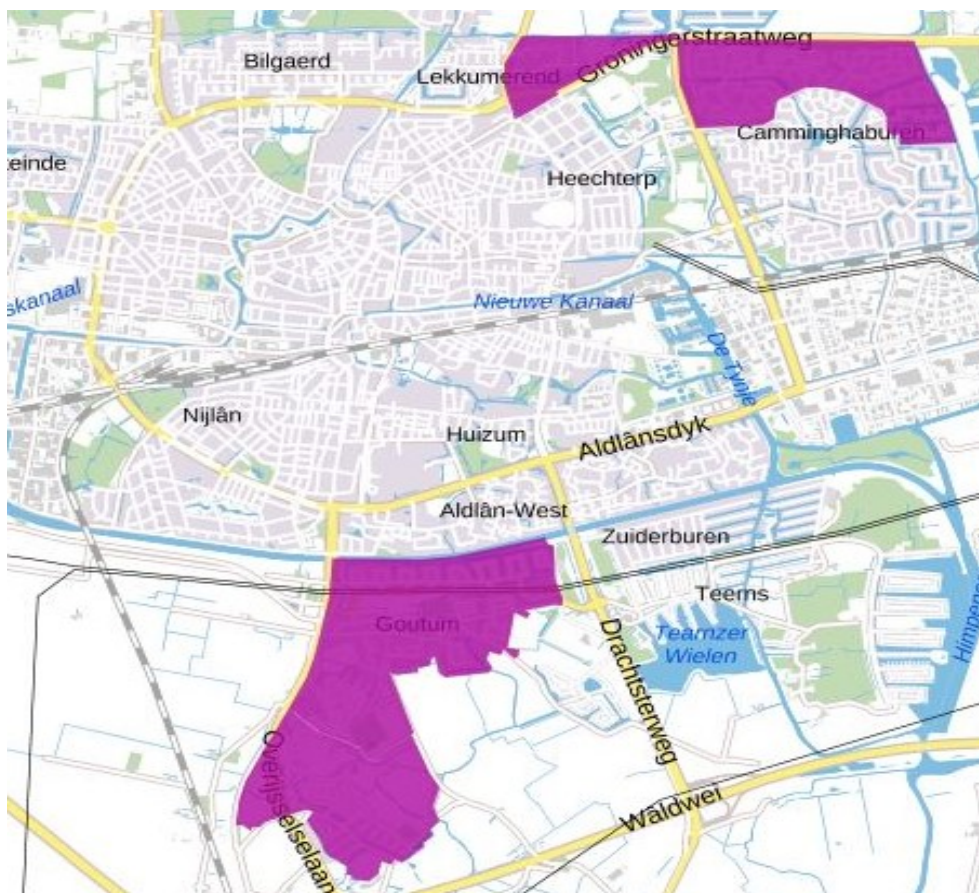


Figure 8 Existing heat networks in Leeuwarden (Warmteatlas, 2019)

In the previous chapter, it was already described that the presence of a district heating network can greatly improve a project while significantly decrease the costs (Personal Communication, DAGO, July 31, 2019). The already existing network in Leeuwarden can serve as a starting

point, but as it can be seen on the map, the majority of the city still does not have the necessary infrastructure as the networks only cover two, relatively small area. This has significant importance in the planning of a geothermal system that is aimed to cover the entire city. The results are much higher costs, longer payback period and also longer time-period for the establishment of the infrastructure and the project in general (Personal communication, Ennatuurlijk, April 2, 2019).

Within the city of Leeuwarden, the two already existing heat networks managed by Ennatuurlijk, namely: Camminghaburen and Zuidlanden. The district heating network in the North, Camminghaburen is connected to a cogeneration power plant, that is fired by natural gas. Currently, this network supplies warm water to 1500 households, however, approximately 200 houses are under reconstruction, that will be connected to the network. Furthermore, the Camminghaburen network provides heat to a swimming pool and a gym within the district. On the South of Leeuwarden, the Zuidlanden heat network supplies 750 households with biogas, that comes from the Dairy Campus (also located on the South). An average household consumes 30-35 GJ energy from the district heating network. The temperature of the supplied water in both networks is between 75-85°C with a deviation of 25°C. The water that comes out from the household has a residual temperature of around 40 °C, which is below the re-usability level (Personal communication, Ennatuurlijk, April 2, 2019).

4.3 Stakeholder analysis

Within the following section, the most influential players and their interests within the geothermal project are described, namely Ennatuurlijk, FrieslandCampina, housing corporations, and Vermilion Energy. Ennatuurlijk as the energy supplier, WoonFriesland, as the leading housing company in Leeuwarden, that can represent the consumers' needs, and Vermilion Energy, that is anticipated to conduct the implementation and maintenance of the geothermal plant. Furthermore, the Province and the Municipality of Leeuwarden as a state actor also play an essential role as these are able to put pressure on other participants within the project and can control the landscape through legal and financial incentives (Personal communication, Ennatuurlijk, April 2, 2019; FrieslandCampina, March 21, 2019).

4.3.1 Friesland Campina

FrieslandCampina, as a leader of the Dutch dairy industry, has a high energy consumption, with 13 million m³ natural gas used annually in the company's Leeuwarden located production

facility. The reason for this high consumption originates from the fact that in the site, milk powder and condensed milk are being produced, and for both products, evaporation (a highly energy-intensive process) is a necessary step. For the evaporation step, steam is generated in enormous boilers, that currently run on natural gas. Additionally, 1.6 MW of residual heat is produced throughout the whole production process, that is wasted. As the boilers were installed around 30-40 years ago, and as a result of the company's great efforts to find more energy-efficient production processes and reduce the residual heat, the natural gas boilers will be replaced (Personal communication, FrieslandCampina, March 21, 2019). There is a vast question mark at this plan, as the type of the new boilers will depend on the 'fuel' they run on, that could be natural gas, biogas, hydrogen, or geothermal fluid as well. Based on personal conversations with the employees of FrieslandCampina, the current issue is not surprising, the company is profit-oriented. The sustainable and green heat source would only come as a side benefit, the most important factor is that they need the heat, at a cost as low as possible. The same goes for the heat recovery systems for the production processes. The company spent a significant amount of money on research, but none of the business cases were good enough to actually implement a new system (Personal communication, FrieslandCampina, March 21, 2019). On the other hand, as on the long term, geothermal energy would save money for the company, and as the plan of connecting the FrieslandCampina site with the district heating network, both issues of the company could be solved. From one angle, the heat for the production would come at a lower cost than natural gas, while with the connection to the heat network, the residual heat of the company could be sold. Of course, the investment costs are high, but if the project gets selected from the seven pilot plans and receives the grant, 50% of the total 85 million euros of the cost would be paid by the state (Personal communication, Ennatuurlijk, April 2, 2019) while the rest would be split between the involved partners.

4.3.2 Ennatuurlijk

A Dutch sustainable heat supplier, Ennatuurlijk is one of the leaders within the national green energy companies in the Netherlands. It is owned by two organizations, namely Veolia and PGGM. The latter, PGGM (Stichting Pensioenfonds Zorg en Welzijn) is a non-profit pension fund, that owns 80% of the company, while the remaining 20% is owned by Veolia, which company takes care of the maintenance of the energy infrastructure. The aim of the company is to provide affordable heat and cold for customers with a small environmental footprint while cooperating with local actors, and the government. Based on the personal conversations, within Ennatuurlijk, financing the projects is barely an issue ('money is not the problem') (Personal

communication, Ennatuurlijk, April 2, 2019). From the side of the company, it was a great time to start planning and developing geothermal projects. If the project in Leeuwarden will be chosen for the pilot, Ennatuurlijk could gain a lot of knowledge and experience, which will be beneficial on a long-run, with the expansion of the sector. The company has several small-scale projects and also keeps good communication with customers at the top of the priority list. The later one is at high importance since consumers might not be aware of the opportunities given, especially when it comes to renewables or even geothermal energy. For instance, in January 2018, Ennatuurlijk organized a customer panel at Leeuwarden and invited customers and relevant stakeholders to discuss diverse topics included the geothermal energy plans for the city (Ennatuurlijk, 2019). With these actions, the company is doing exactly what was mentioned in the previous chapter, namely communicating with stakeholders and sharing information with them from the very first step. A company with experience and knowledge within the geothermal sector is inevitable, and Ennatuurlijk could become a key player and an expert in the sector (Personal communication, Ennatuurlijk, April 2, 2019).

4.3.3 Housing Corporations

Three major housing corporations are important to be mentioned when the receiver of the geothermal heat is the housing sector, these are WoonFriesland, Elkien, and Habion. The interests of each are the same: to provide their customers with high quality, reliable, affordable, sustainable and renewable heat. Reliability and affordability are a priority for all, but for instance, WoonFriesland has a focus on sustainability as well. The company owns approximately 20.000 households in Leeuwarden, and a significant number of these is either within the area of FrieslandCampina or already connected to the district heating network. Furthermore, the company is working on installing energy-saving measures on its current houses, while designing and building new, natural gas-free houses as well (WoonFriesland, 2019). As at this point, it is quite uncertain what costs would the geothermal projects exactly mean for the housing corporations it cannot be stated for certain that they all will be interested and willing to cooperate. Just as in most cases, finances matter the most, and since higher prices would decrease one company's competitiveness compared to others, which is a risk they might not be willing to take. On the other hand, many people would specifically opt for a house that is natural gas-free and uses heat from a renewable source, that would extend the customer network of the company.

4.3.4 Vermillion Energy

Vermillion Energy is a prestigious, multinational oil and gas supplier company, with operations all around the world. Currently, it could count as a unique situation that a fossil fuel company is dealing with geothermal energy, however, just as it was described with Shell, the oil and gas companies eventually will open for renewable directions, if they want to maintain their competitiveness (that is their main interest) (Vermilion Energy, 2018; Personal Communication, DAGO, July 31, 2019). However, in the case of the Ennatuurlijk-FrieslandCampina project, Vermillion Energy only plays the third party role, as the establisher and maintainer of the geothermal plant. Vermillion has the necessary expertise and know-how to do the drillings, and all steps that are necessary to reach the stage when heat can be supplied for FrieslandCampina and for the heat networks. Even though Vermillion has experience in drillings, they have never done an ultradeep geothermal project before, that might pose a risk for the company. The conditions under which Vermillion Energy would conduct the project is, of course, payment for their services by the three involved parties (FC, Ennatuurlijk, and the government) (Personal communication, FrieslandCampina, April 2, 2019).

4.3.5 Province of Friesland

Friesland, located on the northwest of the Netherlands has 656,874 inhabitants and occupies 5,748.74 km² of the country. Among the 24 municipalities, Leeuwarden is the biggest one with 122.000 inhabitants (Province of Friesland, 2018a). Each of the provinces' has the responsibility to contribute to the Dutch National Climate Agreement, which is in contribution to the Paris Agreement. The climate tasks are decentralized and specifically developed for each of the provinces and municipalities by regional authorities (Province of Friesland, 2018b). Two policies, namely the Sustainable Energy (adopted in September 2016) and the coalition agreement 'Mei Elkenien Foar Elkeinen' (With Everyone, For Everyone) from 2015 are determinative regarding energy strategy within the province. These policy documents support small and large scale initiatives that can have an impact on the Frisian energy sector, such as Circular Friesland, or the Noordelijke Energieagenda SWITCH (Province of Friesland, 2018). The energy demand of the province is around 65 PJ, from which 10% was generated by renewables in 2017 (Klimaatmonitor, 2018). Renewables, especially wind (due to the location) and solar are favored the most, but biomass and waste incineration are also applied widely. One of the best alternative energy sources could be geothermal energy for the province, in order to lower the emissions on the long-term and comply with national and provincial policies (Province of Friesland, 2018b).

4.3.6 Municipality of Leeuwarden

Two main goals of the Municipality of Leeuwarden were adopted with the energy strategy plan of 2016-2015. First, to save 20% of energy in the housing sector (compared to the consumption of 2010), and second to generate 1.41 PJ of renewable heat in 2020. The municipality's role is to act as an active facilitator and support all sorts of projects and initiative with subsidies, permits and new regulations (Gemeente Leeuwarden, 2016). The expected renewable energy mix in 2020 within the Municipality can be seen in Table 2.

Renewable Energy in the Municipality of Leeuwarden	Goal 2020
Existing Wind Mills (5.18 MW)	0,043
Solar Power - to be installed (objective 75 MW)	0,238
heat and geothermal energy: geothermal energy (1 source)	0,28
Energy from Biomass	0,289
RWZI (biogas)	0,027
Diary Campus	0,231
Conservation Processes of dairy farmers	0,025
Mono-fermentation dairy farmers	0,008
BV Sport and Blokhuispoort	0,016
Total within Leeuwarden	0,85
Renewable Energy generated outside Leeuwarden	
Omrin/Ecopark De Wierde	0,31
Gas	0,06
Purchase of Wind Energy	0,25
Total Outside Leeuwarden	0,56
Total Energy Mix of Leeuwarden	1,4

Table 2 Renewable energy mix 2020 (Gemeente Leeuwarden, 2018)

As the table shows, the aim is to develop geothermal projects and reach the 30% share of the renewables with geothermal energy. Furthermore, biogas from the dairy campus (25%) is expected to be one of the major renewable source, followed by solar and wind energy. Apart from increasing the share of renewable energy sources within the energy mix, the municipality has a focus on decreasing the energy consumption of the housing sector by making houses more efficient. In order to achieve this, the currently existing district heating networks must be expanded, and switch the currently used fuel (natural gas) to a sustainable, renewable source. As the heat networks are developed and maintained by Ennatuurlijk, active cooperation is necessary between the two parties.

The Municipality created a grant, the so-called Innovation Fund, to provide financial support for companies and knowledge institutions with innovative ideas within the area of sustainable energy, water technology, and circular economy (Gemeente Leeuwarden, 2018))

4.3.7 Citizens of Leeuwarden

The citizens of Leeuwarden could have several concerns regarding the geothermal project. Even though geothermal plants do not raise issues concerning the landscape (which is, for instance, a common issue with windmills) but when people hear ultra-deep drilling, they are automatically get worried about the earthquakes, since the Groningen incidents are relatively recent and happened close by. The other issue is the lack of awareness, which is almost as important as the fear of earthquakes since it makes people mistrustful, and easier to manipulate (Personal communication, Ennatuurlijk, April 2, 2019). The latter is a serious concern since negative media regarding geothermal energy is a reoccurring phenomenon. For society, as consumers/customers, the prices, safety, and reliability are the main priority. As geothermal energy could not be more expensive than gas prices, it might be even attractive to consumers, also the fact that they would use green energy and contribute to the reduction of CO₂ emission could increase its attractiveness, as more and more people are getting environmentally aware of their energy consumption.

4.4 Risks, barriers, and uncertainties

Most of the traditional technologies of the energy sector come with risks. Nuclear explosions (Chernobyl 1986, Fukushima 2011), oil spills (Deep Horizon 2010), gas leakages can and do happen every now and then with serious consequences, and geothermal technologies are not an exception (Sovacool et al., 2015). Geothermal energy is not nearly as commonly applied or known source of energy as other renewables, like solar or wind energy. In the Netherlands where there is almost no previous experience in this field, and also where the drillings for natural gas already caused issues (earthquakes around Groningen), the following main risks and barriers of the extension of the geothermal energy sector are present:

4.4.1 Technical risks

Since the process of geothermal energy exploitation can be paralleled with natural gas extraction, eliminating the seismic risks caused by the drillings (as one of the most notable risks) is essential. Unwanted tremors and earthquakes can occur even after the drillings, when the plant is already in operation, due to high differences between the pressure values at the surface and the deep subsurface, and also due to active subsurface faults. One of the most serious earthquakes with the magnitude of 3.4 happened in 2009, Switzerland which led to the total abandonment of the geothermal plant (Glanz, 2009). However, with proper safety

precautions, the continuous monitoring of the pressure values and the seismic activity, the chance for these unwanted events can be avoided.

The stored gas content within the drilled subsurface strata can be another risk that needs safety precautions. It is natural, that the rock layers have gas content, especially in case of those that store water, and have higher porosity and permeability. These are often targeted by geothermal exploitations, and throughout the drillings and with the newly established boreholes, these gases can ‘escape’, due to the great pressure differences between the deep strata and the surface. With valves or gas separators these gases can be captured and/or reinjected, as such, it would not cause explosions or pose a risk of air pollution (Bauer et al., 2013).

The third technical risk related to geothermal energy originates from the fact that the subsurface water can contain either radioactive particles or other dissolved materials. When the water is pumped to the surface, it must be filtered as these radioactive or other polluting particles cannot enter the tubes that directly distribute the water to the greenhouses, houses or to industry. This additional filtering step can result in higher costs of equipment, maintenance and also requires specific measures to store these particles (especially the radioactive elements). (Murat et al, 2013).

The proper equipment and the design of the wells is another factor when it comes to risks as if any leakage happens the consequences can be remarkably serious. For instance, if leakage occurs and the warm water can get in contact with groundwater aquifers, or if it occurs closer to the surface, then even with the soil. It can have a serious impact on drinking water supplies or the agricultural lands, not only as thermal pollution but also as chemical pollution if the geothermal fluid contains radioactive elements or other dissolved gases (Murat et al., 2013).

4.4.2 Financial risks

The process of upscaling geothermal energy will take an extended time and involves high upfront capital. The financial aspects matched with the uncertainty that is present in the sector results in relatively high financial risks, that include the risk of dry wells, or technical failures. The risk of dry wells is covered by the RNES guarantee scheme. Currently, in case the realized capacity is lower than the P90 value, operators can use the scheme and secure themselves. However, the scheme needs to be improved, as due to the numerous cases, different locations, expected capacities and other various properties of each project, the same P-value cannot be used for all. Furthermore, the fact that third parties will be involved in the projects acts as another liability (Masterplan, 2018).

4.4.3 Social risks

Geothermal energy projects are almost entirely unknown within society, as such, the concerns around the development of induced seismic activity due to geothermal heat production must be stopped by increased public awareness on the topic (DAGO, Personal communication, July 31, 2019). If any undesired seismic activity, an earthquake would happen within the first stages of geothermal development, the resistance of society could completely stop the further projects and the upscaling of the sector (Wallquist and Holenstein, 2015). Health and safety must be a priority in the sector and the likelihood of an accident has to be reduced, but sharing the possible risks is also important. The support by the general public is key, which is why it is crucial to establish reliable, transparent channels for information flow from the sector to the public from the earliest stage of the project developments (Pasqualetti, 2011).

4.4.4 Political risks

The government could play the role of a facilitator of the geothermal projects, which poses a great risk. Without continuous commitment, the establishment of adequate regulatory circumstances and financial/subsidy support, geothermal energy cannot compete with natural gas or any other energy source (DAGO, Personal communication, July 31, 2019). The government must have a clear, long-term vision for the future of the energy sector. In case the government chooses (for any reason) not to reduce the natural gas usage of the country, it would not only postpone/stop the geothermal energy sector but also raise geopolitical issues and jeopardize energy security and independence. These are all political decisions, that market players have barely any influence on (Goldthau, 2014).

4.4.5 Legal risks

As the geothermal sector is under development, several legal and liability issues might emerge throughout the coming years. At the moment, for instance, it is unclear, that who is responsible for the subsurface risks. The greenhouse owner? The company in charge of the drilling? The owner of the property? Standardization is also missing at this point, just as a clear, up-to-date legal framework. In a new industry, these questions, regarding the tasks and responsibilities of actors must be answered and clarified. When a failure happens, legal cases will open, which could have a negative impact on the development of the geothermal sector (Haehnlein et al., 2010).

4.5 Concluding remarks

The chapter gives a comprehensive overview of the current state of the geothermal energy plans of Leeuwarden. The analysis of the project itself, the relevant stakeholders and the risks and barriers was made which enables the researcher to answer the third and fourth sub-research questions, that are the following:

What is the current state of the art of the geothermal pilot in the city of Leeuwarden, who are the stakeholders, how are they involved in the pilot, and how do they perceive the potential of the geothermal energy as a sustainable and affordable heat resource for residential heating in Leeuwarden?

Within the city of Leeuwarden, there is a plan, developed by Ennatuurlijk to increase the share of geothermal energy in the energy supply. This plan is based on three pillars, two geothermal wells, from which one is an ultra-deep one, and the establishment of a district heating network that covers the majority of the city. The first well would be located on the site of Dijkstra Draisma, while the second, ultra-deep technology is planned to be on the site of FrieslandCampina. These would eventually be connected to the already existing and also to the newly established district heating networks. As a result, a circular, sustainable and renewable energy-based district heating network could supply the heat of the consumers in Leeuwarden. The major stakeholders are Ennatuurlijk, FrieslandCampina, Dijkstra Draisma, housing corporations within the city, the Municipality of Leeuwarden, and the end-users of the energy. As a conclusion of the detailed analysis of the interests, benefits, and barriers of each of the stakeholders, it can be stated that even though several risks and uncertainties are present regarding the projects, geothermal energy would be a great option with a lot of opportunities and benefits for all of them. The production costs of the investors could partly be covered by the SDE+ subsidy, while with adequate planning, constant monitoring and implementation of the wells, the technical risks can also be significantly reduced.

What are the risks and barriers that stakeholders involved in the pilot perceive with respect to the full-scale geothermal heat supply for residential heating in Leeuwarden?

The risks and barriers were divided into five categories, namely: financial, political, social, legal and technical risks, but these can significantly influence each other. For instance, technical risks, like smaller tremors or earthquakes would result in social resistance, and could entirely stop the upscaling of the sector. It is one of the reasons why raising social awareness and creating a transparent information channel between society and the sector is important. The

constant political support is also inevitable not only for the finances (subsidy schemes) but also for the establishment of an adequate, detailed and up-to-date legal background.

5. Conclusion

The research is divided into two major segments, with each part addressing two-two sub-research questions. Answering the sub-research questions at the end of Chapter 3 and 4 allows a conclusion to be made on the problem statement and the central research question stated in Chapter 1. The identified problem is the following:

The Netherlands with its rich natural gas reserves has played a key role as a major hydrocarbon producer and consumer of Europe. Consequently, it is one of the nations most distant from meeting the EU renewable energy share targets, as only 7.4% of the Dutch energy mix was generated via renewables in 2018. The 2050 goal is to get as close to the zero-carbon energy system as possible and to use almost entirely renewable sources. It can be stated that there is a great need for fast improvements, as based on the current pace of development, that goal seems almost impossible to be achieved. Furthermore, the intense production of natural gas is leading to the depletion of the reserves and also induced undesired seismic activity in previous years (Groningen area, 2018 January). The planned shutdown of natural gas exploitation combined with global issues, like climate change, energy transition, and energy security results as in an immense challenge and also as an opportunity for Dutch society.

Main research question:

Could geothermal energy become a significant, affordable and sustainable energy resource for residential heating in the Netherlands and if yes, what would be the time perspective?

Currently, the heat demand represents around 40-50% of the total energy demand, from which 95% is supplied by natural gas. This number must be significantly decreased in the near future in which process, geothermal energy could play an important role. Geothermal energy originates from the earth's interior warmth. It is brought to the surface by extracting the hot fluids stored underground via production wells. After either direct application of the fluids or the electricity generation, the reduced temperature water is reinjected to the subsurface, where it is heated up again. The relevant technologies that can be applied in the country are geothermal heat pumps, liquid-based plants, binary cycle plants, and enhanced or ultra-deep geothermal energy systems. The production of geothermal energy is a circular, sustainable and renewable energy production process.

The Dutch geothermal sector has seen a rapid growth in the past decade, mainly initiated by the greenhouse horticulture. However, other than the horticulture, geothermal energy has a high potential to be used for heating purposes and also in industrial processes. At this stage, the

precise pathways to use geothermal energy in an extended manner is being worked up by the Dutch administration, but there are numerous ideas and opportunities.

Ideas:

The current plans for the upscaling extend to 2050 when according to the Masterplan, more than 700 geothermal wells will be established. This number is relatively optimistic, but not impossible to reach. The uncertainty originates from the fact that the geothermal sector in the Netherlands is relatively new, research on the subsurface properties needs to be done, a proper regulatory background must be established, and the standardization of processes and procedures is required. An advantageous circumstance is that the SDE+ subsidy in the Netherlands covers not only electricity generation (as in many other EU countries) but renewable heat production as well. With the application of the play-based portfolio approach, and also with the full exploitation of the available capacity (cascading approach) the risks can be reduced and the better and better business cases can be executed. The further opportunities to attract investors include the subsidization of geothermal heat and the increase in fuel prices. Since the maintenance of a geothermal energy plant does not necessarily require any fossil fuels, the stability of the prices comes as another beneficial circumstance. These advantageous factors could increase the support and also enable the sector to develop faster.

Institutions:

There are several institutions involved in the Dutch geothermal energy sector, with DAGO (Dutch Association Geothermal Operators), SPG (Stichting Platform Geothermie), EBN (Energie Beheer Nederland), SW (Stichting Warmtenetwerk) and also TNO being the most important ones. The specific role of each institution has been elaborated before, but overall, these parties are responsible for sharing their knowledge, initiate research and innovation, assigning tasks and coordinating the development of the sector.

Interests:

The interests of each party can vary, however in several cases, these are overlapping. The interests of the institutions involved in the geothermal sector are to develop a sustainable, reliable, secure energy sector that can provide affordable heat not only to the greenhouse horticulture but to industry and more importantly to the housing sector. It would also be beneficial for the government as the country has to find a way to break out of the current energy system that is almost entirely based on fossil fuels. Furthermore, it would help to comply with global regulations (Paris Agreement) and also with national climate goals. Society, as the third

major involved party could also benefit, as the energy security, reliability and affordability are just as important to them as to the other two parties. Also, energy awareness and sustainable living are also getting more and more widespread among society, which makes geothermal energy an attractive energy source. However, the uncertainty, lack of knowledge and experience, and also the risks related to geothermal energy could jeopardize the successful upgrading of the sector if any unintended situation, accident or earthquake (drilling) occurs.

Case study: Geothermal energy project in Leeuwarden:

The Green Deal in 2019 was a major milestone in the Dutch ultra/deep geothermal energy sector, as seven locations are working on research and development of an enhanced geothermal plant, from which the best three will be selected for pilot testing. The Leeuwarden project appears to be one of the most promising cases. The idea of Ennatuurlijk (one of the main institutions involved) is to with the establishment of an extended district heating network and the help of two geothermal wells (a shallow and an ultradeep) to supply the baseload energy demand of the housing sector and also to provide heat for industrial production (FrieslandCampina) by geothermal energy. As it is still unknown which project will be chosen for the ultra-deep pilot project, the future energy supply of the city greatly uncertain as well. However, benchmarking will recognize best practices, that could become available for the entire sector. The current barriers and risks (high upfront costs, dry wells, induced seismic activity, social unawareness, etc.) are well known, however, with time, development and different future scenarios, these can change and new risks can arise while other current ones can cease.

Final conclusion:

Based on the concluding remarks of each chapter, and also the aforementioned summarization of the findings, the following final conclusion can be stated. The analysis confirms that geothermal energy could play a significant role in the Dutch energy transition as an excellent fossil fuel alternative for base-load energy supply. Geothermal energy is a renewable, reliable, sustainable source of energy that is not dependent on weather or fossil price fluctuations. Even though the subsurface of the Netherlands has good geothermal potential, due to the lack of experience, this role is greatly dependent on the results of the ongoing theoretical research and also on the pilot testings of the upcoming years. Other barriers, such as the high costs and social unawareness can also jeopardize the upscaling. As such, at this point, it is uncertain to state that at what extent could geothermal energy is involved in the energy mix by 2030 or 2050.

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Appendices

Appendix 1 Dry Steam Power Plants

Dry steam plants were the first kind of geothermal power generation plants built, as the locations are easy to find since these type of geothermal aquifers mostly have visual surface manifestations (geysers). This technology uses dry hot steam that is piped from the production wells to the plant, directly towards the turbine. The rotation of the turbine blades drives the generator which produces electricity. The steam content of the dry steam aquifers originates from the water of the Earth's crust that was heated up by the mantle and released through vents. The temperature of the pressurized steam is between 180°C- 350°C (DiPippo, 2012). After the steam is condensed into water, which increases the efficiency of the turbine and avoids environmental obstacles, it is placed back to the subsoil via injection wells, where it is heated again by the heat of the Earth. The number of locations suitable for this type of technology is limited as it requires very specific subsurface circumstances. The emission of dry steam power plants is only excess steam and insignificant quantities of other gases (DiPippo, 2012).

The most significant dry steam power plant, the Geysers Geothermal Field, is located in California, 130 km North from San Francisco. It is the world's greatest dry steam complex with 18 green electricity-generating power plants and 1517 MW of installed capacity. The resource field is spread over 117 square kilometers, but the original heat source is a 14 km diameter molten rock chamber spinning over seven kilometers underground. The region has more than 350 production wells installed into the greywacke sandstone reservoir, some of these around three kilometers deep. The generated electricity is supplied to nearby counties, such as Sonoma, Marin, Napa, and Lake. The Geysers complex covers one-fifth of California's green power generation (Elkibbi et al., 2005).

Appendix 2 Ennatuurlijk interview

Date: 2019-04-02

Location: Eindhoven, Ennatuurlijk head office

The Leeuwarden project:

- Geothermal energy is suitable for Leeuwarden for two main reasons. As the city is the capital of the Province with the highest energy demand in Friesland, and the concentrated demand makes geothermal a good alternative. Second, the geology of the area including the permeability and the types of stones are adequate. The geological studies of the last few years showed that the subsurface potential is better on the south side of the city than on the west, but both are suitable for geothermal exploitation.
- Currently, Ennatuurlijk is working on the establishment of a district heating network that covers the majority of Leeuwarden. The creation of this network will be executed in different phases. First, the focus will be on the south and the west of the city, which will be followed by the northern areas at the end. The two already existing, relatively small networks (Camminghaburen and Zuidlanden) are a great starting point.
- The heat network (in the realization phase) will cause some inconvenience for the citizens, as the pipelines need to be installed underground (the process involves digging). When operating, there is no nuisance.
- To provide heat for the network, two geothermal wells are planned to be drilled: a shallow (2500m) and an ultra-deep (around 5-5500m).
- Ennatuurlijk, in cooperation with FrieslandCampina, is part of a national plan, to establish an ultra-deep geothermal energy plant. It is part of the Green Deal, and if the research goes as planned, at the end of the year, three of the seven locations (where the research is ongoing) will be selected for pilot testing. As the temperature of the water (due to the 5000m+ depth) is adequate for industrial usage, the cascaded approach is being developed. Namely, after FrieslandCampina used the hot water for their processes, it is still suitable for household heating, or other processes that require lower temperature water. Even if the FC site is chosen, the drillings will definitely not start before the middle of 2020.
- The main involved parties are Ennatuurlijk, FrieslandCampina, Dijkstra Draisma, and the Municipality. One of the most important roles of the Municipality is to facilitate residents, to inform them about the opportunities and risks. Also, the municipality is

working with housing corporations in order to make social rental homes sustainable, for which geothermal energy could serve as a great option.

- Ennatuurlijk is working closely with the geothermal sector, especially with (DAGO) in order to establish the necessary requirements and laws.

Appendix 3 FrieslandCampina interview

Date: 2019-03-21

Location: FrieslandCampina Leeuwarden.

- The factory of FrieslandCampina has two main product in Leeuwarden, condensed milk and milk powder. The production processes involve highly energy-intensive steps, for instance, evaporation and drying. The two currently installed gas-fired boilers were installed in 1968 and 1974. These will be switched to new ones, however, until the type of energy source that will be used in the company is unclear, the type of new boilers cannot be chosen. About a decade ago, the management of FrieslandCampina started to have a discussion about changing the energy system, making the processes more efficient, and lately about having sustainable energy sources involved. Several researchers and institutions were hired to investigate how to achieve the aforementioned targets, however, none of the business cases were good enough for FrieslandCampina so far (as profit is the priority).
- FrieslandCampina with Ennatuurlijk is working on the development of an ultra-deep geothermal energy plant. Everything depends on the results of the still ongoing research, and also on the success of the research of the other locations in the country. If the others appear more promising, then the Leeuwarden project will not be realized. The business case is done, with a detailed risk analysis. If it will be chosen for the pilot testing, fifty percent of the costs will be paid by the Dutch government, while the rest would be split between the involved companies. FrieslandCampina would only use the water, they don't want to deal with anything else (drilling, maintenance, etc.). The realization will be done by a third company, probably Vermilion Energy since they have experience and expertise in drillings. The plan is to use the geothermal energy in a cascaded approach. FrieslandCampina needs the water until it is as low as around 80°C. The water with a lower temperature

could still be used for household heating, which results in at least two cascades. One complication factor is that FrieslandCampina has peak production periods, for which geothermal energy could not be used. Currently, the plan is to use geothermal energy as baseload, and natural gas/biogas for peak hours.

- The only detail that can be enclosed (because of confidentiality reasons) about the ongoing seismic research is that they found higher pressure values underground than expected - with around 140kbars.

Appendix 4 DAGO Interview

Date: 31-07-2019, Via Skype

- DAGO has 30 member companies, with Shell being company lastly applied to become the member. In the last 2 years, the conversation with stakeholders and the member companies become more and more intensive, and a great improvement can be expected.
- The infrastructure needs to be there, and the establishment of the district heating systems in cities for example in Amsterdam or The Hague is quite difficult and might require more time than currently stated in the Masterplan. The age and the isolation status of the houses can greatly influence the establishment of the district heating systems. The plans for 2030 and 2050 are optimistic, and maybe delayed with 5-10 years, but eventually, the sector will get there. The social power of the society is getting bigger, and also companies like Shell are rethinking their position, which will play a big role in the whole energy transition.
- The social license to operate geothermal energy is needed for the expansion, the government is not necessarily an investor, and will not take over control. In the end, the transition will be a social revolution. The necessary background must be there: safety, security, and affordability.
- Societal awareness: Is in the very early phase. Society needs to be informed from step to step about the risks and opportunities. The information-sharing must be completely transparent about risks, mitigations, costs, benefits. However, even if there is an earthquake caused by geothermal drilling in the United States, that can have an influence on societal acceptance.

- One of the challenges is that the required demand needs to be there for the establishment of a geothermal plant. In cities where the demand is significantly smaller than the capacity of the plant, there is no chance for geothermal energy becoming affordable.
- If you want to get the most of the geothermal energy system, the in-going temperature, for example, is 90°C, then the return temperature should be around 20°C. That is why geothermal energy is great within the greenhouse horticulture because the delta temperature can be that big. For instance, as inefficient central heating systems (for example in old, communist countries, e.g. Hungary) use the water, the ingoing temperature is around 90°C while
- Cascading is quite theoretical at the moment. It should grow, as an integrated solution, used with heat pumps, but then the more electricity is used to generate heat. It would result in an 'electrified' heat generation system, that is not sustainable in the long term.
- The biggest challenge is to make the cost-price as low as possible. Of course, it is related to innovation, the demand and the enlargement of scale.
- Big multinational oil and gas companies are opening for new sources, like Shell, Engie, and Vattenfall as well. If the business case is good enough, why should they not invest? At the moment small and medium-sized companies are investing of course, but in the long term, the big players are needed.
- SDE+, the production subsidy, is working, but it is not tailor-made for geothermal energy. There should be one developed for geothermal energy since heat is not a commodity. Innovation subsidies also exist, but these are also in the first phase and should be developed further.