Accelerating the energy transition

Exploring opportunities for accelerated upscaling of geothermal district heating applications in Europe

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Master Thesis Report

TU Delft

Accelerating the energy transition

Exploring opportunities for accelerated upscaling of geothermal district heating applications in Europe

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Preface

Dear reader,

Before you lies the thesis report called ”Accelerating the energy transition - Exploring opportunities for the accelerated upscaling of geothermal district heating applications in Europe”. During the study leading to this report, three European countries have been investigated in particular. This thesis is written in fulfilment of the requirements to obtain the degree of Master of Science in Complex Systems Engineering and Management at the Delft University of Technology. Between April 2021 and November 2021, I have been conducting the study and writing this report.

As the final period of my studies neared, I already knew that I wanted to choose a thesis topic related to the energy transition. Together with my first supervisor, prof. dr. Blok, I determined the subject and scope of this research. My interest in Earth Sciences and its slightly invisible yet unavoidable influence on everyday life motivated me to choose this subject. I experienced the research project as particularly complex and interesting due to the many implications of the energy transition. Fortunately, the selected research methods enabled me to answer the research question.

I want to express my gratitude to my first supervisor, prof. dr. Blok for his support and valuable feedback. Your guidance and suggestions for interesting analyses have kept me excited throughout the research process. Additionally, I want to thank dr. Correljé, for his feedback, and especially for his help in finding a suitable conceptual framework. Finally, I want to thank prof. dr. Bruhn. Thank you for your assistance in finding experts to interview and your contagious enthusiasm for my thesis subject. I thank you all for your supervision in challenging times. Your inspiring advice, comments and support have been invaluable.

Additionally, I am grateful for the interviewees. You have provided me with an in-depth insight into the conditions concerning geothermal district heating in your country. I thoroughly enjoyed our conversations and discussions. Without your contributions, I wouldn’t have been able to complete this project.

A big thank you to all my friends and family, who have supported me with engaging conversations, encouraging words and a taste of humour. These final months of my studies ended up being quite a challenge for me. Finally, I would like to thank my parents especially. Their wisdom and reassuring words have helped me to bring this thesis to a successful conclusion.

I hope you enjoy reading.

P. F. W. M. van de Weijer
Delft, February 2022

Executive Summary

Introduction

Deep geothermal heat is considered an energy source that can supply society with sufficient renewable heat for many years. An application of geothermal heat that could massively accelerate the energy transition is in district heating systems. A single geothermal system could provide entire city quarters with clean and affordable heat. Despite the geothermal potential in Europe, geothermal district heating is yet to be implemented at a large scale.

While previous studies have investigated the barriers and possibilities to geothermal energy use in general, no specific research has been performed on the opportunities for the upscaling of geothermal district heating in Europe. Hence this study aims to address this research gap by answering the following research question:

"How can the implementation of geothermal district heating in European countries be accelerated within this decade?"

Methods and structure

Through a literature review and interviews, several barriers to the upscaling of this technology have been identified. Subsequently, interactions between these barriers' institutional, economic, and technical factors were analysed. By applying a conceptual framework, the barriers were decomposed into their elements, which are the primary causes of a barrier. This approach provided a detailed understanding of the mechanics behind a barrier or its elements.

A combination of research methods was used. First, energy statistics analysis was used to determine the speed of upscaling of geothermal district heating in Europe in the past decade. From this analysis, three countries were selected for in-depth analysis. These countries are Germany, Hungary and the Netherlands. An extensive document analysis, consisting of policy documents, market reports, and additional scientific literature, was performed for each country. In support of that, interviews with experienced members of the geothermal (district) heating sector in each country were conducted.

The presence of the identified barriers was tested for each of the selected countries. An early observation was that, although the same barrier may be present in different countries, the mechanisms behind that barrier can vary significantly.

Furthermore, the actions taken by the government and the geothermal energy sector to accelerate the upscaling of geothermal energy were analysed. The findings from the previous actions have been combined with additional document analysis of policy documents. This enabled the study to advance towards the future perspective of geothermal district heating in Germany, Hungary and the Netherlands. Finally, the countries' ambitions were examined regarding the present barriers and previous actions. As a result, policy recommendations have been formulated to assist governments in fulfilling the requirements for accelerated upscaling of geothermal district heating.

Results

This study shows that several barriers need to be mitigated to achieve accelerated upscaling of geothermal district heating. One of the most significant barriers was the economic non-viability of geothermal district heating. Several reasons for the non-viability were identified. One reason is that geothermal district heating is more expensive than alternative heat sources. Another reason is the high implementation cost of geothermal district heating. Consequently, economically viable development of geothermal district heating is very challenging without government support in the form of subsidies.

Besides that, poor insulation of buildings was identified as a barrier since many buildings do not have a sufficiently high energy efficiency to enable geothermal district heating. The reason is that especially low or medium-temperature district heating systems are suitable for direct input from a geothermal

source, without the need for heat pumps to increase the temperature. However, the energy losses in poorly insulated buildings are too high to implement low or medium-temperature district heating.

Finally, legislative and regulatory barriers have been found to cause uncertainty for developers and investors. A lack of legal standards, together with complex and ambiguous licensing procedures and unfavourable regulation of heat prices, have proven to cause a challenging environment for the upscaling of geothermal district heating.

When looking at the individual countries' future, the Netherlands seems to be taking significant steps to create conditions in which geothermal district heating could provide a substantial share of the heat for the residential, commercial and public services heat sector in the future. In contrast, there is some uncertainty regarding the upscaling of geothermal district heating under the present conditions in Hungary. The Hungarian government has been inconsistent in their communication regarding the future of geothermal district heating within the country's heat sector, making it challenging to formulate a prognosis accurately. In Germany, the development of geothermal district heating is very much dependent on federal, state and municipal policy. Hence, the expectations for geothermal district heating use vary for every region. Promising developments are observed in Bavaria, where the municipality of Munich, in particular, has set ambitious targets for the role of geothermal heat in district heating.

Under the current conditions, a prognosis was formulated for upscaling geothermal district heating up to 2030. This prognosis was devised based on the developments in the past decade and the current state of affairs. Hence, under present conditions and governments' plans, achieving a share of 10% geothermal district heat in the residential, commercial and public services heat sector is not very likely. Nevertheless, the countries are expected to achieve the following shares of geothermal heat in the residential, commercial and public services heat sector: 2.6% for Germany, 5.4% in Hungary, and approximately 4% in the Netherlands. Though, by implementing the recommended actions mentioned below, the chances of the selected countries reaching a 10% share of geothermal district heating in the sector can be increased significantly.

Policy recommendations

Following the results, a generalised set of requirements for accelerated upscaling of geothermal district heating was formulated to answer the main research question. In order to provide a set of suitable recommendations, a target was set. This target is for the countries to achieve a 10% share of geothermal district heat use in the residential, commercial and public services heat sector.

Governments that wish to reach accelerated upscaling of geothermal district heating are recommended to implement the following actions. These actions are not the only possible actions that could accelerate the upscaling of geothermal district heating. However, from the analyses, it became apparent that the measures recommended below are likely to mitigate the most significant barriers. Considering other European countries' general economic, regulatory, and technical environment, the recommendations mentioned below could also be valid for countries outside the investigated selection.

- Restructuring heat price regulation to enable profitable operation of geothermal district heating installations.
- Reduce subsidies for conventional heating systems (e.g. household gas boilers, centralised fossil fuel heating).
- Increase and reserve subsidy funds for geothermal district heating specifically. This subsidy is estimated to cost governments a maximum of between approximately one hundred million to one billion Euros every year until 2030, depending on the country. After 2030, some form of subsidy is expected to be still required, albeit less.
- Provide attractive subsidies or tax discounts for energy efficiency improvements in buildings to enable the implementation of low and medium-temperature district heating. Communal residential buildings owned by housing corporations should receive special attention since their heat demand is substantial. This would result in the possibility to implement low and medium-temperature district heating for multiple home equivalents at once.
- Governments should establish clear legal and regulatory arrangements for geothermal district heating, like legal boundary temperatures for low and medium-temperature district heating, and specific legal standards and requirements for licensing procedures.

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1
Introduction

1.1. Background information

In light of measures taken to mitigate climate change, many countries are looking to implement renewable energy sources. The pressure to transition to renewable energy sources forces governments worldwide to change their energy strategies and invest in alternative energy technologies. Generally, renewable energy sources are assumed to be geothermal, wind, solar, hydropower, biomass and marine energy (World Energy Council, 2016). From these, geothermal energy has enormous potential as a renewable energy source (United Nations Development Programme, 2000). Moreover, geothermal energy is considered to be available in abundance as long as planet Earth exists (Tulley, 2017). Additionally, unlike renewable energy sources such as wind and solar, geothermal energy can provide a stable and continuous energy supply, independent of external conditions (Colmenar-Santos et al., 2018). Therefore, widespread adoption of geothermal energy would be an ideal solution to climate change.

For laypeople, geothermal energy is most well known as hot springs or geothermal baths. Historically, these geothermal resources have been used for leisure. Nowadays, possibilities for harnessing the Earths energy are ever-expanding. Geothermal energy is generally used for direct-use (heat) or electricity generation (Rybach, 2010). The principle behind extracting energy from the deep subsurface is similar for both applications. However, significant differences exist in the costs and difficulty of developing geothermal sources for feasible operation. In Europe, geothermal electricity is only produced in specific areas with subsurface reservoirs containing high-enthalpy fluids. Apart from specific countries like Italy, Turkey, and Iceland, electricity from geothermal energy in Europe is yet to be implemented on a large scale (European Geothermal Energy Council, 2019).

1.2. Geothermal heat

The other application of geothermal energy, geothermal (direct) heat use, has increased more than 50% worldwide in the past five years (Karlsdottir et al., 2020; Lund and Toth, 2021). Within the field of geothermal heat use, geothermal district heating is presumed to be a high potential application.

Deep geothermal energy is generally extracted from the Earth by using a hydrothermal doublet (Figure 1.1). This doublet consists of an injection well and a production well which are drilled into the deep subsurface (2000-3500 m) (Shortall and Uihlein, 2019). Aquifers containing hot water or hot rock formations can be found at these depths. If aquifers are present, the hot water can be extracted for (heating) applications, after which it can be injected back into the well at a lower temperature. When no aquifer is present, a low-temperature brine solution or water is injected into a porous layer, surrounded by hot rock formations in the subsurface. The geothermally heated water or brine is extracted at the production well, creating a cycle. The hot water or brine is either pumped through the district heating infrastructure or is used to heat a distribution fluid (refrigerant) via a heat exchanger. The latter of the two methods is most common since geothermal fluids are usually not suitable for district heating distribution networks (Sigfússon and Uihlein, 2015).

In most cases, geothermal heat is used in low or medium-temperature district heating systems. It can, however, also be used in high-temperature district heating systems by augmentation using heat pumps. However, within the context of this research project, deep geothermal district heating is considered to be the use of geothermal energy for direct heating purposes without the use of heat pumps. Therefore, heat pumps are not considered in this research project.

Similar to oil and natural gas production, geothermal district heating requires specific geological features not present everywhere. However, the geological features that enable geothermal district heating are relatively more common. These features include a permeable, water-bearing, usually sedimentary layer surrounded by hot rock. Approximately 25% of all European cities are located in areas that have suitable geologies for geothermal heat use (Dumas and Barros, 2021). This is important since it is highly energy-inefficient to transport heat over long distances. In Europe, geothermal heating has been implemented at a larger scale than geothermal power production. In 2016, the total global geothermal power production capacity was approximately 13 GW_e (IRENA, 2017), whereas the installed capacity of direct-use applications was 71 GW_{th} (Lund and Boyd, 2016). The maturity of geothermal district heating technologies, combined with the knowledge base on geothermal (direct) heat use identified in chapter 2, makes this technology the focal subject of the research project.

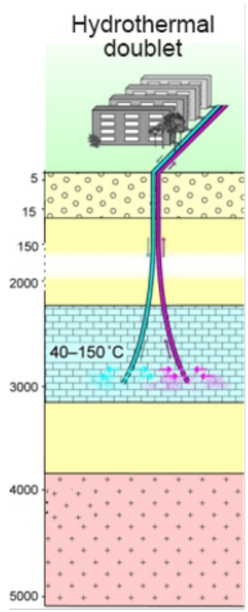

Figure 1.1: A schematic overview of the principle behind geothermal district heating systems. The numbers on the left represent the depth in metres (source: Bayerisches Landesamt für Umwelt, 2021)

Geothermal district heating, in particular, can provide part of the solution to the climate change problem. Although the number of installations for geothermal district heating grows steadily, there is a need for further upscaling (IEA, 2020). One of the primary reasons to use geothermal district heating is to reduce the emission of greenhouse gases for heating.

1.3. Research gaps related to geothermal energy use

As mentioned earlier, the main applications for geothermal energy are electricity production and (direct) heat use. Within these two applications, several technologies are employed. In the research field, technological developments seem to have had quite some attention, with studies analysing factors like the current status of the technology and efficiency (Rybach, 2010; Vatopoulos et al., 2012.

Other studies aimed to determine the growth potential and the prospects of geothermal energy use. Especially the potential and the challenges for geothermal energy use have been studied, resulting in road maps for further implementation (Soltani et al., 2019). In a study into the possibilities for using depleted oil and gas fields for geothermal energy generation, Alimonti et al. (2021) found that the potential for this application in Italy is encouraging. From another analysis, researchers identified several fields within the technology development that should receive special attention (Zhu et al., 2015). These fields are sustainable geothermal resource management and cascaded utilisation, among others. Additionally, through scenario analysis, Dalla Longa et al. (2020) have researched the long term future of the geothermal energy sector in Europe.

In a more generalising study, Moya et al. (2018) discussed the developments in geothermal energy applications to provide policymakers, researchers and anyone interested in geothermal energy with state-of-the-art development. They identified several challenges that need to be overcome for geothermal energy to be developed on a large scale.

Geothermal power production, in particular, received much attention from scholars. Several researchers focused on the effects of geothermal power production on society. Various environmental, social, and economic effects were discussed by Soltani et al. (2021). On the other hand, Karlsdottir et al. (2020) studied the implications and limitations of the European regulatory framework concerning high-temperature geothermal energy. Similarly, a study by Daniilidis et al. (2017) aimed to identify the effects of technical and economic uncertainty on deep geothermal heat systems.

On the one hand, some studies aimed to determine the impact of regulatory, social and economic conditions on geothermal energy development. On the other hand, scholars have also studied the effects of deep geothermal energy use on society. Pellizzone et al. (2017) focused their study on the social and economic effects of geothermal heat use. Besides analysing multiple factors, several studies analysed only a single factor within the geothermal heat sector. In that regard, Šušteršič et al. (2010) studied the regulatory framework for geothermal energy in Europe, as did Dumas and Angelino (2015). The considerable potential of geothermal energy in the future has led researchers to study the barriers to geothermal energy development. Colmenar-Santos et al. (2018) proposed measures to mitigate barriers to geothermal energy use in Europe. In yet another study on geothermal district heating in the US, several factors that influence the development have been identified (Thorsteinsson and Tester, 2010). This study focused mainly on Enhanced Geothermal Systems, which is not used on a large scale in Europe yet. Additionally, there is a significant difference in institutional, economic and market structures between the US and Europe. Therefore, no conclusions about mitigating the barriers for the deep geothermal district heating systems in Europe can be drawn yet.

In the existing scientific literature, several barriers to the upscaling of geothermal energy use, in general, have been discussed. Furthermore, multiple scholars have identified a root cause of these barriers. Many European countries have sufficient geothermal potential for large-scale use in district heating systems. However, there has not been specific research into what is needed to achieve further upscaling of geothermal district heating within that European context. This observation allowed the researcher to establish the following research gap:

'Although general barriers to geothermal energy use in Europe have been identified, no specific studies into mitigating barriers to the upscaling deep geothermal district heating systems in Europe have been performed'.

1.4. Research questions

Following the research gap that was determined above, this study aims to identify and analyse the presence of barriers to geothermal district heating for a selection of European countries, after which possibilities to alleviate these barriers are explored. Consequently, the main research question for this study and five supporting sub-questions have been determined. The main research question of this research project is

"How can the implementation of geothermal district heating in European countries be accelerated within this decade?"

This question is answered by consecutively answering the following sub-questions:

- Q1 How has geothermal district heating developed itself in the European context over the past decade?
- Q2 Why have certain European countries achieved a high degree of geothermal district heat use while others have not?
- Q3 What actions have been taken to achieve further upscaling of geothermal district heating, and why have the actions taken been (un)successful in the investigated countries?
- Q4 What is the future perspective for the investigated countries concerning geothermal district heating up to 2030?
- Q5 What additional actions are required to achieve accelerated geothermal district heating systems deployment in European countries?

The remainder of this document is structured as follows: Chapter 2 consists of a state-of-the-art literature review to identify the knowledge gap that provides the basis for this study. Subsequently, in chapter 3, the conceptual framework is introduced, explained and applied. Chapter 4, presents the research methods used in this study. Additionally, the sub-questions leading to the answer to the main research question are presented and elaborated on. Next, chapter 5 discusses the developments of geothermal district heating in European countries. Besides that, the countries that are investigated in-depth are selected. Then, in chapter 6, the presence of barriers in the selected countries is determined and previous actions to alleviate the barriers are discussed. In the following chapter (7), the future perspective of geothermal district heating and the additional requirements for upscaling are presented. Finally, the discussion is presented in chapter 8, followed by the conclusion in chapter 9.

2
Literature review

In this chapter, a state-of-the-art literature review is presented. This review aims to identify the knowledge gap(s) in research in the field of deep geothermal heating technologies. First, the method for conducting the literature review is described. An analysis of the selected literature follows this. Subsequently, a synthesis of the literature presenting the knowledge gap is presented. Finally, the main research question that follows from the knowledge gap is formulated.

2.1. Method

For this literature review, multiple search engines have been used. The literature consists of scientific journal articles sourced from the Web of Science. In addition, some articles have been sourced from Google Scholar and Scopus. Only articles published in the past ten years have been included in this review to ensure that the discussed literature is up-to-date. Also, the snowballing principle has been performed to find relevant journal articles.

In order to find journal articles that fit the topic, scoping of the search terms was required. In the end, the primary search terms were ’geothermal’ AND ’heating’, ’geothermal’ AND ’Europe’ and ’deep geothermal’ AND ’heat’.

Within the field of deep geothermal heating, the focus of this literature review has been on policy and legislation, technology development, current status, as well as drivers and barriers to the implementation of the technology. A visualisation of the scoping strategy for this literature review is presented in Figure 2.1.

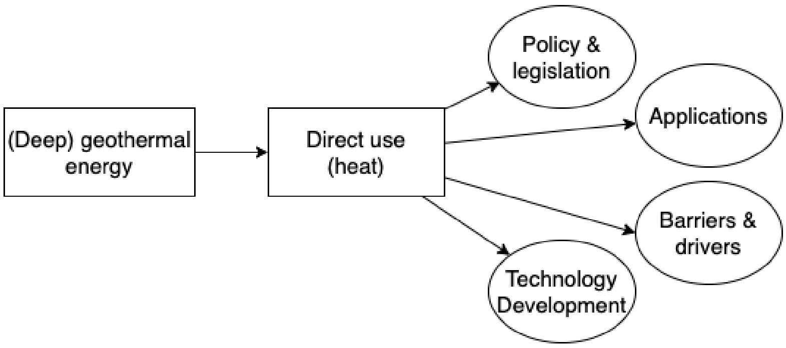

Figure 2.1: A schematic overview of the scoping procedure that was used to select the scientific articles for this literature review.

2.2. Analysis

From the literature search results, it becomes clear that many research activities in the past decade focused on geothermal power production and enhanced geothermal systems. Although many articles present studies into a wider variety of applications of geothermal energy, or with scope outside of Europe, they have still proven to be valuable for this literature review. The reason is that, although these systems are not exactly the same, regulations, materials, and drilling techniques are comparable. The table in Appendix A.1 presents an overview of the articles that have been used for this literature review.

Developments in the past ten years

Between 2010 and 2014, the installed capacity of geothermal heat systems has grown by 46.2%, resulting in an annual compound growth rate of 7.9% (Lund and Boyd, 2016). Several direct use technologies have developed further over the past decade, of which geothermal district heating is considered to be mature (Pujol et al., 2015). At the time, 15% of the global installed capacity of direct-use geothermal energy was used for space heating. From that percentage, 89% accounted for geothermal district heating Lund and Boyd, 2016). Over the past five years, the implementation of geothermal installations has seen steady growth at rates varying between 20% and 50%, depending on the type of installation (Karlsdottir et al., 2020). Over this same period, an updated overview of the worldwide developments of direct use geothermal has been constructed. From this study, it becomes clear that the installed capacity of direct-use geothermal energy applications has increased by 52.2%, with growth at a compound rate of 8.73% annually (Lund and Toth, 2021). Currently, from the global installed capacity of direct use geothermal, 16% is used for space heating, which indicates that in 5 years, the installed capacity of geothermal space heating has not increased as much as other direct uses of geothermal heat. Nevertheless, within the space heating segment, 91.0% of the applications are geothermal district heating systems (Lund and Toth, 2021). The fact that geothermal district heating already accounted for a large part of the space heating segment, and has grown even further, emphasises the maturity of the technology.

Although the use of deep geothermal heat technologies has increased steadily over the past decade, the technology has not seen a real breakthrough yet. However, deep geothermal heat could play a significant role in the combat against climate change. Therefore, ways need to be found to accelerate the upscaling of deep geothermal heat systems. Several factors have played a role in the introduction of deep geothermal heating. For instance, fossil fuel prices have been and still are of much influence since this is a competing energy source (Lund and Toth, 2021; Soltani et al., 2019). Besides that, there is a solid pro-fossil fuel lobby that aims to influence the speed of implementation of geothermal (Strunz et al., 2016).

Additionally, the possibilities for using geothermal heat have expanded. In a review of geothermal power plants and direct use applications, Moya et al. (2018) discussed the application of geothermal energy in a cascade structure. In such a structure, residual heat from applications with high heat requirements can benefit uses with lower heat requirements. This application of deep geothermal heat will likely increase in size in the future.

Current status

Although the growth of geothermal heat use over the past decade has been steady, to meet the 2030 climate goals, further growth is required (IEA, 2020). In order to scale up renewable energy applications, the European Commission proposed the development of a renewed climate and energy framework for the period 2021-2030 (European Commission, 2014). It is, however, unsure how this new framework will work out in practice. Research has provided insight into the role that government policies play in the growth of geothermal energy. Tsagarakis et al. (2020, p. 2557) found that ”at European level, there is no specific regulatory or legal document to assist the increase of geothermal energy applications, though several European countries have taken significant steps towards to technical and permitting standardisation.” However, it is debatable whether such a framework could and should exist. The reason is that regulations can hardly be generalised since the physical conditions within a country determine much of the geothermal potential.

A number of countries have dedicated themselves to increasing their geothermal heat use. Although climate policy seems to support the upscaling of geothermal energy, a recurring observation from studies is that policies regarding the installation and use of geothermal energy itself are often vague or inconsistent (García-Gil et al., 2020; Hähnlein et al., 2013). On the other hand, Dalla Longa et al. (2020) found that currently, climate policies seem to have more of a positive effect on the implementation of geothermal installations than cost reductions in the technology itself. Hence, several countries have adopted promotion policies for geothermal energy applications, and the effectiveness seems to vary. There seems to be a positive correlation between the number of installations and promotion policies in some countries (Liu et al., 2015).

Barriers identified in research articles

In the existing literature, important insights regarding geothermal district heating have been mentioned. Previous studies indicate various barriers to the upscaling of deep geothermal heat use. To that end, these barriers have been studied extensively. Barriers that are recurrent in the existing scientific literature are discussed here. In chapter 3, a conceptual framework is applied to decompose the barriers and their elements.

Colmenar-Santos et al. (2018) revealed that European institutional and regulatory obstacles are the third most significant barrier for the implementation of geothermal energy in Europe, after financial and energy type related discriminatory barriers. Another barrier was already mentioned in section 2.2, which is the fact that current policies for the promotion of geothermal energy are ineffective (García-Gil et al., 2020). At the same time, regulations and policies regarding the installation of geothermal systems are often contradictory (Hähnlein et al., 2013). Some countries do not have specific legislation for geothermal energy development. Consequently, monitoring agencies and regulatory authorities are unable to enforce regulations, which could lead to excessive use of the available resources (Soltani et al., 2021).

Furthermore, dependencies and misalignment between various government levels have been mentioned to pose a barrier in various cases (Liu et al., 2015). On the other hand, promotion policies are popular with governments for the climate aspect. Similarly, these policies are popular with consumers for the financial aspect. There are different types of promotion policies for geothermal energy, but subsidies appear to be most prevalent.

Another barrier was described by Thorsteinsson and Tester (2010), who found that that there is a general lack of knowledge regarding geothermal heating systems with local governments. Geothermal projects are perceived to be complex, high-risk undertakings. That, in combination with negative media coverage or concerns for the environment, causes public opposition towards geothermal energy (Soltani et al., 2021). These environmental concerns are indicated to include the fear of induced seismicity and the potential risk of subsidence due to human activities in the subsurface (Lee et al., 2019; Milicich et al., 2013). As illustrated by Pellizzone et al. (2017) public discussions on geothermal energy revolved strongly around technical and ethical issues. Specifically, a lack of information about the risks of using geothermal energy and general distrust towards decision-makers were significant public concerns. It evolves clear that ethical and environmental concerns could partly cause public opposition towards geothermal energy use. Another factor that plays a role is the fossil fuel industry. Lobby groups have a solid incentive to slow the introduction of geothermal heat applications (Strunz et al., 2016). Also, the prices of fossil fuels are said to play a role. If prices are high, geothermal energy becomes more popular. However, when fossil fuel prices are low, there is less incentive for people to consider geothermal energy projects since financial savings are not that attractive anymore (Lund and Toth, 2021; Soltani et al., 2019).

Other limitations that make it difficult to scale up the use of geothermal energy systems are identified as well. First of all, there are few possibilities to standardise such systems (Self et al., 2013), resulting in applicability difficulties in, for example, existing district heating systems. Another barrier that seems complicated to overcome is that the geothermal system's feasibility can only be determined after commissioning. Although test-drilling provides valuable information for exploitability, it does not guarantee success. Other factors that have not been mentioned explicitly in literature but could still play a role are finding sufficient consumers/demand for project feasibility and adjusting heat networks to become suitable for geothermal heat. Besides the highly geological barriers, another barrier is the fact that decision-makers have insufficient comprehensive geological information (Acheilas et al., 2020; Dumas and Barros, 2021). This information should provide decision-makers insight on various project-specific topics, such as risks, costs and potentials.

Deep geothermal heating systems have always had high investment costs combined with high financial risks (Carrara et al., 2020). One of the causes is the fact that every system is custom-designed for a specific project. On the other hand, the operating cost of such systems are generally low, and they usually have a relatively long lifetime of 30 years (Soltani et al., 2021). Though, there have been cases in which the payback time of a deep geothermal heat project was up to 33 years (Thorsteinsson and Tester, 2010). This illustrates an issue with the economic viability of these systems. Besides financing barriers, there is also the possibility for market imperfection, where revenue from demand does not cover the cost of production. This has happened in cases where, for example, the urban development that was meant to provide demand for produced heat was halted or severely delayed.

Some policies seem to have a positive impact. A study in the US found that geothermal district heating system operators that tied the heating costs to the heating fuel prices in the same region created an incentive to use geothermal energy. The operators guaranteed that the price of geothermal district heating systems would always be a certain percentage lower than natural gas (Thorsteinsson and Tester, 2010). Finally, low-interest loans from banks, with a guarantee from the government, are sometimes used to promote geothermal energy use (Liu et al., 2015). In Table 2.1, the barriers that have been identified in the scientific literature are presented.

Table 2.1: A table representation of the Financial or economic barriers that have been mentioned in the text above.

Barriers from the literature
Inconsistent or contradictory regulation and legislation
Misalignment of European, national and local policies
Lack of regulatory/legal framework
Ineffective renewable energy technology promotion policies
High investment costs, combined with high financial risk
long payback times (up to 33 years)
Uncertain economic viability
Revenue from demand does not cover cost of production
Applicability difficulties in existing district heating systems
Insufficient comprehensive geological information
Ignorance of the public
Lack of social acceptance due to adverse media coverage, local environmental concerns, and ethical issues
Lack of public interest due to influence of fossil fuel industry and perceived as high cost, high-risk investment
Environmental concerns such as induced seismicity and subsidence caused by human subsurface activity
Distrust towards decision-makers due to lack of information on risks and little transparency

2.3. Synthesis

From this literature review, several barriers to the upscaling of geothermal district heating have been found. Previous research also identified some important drivers of the technology. These studies provided valuable insights into the different factors that play a role in the geothermal energy sector. Nevertheless, there is a knowledge gap on how accelerated upscaling of geothermal energy systems can be achieved. A single application of geothermal heat was selected to converge the scope of the research project. Due to both its above-surface and below-surface complexity, geothermal district heating is investigated further. Therefore, this study explores the possibilities for the upscaling of geothermal district heating by exploring ways to mitigate the barriers and to determine how upscaling of geothermal district heating can be achieved.

3
Conceptual framework

From the previous chapter, the barriers to the upscaling of geothermal district heating have been determined. In this chapter, the conceptual framework is explained and applied. First, in Section 3.1 the framework is introduced and explained. Then, Section 3.2 focuses on the application of the conceptual framework.

3.1. Conceptual framework description

A systematic approach for identification and analysis is required to understand the barriers that hamper the upscaling of deep geothermal district heat use. The aim is to eventually come to a set of approximately ten general barriers that are encountered often. To that end, a combination of conceptual frameworks is applied. The primary framework used for this study, was created for the identification and analysis of barriers for renewable energy technologies, as presented by Painuly (2001). This framework is aimed at understanding the different levels of aggregation of these barriers. These levels enable the researcher to decompose the barriers into understandable root causes. The application of this framework allows the development of policy changes to alleviate barriers or to create conditions in which the sector or market is forced to act and remove barriers. Figure 3.1 shows the barrier levels. One downfall of this framework is that it only considers the barriers and the solution to these barriers within their category. Realistically, it is not possible to isolate the barriers from the environment that they interact with.

Therefore, the barrier categories of the framework in Figure 3.1 are replaced by a triangular framework that accounts for a more comprehensive analysis that takes into account the interactions between the factors of the barriers. This extension of the framework is the triangle that displays the interactions between the institutional, economic and technical factors (Figure 3.2). In this framework, it is not the factors themselves that are of interest. Instead, the interactions between the three factors are more important. Consequently, these interactions between the factors are described for every barrier.

In general, economic factors can influence the use of technical applications in various ways. At the same time, the institutional factors can be influenced by the economic factor. Similarly, certain technologies require additional financing, resulting in interactions with the economic factors. The use of particular technologies can also influence the institutional factors. These are, for example, rules related to the safety of using a specific technology. On the other hand, institutions can also influence the technical factors by obliging the use of certain technologies for, for example safety purposes. Likewise, institutions can influence the economic factors. An example is added cost related to an obligation or a prohibition.

The institutional factors require some additional elaboration. The reason is that institutions can be more than just formal rules. Institutions can range from explicit, formal rules to norms, customs and habits. Therefore, it is important to keep in mind that the institutions should be viewed in the broadest perspective.

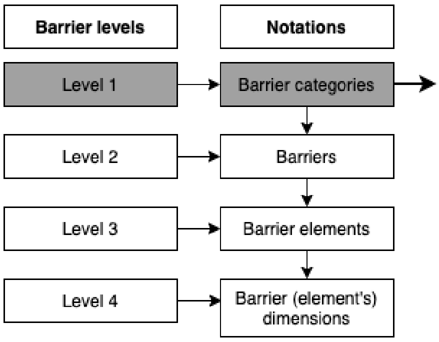

Figure 3.1: Conceptual framework for identification and analysis of barriers for the introduction and upscaling of renewable energy technologies (Painuly, 2001).

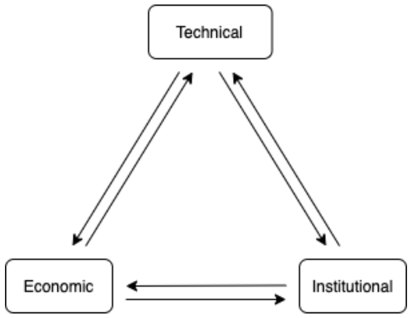

Figure 3.2: A representation of the Technical system, Process, institutions framework

From Figure 3.1, it becomes clear that the first three levels are of the highest importance for identifying and analysing the barriers. As mentioned in the previous paragraph, part of the Painuly (2001) framework is replaced by the triangular framework from Figure 3.2. More specifically, the first level of the framework, 'barrier categories', is replaced by this triangular framework since analysing barriers within the context of their institutional, economic and technical factor is comprehensive. Level two of the framework consists of the barriers themselves. The third level is used for various elements of the barrier. These provide the causes or context of the barrier. Finally, the fourth level is aimed at quantification of the identified barriers. This fourth level is deemed optional. The reason being, that this level is only used for quantification of barrier elements' which might not be used in qualitative analysis. This fourth level could be helpful for some barriers in this study. However, quantification could be challenging for most barriers or have little added value.

3.2. Conceptual framework application

In Section 3.1, the application of the framework with various levels and the triangle of institutional, economic and technical factors has been described. In this section, the barriers that have been identified in the literature review in Chapter 2 are decomposed by applying the combination of the two frameworks. Additionally, some restructuring of the barriers has been performed. This means that some barriers have been combined, or some barriers became element(s) of other barriers. The reason for this restructuring procedure is that some barriers displayed significant overlap. Another issue is that some of the barriers from the literature can appear as vague or ambiguous. These restructured barriers are found in Table 3.1.

In Table 2.1 from Chapter 2, the barriers described in the literature are presented in short. In total, fifteen barriers have been presented in the literature review. In this chapter, these barriers are translated into the combined framework that was previously introduced.

The barriers are decomposed with the second, third, and fourth level of the framework from Figure 3.1. Additionally, their factors are analysed with the triangle from Figure 3.2. The barriers identified from the literature review are displayed in Table 3.1. Some barriers have been combined to prevent unwanted overlap between them, while others share some of their elements to show that they are related to multiple barriers. Additionally, for every barrier, its primary factor is marked.

Table 3.1: The barriers from the literature review, rewritten into general barriers that allow for decomposition and further analysis. *RET: Renewable Energy Technology

Barriers from literature	**Technical**	**Economic**	**Institutional**
Lack of regulatory/legal framework			**X**
Inconsistent regulation and legislation			**X**
Economic non-viability		**X**	
Financing difficulties		**X**	
Ineffective RET* promotion policies		**X**	
Applicability difficulties	**X**		
Insufficient comprehensive geological information	**X**		
Lack of social acceptance			**X**
Lack of public interest			**X**
Distrust towards decision-makers			**X**

3.3. Decomposition of barriers

In this section, the barriers from Table 3.1 are decomposed into their respective elements. Additionally, every barrier's institutional, economic, and technical factors and their relationship are discussed.

The first barrier is the *lack of regulatory/legal framework* for geothermal development (Figure 3.3). Although a lack of rules and regulations might appear beneficial for geothermal project developers, the opposite is true. The two elements that have been determined to be at the core of this barrier are a government's *little experience with geothermal district heating* and the presence of an *ineffective regulatory body*.

When considering this barrier in the triangular framework, the tension between the institutional and economic factors is most notable. The lack of a legislative basis for geothermal development requires project developers to be prepared for anything. This is especially the case in countries with little experience with geothermal energy. Therefore, developers need to make investments to ensure that they take as little risk as possible. There have been instances in which developers needed to comply with specific standards retroactively, which resulted in unexpected added costs.

Another interaction is that a lack of institutions for technical requirements of the system could result in various issues (e.g. environmental). Therefore, there must be a sufficiently comprehensive regulatory framework. This framework can only be developed with the proper knowledge of the technical characteristics of geothermal systems. If the technical requirements are unclear or nonexistent, regulatory bodies cannot effectively fulfil their task.

Tensions between the technical and economic factors can be found as well. Especially when the lack of, for example, environmental regulations result in environmental pollution or related problems. In those cases, developers are still held accountable for the damages. This could mean that there are costs incurred with these situations. Additionally, environmental issues could also result in added societal costs.

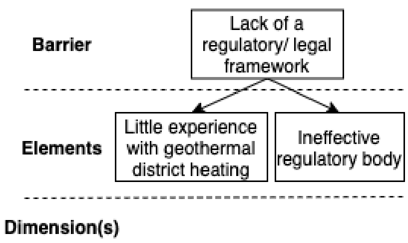

Figure 3.3: The structure of the barrier *lack of regulatory/legal framework* with its elements.

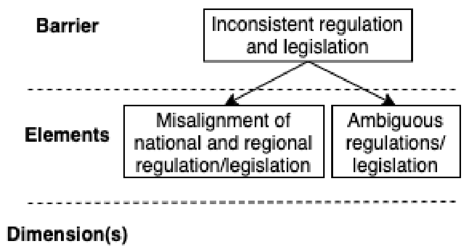

Figure 3.4: The structure of the barrier *inconsistent or contradictory regulation/legislation* with its elements and dimensions.

The next barrier that is analysed, is the barrier *inconsistent regulation and legislation* (Figure 3.4). This barrier has two elements that are specifically related to it. The first element is the *misalignment of national and regional regulation/legislation*. It becomes apparent that this barrier from the literature review has been relocated as an element of a higher-order barrier. The second element is *ambiguous regulation or legislation*.

When looking at the triangular framework, it becomes clear that the inconsistency in regulation and legislation can cause tension on the institutional-technical edge of the triangle. This is related to the fact that the technical specifications of geothermal projects need to adhere to regulations or legislation. If these regulations are inconsistent or contradictory, the tension between the factors becomes visible.

The institutional requirements could result in added complexity concerning licensing procedures. This complexity requires increased attention for project developers. In many cases, this adds time to the licensing phase of a project. Delays in the licensing procedure are likely to result in a financial consequence, mainly since these procedures are linked directly with the system's commissioning, and therefore, the moment the project starts generating revenue.

Besides the regulations themselves, the technical changes resulting from these regulations come at a certain cost. These costs can be the result of the necessity to comply with technical requirements stated in these regulations. Therefore, it is difficult for project developers to avoid these costs.

A barrier that is mostly related to economic factors, is *economic non-viability* (Figure 3.5). The essence of this barrier is the business case of geothermal district heating systems. There are four elements to this barrier. From the literature review, it became clear that concerns about the economic viability of a geothermal resource are common (Thorsteinsson and Tester, 2010).

The element *uncertainty of successful resource* is shared with the barrier *financing difficulties*. This element relates to the fact that the real success of a geothermal project can only be determined after the commissioning of the system. Although predictions about the geothermal potential and expected production are based on numerous measurements and simulation models, there is no certainty until the system is actively extracting geothermal heat.

Another element that contributes to the difficulty of establishing an economically viable geothermal district heating is the *high implementation costs*. This element should not be confused with investment cost, which is solely related to constructing the geothermal doublet. Instead, it considers the costs of exploration and drilling, retrofitting buildings' heating systems, creating a market structure and more. These costs are not explicitly allocated to the developer. Parties such as housing corporations, municipalities, heat distribution system operators are all involved and have to invest in implementing a district heating system. If one of these parties decides not to invest, that could jeopardise the entire business case.

Additionally, the element *economies of scale only at large project sizes* plays a role in the economic viability of geothermal district heating. If a sizeable geothermal source is developed, economies of scale can be achieved. However, this could only be the case when, for example, multiple city blocks near a geothermal installation are simultaneously connected to the geothermal district heating system.

The last element of this barrier is *insufficient heat demand*. Geothermal district heating systems are planned meticulously to ensure that the available geothermal heat is used optimally. Thus, the size of the district heating network is planned based on the expected heat production from the geothermal well, not the other way round. There are examples of geothermal district heating systems planned in areas with accelerated urban development when this urban development suddenly came to a standstill. This resulted in a loss of revenue since the available heat from the geothermal well was not used, causing a failure of the expected business case.

The agreements between geothermal energy developers, housing corporations, municipalities or other stakeholders can be seen as the institutional factors in this barrier. These agreements are usually established in contracts. An example in which institutions become visible is in contracts on the ownership of the geothermal doublet, the distribution system and the heated medium itself. Additionally, the arrangements can include transaction costs for several parties that need to be allocated. That way, the institutions influence the economic factors. Based on these arrangements, the project is developed. The arrangements include the layout of the district heat network, planning for drilling and pipe laying, and more. That way, the institutions impact the technical specifications of the project as well.

The techniques for drilling, pipe laying, and distribution are all dependent on the arrangements between the parties involved. The selection of a particular technique or type of pipe can affect the costs of the project. Hence, technical factors can influence economic factors. The technical factors can influence the institutional factors, as well as some technical applications require additional regulations than others.

Lastly, the economic factors in this barrier are primarily the project's revenue, costs, and debt. These factors affect the technical applications since finances are a limiting factor for technical possibilities. On the other hand, economic factors can also influence the institutions.

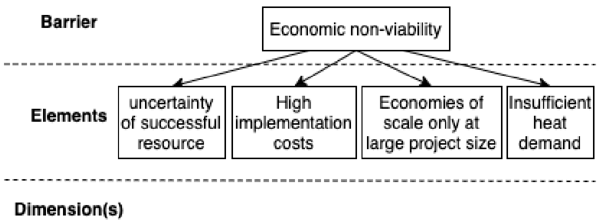

Figure 3.5: The structure of the barrier *economic non-viability* with its elements.

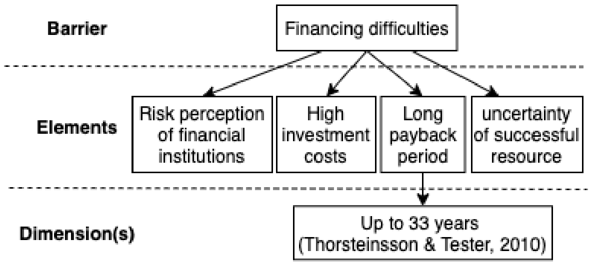

Figure 3.6: The structure of the barrier *financial difficulties* with its elements and dimensions.

The barrier *financing difficulties* is mainly about the upfront finances of a geothermal district heat project (Figure 3.6). From the literature, it has become clear that this barrier has four main elements that play a role. Some of the elements are shared with other barriers due to high levels of interaction.

The first element is *risk perception of financial institutions*. The development of geothermal district heating comes with uncertainty (e.g. unsuccessful resource). Hence, financial institutions (i.e. banks, private investors) are generally reluctant to provide large loans when there is no certainty that they will get their money back. Even if, for example, a bank is willing to provide a loan, the interest rate is likely to be very high. The same holds for private investors. If they are not confident that they will recover their costs, investors probably will not invest.

The second element is the *high investment costs* that are needed to develop a geothermal district heating system. Geothermal district heating systems generally have relatively low maintenance and operations costs. On the other hand, high initial investment costs make it difficult to establish the means to develop the geothermal doublets.

The third element is *long payback period*. During the literature review, this was identified as a barrier. However, it was found to be part of a barrier. Due to the high capital expenditure of deep geothermal projects, the payback period of these systems tends to be quite long. In the literature, exceptionally long payback periods of up to 33 years have been reported (Thorsteinsson and Tester, 2010). Although this is an extreme case, payback times of fifteen to twenty years are typical. This is close to the average lifetime of geothermal heating systems (Alimonti et al., 2021).

The final element is *uncertainty of successful resource*. Although geologists, geophysicists, and many more experts are involved in developing geothermal district heating systems, there is no certainty that the geothermal resource will be successful. Additionally, a reservoir's production might not be as successful as expected. Naturally, this is a calculated risk, but that does not assure investors or banks. This uncertainty makes it difficult to determine whether a loan or investment is worth the risk, resulting in banks' or investors' reluctance to provide loans or investments.

The institutional factors of this barrier can be found in the transaction costs that play a role. Note that these transaction costs could but do not necessarily involve monetary costs. Hence, it is clear that the institutions could influence the economic factors. On the other hand, the institutions could also affect the technical factors through the requirements resulting from regulations.

The economic factor is consequently mainly related to the costs of the pre-development investigation by geologists and geophysicists. A more comprehensive investigation will cost more, but it would likely lead to more valuable technical information. The value of added information indicates a tension between technical and economic factors. Additionally, the economic factors influence the institutions, as, for example, the profits need to be allocated as well.

The technical factors are related to the information that has been gathered. The pre-development research will likely result in information that requires changes to the technical design or the approach. For the interaction between the technical and economic factors, there is a clear bi-directional interaction. On the one hand, more information could lead to changes in the technical design, resulting in added costs. On the other hand, the additional investment in the pre-development research will result in information that leads to a more appropriate technical approach. The influence of technical factors on the institutions is found in the ownership over certain information.

Ineffective renewable energy technology promotion policies has also been named as a barrier (Figure 3.7). In this context, promotion policies are policies like subsidies, financing schemes, feed-in tariffs and tax discounts.

The first element of ineffective renewable energy promotion policies is said to be the use of *decentralised support schemes*. These decentralised support schemes are expensive to execute, and the reason is that these schemes need to be differentiated for various regions or states within a country. From a country perspective, this decentralised approach should result in a more appropriate application of the policy in the area it is specific to. However, the costs of these schemes is generally a reason to prefer centralised funding.

The second element is *highly specific requirements*. This affects the effectiveness of renewable energy technology promotion policies since it can be difficult for developers to fulfil the requirements. Additionally, the requirements are sometimes more focused on other applications, which could cause them not to apply to deep geothermal development.

Tensions could arise between the institutional and technical factors in those situations. The requirements for promotion policies could include technical factors like location, drilling techniques and network layout, resulting in added complexity in becoming eligible for these promotion policies.

Besides the tension between the institutional and technical factors, there is a strong interaction between the technical and economic factors. The requirements for renewable energy promotion policies can force developers to change (part of) their technical design in order to become eligible for specific subsidies. In that case, these changes in technical design are likely to result in added costs for the project developer.

Finally, tensions between the institutional and economic factors can be identified as well. The requirements of the promotion policies should be seen as institutions. They aim to incentivise developers to follow specific rules and requirements, resulting in increased use of particular renewable energy technologies. The tensions arise in the determination of the strength of the economic incentive. The incentive needs to be strong enough to motivate developers. At the same time, the economic incentive should not be too high since that could cause an imbalance in the market. Hence, there must be a balance between incentives and market forces.

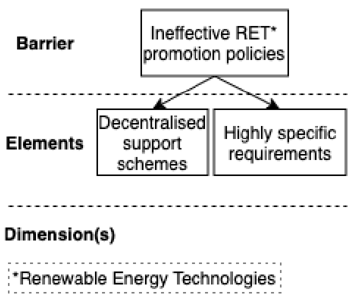

Figure 3.7: The structure of the barrier *ineffective renewable energy technology promotion policies* with its elements.

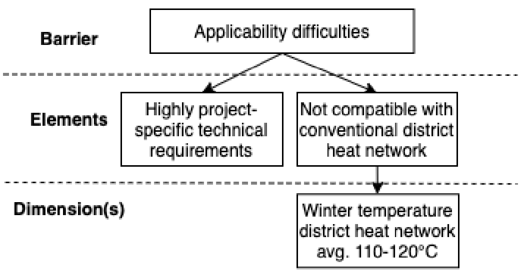

Figure 3.8: The structure of the barrier *applicability difficulties* with its elements and dimensions.

The next barrier is *applicability difficulties*. This barrier is caused by the technical factors of geothermal district heating systems. Two elements have been identified for this barrier. Figure 3.8 visualises this barrier in the framework.

Highly project-specific technical requirements make it challenging to create a single way of developing a geothermal district heating system. Many geothermal heat project characteristics are dependent on local geological, urban, and environmental features. This means that every project requires a project-specific design of the distribution infrastructure and well layout.

The second element of this barrier is the fact that geothermal heat is *not compatible with conventional district heat networks*. The reason is that conventional district heat networks operate average winter temperatures of 110-120°C. The water temperature from geothermal sources is generally lower. This means that the heat from this geothermal source can not be used as input for conventional district heat systems since the network temperature is too high. A solution would be to upgrade the heat to these higher temperatures. However, this requires additional investments, and it increases the operational costs due to the use of electricity for the heat pumps. Another option could be to modernise existing high-temperature systems, but that is very complex since it also requires changes on the individual consumer level.

From these elements, it is clear that the technical requirements for geothermal district heating are relatively specific. These create tensions with the institutional factors, which are, in this case, the agreements on the temperature of conventional district heating systems. These agreements have been established in contracts about the delivery of heat to consumers. Furthermore, these agreements are aimed at allocating the ownership of the heat in the district heat network. Finally, the operating temperatures are also established in contracts, as some types of use require specific temperatures.

The tension between economic and technical factors of this barrier results from costs incurred by a specially designed infrastructure and the costs of constructing installations to upgrade the heated medium to become suitable for use in conventional district heating. Furthermore, tensions between the economic and institutional factors are related to costs that are associated with establishing the contracts, and these are, for example, negotiation costs.

Yet another barrier that is decomposed is *Insufficient comprehensive geological information*. It was explicitly raised during the Geoscience, Policy, and Society conference attended by the researcher in 2021 (Dumas and Barros, 2021). Although decision-makers usually get advice from experts like geophysicists and geologists, only the combination of the knowledge from these experts enables them to make a fully informed decision. This information could include, but is not limited to geothermal potential, cost estimation and more.

One of the elements is *incomplete geological information*. This is partly because the information from the experts is delivered in separate parts, generally one for every field of research. However, only combining these information packages can give the decision-maker a full view of the project possibilities.

The next element of this barrier is the fact that the *geological information is not understandable for decision-makers*. The reason is that decision-makers are not necessarily educated in the field of geothermal energy. Therefore, it will be more difficult for them to understand the information that the experts in the field provided.

The final element of this barrier is that the *reservoir performance is uncertain*. This element is also related to several other barriers. The reason is that decision-makers have little insight into the risk of reservoir performance being below the predicted level or that reservoir performance could potentially decrease over the lifetime of the geothermal well. If this information is not understood from the first stages of the project development, there is a risk of miscalculations in the project's business case.

The economic factor of this barrier is the cost incurred with the subsurface research prior to the development. Tension with the technical factors arises when determining the value of information.

Between the economic and institutional factors, there is tension in the predicted production levels and the price that results from that.

Tensions between the institutional and technical factors arise in cases where ownership of technical information is involved.

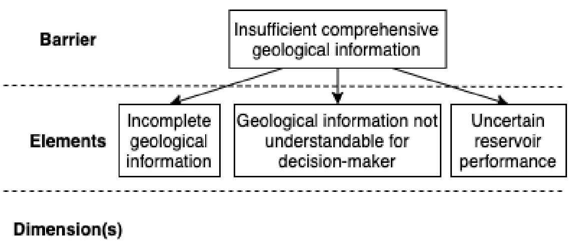

Figure 3.9: The structure of the barrier *Insufficient comprehensive geological information* with its elements.

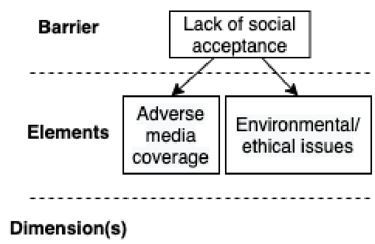

Figure 3.10: The structure of the barrier *lack of social acceptance* with its elements.

Another barrier from the literature review, is the *lack of social acceptance* (see Figure 3.10). This barrier is prevalent in areas in which geothermal district heating is a new technology and if previous developments have had negative side effects. Reasons for the lack of social acceptance concerning geothermal district heating are reluctance due to unfamiliarity or fear of negative side effects.

One of the elements is *adverse media coverage*. The media has a platform to reach many people in a short time. An issue becoming apparent nowadays is that some media outlets are known for publishing incorrect or biased information. However, that is not to say that all the negative media coverage is misleading by default. The result of negative media coverage is that the public perception could become negatively influenced based on incomplete or incorrect information.

Another part of this barrier is the existence of *environmental/ethical issues*. These are mainly related to fear of subsidence, earthquakes, and environmental pollution. Although subsidence and earthquakes are not common with deep geothermal energy projects, there have been instances where they did occur. Additionally, people could be concerned about the effects of extracting heat from the deep subsurface. Although many scientific studies have shown that this heat can be extracted without causing environmental problems, concerns are still present.

The institutional factors of this barrier are institutions like norms. If there is no public acceptance of geothermal energy in a region, it is unlikely that it will be used there. This could create tension with technical factors since it could mean that alternative technologies have to be found to generate renewable heat in that location, creating new challenges.

The technical challenges that could arise from the alternatives are likely to require additional research projects. Tension with the economic factors appears in the form of the added costs of alternatives to geothermal heat.

The economic versus institutional tensions arise in the investments that need to be made to convince the public that geothermal development is safe. On the other hand, these costs may be calculated in the heating price, which might not be in line with the norms of the public.

The last institutional barrier that is discussed in the literature is the *lack of public interest* in geothermal district heating (Figure 3.11). According to the literature, this lack of public interest is mainly caused by two elements. The first element is *the influence of the fossil fuel industry*. As the fossil fuel industry is a multi-billion industry, it is in their interest that the energy transition is slowed since a fast transition to renewable energy sources would lead to enormous losses for the sector. Therefore, the fossil fuel industry has many lobbyists that try to influence the development of climate policies on both a national level and the European level. Part of their goal is to generate doubt about climate policies and to slow down the energy transition.

The other reason that geothermal energy is subject to a lack of public interest is that its *perceived as a high-cost/high-risk energy resource*. In general, geothermal doublets are more costly than other systems that produce heat. Hence, the perception may appear logical. However, most people forget that geothermal doublets can result in a much bigger resource for the increased investment costs.

Besides the first two elements, the third element is the *general ignorance of energy systems* with the public. Although we use various forms of energy every day, many people do not know exactly where their energy comes from and how it got to them. This could be seen as an issue for the acceleration of geothermal energy systems. An essential factor of the energy transition is that the public sees the importance of the energy transition and what alternative energy sources are available.

Several interactions between the three factors are identified. The economic factor is the fact that the initial investment for geothermal energy is generally higher than conventional energy sources. This is the result of expensive techniques required to develop a geothermal well, resulting in higher energy prices.

The risk that is involved with oil and gas exploration is translated by the public into apprehension towards geothermal energy. That is where the institutional factor appears. The combination of the high costs and the perception of the increased risk causes the public to choose other energy resources before geothermal energy is chosen. This creates tension with bot the technical and economic factors since it is difficult to develop geothermal district heating cheaper.

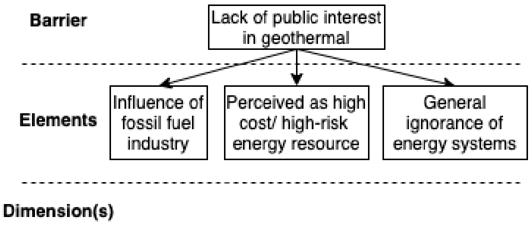

Figure 3.11: The structure of the barrier *lack of public interest* with its elements.

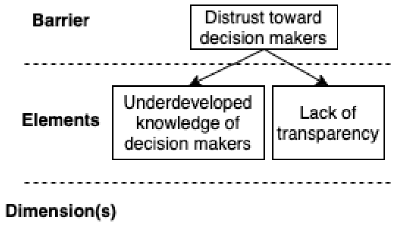

Figure 3.12: The structure of the barrier *distrust towards decision-makers* with its elements.

Distrust towards decision-makers has been identified (Figure 3.12). Two elements mainly cause this distrust. The first element is the *underdeveloped knowledge of decision-makers*. In many cases, decision-makers, specifically government officials, are not necessarily experts in geothermal energy development. Therefore, there is some level of distrust from citizens but also from developers. The assumed reason is that government officials cannot make well-informed decisions due to a lack of knowledge.

The second element is *lack of transparency*. Decisions by the government are established in varying degrees of transparency. The problem might not necessarily be the transparency presented by the government itself, but more in the level of transparency that the public or developers expect from it.

When looking at the triangular framework, it can be determined that the expected level of transparency can be seen as an institutional factor. This expectation is the result of norms of citizens regarding transparent government operation, which can cause frictions with the technical factors related to the decision-maker's substantive knowledge.

There is also friction between the economic and institutional factors since the expectation of transparency can result in delayed decision-making processes. If decision-making processes are entirely transparent, this could result in endless discussions before making an actual decision. These delays can result in longer permitting procedures or waiting times, which eventually translate into later commissioning of a system. Consequently, the incoming revenue is also delayed.

Finally, the tension between economic and technical factors can be identified from government decisions that adversely affect developers due to insufficient knowledge. This could result in geothermal energy system developers making additional investments that could be avoided if the decision-makers had sufficient knowledge.

4

Research questions, methods and country selection process

In this chapter, the sub-questions leading to an answer to the main research question are discussed, and the research methods are introduced. By first addressing a set of sub-questions, the researcher can formulate an answer to the main research question. To recap, the main research question for this study is:

"How can the implementation of geothermal district heating in European countries be accelerated within this decade?"

Various research methods have been used for this study. The research project identifies and analyses different barriers to upscaling geothermal district heat use in European countries. Three European countries have been explicitly investigated. In essence, this is a comparative investigation of barriers encountered in these countries. Therefore, the research methods that are used should allow for a certain degree of comparison. The investigation aims to get insight into the barriers encountered in the selected countries, compare differences between these countries, and find possibilities for alleviating the barriers. First, the research methods related to the conceptual framework are presented in Sections 4.2. Then, the selection process for these countries is discussed in Section 4.3.

4.1. Research questions explained

A set of five sub-questions has been formulated. These questions enabled the researcher to perform an in-depth analysis of the research problem. Additionally, the answers to the sub-questions logically flow to the answer of the main research question stated above. This section first provides an overview of the formulated sub-questions and the research method for every question. Then, the choice for and the objective of every sub-question is shortly explained. Finally, the research methods are explained in more detail in the next sections.

Table 4.1 provides an overview of the sub-questions and the research methods that have been applied for every sub-question. For the answering of the sub-questions 2 to 5, the conceptual framework is employed. First, it is used to analyse the presence of barriers and mitigating actions in the selected countries. Later on, the conceptual framework is used to determine the necessary steps for the mitigation of barriers.

Table 4.1: A table displaying the research methods that have been used for every sub question.

Research question	Research method
1. How has geothermal district heating developed itself in the European context over the past decade?	Energy statistics analysis
2. Why have certain European countries achieved a high degree of geothermal district heat use while others have not?	Document analysis Interviews
3. What actions have been taken to achieve further upscaling of geothermal district heating, and why have the actions taken been (un)successful in the investigated countries?	Document analysis Interviews
4. What is the future perspective for the investigated countries concerning geothermal district heating up to 2030?	Document analysis
5. What additional actions are required to achieve accelerated geothermal district heating systems deployment in European countries?	Document analysis Interviews

4.1.1. Sub-question 1

The first research question has two objectives. The first objective is to gain an insight into the past decade's developments of geothermal district heating in Europe. The second objective is to use those insights to select three countries for in-depth analysis in the remainder of the study. This question is answered by primarily using energy statistics analysis. First, the energy statistics analysis is used to see how the installed capacity of geothermal district heating has developed in the past decade.

Furthermore, it is used to determine the current status by presenting the share of geothermal district heating in the household, commercial and public services heat sector. In addition to that, the overall European potential for geothermal heating is considered. Together, the insights from the first research question are used to highlight interesting differences between countries. Finally, the analyses are used to select three countries that will become the main subjects of the in-depth analysis in the remainder of this study.

4.1.2. Sub-question 2

Research question two aims to identify the factors that have played a role in the development of geothermal district heating implementation in the three selected countries. These factors are determined by applying the conceptual framework already presented in Chapter 3. By means of document analysis and interviews, the presence of barriers and their elements is tested for each of the countries. Initially, this will lead to the identification of a set of barriers in the countries.

First the presence of barriers is tested by analysing various types of documents explained in subsection 4.2.2. Then, the interviews are used to get a more detailed view of the barriers and the elements behind them. Additionally, the experts are consulted if the information from the literature is vague or if its reliability is uncertain.

4.1.3. Sub-question 3

For research question three, the conceptual framework is applied to determine the effect of previous government or geothermal sector actions on the presence and magnitude of the barriers or their elements. This objective is achieved by examining the literature and consulting the experts during the interviews. Hence, to answer this research question, the additional information collected on actions to mitigate barriers is reviewed in light of the barriers and their causes.

4.1.4. Sub-question 4

Research question four aims to formulate a prognosis for the developments of geothermal district heating in the three selected countries up to 2030. The answer to this question is based on several types of information. First, the current status of development provides the basis from which the upscaling within this decade is determined. Then, the information on the analyses of barriers and mitigating actions is interpreted by using the conceptual framework to estimate the potential for upscaling in this decade. Finally, from that estimate, a prognosis for the future development of geothermal district heating is formulated for each of the countries.

4.1.5. Sub-question 5

The final sub-question, research question five, aims to generate a set of requirements that enable accelerated upscaling of geothermal district heating. The objective for accelerated upscaling is set at a share of 10% geothermal district heating in the household, commercial and public services heat sector by 2030. The requirements to reach that objective are determined by first considering the answers to the previous research questions. Additionally, the experts are asked to give their views on the possibility of reaching accelerated upscaling and the necessary actions to do so. That information is used in the conceptual framework to formulate actions that positively affect the elements at play to mitigate their respective barrier.

4.2. Research methods

4.2.1. Methods related to the conceptual framework

In the paper presenting the conceptual framework, Painuly (2001) presses the importance of a thorough analysis. He presents three types of research activities imperative for a complete understanding of the barriers to renewable energy technologies. These research activities are:

1. Literature study (document analysis)
2. Site visits where possible or suitable
3. Interaction with stakeholders through interviews or questionnaires

For this study, the first and last research activities of the list mentioned above are most important. That is why the literature study and interviews with experts are an integral part of this research project. There is a reason why the second research activity is not as crucial for this research project. That is that geothermal heat production systems generally have a minimal footprint on the Earth's surface, and this could render a site visit somewhat useless. Additionally, it is not the visible part of the geothermal projects to which the barriers are related. Instead, the barriers apply mainly to the subsurface (technical) characteristics. Therefore, omitting this research activity from the research process will have minimal influence on the study's results, if any at all. Nevertheless, if suitable and of added value, a site visit could be planned.

4.2.2. Literature study

The first research activity consists of an extensive literature study. In the remainder of this report, the literature study is further referred to as 'document analysis' for several reasons. One, the actual method used is document analysis. Two, the used literature consists of more than reports or scientific articles, and finally, to avoid confusion with the literature review presented earlier. For this research project, various types of documents have been consulted. These types can be divided into the following:

- Scientific literature
- Government (policy) documents (e.g. European Commission, national governments)
- Geothermal energy technology and market reports
- literature containing statistics about deep geothermal heat use

The document types mentioned above have been used to gather data and better understand the developments in the field of deep geothermal heat use. Scientific literature has been used to get a better insight into the field of research. Furthermore, scientific literature was used in the literature review to find the barriers to geothermal heat use. Only scientific literature published in the past decade has been used to ensure that the consulted literature contained barriers that have been encountered in relatively recent years.

Besides scientific literature, government documents have been consulted. These documents varied from national policies to regional or local policies. The reason behind using documents from various levels of government is that in an early stage of the research, it became apparent that dependencies between various layers of government could result in institutional barriers in the field of deep geothermal heat use.

Market and technology development reports have been used to determine the status of deep geothermal heat use in European countries. These reports have been especially useful in analysing the technology developments and implementation on national and international levels. The reports and energy statistics analysis provided the basis for the country selection process since they allowed to identify both the frontrunners and the backmarkers in the sector. That information was used to find countries of interest for this investigation.

Finally, energy statistics on geothermal district heating have been used to examine the size of a country's geothermal sector. This statistical information has been reviewed in the context of a country's geothermal potential. The geothermal potential is generally expressed by presenting high and low-enthalpy zones on a geological map, combined with the presence of reservoirs. This reservoir is typically a permeable layer of sedimentary rock. Section 4.3 provides a more detailed description of the data and methods for the country selection.

A goal of the document analysis is to find if barriers or elements from the conceptual framework can be identified for a country. Additionally, the document analysis is used to find which actions governments have taken to mitigate barriers and to determine if these actions have been successful.

4.2.3. Interviews

Besides the document analysis, local knowledge is essential to ensure a thorough analysis of the barriers to deep geothermal heat use in the selected countries. For this research project, interviews are chosen to be the most suitable method of interaction with experts and stakeholders. The reason is that some types of interviews allow a certain degree of freedom for the respondent to answer the interview questions. Since this freedom enables respondents to explain specific structures behind the barriers encountered in their country, a complete perspective and thus analysis is expected. The interview protocol containing information on the interviews can be found in appendix A.2. Furthermore, appendix A.3 provides the interviewee reference numbers and a description of the interviewees.

The interviews are meant to gain insight into the less explicit yet existing structures that influence the implementation of geothermal district heating. By interviewing experts from the selected countries about their experiences with these barriers, the researcher intends to identify possibilities for removing the barriers. Based on the barrier removal or alleviation possibilities, necessary actions are explored and recommended.

There are different types of interviews with different techniques and goals. For this research project, semi-structured interviews are most suitable for two reasons. The first reason is that semi-structured interviews are more conversation-based interviews instead of question-answer interviews. This allows the researcher to deviate from the main conversation subject when potentially valuable information arises. At the same time, this type of interview enables the researcher to control the conversation by adhering to a rough interview structure. The second reason is that conversation-based interviews invite interviewees to provide more in-depth responses to the questions raised. Simultaneously, the researcher can investigate certain subjects in even more detail by asking follow-up questions.

During the interviews, the barriers and their elements are discussed as presented in the conceptual framework. The conceptual framework is used directly as a guide during the interviews. The objective is to have the interviewee react to the barrier itself and the elements within the context of their own country. Primarily to discover why certain barriers play a role in a particular country and why other barriers do not (anymore). It is critical to place the answer provided by the interviewee within that country's institutional, political and economic context and draw conclusions accordingly.

The usefulness of the interviews for the analysis increases if the appropriate respondents are interviewed. Hence, it is crucial to have some criteria concerning the respondents. To start, a respondent has to be working in the deep geothermal heating sector or affiliated sectors. Second, respondents should have more than five years of experience within the sector to ensure that their knowledge is detailed enough to provide concrete and complete answers to the questions. Ideally, respondents are not biased or otherwise influenced to give certain answers to the interview questions. In that case, a situation could arise where the bias is difficult to recognise and even harder to overcome. Therefore, the respondents have been asked to be as impartial as possible. Nevertheless, the complete objectivity of the analysis cannot be guaranteed.

The interviews would ideally be conducted with three types of experts to get a comprehensive picture of the status of geothermal district heating in the countries. The first type is scientists/researchers, and these experts are expected to be least biased toward either government policy or commercial development. Although some apprehension toward their independence is appropriate, their answers will likely be objective.

The next type of interviewees is that of policymakers. These interviewees can provide an overview of past and expected policy developments related to geothermal district heating in their country. In some cases, researchers may have a part-time position within a government think-tank or committee. This may cause these interviewees to have some degree of positive bias towards government policy, mainly since they are involved in creating it. Therefore, it is essential to know beforehand whether a researcher also fills a position within a government department.

The final type of interviewees for this research project are developers or operators in geothermal district heating systems. These people are essential for this research since they generally have a good overview of the commercial sector and its needs. However, since geothermal district heating development is a commercial endeavour, the answers by this type of interviewees are likely somewhat biased toward creating better market conditions for their gain. Therefore, it would be good to expect at least some degree of bias and to be aware of that during the interview itself.

4.3. Country selection process

As mentioned before, this research project is based on a comparative analysis of different countries in Europe. In this section, the country selection process is explained. The objective of the country selection process is to select three countries that are at varying stages of development of geothermal district heating.

First, the developments on a broader European level are considered, and later in the study, the focus converges towards separate countries. By gathering knowledge from the developments on a higher level, changes on the national level could be easier to interpret since the broader context is known.

Several market and technical developments have taken place on a European level. The organisation that keeps track of the market and technical developments on a European scale is the European Geothermal Energy Council (EGEC). Their annual reports provide a valuable source of information on the developments in the geothermal energy sector. Although summaries of these reports are publicly available, the comprehensive versions reports are confidential. Therefore, these documents can only provide a general overview of the market developments of geothermal district heating in Europe.

Next, a closer look is taken at separate countries within Europe. First, this is performed by looking at the developments in installed capacity of geothermal heating systems for various countries over the past decade. The development speed can be indicated by the growth of the installed capacity of geothermal district heating throughout the years. The speed of geothermal district heating development in a country can be a good indicator of that country's attitude towards using geothermal energy. When viewed in combination with government policies, it is possible to gain a general insight into the success of geothermal energy promotion policies by determining the economic viability with and without those policies. Finally, a geological map of Europe, displaying regions containing hydrothermal reservoirs suitable for economic development, is considered in the selection process to understand the geothermal resource potential in European countries.

After considering the European context of the geothermal energy sector, it is possible to select countries that become part of the comparative study. This part of the selection process is important because a set of countries worth investigating would meet several criteria. These criteria should enable the researcher to analyse and compare a diverse set of countries. Below, a description of the criteria for the country analysis is provided.

First of all, a country has to have at least some level of geothermal resource potential. The reason is that it would be nonsensical to investigate geothermal district heating in countries that do not have suitable geology for the application of this technology. No numerical lower bound value for geothermal resource potential is applied to select a country, mainly since the numerical theoretical resource potential is difficult to estimate. Additionally, when a numerical geothermal resource potential is mentioned in the literature, it is usually unclear under what assumptions this potential has been determined. Therefore, a numerical potential will only be mentioned in this report if there is a clear understanding of the data source and assumptions. In this research project, the geothermal resource potential is derived from a map that displays known areas with hydrothermal reservoirs suitable for economic development.

The second criterion is that there needs to be some level of diversity in the development of geothermal district heating between the investigated countries. This means that, for this investigation, the plan is to compare countries with varying technology implementation levels. A complete set of countries would consist of: a country that can be seen as a frontrunner in the development of geothermal district heating, a country that has developed geothermal district heating to some extent, but seems to experience stagnating growth, and a country that is a relative newcomer (in the final stages of completing their first systems) in terms of geothermal district heating development.

For the final criterion, sufficient information regarding deep geothermal heat use is required for a country to become the subject of this investigation. Before the definitive country selection, the availability of data was discussed with one of the thesis supervisors. The required information should include statistics on geothermal district heat use, geothermal potential, and policy documents. Additionally, this information should be up-to-date and verifiable. This verification, if needed, can take place during the interviews with experts of that particular country.

In this chapter, the research methods have been presented and explained. In the next chapter (5), sub-question 1, the developments in geothermal district heating in Europe is discussed, in combination with the selection of three countries that are investigated further.

5 Country developments and country selection

This chapter discusses the past decade's developments in deep geothermal heating in a European context. The objective is to get insight into the conditions that enabled the growth of the geothermal energy sector. The goal of this chapter is to formulate an answer to sub-question 1, presented in Chapter 4. This is: *"How has geothermal district heating developed itself in the European context over the past decade?"*

5.1. Market developments in European countries

Over the past decade, the number of installed deep geothermal heating systems has increased significantly across European countries. Some countries stand out in terms of (relative) growth or the size of their geothermal heating sector. The European Geothermal Energy Council, a non-profit organisation that promotes geothermal energy use in the European Union and beyond. Besides their promotional activities, the organisation also keeps track of geothermal energy's current status and developments. From their records, it becomes clear that the deep geothermal heating market has seen steady growth in Europe. The European Geothermal Energy Council also managed the GeoDH project. GeoDH is an EU-funded information hub that was actively moderated between 2011 and 2014. The project aimed to overcome the non-technical barriers to the development of geothermal district heating specifically. Although the information is relatively dated, a lot can be learned from the portal, even today. It is mainly beneficial to compare the installed capacities for geothermal district heating through the years. Figure 5.1 presents the development of the installed capacities (in MW_{th}) of various countries in from 2012 to 2018.

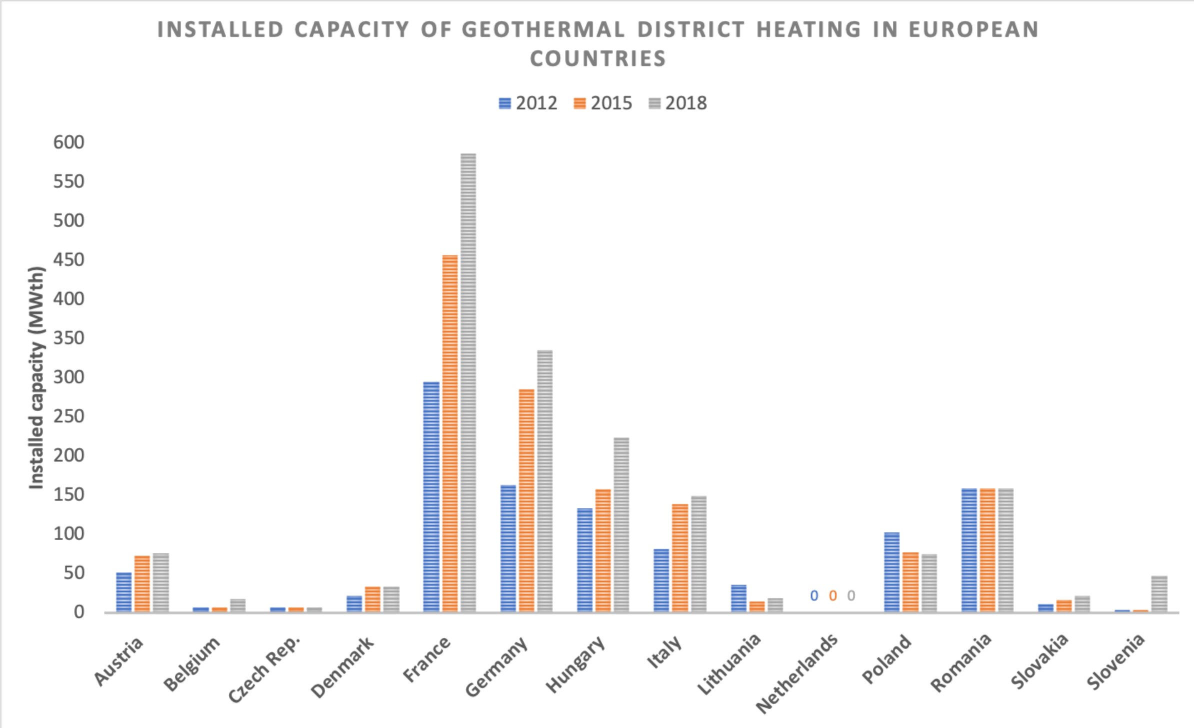

Figure 5.1: The installed capacity of deep geothermal district heating systems in MWth for European countries in 2012, 2015 and 2018 (data sources: Antics et al., 2013, 2016; Sanner, 2019).

From a historical point of view, several European countries have a well-established base of direct use geothermal energy. These are, among others, Italy, France, Germany, and Hungary (International Geothermal Association, 2020). However, compared to their total direct use of geothermal energy, not all of these countries have a large share of geothermal district heating. For example, most of the geothermal installed capacity in Italy is used for balneology (spas and geothermal baths, 34%) and individual heating and cooling systems (38%). Similarly, in Hungary, balneology (32%) and agriculture (43%) are the primary direct uses of geothermal heat.

On the other hand, France and Germany have dedicated more of their installed capacity of geothermal heat use to district heating. In 2015, these countries had an installed capacity for geothermal district heating of 465 MWth (91%) and 285 MWth (85%), respectively (Antics et al., 2016). In contrast to countries that have developed much of their geothermal energy potential, countries like the Netherlands and Denmark are relative newcomers. Although the Netherlands is well known for its use of geothermal heat in agriculture, it currently has no operational geothermal district heating plant.

Although many countries have a certain installed capacity of geothermal district heating, it is more valuable to know the share of heat demand by households and commercial and public services covered by geothermal district heating systems. The reason is that countries with many citizens tend to have a higher total heat demand than countries with fewer citizens. This also means that their geothermal district heating production capacity needs to be significantly higher to cover a percentage of the total heat demand. In Table 5.1 below, the total heat demand is compared with the available heat from geothermal district heating. A striking observation is that the contribution of geothermal district heating systems towards the total heat demand is very small for most countries.

Table 5.1: The contribution of geothermal district heating to the total heat demand in households and commercial and public services in 2019 for various European countries. (data sources: Eurostat, 2020; Sanner, 2019.)

Country	Annual geothermal district heat production 2019 [GWh_{th}]	Annual heat consumption households, commercial & public services [GWh_{th}]	Share geothermal district heating of total
Austria	225	17004	1.3%
Belgium	15	739	2.0%
Czech republic	21	16801	0.1%
Denmark	99	27539	0.4%
France	1652	24273	6.8%
Germany	1002	62179	1.6%
Hungary	280	7176	3.9%
Italy	237	13774	1.7%
Lithuania	34	7220	0.5%
Netherlands	0	5926	0.0%
Poland	250	54564	0.5%
Romania	300	9913	3.0%
Slovakia	41	5550	0.7%
Slovenia	47	1401	3.4%

From Table 5.1, it can be observed that there are only a few countries that can cover a significant amount of their household, commercial and public services heat consumption with geothermal district heating. Hungary, Slovenia, France, and Romania stand out because of their heat consumption percentage covered by geothermal district heating. On the other hand, it also becomes clear that these percentages are all below a ten per cent share of the total heat consumption. This implies that there is room for improvement in terms of geothermal district heat use. The combined share of geothermal district heating as part of the household, commercial and public services heat sector was 1.1% in 2012. In 2019, that share had grown to 1.7% (Antics et al., 2013; Eurostat, 2021; Sanner, 2019).

Besides that, another striking observation is made. When comparing the geothermal district heat production from Table 5.1 to the installed capacities in Figure 5.1, it can be observed that the capacity factor in some countries is extraordinarily low. The capacity factor is a measure of productivity. It is the ratio between the actual production and the maximum possible production from all geothermal installations. It can also be interpreted as the percentage of time in a given period (here, one year = 8760 hours) that the installations provide maximum output. For example, in Hungary, the capacity factor is about 0.14, which equals 1256 full load hours, while in Germany, the capacity factor is 0.33, equalling 2914 full load hours. Possible reasons for a low capacity factor in geothermal district heating are seasonal demand and that some installations might not provide baseload heat production.

5.2. Current status and country potential

Over the years, various types of geological maps have been developed. These vary from maps that display the types of rock formations in the subsurface to ones that display the presence of oil or gas reservoirs. A particularly useful map for geothermal applications is a geological map that displays the subsurface heat distribution combined with reservoirs. These are maps commonly used to identify areas that have the potential for geothermal heat use. Although these maps are useful to geologists, they provide only part of the information decision-makers need regarding geothermal installations. The maps lack information about the risks, information about predicted costs, and potential.

A challenge for deep geothermal energy development raised during the 2021 Geoscience, Policy, and Society conference (2021) is that there is a pressing need for more comprehensive geological information to assist decision-makers. Mainly since, currently, geothermal heat use projects are still perceived to be high-risk activities. Combined with high capital and exploration costs, financing of geothermal heating systems is troublesome.

Difficulties with feasible exploitation of geothermal resources are encountered all over the world. Also, in places like Iceland, known for its extensive use of geothermal energy, thanks to relatively shallow, high-enthalpy resources (Ingimarsson, 2012).

Although not everywhere, the geothermal potential in Europe is relatively high. Some areas have more potential than others. Figure 5.2 shows the areas with potential for economic geothermal heat use in Europe. This map indicates that some places in Europe are more suited for geothermal heat use than others. There are several reasons for using a map to present the geothermal potential instead of using numerical values. First of all, the geothermal potential is hard to determine numerically. Additionally, the theoretical geothermal potential does not provide any information about the actual practical geothermal potential. Furthermore, when the geothermal potential of an area is presented, it is usually unclear under what assumptions this potential has been determined.

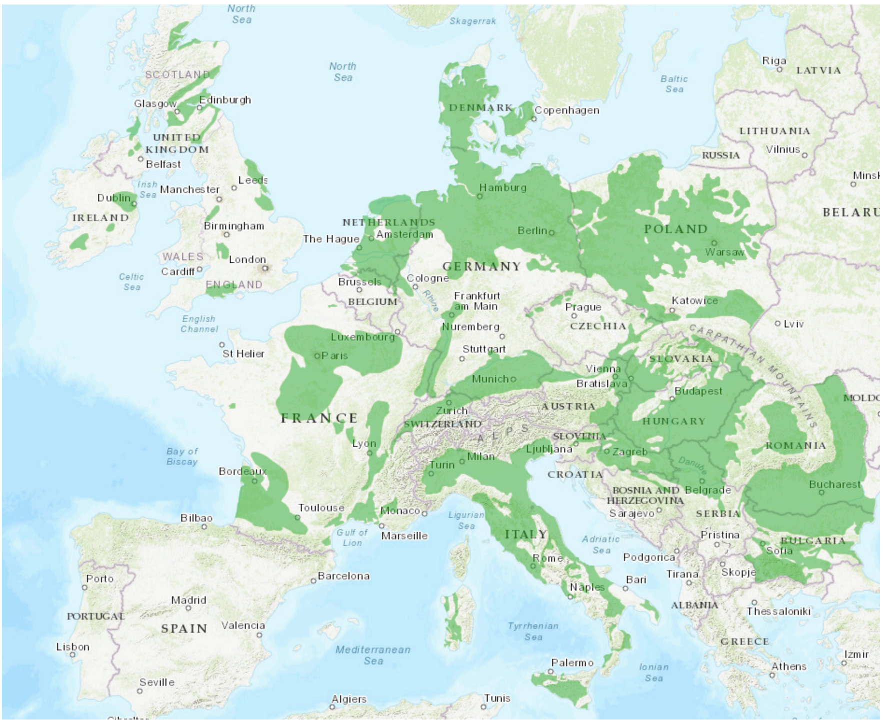

Figure 5.2: A map of Europe where the green areas display regions with economic hydrothermal potential. In short, this means that an area's subsurface contains sufficient geothermal energy, combined with subsurface characteristics that make it suitable for economic exploitation. Note: Portugal has not been included in the study resulting in this data set (source: Europa-Universität Flensburg et al., 2021).

5.3. Selected countries

As can be observed in the map of Figure 5.2 above, some countries have much potential for geothermal heat use. Combined with the information about installed capacity presented earlier, it seems that some countries have potential geothermal resources, but only little of that potential is used. Several countries stand out when looking at this map displaying geothermal potential. Especially when this observation is compared to the installed capacities presented in Figure 5.1, it can be concluded that not all of these countries seem to have tapped into their potential yet. This difference between a country's installed capacity and its geothermal potential is crucial in selecting countries that become part of the comparative section of this research project.

At this point, it has become possible to determine the selection of countries that are investigated further. First of all, it is important to keep in mind that not all countries have the same availability and accessibility of information. With that thought in mind, several countries remain available for comparison. Two countries are deliberately omitted from the study to make sure that a fair comparison is conducted. These are Turkey and Iceland. The geothermal potential in these countries is exceptional, and including them in this study would result in an unfair comparison. For that reason, they are not considered in the selection process.

From Figure 5.2, it can be observed that Germany has many areas with hydrothermal potential. Besides that, it also has a relatively high installed capacity of geothermal district heating systems. In 2018, the installed capacity of geothermal district heating systems in Germany was 344 MW_{th}. Additionally, the share of geothermal district heating on the total residential and commercial heat demand is fairly average (see Table 5.1). Hence, Germany is selected as one of the countries that is investigated further.

The second country that is selected is Hungary. The reason is that the country has a relatively high potential compared to other European countries (Figure 5.2). Besides that, the share of geothermal heat in district heating is higher than in other European countries (Table 5.1). The installed capacity of geothermal systems in Hungary is high. Though, much of the installed capacity is used for agriculture, balneology and industrial purposes. Another factor that makes Hungary an interesting country is that Hungary keeps reasonably detailed records of their geothermal energy industry. This is not necessarily the case for other countries that could be considered for this configuration.

The last country of the selection is the Netherlands. The Netherlands has good potential for geothermal heat use. The country has seen some geothermal heat use already, be it mostly in agriculture. Geothermal district heating, on the other hand, is relatively new to the Netherlands. In 2011 the Dutch government made commitments towards increasing the share for geothermal installations soon (Ministry of Economic affairs agriculture and innovation, 2011). A 7 MW_{th} geothermal district heating project was developed in The Hague in 2013. However, shortly after completing the project, the owners filed for bankruptcy. Although this plant is expected to be operational again by the end of 2021, the Netherlands has not had any prior experience with geothermal district heating. Another reason for selecting the Netherlands is that detailed maps about the Dutch subsurface have been created thanks to widely spread historic oil and gas recovery.

Considering the research question presented at the beginning of this chapter, it has become apparent that the development of geothermal district heating has varied significantly throughout Europe. Countries like France and Hungary have been using geothermal heat for decades or centuries. Their experience has played a role in the early development of geothermal district heating systems. Resulting from that experience, their use of geothermal district heating has grown significantly in the past decade. At the same time, it is apparent that the geothermal district heating use in some countries has been concentrated in a relatively small area. That could be explained by the fact that only this concentrated area has sufficient geothermal potential for district heating. Another possibility is that the distance from the geothermal source to suitable district heating systems is too far.

Besides the countries that use a lot of geothermal district heating, countries like the Netherlands and Slovakia have developed only little geothermal district heating, despite the potential. This could give a false impression that these countries do not use geothermal heat. In contrast, their uses of geothermal heat are primarily in agriculture.

As a part of this chapter, three countries have been selected for a more in-depth investigation of the barriers to geothermal district heating and the actions that have been taken to accelerate the upscaling of geothermal district heating. Furthermore, a prognosis of the status of geothermal district heating in 2030 is made for each country. Finally, additional requirements are identified, and further actions are made accordingly.

6 Presence of barriers and previous actions

In the previous Chapter (5), the developments of geothermal district heating have been discussed within a European context. Additionally, a selection of three countries has been made. These countries will be investigated further. The selected countries are Germany, Hungary and the Netherlands.

To begin with, a short history of geothermal district heating in the selected countries is provided. Then, this chapter aims to achieve several objectives. The first objective is to identify the presence of barriers in every country. Subsequently, the actions that have already been taken to mitigate the barriers to geothermal district heating are identified. The barriers and actions are identified for every country. They are identified by applying the conceptual framework and by structuring them according to their primary factor within the framework, as indicated in Table 3.1 from Chapter 3.

As mentioned in Chapter 4, the presence of barriers for the countries has been determined through document analyses and expert interviews. In total, ten interviews have been conducted with experts in the field of geothermal (district) heat use. For Germany, three experts have been interviewed, one for every type of interviewee described in Chapter 4. For Hungary, two experts have been interviewed, and these were a geoscientist and a developer. Despite multiple attempts to contact policymakers at several ministries, interviewing a policymaker from Hungary has not been possible. For the Netherlands, five experts have been interviewed. Two interviewees are developers of geothermal systems, and the other three are a district heat network developer, a geoscientist, and a policymaker. Information from the interviews is referenced by putting the interviewee-ID of the interviewee within parentheses. The details about the interviews can be found in Appendices A.2 and A.3.

Two research questions are central to this chapter. The question that is addressed in Section 6.2 is *"Why have certain European countries achieved a high degree of geothermal district heat use while others have not?"*. This section also summarises the barriers that have been found to be present in the selected countries. The research question that is addressed in Section 6.3 is *"What actions have been taken to achieve further upscaling of geothermal district heating and why have the actions taken been (un)successful in the investigated countries?"*. This section also aims to identify which barriers are (nearly) mitigated and which require additional action.

6.1. Developments in the selected countries

Germany

History of geothermal heat use

In Germany, geothermal heat was originally used primarily for spas and greenhouses. The first geothermal district heating systems emerged in the 1990s (Agemar, Alten, et al., 2014). Though, fast paced development only started around 2011. In 2009, the government introduced the Renewable Heat Act (EEwärmeG). At first, this act was mainly specified for the use of heat pumps and the installation of renewable heat sources in buildings (Weber et al., 2015). However, several revisions led the Renewable Heat Act to also apply to deep geothermal heat systems. In the beginning combined heat and power production from geothermal sources was most common, as a result of the high feed-in tariff for renewable electricity. This simultaneously helped the development of geothermal doublets for district heating, resulting in an increase in the use of geothermal energy for district heating. Nowadays, geothermal district heating accounts for the largest share of direct use geothermal in Germany, which is about 85% (Weber et al., 2019).

Considering the potential for geothermal energy in Germany, it has been estimated that deep geothermal energy could exceed the annual energy use multiple times Agentur für Erneuerbare Energien, 2017). Most of that potential is located in three regions of the country. These are the North German Basin (NGB), the South German Molasse Basin (SGMB), and the Upper Rhine Graben (URG) (Figure 6.1). These three zones have been marked as suitable areas for (deep) geothermal development. This is because the subsurface in these areas consists of sandstone aquifers or karstic structures. Karst is a type of topography that is the result of the dissolution of soluble rocks like limestone and dolomite, which results in cavities in rock formations allowing the development of aquifers (ESI-University of Texas, 2006).

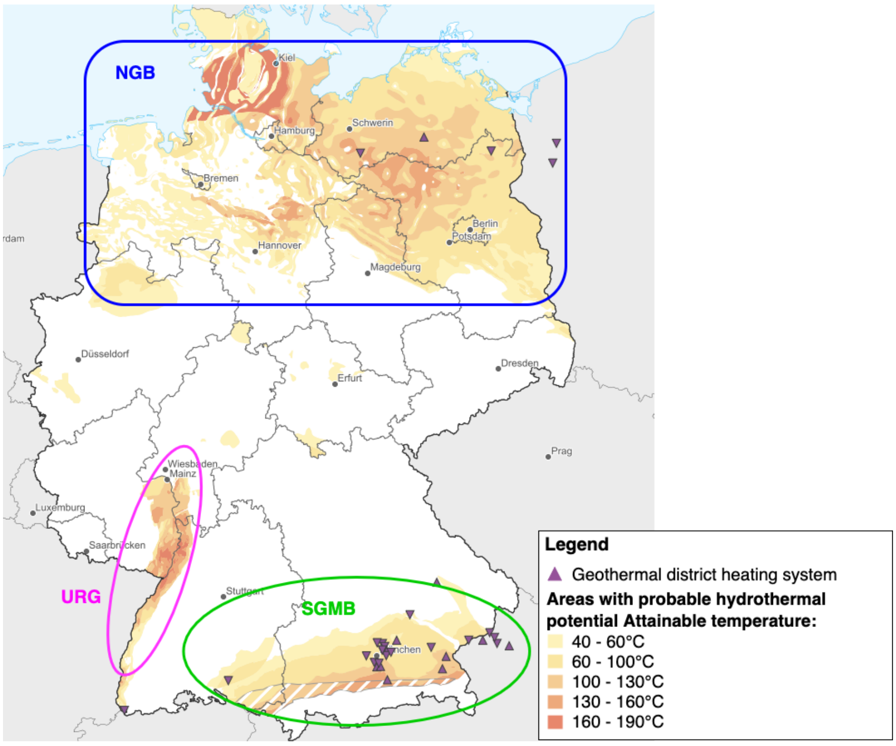

Figure 6.1: The known hydrothermal potential in Germany. Source:(Agemar, Alten, et al., 2014)

One of the states where geothermal district heating has developed substantially is Bavaria. Some decades ago, during exploration activities for natural gas deposits, large geothermal sources were found (Clean Energy Wire, 2020). The South German Molasse Basin was found to have very suitable and safely accessible thermal reservoirs. In many German cities, the residential and commercial heat production is organised by so-called 'Stadtwerke'. These are utility companies that are owned and operated by a public entity, usually the municipality. This has played a major role in the development of geothermal district heating in this state. The development of geothermal district heating systems has been growing relatively steadily in Bavaria (Statistische Ämter des bundes und der Länder, 2020; Wirtschaftsministerium Bayern, 2021). Several reasons for this development are good geological conditions, the second highest gross regional product in Germany, and a progressive state policy regarding renewable energy sources.

Barriers and actions

Institutional barriers and actions

One reason why geothermal district heating has been developed widely in Bavaria is the relatively high social acceptance. This social acceptance is strongly related to the geological conditions in the state. As mentioned before, the safely accessible geothermal reservoirs in Bavaria played a role in developing geothermal district heating because the risk of induced seismicity and subsidence is low. This high public acceptance partly enabled the possibility to create plans for a CO_2-neutral Munich by 2050 (Agora Energiewende, 2019; Landeshauptstadt München, 2021).

Social acceptance is lower in other regions, like the State of Baden-Württemberg (Upper Rhine Graben). The geothermal potential in the region is significant, but the public might be reluctant to welcome further geothermal developments due to the relatively high risk of induced seismicity. This reluctance is the direct result of environmental problems caused by previous geothermal development (Sass and Burbaum, 2010). Also, during the interviews, it was mentioned that the social acceptance of deep geothermal energy varies significantly throughout the country (DE-2; DE-3).

The two paragraphs above clearly describe the varying social acceptance of geothermal district heating in Germany. When considering the barrier *lack of social acceptance* in the conceptual framework, *adverse media coverage* does not appear to be a factor. On the other hand, the element *environmental and ethical issues* plays a significant role in social acceptance in Germany. This element was also found to play a significant role in the barrier during a study on social acceptance of deep geothermal developments in Germany (Kunze and Hertel, 2017). Additionally, the federal and state governments have stringent regulations regarding the acceptance of the local public for geothermal projects, which, in the past, have reportedly led to the suspension of geothermal developments. Hence, it is determined that the barrier *lack of social acceptance* is present in Germany.

In that context, investing in social acceptance is seen as highly important (Informationsportal tiefe geothermie, 2021). To that end, the German geothermal sector has also taken meaningful steps to involve the public in geothermal developments. This is primarily achieved by investing in information provision and by organising geothermal plant tours. Furthermore, state ministries see social acceptance as a priority for the coming years (Bayern, 2019; Umweltministerium Baden-Württemberg, 2019). The interviewees also emphasised the importance of involving the public in geothermal development. They indicate that the focus should be on providing accurate information that is understandable for the public. Furthermore, fulfilling the needs of the local population (i.e. heat production) should have priority. Hence, add-on applications like geothermal power production and lithium production (in some regions only) should be minimised (DE-1; DE-2; DE-3).

Despite the efforts of the governments and the geothermal sector, the lack of social acceptance is said to remain somewhat of a barrier in particular regions because of differences in people fundamental principles (Kunze and Hertel, 2017; DE-3). The current actions are focused on providing factual information to citizens. By doing this, part of the element *adverse media coverage* could be mitigated since including factual and understandable information in news publications could help the public to see the story within its entire context of environmental, economic, and geological conditions.

Economic barriers and actions

In 2017, the Fraunhofer Institute published a study that investigated the role of renewable energy technologies that are key for reaching Germany's 2030 climate goals (2017). In their report, the researchers indicate that it is essential that technologies like geothermal district heating replace their fossil counterparts if Germany is to reach its climate goals by 2030. Hence, their primary recommendations to the government are tax reform and a shift towards centralised heating systems, explicitly naming deep geothermal district heating. The reasons are that fossil fuels for heating are inexpensive, combined with low taxes. At the same time, the German government subsidises conventional combined heat and power plants. These subsidies can range between approximately €1500/kW and €4000/kW (Deutsche Umwelthilfe, 2021). These subsidies generally cover all of the initial investment and even part of the fuel cost. Consequently, the consumer price for conventional district heating is substantially lower than the cost of geothermal district heating. This is advantageous for consumers, but it also hampers the introduction of more expensive, renewable heat sources like geothermal energy (DE-2).

Besides that, the implementation of geothermal district heating is expensive compared to other heat sources. The investment cost of a geothermal plant is 1.2 million Euros per MW_{th} on average (Attard et al., 2018). This does not include the cost of the heat infrastructure itself. The high implementation cost of geothermal district heating has been an issue in general (DE-2; DE-3). Furthermore, during the interviews, it was mentioned that the geothermal heat sector in Germany is relatively small, and municipalities take a very individualistic approach to developing their heat systems. Therefore, scaling advantages are difficult to achieve at the moment (DE-1; DE-2).

Additionally, the success of exploration drilling varies significantly per project and region. In Bavaria, the success rates of geothermal drilling are relatively high. In other regions, however, success rates can be significantly lower. For example, in Bavaria, the first-try success rate of geothermal heat drilling is 94% (Flechtner and Aubele, 2019).

Looking at the conceptual framework, three elements that are linked to a barrier can be observed. These elements are *high implementation costs*, *economies of scale only at large project size*, and *uncertainty of successful resource*. In addition to these elements, the government policy on subsidising conventional combined heat and power plants also plays a role. This results in an new element called *uncompetitiveness with alternative heat sources*. Altogether, these elements can be relayed back to the barrier *economic non-viability*.

The taxes on renewable heat sources have been abolished in the past years, which is advantageous for geothermal district heating. However, this is not expected to result in a substantial change in the development of the technology. According to the interviewees, geothermal district heating is on the agenda of formation talks for the new German government (DE-1). It is expected that this will result in changes to the subsidisation of conventional combined heat and power plants in order to create a more level playing field for geothermal heat sources. There is, however, no assurance that this idea will develop into action in the short term. Therefore, the economic viability of geothermal district heating remains uncertain.

In the first years of the Renewable Heat Act, support schemes were aimed primarily at research and development of geothermal energy in general, with a strong focus on power production. Between 2011 and 2014, governmental support for research and development of deep geothermal energy was provided. This was part of the 6th energy research funding programme (BMWi, 2014). In that period, several projects received financial support. In total, approximately €15 million was invested into the research and development of deep geothermal projects that could also benefit geothermal district heating systems (Weber et al., 2015).

In 2015, another revision to the Renewable Heat Act was completed. This revision also included the use of deep geothermal heating systems (BMWi, 2021c). The goal was to create an incentive for geothermal heat use, among others. This resulted in two federal financial incentives for deep geothermal heat development that are still in place. The first incentive is a €2 million bonus for completed geothermal plants. The second incentive is a financing scheme from the KfW banking group, the German investment bank. One of its objectives is to provide a financing scheme for renewable energy systems on behalf of the German federal and state government. Therefore, it could be seen as a form of government incentive. This financing scheme enables developers of deep geothermal projects to receive a low-interest loan for a maximum of 80% of the drilling costs, up to €25 million. However, the eligibility of this financing scheme is bound to particular rules regarding the application of geothermal heat. In many cases, combined heat and power production from deep geothermal sources is more eligible than district heating only. Hence, some developers of geothermal district heating systems have decided to construct a combined heat and power installation with minimal electrical output (DE-2).

Additionally, the incentive includes low interest rates and a repayment subsidy up to 50%, depending on the project. As a result, up to 50% of the loan does not have to be repaid (BMWi, 2021b). This incentive should be seen as an investment subsidy from the KfW banking group. As a part of that financing scheme, risk insurance is included, covering full risk in case of unsuccessful exploration (Ganz et al., 2013). Note that these incentives are specifically aimed at the exploration phase of geothermal development.

These promotion policies by themselves are relatively advantageous for geothermal district heating.

However, considering the conditions in which geothermal district heating has to operate, with subsidised conventional combined heat and power plants for district heat production, these promotion policies are a lot less effective. From the conceptual framework, the barrier *ineffective renewable energy technology promotion policies* can be identified. One of the elements is *highly specific requirements*, as geothermal district heating systems are not necessarily eligible. Besides that element, the promotion policies are ineffective due to the uneven playing field between conventional district heating and geothermal district heating. Thus, the economic environment significantly affects the effectiveness of promotion policies.

As was mentioned, the federal government provides some incentives for the development of geothermal energy. Though, these incentives are relatively ineffective, given the conditions. Some individual German states aim to develop incentives that are more specifically aimed at the potential for renewable energy sources in that specific state. These policies could be more effective in this case, given the varying potential of geothermal energy between the states. Nevertheless, there is one caveat. That is because developers may only have one promotion scheme, either a federal or a state incentive. Therefore, the effectiveness of renewable energy promotion policies is higher in some states than in others.

Technical barriers and actions

The development of district heating in Germany is relatively slow. Part of this slow development was ascribed to the fact that subsidy schemes for the development of renewable district heating, in particular, are not available (Fraunhofer IWES/IBP, 2017). Another issue that was indicated was the need for legislative boundaries to prescribe lower temperatures in district heat networks (Agora Energiewende, 2019). This problem was also brought up during the interviews (DE-1). The boundary conditions would enable faster development of low and medium-temperature renewable district heating sources like solar thermal and geothermal. The operational input temperatures of these systems vary from 40°C to 80°C, while conventional district heating systems operate at much higher temperatures, of up to 130°C. The reason is that for residential and commercial heating, it is not necessary to have high-temperature district heating. An essential prerequisite is that homes have a high level of energy efficiency.

The paragraph above describes the need for boundary conditions for low-temperature district heating systems in Germany. This can be linked to the barrier *applicability difficulties*. One of the elements mentioned in the text is *not compatible with conventional district heat networks*, which can be drawn from the temperature mismatch between conventional and low or medium-temperature district heating.

As of yet, there have not been any decisions on legal boundary temperatures of district heating systems. However, these rules are expected to be developed within the coming years. As the German government is already working on a more comprehensive legal framework for the energy transition, there will likely be legal boundary temperatures for low and medium temperature district heating systems within the coming years (Jahrfeld, 2020). These boundary temperatures could result in the (partial) mitigation of the barrier *applicability difficulties*.

From the interviews, it has also become clear that there is insufficient knowledge on the German subsurface to develop geothermal systems on a large scale (DE-2; DE-3). In the past decade, the Leibniz Institute for applied geophysics has developed the GeoTIS platform. On this platform, geological information is compiled into easily understandable data sets. However, there are still many so-called white spots. Additionally, the platform does not provide comprehensive information that is useful for decision-makers (DE-2; DE-3). Since the current accuracy of the information is uncertain, it provides little help for developers. Moreover, the individualistic approach of municipalities in developing geothermal district heating does not help the speed of development in the country (DE-2). The Leibniz institute currently provides geothermal developers with geological information on their area of interest for free in an attempt to support developers.

It is apparent that the barrier *insufficient comprehensive geological information* is experienced in Germany. All three elements from the barrier decomposition with the conceptual framework have been identified to be present. Due to the white spots, there is *incomplete geological information*. Additionally, the information on the GeoTIS platform only provides geological information. Therefore, the element *geological information not understandable for decision-maker* is experienced as well since the current platform does not aid decision-makers themselves. Finally, the element *uncertain reservoir performance* has been mentioned in the previous subsection. The uncertainty, combined with the other two elements, causes the presence of this barrier.

In some states, this barrier may be mitigated soon, as they take meaningful steps towards collecting useful data resulting in more comprehensive geological information. The city of Munich, for instance, has recently performed a large seismic study in the southeast of the city (Jahrfeld, 2020). These individual actions are advantageous for the local development of geothermal district heating. However, on a national level, the impact of these actions is virtually negligible.

Additionally, Germany's energy transition think tank indicated what is needed to make heat networks greener. Several challenges for current district heating system operators are mentioned. One of these challenges is to improve the insulation of buildings that use district heating (Agora Energiewende, 2019). Although the energy efficiency of German residential buildings has improved substantially in comparison to the year 2000, the improvement is stagnating (Enerdata, 2021a). As mentioned earlier in this subsection, high levels of energy efficiency are a prerequisite for the use of lower temperature geothermal district heating systems.

During the literature review, *poor insulation of buildings* has not been found as a factor in geothermal district heating. Nevertheless, it has been found in reports on energy policy as being an issue. Therefore, this barrier is added to the analysis.

The German government appears to acknowledge the problem since, in July 2021, the project "Deutschland Macht's Effizient" (Germany makes it efficient) was launched. As part of the 2030 climate action plan strategy, the project aims to improve energy efficiency in society. The total amount of loans and grants that are available through this campaign is estimated at an enormous €27 billion (BMWi, 2021d). It currently provides an incentive to improve the insulation of existing buildings. This incentive is a tax deduction scheme with which 20% of home improvement costs up to €40,000 can be used as tax deductions. The project also includes incentives for new residential buildings, commercial buildings and municipalities.

Several barriers have been found to be present in Germany. Not all barriers that have been indicated in the conceptual framework have been found to play a role within the context of this study. Hence, those barriers are omitted from further investigation for Germany.

Outlook for the coming years

Since the introduction of the Renewable Heat Act, the installed capacity of geothermal district heating systems increased steadily up to 2016. However, from 2016 onward, the development of geothermal district heating systems is stagnating (Figure 6.2). In 2009, the total installed capacity was 108 MW_{th}, which had almost tripled to 317 MW_{th} by 2016. Though, between 2016 and 2019, the installed capacity only increased with 27 MW_{th}, to a total of 344 MW_{th} (Leibniz Institute for Applied Geophysics, 2021). Hence, it currently appears that there is no further growth in the geothermal district heating sector.

It is expected that Germany's energy efficiency campaign will substantially improve energy efficiency in buildings. If that objective is achieved, it opens possibilities for large scale deployment of low and medium-temperature district heating systems. In suitable regions, this could result in the increase of geothermal heat as a source. Nevertheless, several other barriers need to be overcome before this is achieved.

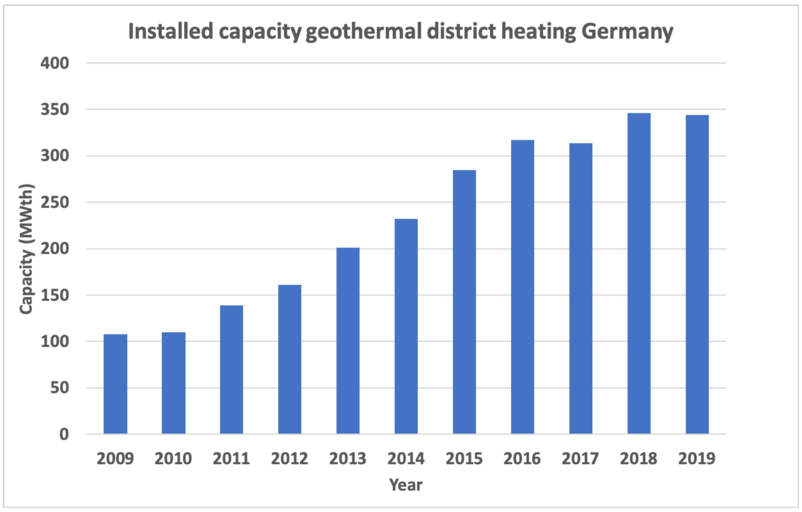

Figure 6.2: The development of the installed capacity in geothermal district heating systems from 2011 to 2019. Source (Agemar, Weber, et al., 2014)

Hungary

History of geothermal heat use

Due to the long history of using thermal waters, Hungary has much knowledge about the subsurface and the potential for geothermal development. The potential for geothermal district heating in Hungary is large for several reasons. First of all, the country's subsurface has a geothermal gradient of 45°C/km, which is about 1.5 times the global average Olajos and Bencsik, 2010; A. Toth, 2020). Second, as can be observed from Figure 6.3, large areas of the country's subsurface contain porous sandstones or karst. At relatively shallow depths of 700 to 1800 metres, sandstone reservoirs hold water at temperatures between 60°C and 90°C (A. Toth, 2020). At depths more than 2000 metres, karstified zones carry water at temperatures between 100°C and 120°C. These medium to high-enthalpy resources are more suitable for cascaded use or combined heat and power production. Finally, high-pressure, high-temperature systems are found at even deeper levels, suitable for enhanced geothermal systems.

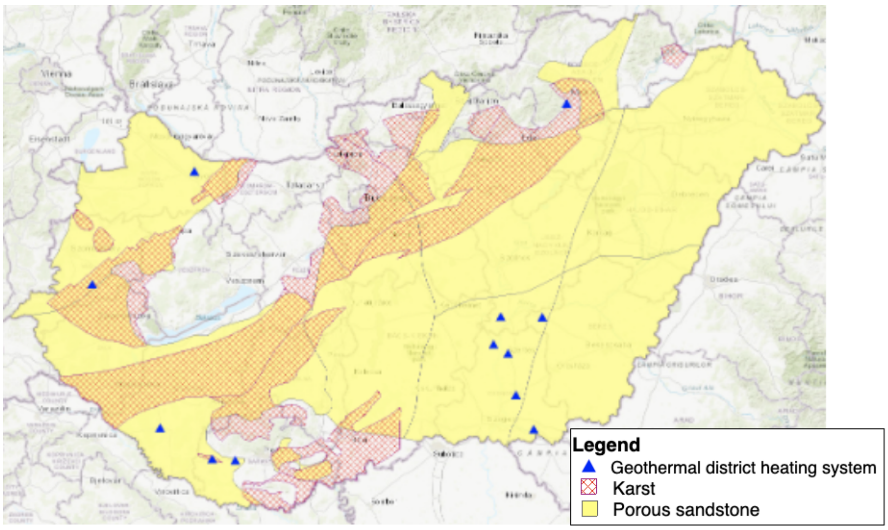

Figure 6.3: A map of Hungary that displays the presence of thermal groundwater bodies and potential reservoirs. source: (Mining and Geological Survey of Hungary, 2021)

In addition to the suitable geology, the social acceptance of geothermal energy is high. This also has to do with the fact that the risks of subsidence and earthquakes are low compared to other countries (HU-1). The use of geothermal energy in district heating in Hungary is relatively old, with the first systems emerging somewhere between 1920 and 1940 (A. N. Toth, 2016).

Barriers and actions

Institutional barriers and actions

The legislation and regulations for geothermal development in Hungary are very detailed. According to the interviews with experts, this is, in general, advantageous. However, they also indicated that this level of detail sometimes creates problems for developers. The problem is related to the boundary that delineates the authority between two regulatory agencies. Projects with a maximum depth of fewer than 2500 metres are subject to the Water Management Authority regulations, while projects deeper than 2500 metres are also subject to the Hungarian Mining Authority regulations. There is, however, overlap in some of the regulations of the Mining Authority and the Water Management Authority. This means that the rules beyond 2500 metres do not align with the rules for shallower depths. The interviewees mentioned that this overlap in regulations is often experienced as a barrier (HU-1; HU-2).

Consequently, the permitting procedures for deep geothermal wells (2500+ metres) are managed by both authorities, with different regulations, which results in conflicting or restrictive conditions for developers. Thus, geothermal projects' licensing procedures beyond 2500 metres are usually very complex, balancing between water management and mining laws. Hence, many geothermal projects in Hungary are close to but do not exceed 2500 metres in depth.

Considering the conceptual framework in light of the information above, the barrier called *inconsistent regulation and legislation* is present in Hungary. The primary element that causes this barrier is *ambiguous regulations and legislation*.

Nevertheless, the government has taken action to remove part of this barrier. In an attempt to simplify a part of the licensing procedure, the government created regional permitting offices for deep geothermal development (Nádor et al., 2016). By decentralising licensing procedures, the government aimed to create a one-stop-shop for licensing, lowering the threshold for geothermal exploration. However, that action did not result in the alleviation of the barrier, but rather the opposite. The licensing procedures for geothermal district heating, in particular, became more complex due to this action. The reason is that exploration licenses are applied for with the regional office, which is more efficient for most geothermal applications. However, the licensing procedure for both district heating infrastructure, as well as the supply of district heating itself, is managed by the Public Utility Regulatory Authority, which operates at the national level (Nádor et al., 2016). So, instead of applying for all the required licenses at a single office, the licensing procedure for geothermal district heating has been spread over two different authorities, operating at different government levels, which is less beneficial for geothermal district heating than the previous situation.

From the paragraph above, it becomes clear that some action has been taken to mitigate the barrier *inconsistent regulation and legislation*. However, decentralising part of the permitting procedures for geothermal district heating is likely to have resulted in a *misalignment of national and regional regulation and legislation*. Hence, the barrier has not been mitigated, and this action might even have caused added complexity in this barrier.

Besides inconsistent legislation and regulation, distrust toward decision-makers is a general issue in Hungary, not specific to the geothermal sector. A remarkable observation is that the Ministry of National Development states the following, "...realistically thinking, geothermal district heating will not play a decisive role in the future, despite the significant potential" (Ministry of National Development, 2015, p. 134). This citation is representative of the inconsistent communication of the government regarding geothermal district heating. On the one hand, the government believes geothermal energy has enormous potential as a primary heat source.

On the other hand, it seems reluctant to invest in geothermal development (HU-1). This inconsistent communication feeds the distrust among developers of geothermal district heating. Specific distrust from the geothermal sector is aimed at policymakers, partly since those officials are unreceptive to invitations to educate themselves on geothermal district heating and the possibilities of geothermal energy in general (HU-2).

Moreover, in 2017, tensions between the Hungarian government and part of the geothermal energy sector rose due to publishing a formal declaration by the Hungarian Geothermal Association (HGA). In this declaration, the HGA criticised the lack of meaningful government action since 2013 (see Appendix A.4). The geothermal association expressed their concerns about mismanagement of licensing procedures, inconsistent regulation and legislation, and erroneous allocation of funds. This declaration was sent to five different ministries, of which two accepted the document, and the other three rejected the declaration and the contents thereof.

The two paragraphs above illustrate that the barrier *distrust towards decision-makers* is an issue in Hungary. When considering the conceptual framework, only one of the elements can be identified. This element is *underdeveloped knowledge of decision-makers*, which has been mentioned during the interviews. One element has not been identified in the conceptual framework but seems to play a role here. That is the indifference of the government towards geothermal energy. That was mentioned in both the literature and during the interviews (Ministry of National Development, 2015; HU-1; HU-2). On the one hand, the government is aware of the potential of geothermal energy, but on the other hand, it is reluctant to invest in the applications.

A recent government decision could result in action. This is Government Decision 1345/2018 (VII. 26.) on the Action Plan for the Utilisation and Management of Energetic Mineral Resources (Orbán, 2019). With this decision, the Hungarian government has pushed several ministries to take meaningful action to implement renewable energy sources, of which geothermal is one. Since the Action Plan includes clear objectives and deadlines, the decision is expected to lead to real action.

Following this government decision, the *distrust towards decision-makers* could potentially decrease in the coming years, primarily since it could reduce part of the indifference of the government. However, this will only happen if the intentions are translated into meaningful action.

Economic barriers and actions

Many Hungarian district heating systems are owned and operated by municipalities. The supply of municipality-owned district heating is generally exclusively to public buildings (Nádor et al., 2019). These are mainly city halls, schools and hospitals. The municipality-owned systems only require a license from the Water Management Authority. Since these district heating systems do not operate under market conditions, price regulation is not possible or necessary. However, a Public Utility Regulatory Authority license is required when private parties become involved in district heating supply to private houses. That is also where controlled pricing of district heating starts to play a role. The current price regulation scheme allows for a maximum total rate of return of 4.5% of the initial investment for renewable district heating plants. In the case of a higher rate of return, the district heating supplier will have to pay the the excess to the government. This ex-post profit re-calculation makes it difficult for suppliers to predict their profits. Currently, the government protects consumers by setting a fixed price and low VAT for district heat (Mezősi et al., 2017). This causes more uncertainty for suppliers since they have little influence on that price. Consequently, it is difficult for geothermal district heating developers to find investors willing to take a financial risk. This risk is different from the geological risk associated with drilling, which is relatively low in Hungary (HU-1; HU-2). Finally, the investment costs of geothermal district heating systems are significantly higher than those for (district) heating from conventional gas boilers (Mezősi et al., 2017).

A government decision to lower the price of district heating by 23% between 2013 and 2014 has caused even more issues. This decision directly affected the financing possibilities for geothermal projects since the controlled price of district heating is still higher than the consumer price for natural gas, which led consumers to prefer single-household gas boilers over district heating (HU-1; HU-2). On the other hand, value-added tax for district heating has also been reduced from 27% to 5%. Unfortunately, this had little effect on the possibilities for geothermal sources.

Furthermore, the Hungarian heating sector is highly dependent on imported natural gas. More than 80% of the natural gas in Hungary is imported, mainly from Russia. This dependence on Russian natural gas has recently been invigorated. In May 2021, the Hungarian Ministry of Energy signed a 15-year natural gas import deal with Gazprom (Reuters and Dunai, 2021). Surprisingly, the residential price of natural gas in Hungary is fixed at a certain level below the market price because of government subsidisation. Between 2013 and 2014, the subsidisation was initiated step by step. In 2013, the consumer price was first reduced by 10%. Later in that year, an additional 11% price reduction was established, to be completed with a third 6.5% reduction in 2014 (International Energy Agency, 2017). In early 2021, The household price for natural gas in Hungary was approximately €0.03 /kWh, while the European average was €0.07 /kWh (Eurostat, 2021). Hungary has one of the lowest consumer natural gas prices in Europe, while the country has few indigenous sources, which suggests heavy subsidisation. The monetary value of the subsidisation is unknown since nearly all consumer natural gas is imported and supplied by a state-owned company. Hence, the magnitude of the subsidisation remains largely invisible. This subsidisation of natural gas has protected consumers against energy poverty. Conversely, it has also prevented the large scale introduction of alternatives to heating from natural gas that are generally more expensive (HU-1; HU-2).

From the information above, two barriers can be identified. First of all, *economic non-viability* can be considered as a barrier. The first element that plays are role is *implementation costs* of district heating. The second element has not been explicitly identified in the conceptual framework. Nevertheless, it can be assigned to this barrier. This element is *uncompetitiveness with alternative heat sources*.

The other barrier is *financing difficulties*. Two elements for this barrier are mentioned, which are *risk perception of financial institutions* due to controlled prices and the uncompetitiveness with other heating sources, and *high investment costs* compared to the alternatives.

In 2018, the Hungarian government established the Ministry of Innovation and Technology. This ministry could yield positive effects for geothermal development. One of the actions of the ministry has recently been announced. In June 2021, The Ministry of Innovation and Technology presented an exploration risk mitigation scheme with funding of up to €5.5 million, depending on the exploration success (GEORISK, 2021). This scheme targets explicitly deep geothermal wells (1,000-2,500 m) that apply re-injection techniques. This scheme could yield positive effects for geothermal district heating development in Hungary in the coming years.

On the other hand, the size of the fund is relatively moderate, considering the costs of the drilling operation, which average at approximately €4.5 million per well (at 2000 metres) (Mallin, 2020). Although the geological risk in Hungary is relatively low, and the size of the mitigation scheme is only moderate, the scheme could still persuade investors to finance geothermal projects. The reason is that a part of the financial risk is covered, thereby decreasing the element *risk perception of financial institutions*, which would be beneficial for resolving the barrier *financing difficulties*.

Some incentives that aided the development of geothermal district heating have been installed. The focus of these incentives was primarily aimed at the research and development of specific projects. First of all, several geothermal projects have been made possible by EU co-funding from the Environmental and Energy Operative Plan (European Commission, 2021). This programme resulted in twenty-four small scale exploration drilling projects, as well as two large scale geothermal district heating systems in Miskolc (A. N. Toth, 2016). Secondly, the government supports selected projects through their National Development Fund (Nádor et al., 2019).

Besides these research and development funds, the government provides only limited incentives for geothermal energy projects. The main incentive is a support scheme that offers non-refundable financial support from the government. This is a one-time investment from the government to aid developers in the financing of the exploration phase. Similar government investment is provided for the production phase. However, despite this government support, geothermal district heating systems cannot compete with conventional district heating (HU-1; HU-2). The controlled district heating prices and the heavily subsidised natural gas are strongly related to the uncompetitiveness of geothermal heat but are not solely responsible.

From the observations above, it becomes clear that several incentives are available to aid geothermal district heating development. However, the effectiveness of the incentives is questionable. The International Energy Agency also emphasised this. In an energy policy review of Hungary, the organisation recommends that ”available funds for renewable investment support should be used effectively and special attention should be paid to the district heating sector” (International Energy Agency, 2017, p. 97). This statement indicates that the barrier *ineffective renewable energy technology promotion policies* is present also present in Hungary. One of the elements is *highly specific requirements*, which is identified from the very limited selection of projects that received government support. Another element, which has not been mentioned before, is that the promotion policies might not be suitable for the economic conditions in the country. One of the interviewees also indicated that the government support itself is not necessarily the issue, but the allocation of funds and the economic conditions cause the ineffectiveness (HU-2).

Only recently, the Ministry of Innovation and Technology called for the geothermal sector to propose ideas for supporting the development of geothermal heating projects specifically (Ministry of Innovation and Technology, 2021). The total budget is approximately €16 million, which appears to be a good starting point towards mitigating part of the barrier *ineffective renewable energy technology promotion policies*.

Technical barriers and actions

Besides institutional and economic barriers, there is a technical barrier present in Hungary. In the past decade, the government has incentivised modernising old high-temperature district heating systems in some areas. This action was taken to enable lower operational temperatures, making the district heating systems suitable for geothermal heat input (Ministry of National Development, 2012). According to one of the interviewees, existing district heating networks have been modernised to some extent, allowing the operating temperature to be brought down, which enabled the input of geothermal heat (HU-2). Several other incentives have been installed, like the tax reduction mentioned earlier and obligations to use district heating in energy-efficient buildings, but this has not resulted in a significant shift towards geothermal sources (International Energy Agency, 2017).

A possible reason is the low energy efficiency in buildings in Hungary. Although the government has provided financial incentives for improving energy efficiency in residential buildings, this has only resulted in a slight increase in the energy efficiency of residential buildings up to 2015. Since then, there have been no improvements in energy efficiency in the residential sector (Enerdata, 2021b). This issue was also indicated by one of the interviewees (HU-1). Poor insulation of buildings causes difficulties for low-temperature geothermal district heating. The reason is that the low energy efficiency goes hand in hand with high energy losses. Consequently, low-temperature district heating systems have a hard time delivering sufficient heat. Hence, high energy efficiencies are a prerequisite for low-temperature district heating systems.

From this observation, the barrier *poor insulation of buildings* is identified in Hungary. This poor insulation causes high energy losses, impacting the effectiveness of low-temperature district heating. Additionally, the single-building demand is high, resulting in higher energy costs.

In 2015, the European Union funded an energy efficiency plan of Hungary, which included €300 million for energy efficiency improvements in residential buildings. However, these funds were never allocated to the public. Instead, the government allegedly used the funds to improve the energy efficiency of government buildings only (People's Budget, 2018). Besides this action, there has been little attention to the improvements in energy efficiency in residential buildings. The upcoming government elections could potentially result in renewed action. However, it is uncertain if this will significantly change the energy efficiency in residential buildings soon.

Besides the barriers that have been identified in this section, several other barriers from the conceptual framework were found not to be present. These barriers are therefore, not discussed in the remainder of this thesis.

Outlook for the coming years

In 2010, the installed capacity of geothermal district heating was 95 MW_{th}. Up to 2019, that has grown to a total of 23 geothermal district heating systems, representing a thermal capacity of 223 MW_{th} (Nádor et al., 2019). These systems vary from large district heat systems to smaller town heating systems used for cascade applications. In many of these district heating systems, geothermal heat only partially contributes to the total heat production (Nádor et al., 2019). The residual production is sourced from combined heat and power plants and natural gas boilers. As already presented in Table 5.1, the share of geothermal energy in the district heating sector was approximately 4%.

Despite the potential, the use of geothermal district heating systems appears to have increased stepwise over the past decade. From Figure 6.4, it can be observed that the installed capacity of geothermal district heating systems has not increased substantially after 2016. Considering the changes in geothermal district heating conditions, a possible cause can be identified. This cause could be the separation of licensing procedures over two different government bodies in 2015, though this is no certainty.

At the same time, it is clear that the development of geothermal district heating has seen a relatively stepwise growth. It could be possible that the years from 2016 to 2019 show another period of minor to no increase, which a sharp increase could follow in the coming years. However, this is only speculation.

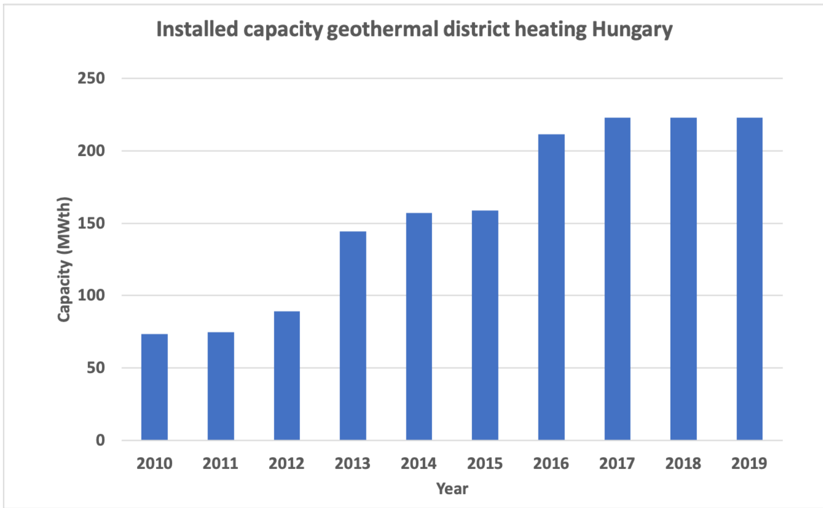

Figure 6.4: The development of the installed capacity of geothermal district heating in Hungary. Source: "OGRe – Geothermal Information Platform", 2021

The Netherlands

History of geothermal heat use

In the Netherlands, geothermal energy could provide a good alternative for natural gas as an energy source. According to prior research, the Dutch subsurface has suitable characteristics for geothermal development. From studies into the potential for geothermal energy of the Dutch subsurface, research organisation TNO estimated that the total geothermal potential of the Netherlands is around 90,000 PJ to a depth of 4000 metres (Victor Van Heekeren and Koenders, 2010). Compared to the annual household and services heat consumption of 400 PJ, the potential resource is enormous (Geothermie Nederland, 2021a). From the map in Figure 6.5, it can be observed that large parts of the Netherlands have suitable subsurface characteristics for the feasible development of geothermal systems. However, there are also significant areas in which little subsurface information is available. Despite the known potential in some areas, there is currently only a single active geothermal district heating system.

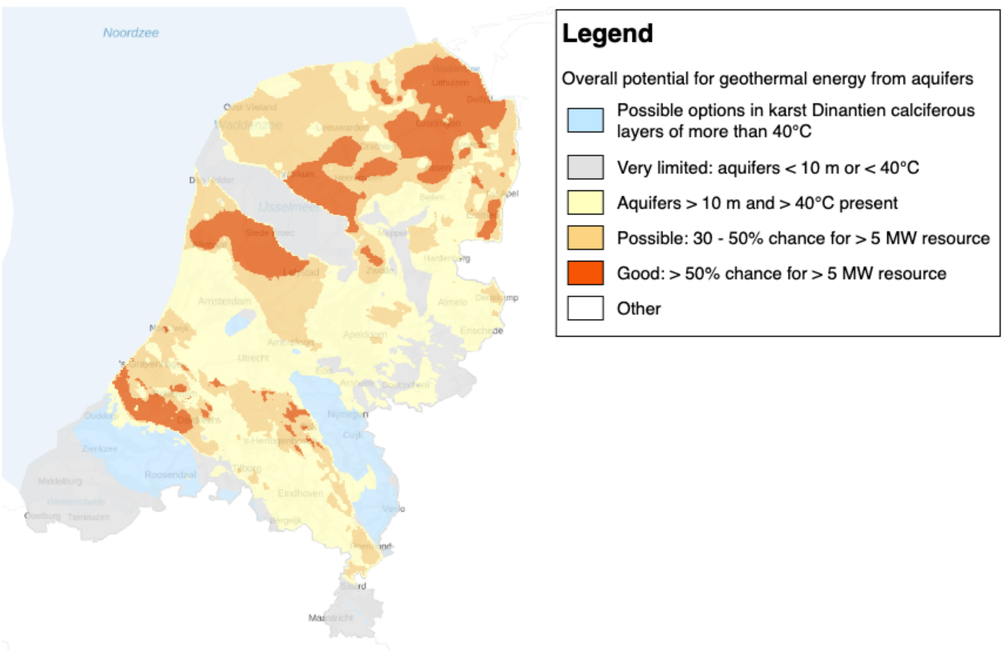

Figure 6.5: A map displaying the geothermal potential of the Netherlands. Source (TNO, 2021)

In the greenhouse horticulture sector in the Netherlands, however, companies have been using geothermal energy as a source of heat since 2007 (Geothermie Nederland, 2021b). In 2019, the annual geothermal heat use in this sector was equal to the amount of heat from 168 million m^3 of natural gas, which is equal to approximately 1.7 TWh (≈6.12 PJ) of heat (Geothermie Nederland, 2021a). One of these greenhouse companies also supplies heat to several residential and commercial buildings (Gemeente Pijnacker-Nootdorp, 2021). This system could be considered the first example of geothermal district heating in the Netherlands, although it is not officially counted as such.

Barriers and actions

Institutional barriers and actions

For a large part of the past decade, standards, norms and requirements for exploration and production licensing were unclear or not specified for geothermal development. This resulted in little monitoring by the mining authority due to an inability to enforce unclear or nonexistent regulations. Eventually, a report of the Dutch mining authority was published to inform the ministry about the poor state of the geothermal sector in the Netherlands (Staatstoezicht op de Mijnen, 2017). In this report, the mining authority underlined the existence of several barriers. The geothermal sector in the Netherlands was said to be in its infancy and in dire need of more professional development. Especially the knowledge and attitude of the sector with regards to safety standards and financial security were indicated to be underdeveloped. This situation caused projects to be developed with regulations not specific to deep geothermal development, potentially resulting in safety issues.

In the text above, two elements of a barrier from the conceptual framework stand out. The first element is *little experience with geothermal district heating*. The second element is *ineffective regulatory body* due to the unclear or nonexistent regulations and standards. Both of these elements are related to the barrier *lack of regulatory/legal framework*, which can be observed to be the case in the Netherlands.

Following the report of the mining authority, the Minister of Economic Affairs and Climate sent a letter to the parliament stating that the Dutch government should put more effort into the professional development of geothermal energy projects (Wiebes and Minister of Economic affairs and Climate, 2018). This letter has led the ministry of economic affairs and climate to actively revise legislation and clarify and determine technical requirements for licensing procedures. One of the revisions is that of the heat law, which is executed now. Unfortunately, delays in the completion of the revised heat law are expected due to disagreements between various layers of government and delays in the clarification and determination of technical norms (NL-4; Staatstoezicht op de Mijnen, 2021).

The sector itself took action towards the more professional development of geothermal energy as well. The sector partners have developed a code of conduct for the involvement of the surroundings of geothermal projects (Geothermie Nederland, 2019). Additionally, an industry standard for sustainable well-design was developed by the sector. The Mining Authority has acknowledged these actions. They indicated that geothermal development companies have learned from past experiences and that they have made significant progress in taking responsibility (Staatstoezicht op de Mijnen, 2021).

Considering these actions by both the government and the geothermal sector, the conditions for geothermal district heating appear to be improving. This observation is also supported by the interviewees, who, on the other hand, indicate that there are additional actions that the government should focus on to incentivise geothermal district heating (NL-1; NL-2). These actions are discussed later in this section.

In the Netherlands, natural gas has been the preferred energy source for many years. However, with the increasing numbers and magnitude of earthquakes in Groningen, social acceptance for natural gas production from the Groningen field has diminished. Besides that, the negative media coverage about the earthquakes and the tedious compensation process of earthquake damage also influence the geothermal sector, albeit mainly locally. The earthquakes in the North of the Netherlands are nearly all classified as induced seismic events by the meteorological institute (KNMI, 2021). Hence, the decreasing social acceptance can be justified in some way. It is difficult to convince a not technically educated general audience about the safety of geothermal energy since that conversation is about very technical subjects (NL-2). Even though the techniques used for geothermal installations are fundamentally different since there is no net extraction of fluids, a slight reluctance towards geothermal energy remains. Similar to the situation in Germany, social acceptance varies significantly between regions. Therefore, generalisation of the level of social acceptance is difficult. Nevertheless, it is indicated as a critical barrier to overcome for accelerated geothermal energy development (NL-2; NL-4; NL-5).

From the information mentioned above, the barrier *lack of social acceptance* can be identified. Both elements of this barrier play a role. *Adverse media coverage* affects the general public opinion towards human activities in the subsurface, which is indicated to result in not-in-my-back-yard (NIMBY) opposition (NL-2; NL-4). Additionally, the element *environmental and ethical issues* can be observed from the presence of earthquakes in the province of Groningen. Even though the earthquakes are not related to geothermal development, but they do impact the acceptance.

Over the past years, more understandable and comprehensive information on geothermal energy has become available. Both the government and the geothermal sector have taken significant steps to involve the public in geothermal energy development. At the same time, it is indicated that social acceptance and support base for geothermal energy is likely to require continuous attention and investment (EBN et al., 2021). At the same time, it is argued that nothing more can be done to improve social acceptance than to provide correct and sufficient information to the public (NL-2; NL-4; NL-5).

Economic barriers and actions

As mentioned before, the Dutch heating sector has been dominated by natural gas for many years. This fact is emphasised by the fact that the Dutch gas law and the heat law (Warmtewet) both had and still have articles that somewhat protect the position of natural gas in the heating sector (Raad van State, 2021). Article 5 of the heat law still states that the supply of heat to consumers has a set maximum price, which is calculated based on the supply of conventional heat from natural gas (Raad van State, 2014). Prices for the supply of heat higher than the maximum price shall be set at that maximum price by operation of law. Since geothermal district heating's actual cost is significantly more higher the alternatives, geothermal district heating is unable to compete. Nevertheless, the regulation scheme for heat pricing is said to be a factor in the uncompetitiveness to introducing geothermal district heating in the Dutch heat sector as well (NL-1; NL-2; NL-4).

Another issue that poses a problem for introducing geothermal district heating is the fact that there is insufficient demand for low and medium-temperature district heating. The main reason developers have a hard time creating an economically viable resource is that there is demand, but the speed of development of the demand is too slow (NL-1; NL-4; NL-5). Geothermal district heating systems of average size need around 5000 home-equivalents to reach their nominal production levels (EBN et al., 2021). Hence, geothermal heat is not economically viable in district heating networks where the heat demand is still under development. The issue has been illustrated by the first geothermal district heating system in the Netherlands. The operator went bankrupt because the development of heat demand was significantly slower than expected, resulting in a changing business case which eventually failed (Haagse Aardwarmte - Leyweg, 2021; NL-1; NL-2).

Besides that, uncertainties regarding the success of a geothermal resource and financial risks of exploration drilling are experienced. The reason is that the production levels of the geothermal installation are unsure until the doublet is completed, and in many locations, there is only limited information about the subsurface. Furthermore, technical norms, standards, and requirements are unclear, resulting in severe consequences regarding financing possibilities. According to the mining authority, especially the last issue should be resolved urgently, as it causes delays in the development of geothermal systems and may lead to investors' reluctance. Additionally, the backlog in judgement on production plans has not been cleared, and this makes it difficult for the mining authority to perform its enforcing duties (Staatstoezicht op de Mijnen, 2021). In addition to that, the current market conditions do not offer a financially attractive environment for investors (NL-1; NL-3). As current support schemes only provide financing support for the production phase, geothermal systems' high initial investment costs prove to be a significant hurdle.

From the description above, two barriers from the conceptual framework can be identified. The first barrier is *economic non-viability*. Two elements have been found to play a significant role in this barrier. The first element has not been identified in the conceptual framework at first. Though, it was mentioned several times during the interviews. This element is the *uncompetitiveness with alternative heat sources* in the Netherlands, which is caused by the higher price for geothermal district heating compared to the alternative and the fact that consumer heat price regulation is established on the basis of natural gas pricing. The second element that plays a role is *insufficient heat demand* for low or medium-temperature district heating, which has a significant impact on the business case of geothermal district heating systems. This element itself is not economic. However, it has a direct impact on the viability of geothermal district heating.

The second barrier that can be identified from this description is *financing difficulties*. The first element is *risk perception of financial institutions*, which is caused by regulatory uncertainties and delayed permitting procedures. Additionally, the current economic conditions regarding geothermal heating in the Netherlands do not allow for much profit to be made, resulting in the reluctance of investors. Finally, *uncertainty of successful resource* is an element as well, since, in many places, there is only limited knowledge of the subsurface.

Currently, the government is revising the heat law (NL-4; NL-5). This revision is aimed at the positioning of geothermal heating in the Dutch heat sector, among others. One of the objectives is to review the current regulation of heat prices. If this results in a regulatory scheme that is more suitable for geothermal district heating systems, enabling less unprofitable operation, the development of these systems is likely to accelerate.

The development of geothermal heat is supported through the SDE+ subsidy scheme. This scheme aims to incentivise the development of sustainable energy products by providing financial support during the production phase. In 2020, this scheme was expanded to the SDE++ scheme, including low carbon production techniques. The most important characteristic of this subsidy scheme is that it only covers the unprofitable part of the production. This subsidy is provided monthly and adjusted to the project's financial status. The requirements for eligibility are very specific, and the application process is extensive. For geothermal heat projects, the subsidy is available for up to 15 years (RVO, 2021c). The effectiveness of this subsidy scheme is, however, up for debate. The reason is that geothermal energy has to compete with other renewable energy sources and CO_2-emission reduction technologies for the same predetermined amount of available monetary funds (International Energy Agency, n.d.). In 2020, six geothermal projects applied for this subsidy. In the end, not a single of these applications was approved due to the strong competition.

Furthermore, a support scheme to cover the financial risk associated with drilling called RNES has been in place since 2009 (RVO, 2021b). This is an insurance-like subsidy scheme, for which the premium is 7% of the total drilling costs. Depending on the success percentage of the drilling, up to 85% of all drilling costs are covered by the fund. To become eligible for this support scheme, developers need to fulfil several requirements. These requirements include, among others, already approved permits for exploration drilling and constraints regarding the time from the start of exploration drilling to commissioning of the installation. To date, this support scheme has aided eight geothermal projects.

Here, it becomes apparent that there are promotion or support policies available to develop geothermal district heating. However, due to the competition with other renewable energy sources for the same funds, the eligibility of geothermal energy projects is affected. Hence, it can be drawn that the barrier *ineffective renewable energy technology policies* from the conceptual framework is experienced. One of the elements that play a role is *highly specific requirements*. Another element that has not been identified during the decomposition of the barrier, but plays a role here, *unavailability of funds*.

Fortunately for the geothermal sector, there are plans to revise the SDE++ subsidy scheme. One of the options that are considered is the reservation of funds, specifically for geothermal energy projects EBN et al., 2021). Although this revision has not taken place yet, multiple interviewees indicated that this would significantly improve the effectiveness of the SDE++ subsidy scheme for geothermal energy projects (NL-1; NL-4; NL-5).

Technical barriers and actions

In 2011, the Dutch Ministry of Economic Affairs, Agriculture and Innovation adopted an action plan for the stimulation of using geothermal heat in greenhouses, households and commercial buildings (Ministry of Economic affairs agriculture and innovation, 2011). The main reason for this action plan was the commitment to reduce fossil-fuel use and reach renewable energy targets. Additionally, several issues concerning the development of deep geothermal energy were addressed since the development was stagnating.

The stagnating geothermal development was indicated to be caused partly by a lack of knowledge about the subsurface. The insufficiency comprehensive geological information seems to be an issue. Hence, one objective of this plan was to increase knowledge building and assimilation. The first step was to make drilling data more readily available to the public and developers. This action has resulted in a dedicated data platform for oil and gas explorations called NLOG, as well as geothermal energy exploration in 2012 called ThermoGIS (NLOG, 2021). This platform was created to provide a more comprehensive overview of the country's subsurface. This objective was achieved to some extent, although there are still many white spots regarding the Dutch subsurface (NL-4). Currently, most of the data in the Netherlands is available from extrapolating data from historical oil and gas exploration drilling (EBN et al., 2018). However, for geothermal development, these data sets are less useful and not accurate enough to support the decision-making process for a specific location.

From the conceptual framework, the barrier *insufficient comprehensive geological information* can be identified. Two elements have been indicated in the literature and during the interviews. The first element is *incomplete geological information* due to the white spots in the Dutch subsurface. The other element is *uncertain reservoir performance*. Although oil and gas exploration data is available for some areas, that does not provide sufficient information to determine reservoir performance.

In 2018, a report on a play-based approach to reservoir data revealed a possibility of improving the accuracy of geothermal data without additional research. Plays are homogeneous rock layers in the subsurface. This approach aims to search for more or less comparable homogeneous rock layers within the heterogeneous subsurface that can be distinguished based on composition and age. Using this method makes it possible to relatively accurately determine the potential of hydrothermal reservoirs without the need for drilling. This is achieved by looking at the subsurface in the context of these homogeneous rock layers. By considering rock layers within the context of these plays, the knowledge and experience from one location can be used for other geothermal energy projects within the same play (J.G. Veldkamp et al., 2018). In simple terms, the characteristics of a rock layer with known geothermal potential in one location are compared to characteristics of a rock layer with unknown geothermal potential in another location. If the characteristics of the two compared rock layers are similar, it is possible to estimate the geothermal potential of the rock layer in the second location.

Furthermore, the SCAN project was created. This project aims to collect more comprehensive data on the Dutch subsurface, including the white spots. This data is collected by performing seismic measurements, reprocessing of existing data, and by research drilling (SCAN, 2021). As this project is ongoing, its effects on the development of geothermal energy are still unknown. Though, it is expected that this research project will result in faster growth of geothermal development since the geothermal potential is mapped in more detail, reducing uncertainty. This is achieved by combining seismic data with drilling data, which makes it possible to make statements on a larger area surrounding these boreholes instead of only the boreholes themselves. One of the interviewees has indicated that they are interested in seeing where new business opportunities for their company could arise (NL-2).

From the actions in the past years, it appears that significant improvements in the availability of comprehensive geological information is expected in the coming years. However, the SCAN project is not expected to be finished before 2025. Hence, in the coming years, the element *incomplete geological information* could be mitigated. The application of the play-based approach could also remove part of the element *uncertain reservoir performance* since it enables a more accurate determination of the potential of a reservoir. When considering these developments, it is expected that the barrier *insufficient comprehensive geological information* is expected to be largely mitigated in the coming years.

Another issue that multiple interviewees addressed was the insufficient insulation of residential and commercial buildings (NL-1; NL-2; NL-4). Presently, district heating is primarily available for newly constructed buildings since those are more energy efficient. However, to develop more and larger district heating systems, existing homes require additional insulation, preferably on a large scale. The building stock of housing corporations could establish that considerable scale improvement since 27% of their buildings have energy label D or lower (RVO, 2020). In total, 34% of all residential buildings has a lower energy label than label C. For the commercial building sector, approximately 29% of all buildings have lower energy labels than label C. The improvements would be essential if the district heating systems operate at lower temperatures, which is generally the case for geothermal heat. Mainly since the minimum energy label for effective implementation of low-temperature district heating is label C (Vereniging eigen huis, 2021). There have been and still are government incentives to improve building insulation. However, these incentives do not seem to target areas suitable for geothermal district heating specifically.

The last paragraph described a barrier that could significantly impact the success of geothermal district heating in the Netherlands. This is the barrier *poor insulation of buildings*. Although the percentage of low-label (D or lower) residential buildings owned by housing corporations is only 27%, the geographical distribution of these buildings is also an important factor. As mentioned before, the development of a geothermal district heating installation requires approximately 5000 home equivalents. Hence, it would be ideal if multiple communal residential buildings with high energy labels were located close to the installation.

Throughout the past years, the Dutch government has provided various ways for homeowners to improve their home's energy efficiency. For example by providing vouchers energy efficiency improvement products. This has led to a reduction in heat losses in the residential and commercial building sector. Hence, the barrier *poor insulation of buildings* has become less of an obstacle for geothermal district heating. Nevertheless, the interviewees emphasise that major improvements are still necessary if geothermal district heating is developed on a large scale (NL-1; NL-4; NL-5).

Similar to Germany and Hungary, several barriers from the conceptual framework have not been identified to be present in the Netherlands. For that reason, those barriers are not presented in the analyses of the Dutch geothermal district heating sector.

Outlook for the coming years

In total, the Netherlands currently has 20 actively producing deep geothermal installations. Two of these systems are (partly) used for district heating (Ministerie van Economische Zaken en Klimaat, 2020). The increase in licenses and license applications could potentially result in the upscaling of geothermal district heating in the Netherlands. Exact figures on the production of geothermal heat for district heating in the Netherlands are not available yet. Primarily since the Netherlands' first geothermal district heating installation reached its production phase (Haagse Aardwarmte - Leyweg, 2021).

Figure 6.6 shows the number of licenses and license applications for geothermal exploration and production through the years. For 2020, the figure also shows the number of licenses that have been applied for. When looking at this figure, it can be observed that the number of production licenses has increased steadily over the past few years. An even more striking observation is that the number of exploration licenses and applications for exploration licenses increased rapidly in the past three years. It can not be decisively concluded that the increase in licenses directly results from the actions described above, but there appears to be a correlation.

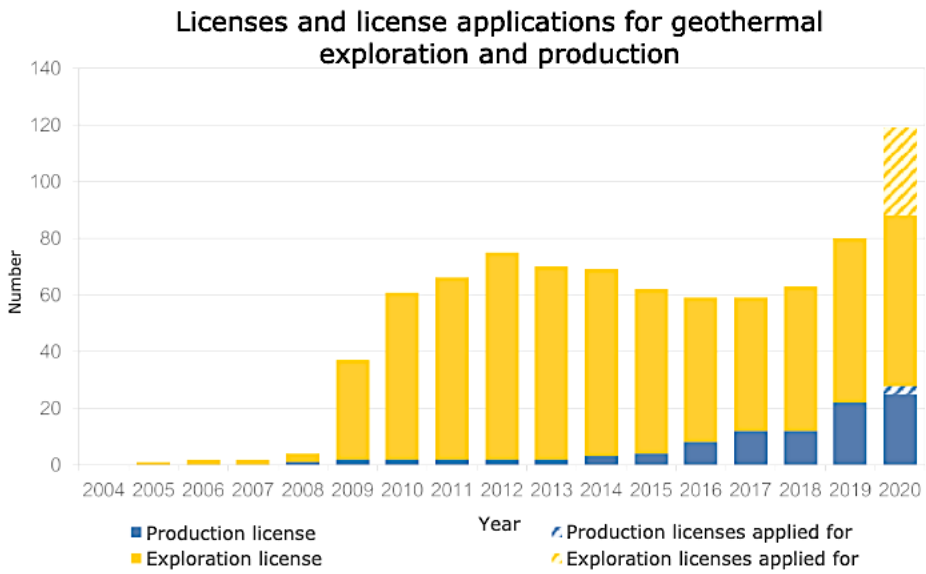

Figure 6.6: The number of exploration ans production licenses in effect in the Netherlands and the number of license applications for 2020. Source: Ministerie van Economische Zaken en Klimaat (2020)

6.2. Barriers in the selected countries

By using the conceptual framework presented in Chapter 3, various barriers to the upscaling of geothermal district heating have been identified for Germany, Hungary and the Netherlands. The presence of the barriers are displayed for each country separately in Table 6.1.

Table 6.1: An overview of the barriers at play in the separate investigated countries. *Renewable Energy Technology

Barriers	Germany	Hungary	The Netherlands
Lack of regulatory/legal framework			✓
Inconsistent regulation and legislation		✓	
Economic non-viability	✓	✓	✓
Financing difficulties		✓	✓
Ineffective RET* promotion policies	✓	✓	✓
Applicability difficulties	✓		
Insufficient comprehensive geological information	✓		✓
Lack of social acceptance	✓		✓
Lack of public interest			
Distrust towards decision-makers		✓	
Poor insulation of buildings	✓	✓	✓

To answer the research question of this section: *"Why have certain European countries achieved a high degree of geothermal district heat use while others have not?"*.

It can be stated that the upscaling of geothermal district heating has not been impressive in any of the three countries so far. Several barriers are present in the selected countries, which have been mentioned in section 6.2 and Table 6.1. The most significant barrier to geothermal district heating was found to be economic non-viability because the application is currently not price-competitive with alternatives.

Besides that, the ineffectiveness of renewable energy technology promotion policies is a barrier found in all three countries. The situation seems most problematic for Hungary, where the financial support system for geothermal district heating is minimal, and the overall economic environment is unfavourable for the profitable operation of a geothermal district heating.

Additionally, poor insulation of buildings was found to be a common reason why the upscaling of geothermal district heating has been relatively low. Due to high energy losses in these buildings, low and medium-temperature district heating systems are currently unsuitable to be implemented.

In countries that did reach some level of geothermal district heating, the relatively high installed capacities have primarily resulted from the expanded development of known resources that have proven their potential. In Germany specifically, nearly all geothermal district heating can be attributed to the region of Bavaria. Nevertheless, the share of geothermal district heating in the household, commercial and public services heat sectors is modest.

6.3. Actions in the selected countries

The presence of several barriers in the selected countries has led their governments to take various mitigating actions. All three governments have repeatedly communicated the ambition to increase the use of geothermal heat in district heating systems. Though, through the analysis, it became apparent that not all actions have been as meaningful. Some actions focused on multiple elements per barrier, while others aimed at only a single element. Similarly, some actions influenced more than one barrier. In Table 6.2, the most important actions of the governments or the geothermal sectors in the selected countries are listed, together with the barrier(s) that the actions were aimed at.

Table 6.2: The actions that have been taken in the selected countries with their associated barriers.

	Actions		
Barriers	**Germany**	**Hungary**	**The Netherlands**
Lack of regulatory / legal framework			Regulatory/legislative revisions: - Heat law (delayed) - Determination of technical norms, standards and requirements for licensing (delayed)
Inconsistent regulation & legislation		Restructuring licensing procedures	
Economic non-viability	Tax removal for renewable residential and commercial sector heat use	Tax reduction on district heat use	Regulatory and legislative revisions mentioned above
Financing difficulties		Risk mitigation financing scheme	Determination of technical norms, standards and requirements for licensing (delayed)
Ineffective RET promotion policies	Include deep geothermal in renewable heat act	Call for support propositions by Ministry of Innovation and Technology	Intention to reserve SDE++ funds for deep geothermal (expected)
Insufficient comprehensive geological information			SCAN programme
Lack of social acceptance	Close involvement of the public in projects		Information and public involvement campaigns
Distrust towards decision-makers		Declaration Hungarian Geothermal Association	
Poor insulation of buildings	Tax deduction of 20% of home improvement costs		Financial support (vouchers) for energy efficiency improvements

The central question in this section is *"What actions have been taken to achieve further upscaling of geothermal district heating and why have the actions taken been (un)successful in the investigated countries?"*.

The most significant actions that the governments or the sector have taken are presented in Table 6.2. Most actions have been beneficial for the accelerated deployment of geothermal district heating systems. However, not all of the actions have been as successful. The actions should be considered in a countries' regulatory, legislative, technical, economic, and social environment. It was found that the effectiveness of various actions is highly dependent on these conditions.

A shared observation for all three countries is that there have been actions to mitigate the economic non-viability. Tax reductions for district heating use appeared to be common. In some countries, there have been actions to improve the growth process of geothermal development in general, for example, by restructuring licensing procedures. However, the effectiveness of some actions is uncertain for geothermal district heating, specifically due to other constricting conditions.

Besides that, actions to promote geothermal district heating as a renewable energy technology have been implemented. However, it became clear that some of the actions were not as meaningful as they might appear at first glance. In some cases, the promotion policies' available funds were large, but the support per geothermal district heating project was limited.

Furthermore, in some countries, actions to accelerate the general use of geothermal energy appear to have negatively affected the upscaling possibilities for geothermal district heating in particular. An example is the restructuring of licensing procedures for geothermal development in Hungary.

Additionally, several actions have only mitigated a part of a barrier. In those cases, barriers either remained in place or were mitigated to a degree. It became clear that the reach of certain actions is limited to a specific area or application of geothermal energy.

Resulting from the barriers and the actions that have been taken to mitigate them, Table 6.3 below has been constructed. It shows which barriers have been (partially) mitigated and which are expected to remain problematic for the accelerated upscaling of geothermal district heating. The table has been constructed with consideration of the actions to remove barriers within every country's economic, institutional, and technical conditions.

Table 6.3: A review of the changes in barriers as a result of actions already taken in the investigated countries. Three colours are used to indicate the level at which a barrier is mitigated. A teal checkmark represents a barrier that has been taken away completely, or meaningful steps have been taken to mitigate a barrier soon. A yellow checkmark indicates that a barrier has been mitigated to some degree, but additional actions are required. Finally, a red checkmark indicates that no actions have been taken to remove the barrier, or that the actions have been unsuccessful.

Barriers	**Germany**	**Hungary**	**The Netherlands**
Lack of regulatory/legal framework			✔ (teal)
Inconsistent regulation and legislation		✔ (red)	
Economic non-viability	✔ (red)	✔ (red)	✔ (red)
Financing difficulties		✔ (yellow)	✔ (yellow)
Ineffective RET* promotion policies	✔ (red)	✔ (red)	✔ (yellow)
Applicability difficulties	✔ (red)		
Insufficient comprehensive geological information	✔ (yellow)		✔ (yellow)
Lack of social acceptance	✔ (yellow)		✔ (yellow)
Lack of public interest			
Distrust towards decision-makers		✔ (yellow)	
Poor insulation of buildings	✔ (teal)	✔ (red)	✔ (yellow)

7

Future perspective and requirements for upscaling

In the previous Chapter (6), the presence of several barriers in the selected countries has been determined by using the conceptual framework. Additionally, previously taken actions to remove (part of) these barriers have been identified. This chapter discusses the future perspective and the additional requirements for upscaling geothermal district heating in the investigated countries up to 2030. In Section 7.2, the future perspective of geothermal district heating in European countries is discussed. Section 7.3 presents the requirements for further upscaling of geothermal district heating in European countries. Table 6.3 presents the current status of the barriers, based on the findings of the previous chapter.

7.1. Geothermal district heating in the future

This section presents a look into the future of geothermal district heating in European countries. First, the countries' energy strategies for 2030 and other information is used to formulate the prospects for geothermal district heating development for every country. Then, the most important additional requirements to achieve accelerated upscaling of geothermal district heating are presented. These requirements are formulated with the insights from previous chapters, the application of the conceptual framework, the interviews and additional knowledge gained during this study.

In the interviews, the requirements for accelerated upscaling of geothermal district heating have been discussed by performing a short thought experiment. For this experiment, the interviewees have been asked what additional actions are necessary to achieve a 10% share of geothermal heat in the residential, commercial and public services heating sector by 2030. Additionally, the interviewees have been asked to react to the feasibility of the objective itself.

Germany

Current plans

According to the Integrated National Energy and Climate Plan for the period 2021-2030, Germany plans to increase the percentage of renewable energy sources in the heating and cooling sector. The share of renewables in the heating and cooling sector is expected to increase from 15.5% in 2021 to 19.2% in 2030 (BMWi, 2019). For district heating in particular, though, the share in renewable sources, in general, is not expected to grow significantly. Nevertheless, the Energy and Climate Plan (2019) also states explicitly that the share of biomass in district heating is expected to decrease slightly, which will be compensated by an increase in geothermal heating.

From Figure 7.1, it is observed that the number of concessions for exploration and development of deep geothermal installations in Bavaria (BY) is significantly higher than in the rest of the country. Two other regions that have concessions with active licenses for development or permissions to explore geothermal energy are Baden-Württemberg (BW) and Lower Saxony (NI). Though, it is evident that the number of concessions in these states is substantially lower.

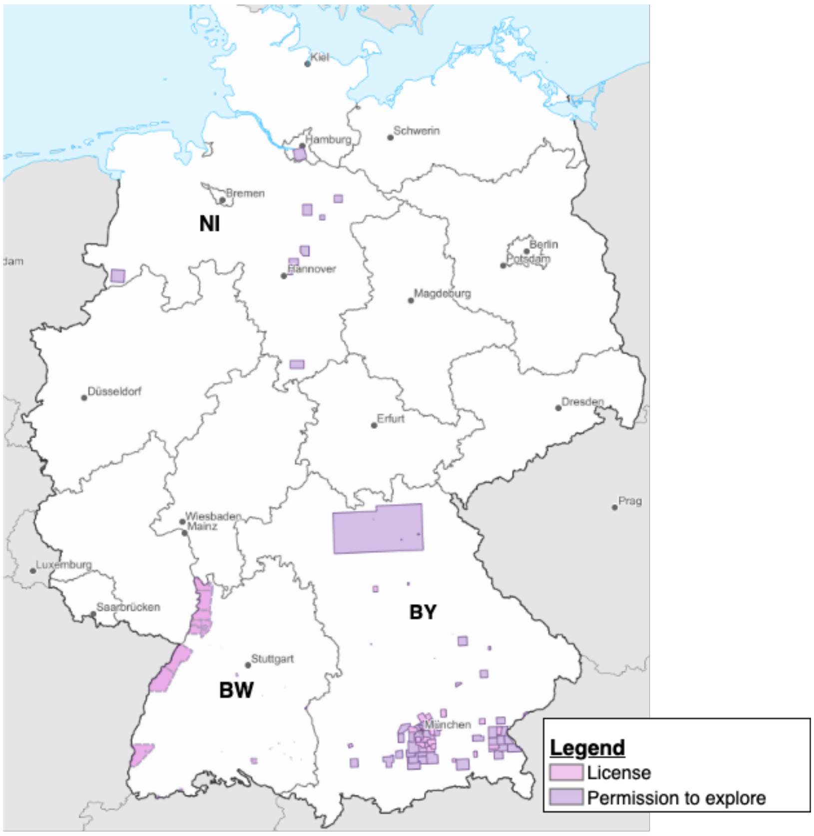

Figure 7.1: A map that displays the concession areas for geothermal exploration permission and development licenses in Germany

As mentioned earlier, the state of Bavaria sees geothermal energy as a primary source of heating. Hence, in the coming years, a further increase in geothermal district heating is expected. The state government aims to supply at least 25% of all residential and commercial heating with geothermal district heating by 2050 (Bayern, 2019). Moreover, the city of Munich has set the objective to be CO_2-neutral by 2035 (Landeshauptstadt München, 2021). The (district) heating sector will significantly contribute to achieving that objective. Hence, the city aims to have a district heating system that is entirely supplied by renewable heat sources by 2040 (Kenkmann et al., 2017). Deep geothermal sources are indicated to provide a substantial share of district heat production.

Another state which has indicated that geothermal heating is likely to become one of their primary heat sources is Baden-Württemberg. Since the state does not have many geothermal district heating systems yet, its government is currently exploring the possibilities. Therefore, the government has created a roadmap that aims to develop a support base for deep geothermal energy and align visions of the public, nature preservation groups, and utility companies (Umweltministerium Baden-Württemberg, 2019).

Finally, the state of Lower Saxony has no deep geothermal installations, despite the potential. Geothermal district heating has been stagnant there since 2013. However, the government has announced their wish to develop deep geothermal heating by reusing old oil and gas reservoirs that are plentiful in the state. Nevertheless, several reasons are provided explicitly, which have also been identified using the conceptual framework. These are, for instance, the need to overcome barriers like economic non-viability and high investment costs. As the geothermal sector is still in the development stages in the last two states, no clear targets regarding installed capacities are indicated.

Only recently, geothermal heat use technologies have gained renewed attention in on the federal level in Germany as well. In September 2021, elections for the federal government took place. Several interviewees indicated that geothermal district heating is one of the subjects on the agenda for government formation talks (DE-1; DE-2). It is expected that the government will take serious action to establish the upscaling of geothermal district heating in the coming election period.

In Chapter 6, it became clear that the development of geothermal district heating in Germany has been stagnant for some years. If the federal targets of the Energy and Climate Plan mentioned here are achieved, a slight increase in geothermal district heating can be expected before 2030. From the information on the separate states, Bavaria will likely be the most significant contributor to that increase.

The state of Baden-Württemberg is well underway towards establishing a geothermal sector. Several relatively large concessions have an active license for geothermal development, potentially suggesting that geothermal district heating systems development can be started in those locations. If this observation is correct, the contribution to the share of geothermal district heating in the residential and commercial heating sector could be substantial.

Additional requirements

As the goal of this study is to find ways to accelerate geothermal district heating development, it is imperative that the barriers identified in Chapter 6 are mitigated. Germany has already taken some actions to achieve this. Nevertheless, the most important additional requirements are proposed here.

Requirements to mitigate institutional barriers

There is only one barrier of which the institutional factor is the primary factor that was identified to be present in Germany was *lack of social acceptance*. This study makes it clear that the government and the geothermal sector have already invested substantially in mitigating this barrier. Due to their focus on the regional character of the barrier, it appears mitigated as much as possible (DE-1; DE-3). Hence, no additional actions are likely to result in a significant change.

Requirements to mitigate economic barriers

In terms of required actions for economic barriers, the most important requirement is to reduce the government subsidy for conventional district heating generation. The current policy on co-generation plants was described as an additional element of the barrier *economic non-viability* (DE-2). This element was not identified in Chapter 3, but through the interviews and document analysis. Currently, the consumer price for district heating is relatively low as a result. At the same time, geothermal district heating is more expensive by default. By reducing this subsidy in areas with geothermal potential, a more level playing field is created. A reduction of that subsidy will result in higher district heating prices, potentially mitigating the element *uncompetitiveness with alternative heat sources* That way, geothermal district heating becomes more competitive since the cost recovery is higher. However, even with less subsidy for co-generation plants, geothermal district heating is not expected to be competitive. Hence this would only result in partial mitigation of the barrier *economic non-viability*.

Additionally, it is essential to create better incentives for geothermal district heat production specifically. One of the issues that has been raised in Chapter 6 is the fact that current incentives are aimed at co-generation by geothermal installations. This resulted in the barrier *ineffective renewable energy technology promotion policies*, primarily caused by the element *highly specific requirements*. Hence, some geothermal district heating developers have opted for a geothermal co-generation plant with minimal electrical output and maximum heat production to be eligible for government support (DE-2). There are two actions that can be taken. On the one hand, the incentives could be expanded to ensure that they also apply to geothermal district heating systems. That way, the element *highly specific requirements* becomes less restrictive.

On the other hand, it might be preferable to create a subsidy scheme solely aimed at developing geothermal district heating systems. Since the geothermal potential varies from region to region, this incentive would best be established by the state governments of states with geothermal potential. Such a scheme could have the same form as the subsidy for co-generation plants. The average capital cost of a geothermal district heating plant is 1.2 million Euros per MW_{th}, which is relatively expensive (Attard et al., 2018). Nevertheless, the subsidy does not need to be excessively high. A subsidy scheme equal to current conventional co-generation subsidy (with a lower bound of €1500 /kW) would make a significant difference. Considering a period of fifteen years of geothermal heat production, that would result in a subsidy of approximately €29 / MWh (assuming a 14 MW_{th} geothermal district heating installation). To reach the goal of a 10% share geothermal district heating, this would require an annual government support package of approximately €1 billion before 2030.

By developing a specific subsidy for the implementation of geothermal district heating, the impact of the element *high implementation costs* from the barrier *economic non-viability* can be decreased, since the costs are reduced. In turn, this would result in lower costs of geothermal district heating. As a consequence, it could become more interesting to implement it on a larger scale.

Requirements to mitigate technical barriers

For the primarily technical barriers, other actions are required. First of all, it became clear that many high-temperature conventional district heating systems are already in place. However, these systems are generally not suitable for geothermal heat input since the temperature from a geothermal source is generally lower. This issue was mentioned as part of the barrier *applicability difficulties* in chapter 6. Hence, a requirement is to create legal boundaries for the operational temperatures in new district heating systems. The issue has been mentioned multiple times throughout this report. These legal boundary temperatures should enable the implementation of low and medium-temperature geothermal district heating. By establishing these temperatures legally, the element *not compatible with conventional district heating systems* could become less of an issue, since newly built district heating systems with lower temperatures could become the standard.

If buildings are sufficiently insulated, there is actually no need for high-temperature district heating. Therefore, a prerequisite for lowering district heating temperatures is that the supplied buildings have higher energy efficiencies. It is expected that this adjustment of district heating temperatures can be implemented within the coming years, as Germany is currently making significant steps toward improving the energy efficiency in buildings (BMWi, 2021a).

During one of the interviews, it became apparent that there is a relatively good understanding of the subsurface for some areas in Germany. However, there is still a significant part of the country's subsurface, of which less information is available (DE-2; DE-3). Therefore, the government should invest in researching these white spots. Hence the first requirement is a large-scale drilling campaign to collect the necessary information for geothermal development. The government should use the collected data to create a detailed and understandable extension of the existing GeoTIS database. This element *incomplete geological information*, is part of a higher-order barrier which is the *Insufficient comprehensive geological information*. To substantially mitigate this barrier, stakeholders in the geothermal sector should also play a role. Developers and operators of geothermal district heating systems in, for example, Bavaria already have much practical knowledge. However, this knowledge is only applied locally due to the individualistic character of municipal utilities. As a result, valuable peer-learning opportunities are not utilised. These developers could make geological information more understandable for decision-makers by applying their knowledge and experiences. By creating a more cooperative geothermal sector, this element *geological information not understandable for decision-maker* could be mitigated as well. Therefore, the second requirement is twofold. One, the government should incentivise cooperation between developers and municipalities with experience and without experience with geothermal energy. Two, this incentive should encourage experienced parties to apply their knowledge and experiences to compile geological data sets into comprehensive and understandable information supporting decision-makers.

These two proposed requirements should enable the (partial) mitigation of the two elements *incomplete geological information* and *geological information not understandable for decision-makers*. If these actions are successfully completed, they will result in significant mitigation of the barrier *insufficient comprehensive geological information*.

During two of the interviews, Germany's current renewable energy policy became a subject of discussion. The interviewees indicated that the German policy had, and still has, a strong focus on electricity production by renewable energy sources (DE-1; DE-3). It was mentioned to be the consequence of a more fundamental problem: the inefficient use of available renewable energy sources. This policy also applies to geothermal energy. An example is that most incentives are primarily aimed at geothermal co-generation plants. The global average conversion efficiency of geothermal power plants is 12%, while geothermal heat in district heating would have efficiencies of around 90%, taking into account transport losses (Zarrouk and Moon, 2014). Thus, using medium-temperature geothermal heat for electricity production is highly inefficient. This insight is not classified as a barrier to geothermal district heating since the use of the application is not necessarily obstructed by this government policy.

Nevertheless, focusing on the efficient use of available renewable energy sources could increase geothermal district heating deployment. Hence, the German government should develop incentives that distinguish between geothermal sources for heating purposes and sources with the potential for electricity production. In that sense, the government should only invest in geothermal power plants in exceptional cases where high-temperature geothermal systems are present since converting geothermal heat to electricity is inefficient.

Hungary

Current plans

For Hungary, the situation is quite different from Germany. The country's geothermal potential is enormous. Still, the use in district heating is only moderate. As of 2019, the total direct use of geothermal energy production was 8.2 PJ, of which only 1 PJ accounts for geothermal district heating (Nádor et al., 2019), which is significantly lower than the previously foreseen targets. The government has acknowledged that implementing their renewable energy plans has experienced significant delays. From earlier analysis, the Government decision on the Action Plan for the Utilisation and Management of Energetic Mineral Resources could increase geothermal district heating. However, this can only be achieved if the objectives and deadlines are met.

In their energy strategy for 2030 and 2040, the Hungarian Ministry of Innovation and Technology indicated that the country has tapped into approximately ten per cent of their geothermal potential. In the coming decades, the government aims to increase the use of geothermal district heating by first supporting improvements to district heated buildings to reduce district heating temperatures, enabling geothermal input (Ministry of Innovation and Technology, 2021). At the same time, the government states that geothermal energy in district heating systems can only be a competitive heat source if the right incentives are introduced (Ministry of Innovation and Technology, 2019). As has been mentioned in earlier chapters, the Hungarian government appears to be reluctant to set measurable targets regarding individual renewable energy sources. Therefore, it is difficult to determine the increase of geothermal energy in district heating.

Figure 7.2 displays the concession areas for geothermal exploration that are currently in place. There are several large concessions with licenses for geothermal exploration. It is expected that some of these concessions will eventually result in new geothermal district heating installations. Moreover, plans for the construction of a 10 to 20 MW_{th} geothermal district heating installation in Budapest have been approved recently. Hence, although the installed capacity of geothermal district heating has been stagnant and even decreasing, it is expected that there will be a slight increase in the use of geothermal energy in district heating systems up to 2030.

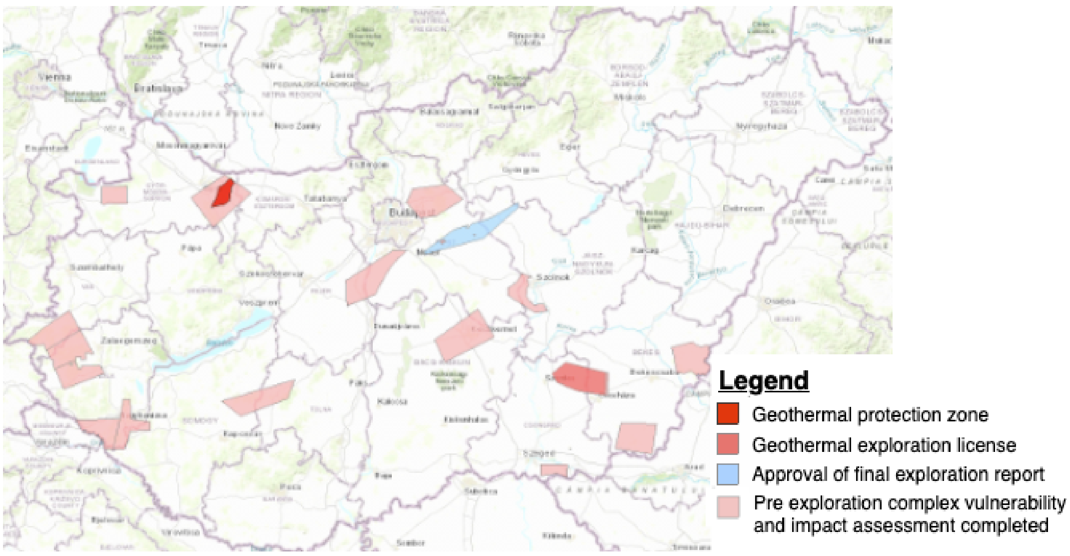

Figure 7.2: A map that displays the concession areas for geothermal exploration licenses in Hungary

Additional requirements

Requirements to mitigate institutional barriers

As mentioned in Chapter 6, the licensing procedures for geothermal district heating are particularly complex. This is the result of the barrier *inconsistent regulation and legislation*. One element of this barrier is the *misalignment of national and regional regulation/legislation*. Most district heating systems can only supply heat locally, or at best regionally. This is also the case for low or medium-temperature (geothermal) district heating since transport of a heated medium over long distances results in substantial losses. Hence, assigning all licensing procedures for geothermal exploration and district heating supply to regional authorities would be logical. The argument for this structure is that these regional offices have a better understanding of local geological and economic conditions. That way, resource allocation and spatial planning of the subsurface can be managed more efficiently and effective this way. Hence, the first requirement is to restructure the current licensing procedures. This action would not necessarily solve the element *misalignment of national and regional regulations/legislation*. However, it would result in this misalignment becoming less of a direct problem for geothermal district heating development.

The second requirement for this barrier is aimed at removing the element *ambiguous regulations/ legislation*. The current regulatory structure that distinguishes between the Water Management Authority and the Mining Authority results in ambiguity of regulations regarding deep geothermal system development. Since changing the entire regulatory structure is difficult due to many existing licenses, the recommended action is for the two authorities to try and better coordinate their regulations for new geothermal projects. The focus of this coordination process should be aimed at ensuring sustainable production of thermal water, meaning that reinjection techniques are applied.

Requirements to mitigate economic barriers

From the analysis, it became apparent that the subsidy on natural gas causes an uneven playing field in the heating sector. For years, the price of natural gas has been regulated to remain relatively inexpensive. Due to the inexpensiveness of natural gas, consumers are hardly encouraged to consider alternative heating sources. Many consumers still have single household gas boilers in their homes. That way, the subsidisation caused the new element *uncompetitiveness with alternative heat sources* of geothermal district heating as part of the barrier *economic non-viability*. By making natural gas more expensive, geothermal district heating could become more financially attractive. However, the flip side of simply abolishing the subsidy on natural gas is the risk of energy poverty for consumers due to rising energy prices. To prevent this energy poverty, a sensible approach should be considered. Hence, the proposed action is for the Hungarian government to gradually reduce the subsidy on natural gas to a price that is closer to the European average. If the Hungarian government reduces this subsidy, the element *uncompetitiveness with alternative heat sources* could be removed. In turn, this could result in the partial mitigation of the barrier *economic non-viability*.

Besides that, geothermal district heating is more expensive than conventional heating. Hence, a subsidy scheme for geothermal district heating would be required to reach accelerated upscaling. Considering the experiences from other countries, it is expected that geothermal district heating is still more expensive without subsidies on natural gas. Since the actual prices of heat and the subsidy on natural gas are unknown, it is challenging to determine the size of a subsidy scheme for geothermal district heating in Hungary. Hence, a subsidy scheme similar to the recommended subsidy in Germany is proposed. this would be €29 / MWh. To reach the goal of 10% geothermal district heating, the Hungarian government should provide up to €102 million in subsidy to geothermal district heating annually, up to 2030.

The second requirement is that the government should change the regulation scheme of the district heating market. It would be better to create a scheme where the suppliers of renewable heat are supported, instead of the consumers. By providing support to the district heating supplier, the costs of of both the initial investment and the operation can be reduced. Subsequently, the government can set maximum prices to protect consumers. The support for suppliers forces them operate as cost-efficiently as possible, since that could increase their profits. For geothermal district heating developers, this could be a more interesting regulation scheme since the overall costs of the district heating plant are reduced. The implementation of this action would have an effect on the element *risk perception of financial institutions* and the element *high investment costs*, further mitigating the barrier *financing difficulties*.

Requirements to mitigate technical barriers

In the technical domain, the most important requirement is for the government to provide support for improvements in the energy efficiency of buildings. Previously available funding, originally meant for residential and commercial buildings, was allocated to government buildings' energy efficiency improvements. This has left much of the building stock in the private sector with low energy efficiencies. By providing support for energy efficiency improvements, (partial) mitigation of the barrier *poor insulation of buildings* can be achieved. That way, the government can establish a building stock suitable for the use of low and medium-temperature district heating. This will eventually enable the upscaling of geothermal district heating.

The Netherlands

Current plans

In the Netherlands, the future of geothermal district heating appears to be very promising. The 2020 total of all deep geothermal heat production is 6.2 PJ (NLOG, 2021). According to the Dutch geothermal association, there is sufficient potential to reach an annual production of 50 PJ of geothermal heat by 2030 (Geothermie Nederland, 2021a). However, the Dutch government aims to reach a total geothermal heat production of 15 PJ by 2030, part of which will be used in district heating (Rijksoverheid, 2021). In terms of geothermal district heating, the first system is expected to be operational by the end of 2021 (EBN et al., 2021).

The Dutch central government has divided the country into 30 regions responsible for creating regional energy strategies for 2030. This approach was chosen to ensure a good support base and efficient use of local energy sources. From those strategies, geothermal district heating is expected to become more adopted, as some regions and cities have already started exploration activities for geothermal district heating. One of these cities is Leeuwarden in the North of the Netherlands (EBN, 2021.

From Figure 7.3 below, it can be observed that there are currently many concessions with licenses to explore for geothermal energy. It is expected that this will lead to an increase in geothermal energy use in general and district heating. Currently, the Dutch government aims to develop various geothermal demonstration projects that should assist in the increased upscaling of geothermal district heating in the future. These demonstration projects follow a "learning-by-doing" approach that should result in best practices. These best practices will be used to further mature and professionalise the geothermal sector.

Figure 7.3: A map that displays the concession areas for geothermal exploration and production licenses in the Netherlands

Another indicator that shows the increasing use of geothermal energy is the installed capacity per project. From 2012, the installed capacity per installation has grown by approximately 2 MW_{th} per year (RVO, 2021a). Although most of the projects in this database are meant for greenhouse heating, this increase could still be a positive sign for geothermal district heating. This increase could reveal that developers are scaling up their operations, resulting in larger systems. Higher-capacity systems can provide district heating to more buildings. Hence, the geothermal district heating sector could benefit from this development.

Additional requirements

The requirements for accelerated upscaling of geothermal district heating in the Netherlands have been somewhat more challenging to determine. The reason is that the Dutch government is currently taking significant steps towards removing a number of the barriers that have been discussed in this report. The most important actions have been described in Chapter 6. Here, the most important additional requirements are mentioned.

Requirements to mitigate institutional barriers

As mentioned in the previous chapter, the barrier *lack of regulatory/legal framework* for geothermal district heating will be largely mitigated as soon as current legislative changes are completed. Hence, no additional requirements for barriers with an institutional character are proposed.

The same holds for the barrier *lack of social acceptance* as the government and the geothermal sector have already invested significantly in involving and educating the public in geothermal district heating. Nevertheless, it requires continuous efforts of the government and the sector to keep improving the social acceptance (NL-1; NL-2; NL4; NL-5).

Requirements to mitigate economic barriers

For the barriers with an economic character, several actions are proposed. First of all, the regulation of the heating sector needs to be reconsidered. The regulation should be changed to a form that allows for the economical introduction of renewable heat sources. Hence, an alternative pricing scheme for the district heating market is proposed. Such a scheme would be based on the cost-price of district heating, plus a percentage of profit for the operator. By choosing this, or a similar pricing scheme, an incentive for investment from private parties would arise since the companies can make a profit. Though, form of regulation would only be effective if the district heating suppliers were completely transparent about their costs. The regulation of heat prices remains possible by periodically reviewing and adjusting profit percentages, forcing district heating companies to operate as cost-effectively as possible.

By implementing the regulation scheme proposed above, two barriers can be addressed at the same time. one of these barriers is mentioned here, the second barrier is discussed later in this subsection. The first barrier is *financing difficulties*. The element that is mitigated to some extent is *risk perception of financial institutions*, since the proposed regulation model allows for a percentage of profit to be made.

The second requirement for the upscaling of geothermal district heating in the Netherlands is to increase the demand for low or medium-temperature district heating. As mentioned in Chapter 6, the baseload heat production of a geothermal district heating installation is approximately 5000 home equivalents (EBN et al., 2021; NL-2; NL-4). Hence, the heat demand in low and medium-temperature district heating systems needs to have developed significantly to allow for economically viable use of a geothermal source. To that end, housing corporations play a substantial role in the accelerated upscaling of geothermal district heating in the Netherlands. Mainly since the heat demand of communal residential buildings is significant. The Dutch government should therefore support the implementation of conventional, low or medium-temperature district heating systems in areas suitable for geothermal heat use. A geothermal heating installation can take over the heat supply from the conventional source when the demand has developed sufficiently high. Financial incentives could persuade housing corporations to use these district heating systems, for example, by providing tax reductions or subsidies to these corporations.

The element that is addressed by the proposed action is *insufficient heat demand*. Since this element has been one of the primary causes of the bankruptcy of the first geothermal district heating system in the Netherlands, it is essential to cover this element. Additionally, the price regulation of the heat market plays a role in this barrier as well. By changing the regulation scheme, the element *regulated residential and commercial heat price* that was identified during the study can be addressed as well. From this second requirement, the (partial) mitigation of the barrier *economic non-viability* can be accomplished.

The barrier *inefficient renewable energy technology promotion policies* can be mitigated by implementing the already mentioned reserved fund for geothermal district heating. This reserved fund is currently an idea under investigation. For geothermal district heating, establishing this reserved fund could mitigate the element *unavailability of funds*. That way, the barrier *inefficient renewable energy technology promotion policies* can be mitigated as soon as the reserved funds are implemented. To that end, this measure is included as one of the additional requirements. By performing a back-of-the-envelope calculation, the amount of subsidy to reserve has been estimated.

It is important to remember that this subsidy scheme is provided for the production phase. Thus, the installed capacity is not only applies for the unprofitable part of geothermal heat production. Hence, the estimated reservation is a maximum subsidy. The calculation is based on the average maximum subsidy over the average available annual production of all geothermal installations that currently use the SDE++ scheme, and the systems that are planned to use the subsidy scheme. There is a reason why the planned systems are also included. This reason is, that there is a growing trend of the installed capacity per installation. Based on these conditions, it is estimated that the maximum amount of reserved SDE++ funds for geothermal district heating should be:

€35.6 / MWh / year (for a maximum subsidy term of 15 years)

Translated to the installed capacity this is:

€206,000 / MW_{th} / year (for a maximum subsidy term of 15 years)

In order to reach a ten per cent share of geothermal district heating in the household, commercial and public services heat sector before 2030, the government would be required to annually reserve a maximum of €305 million of the SDE++ subsidy scheme for deep geothermal district heating within the category of low carbon heat.

Requirements to mitigate technical barriers
Finally, one mainly technical action is required for the upscaling of geothermal district heating. A barrier to the accelerated upscaling of geothermal district heating is the*poor insulation of buildings*. If large scale deployment of district heating systems is to be achieved, a higher energy efficiency of buildings is a prerequisite. Up to now, the government has provided several incentives for increased energy efficiency in buildings. However, further improvements are required. Hence, the required action is for the government to provide additional financial support for energy efficiency improvements in buildings. Specific attention should be paid to apartment buildings and flats. The reason is that the heat demand in these buildings is substantial, which implies that improving the energy efficiency will have a significant effect on the heat demand. The increase in energy efficiency can be achieved with relative ease since many of these buildings are owned by housing corporations. That means that just a single party needs to be incentivised to implement the changes. There are two sides to the improvements in energy efficiency that should be considered.

On the one hand, the higher energy efficiency will make buildings more suitable for low or medium-temperature district heating. On the other hand, the improved energy efficiency causes a decrease in the heat demand, which could potentially jeopardise the business case for geothermal district heating. However, this demand reduction also enables further expansion of such a district heating system. The last situation appears most likely because the Dutch government stimulates centralised heating systems. Therefore, it is expected that investments in improving energy efficiency in buildings owned by housing corporations will largely mitigate the barrier *poor insulation of buildings*.

7.2. The investigated countries' perspective for geothermal district heating

In the previous section (7.1), an outlook on the future of geothermal district heating in the three selected countries has been described. The analysis considered the country's energy strategies and geothermal potential in light of the actions already taken. The question that is central to this Section is *"What is the future perspective for the investigated countries concerning geothermal district heating up to 2030?"*. From the previous Section's analysis, the governments of all three countries have appeared to have different views on the role of geothermal heat in their district heating sector for 2030. In light of the current conditions, a prognosis for the share of geothermal district heating in 2030 is formulated.

Germany

In Germany, the share of geothermal heat in the heating sector is expected to increase up to 2030, albeit slightly. The national energy plans also indicate a slight increase in geothermal district heating. In some regions, the use of geothermal district heating is expected to grow substantially. Though, within the national context, this increase might appear rather small. For the horizon of 2030, the installed capacity of geothermal district heating is expected to become approximately 600 MW_{th}, which would mean a near doubling compared to current figures. This has been determined by considering the speed of previous development and the indication that several deep geothermal district heating installations are being planned or constructed. The share of geothermal district heating of the total heat demand in the residential and commercial sectors would then become 2.6%.

Hungary

In Hungary, the situation is different. The use of geothermal heat in the county is accepted, and the potential is acknowledged to be great. However, the strong dependence on fossil fuels for heating purposes and their cheap availability make it difficult to transition to geothermal district heating. Various actions aimed at increasing the use of geothermal heat in district heating systems have not resulted in a substantial increase in the share of geothermal. Additionally, the installed capacity of geothermal district heating has been virtually stagnant since 2015.

Besides the recently announced plans for the construction of a 10 to 20 MW geothermal district heating plant, there are no signs of additional growth. Hence, the results of the upcoming elections could be the last hope for accelerated upscaling of geothermal district heating in this decade. In that case, it could be possible to reach increased production of geothermal district heating before 2030. For the estimated growth in the installed capacity and share of geothermal district heating of all residential and commercial heating, various sources of information have been considered. Examples are, growth projections of geothermal district heating, and the overall economic conditions in the country. Combined with the knowledge gained during this study, the increase in installed capacity is not expected to exceed 100 MW before 2030. Using this value, the estimated share of geothermal district heating of all residential heating in 2030 is 5.4%*. Thus, the share of geothermal district heating is increased with an additional 1.5% compared to now.

The Netherlands

For the Netherlands, the future of geothermal district heating is somewhat more defined. The government has indicated that geothermal energy will be a significant source of heat in the future. Despite that, up to 2030, the Dutch government prioritises efficient coordination for developing geothermal district heating. In that sense, the focus is on creating the right conditions for upscaling by performing legislative revisions, research activities and pilot projects. Major legislative changes are expected to be completed by 2023, resulting in unambiguous and complete rules and regulations. From that moment on, the development of geothermal district heating is expected to increase gradually. Therefore, the upscaling of geothermal district heating is not expected to have started before 2025. If the government accomplishes their objectives concerning their current plans, the development of geothermal district heating in the period following 2025 could be rapid.

Since there is currently no geothermal district heating system in operation, it is difficult to predict the share of geothermal district heating in the residential and commercial heating sector by 2030. It takes approximately three to five years to develop a geothermal district heating plant from the planning stages to commissioning of the system. At the moment, various systems are in the planning or early development stages. These systems are expected to supply about 120 GWh/year of geothermal district heating by 2025, which comes to approximately 2% of the total residential and commercial heat demand. Beyond 2025, the developments are less certain, but it seems reasonable to expect a doubling of the geothermal district heating production by 2030, compared to 2025. That would result in a total expected share of geothermal district heating of about 4%*.

Although it is unlikely that the countries will achieve substantially accelerated upscaling of geothermal district heating before 2030 under the current circumstances, further growth is expected in the coming years. In total, the combined share of geothermal district heating as part of the residential and commercial heat demand in the three countries is expected to double. This is relatively moderate, considering the potential of the resource.

* *The share of geothermal district heating in the total heat demand of homes and businesses has been estimated based on constant heat demand. However, the energy efficiency of buildings in all three countries is expected to improve, resulting in reduced heat demand. As a result of that improvement, the actual share of geothermal district heating in the total demand is expected to be higher.*

7.3. Requirements for accelerated upscaling of geothermal district heating

This section presents the most critical requirements to achieve accelerated upscaling of deep geothermal district heating. The proposed requirements result from all previous analyses, combined with background information about the investigated country's renewable energy plans. The research question that is answered in this section is *"What additional actions are required to achieve accelerated deployment of geothermal district heating systems in European countries?"*. For every country, the most important requirements are presented. In support of answering this question, the interviewees have been invited to participate in a small thought experiment. As mentioned earlier in this section, they were asked to provide their perspective on the following question: *"What actions are required to reach a share of 10% geothermal heat in the residential, commercial and public services heating sector in your country by 2030?"*. This share of 10% has also been the objective for answering the research question in this section.

Table 7.1: The requirements for accelerated upscaling of geothermal district heating that have been proposed in section 7.1, specified for the barriers that the requirements aim to mitigate *LT & MT : Low-temperature and Medium-temperature

	Requirements		
Barriers	**Germany**	**Hungary**	**The Netherlands**
Inconsistent regulation / legislation		Restructuring of licensing procedures for geothermal district heating Re-coordinate Water Management Authority and Mining Authority regulations	
Economic non-viability	Abolish subsidy on conventional CHP plants Subsidise geothermal district heating systems specifically	Gradually reduce government subsidy on natural gas Increase subsidy for geothermal district heating	Incentivise housing corporations to use LT & MT* district heating Adjustment of heat price regulation scheme
Financing difficulties		Revise regulation of the district heating market	Adjustment of heat price regulation scheme
Ineffective RET promotion policies	Abolish subsidy on conventional CHP plants Subsidise geothermal district heating systems specifically		Reserve funds specifically for geothermal district heating
Applicability difficulties	Legal boundary temperatures for LT & MT district heating systems		
Insufficient comprehensive geological information	Performing a large-scale drilling campaign Incentivise cooperation between municipalities, developers, scientists		
Poor insulation of buildings		Provide subsidies for energy efficiency improvements in residential and commercial buildings	Insulation campaign for residential and commercial buildings

As can be observed from Table 7.1, several essential actions have been found to support the upscaling of geothermal district heating. These required actions are expected to affect the upscaling of geothermal district heating. Nevertheless, it is important to determine if these actions enable the governments of Germany, Hungary and the Netherlands to achieve the goal of a 10% share of geothermal district heating of the total heat demand in the household, residential and public services sector.

Germany

From the German federal or state government's plans, a slight increase in geothermal district heating is expected for 2030. The growth of geothermal district heating can be accelerated further if the government focuses on providing more financial incentives for geothermal district heating. Additionally, other actions are recommended. These recommended actions for Germany are:

- Reduce subsidy on conventional district heat generation.
- Subsidise geothermal district heating installations more extensively. A similar subsidy to current conventional district heating subsidy would have a value of €29 / MWh, which could be very beneficial for the development of geothermal district heating.
- Establish legal boundary temperatures for low and medium-temperature district heating systems.
- Performing a large-scale drilling campaign to collect comprehensive geological data.
- Incentivise cooperation between municipalities, developers and scientists.

If all the proposed actions are implemented, the share of geothermal district heating of the total residential, commercial and public services heat demand is expected to grow significantly. However, the share is not expected to reach 10% by the end of this decade. The reason is that the geology in many regions is not suitable for geothermal district heating or the distances from the geothermal source to the consumers is too high. Additionally, the total heat demand in Germany is massive, which requires the further increase in geothermal district heating to be nearly 1400 MW to reach a 10% share by 2030. Moreover, considering the recommended size of the subsidy, this would require approximately one billion Euros in government support.

Hungary

In Hungary, geothermal district heating can be increased by taking several other actions. The range of actions varies widely since the country's economy and legislative conditions make it challenging to develop geothermal district heating on a large scale. Below, a list of recommended actions is presented.

- Restructuring of licensing procedures for geothermal district heating, preferably assigned to a single government office.
- Re-coordinate Water Management Authority and Mining Authority regulations to remove inconsistencies and to allow for easier licensing for deep geothermal installations.
- Gradually reduce government subsidy on natural gas to create a more level playing field with geothermal district heating.
- Increase subsidy for geothermal district heating to a maximum annual value of €102 million up to 2030.
- Revise regulation scheme of the district heating market to allow for fair pricing of geothermal heat.
- Provide subsidy for energy efficiency improvements in residential and commercial buildings.

Since the share of geothermal district heating in Hungary is relatively high, there are signs that the technology could become a more adopted heating source in the future under the right conditions. By implementing the proposed actions from Table 7.1, it could be possible for the country to reach a share of 10% geothermal district heating by 2030. It is, however, essential that the government actively supports and promotes the development of geothermal district heating.

The Netherlands

In the Netherlands, the proposed actions are primarily aimed at mitigating the barrier *economic non-viability* of geothermal district heating since the current economic situation does not provide profitable conditions for the use of this energy source. Besides that, actions for other barriers have been proposed. The list below presents an overview of the required actions:

- The price regulation on the heat market should be adjusted. However, that would only solve a part of the issue, since geothermal district heating is uncompetitive with alternative heat sources.
- Hence, the subsidy for unprofitable production should be increased, preferably by reserving a part of the SDE++ subsidy for geothermal district heating. The minimum amount of fund that should be reserved is €305 million.
- Housing corporations should be incentivised to transition from block-heating Low and medium temperature (geothermal) district heating, to increase the development speed of low and medium temperature district heating demand.
- An insulation campaign for residential and commercial buildings. An attractive subsidy to improve the energy efficiency in these buildings should be provided. The higher energy efficiency allows for more widespread use of lower temperature district heating.

In light of the proposed actions, the share of geothermal district heating in the Netherlands is expected to grow significantly up to 2030. Geothermal district heating could become profitable if these actions are implemented sufficiently. Considering the relatively low heat demand in the residential, commercial and public services heat sector in the Netherlands, the share of geothermal district heating could grow significantly towards 2030. Therefore, it would be reasonable to expect a geothermal district heating share close to 10%.

The influence of a CO_2-price for conventional heating

Aside from the individual actions that are proposed for the countries, there is another factor that could be beneficial for the accelerated upscaling of geothermal district heating. This would be for the countries' governments to introduce a CO_2-price for conventional heating (household gas boiler). Below, a simplified estimation for a suitable CO_2-price to benefit geothermal district heating is made.

Table 7.2: Assumptions

Assumptions	
Average price natural gas	€20 / MWh
CO_2 emission natural gas	56 g CO_2/ MJ = 202 kg CO_2/ MWh
Compensation non-viable production (generalised from NL)	€35.6 / MWh
CO_2 emission geothermal district heating	assumed 0 g CO_2/ MWh (for simplicity only)

Subsequently, it is possible to determine the necessary CO_2-price for conventional heating to make geothermal district heating equally expensive. This price should be € 35.6 / 0.202 = €176 / tonne CO_2. Thus, if the countries were to introduce a CO_2-price for conventional heating, this price would need to be quite high. Compared to, for example the current price in the European Emissions Trading System, which is around €80 / tonne CO_2, the calculated price is extreme.

In this chapter, the future of geothermal district heating and the essential requirements for the accelerated upscaling of geothermal district heating have been discussed. It was found that for every country, the future of geothermal district heating depends on several barriers, but there is potential for further growth. Essential actions for the governments have been proposed to accelerate the implementation of geothermal district heating. This has resulted in the insight that implementing these actions could result in an accelerated upscaling of geothermal district heating, potentially reaching a 10% share of all residential, commercial and public services heat demand by 2030. In the end, the price for a possible CO_2 pricing scheme for conventional heating was estimated. In the next chapter, the discussion is presented. Here, the robustness of the research questions, the analyses, and this study's limitations are addressed.

8 Discussion

This research sought to explore possibilities for the upscaling of geothermal district heating by identifying and analysing barriers in a selection of European countries. This has been achieved by answering five research questions that enabled the formulation of an answer to the main research question. In this chapter, the findings to the questions are discussed and compared to previous studies. Additionally, the limitations of the study and a reflection on the value of the findings is provided.

8.1. Comparison to previous studies

Similar to Carrara et al. (2020), this study found that a lack of social acceptance can be a significant barrier to the upscaling of geothermal district heating. As was also described by Soltani et al. (2021) and Pellizzone et al. (2017), the barrier has a primarily local or regional character, which makes generalisation difficult. Despite the local character, this study, like (Kunze and Hertel, 2017), also emphasised that some level of public opposition may be unavoidable.

Besides that, the findings of this study support the idea that some promotion policies for renewable energy technologies are ineffective for various reasons (García-Gil et al., 2020). The reasons for this ineffectiveness were found to vary significantly. The primary factors are unsuitable economic conditions for the type of promotion policy and inadequate support schemes considering the cost of alternatives.

In contrast to the findings of Thorsteinsson and Tester (2010), this study did not find the payback period of geothermal district heating to be a significant factor in the economic viability. On the other hand, factors like insufficient heat demand and uncompetitiveness with conventional heating sources were found to play a vital role in economic viability.

Additionally, the impact of the barrier *poor insulation of buildings*, which has been identified in this study, has not been discussed in detail in other studies. A reason for this could be that many studies are solely aimed at the technical characteristics of geothermal district heating, or these studies aim to investigate geothermal energy from a broader perspective. Hence, the significance of this barrier could be less compared to other factors that arise in those studies. The requirement of energy-efficient buildings for district heating has been mentioned by Acheilas et al. (2020). However, they argue that investments in insulation should result in an energy-neutral housing sector, which is complex and expensive to achieve. This study proposes a more feasible approach, aiming for energy efficiency improvements to reach at least energy label C.

8.2. Limitations of study

Although this study has resulted in interesting and possibly valuable insights, it also has several limitations. In this section, the limitations of the conceptual framework and the research methods are discussed.

8.2.1. Conceptual framework

The conceptual framework for this study was introduced in Chapter 3. This framework was chosen since it aims to analyse the penetration of renewable energy technologies (Painuly, 2001). Since this framework was used, the focus of this study was on the barriers to geothermal district heating and ways to mitigate them. A framework to identify and analyse drivers of the technology could have been used as well. Although these technology drivers are important, they do not necessarily solve the problems that prevent the accelerated upscaling of renewable energy technologies. Hence, the study would have resulted in insights on the push of geothermal district heating technology if this framework had been used. However, the applied framework enables the identification and analysis of obstacles regarding the societal desire for renewable district heating, resulting in a more comprehensive overview.

Nevertheless, a conceptual framework that divides the barriers into predetermined categories was not entirely suitable for the study's objective. The reason for this assessment is caused by the cross-dependencies between the barriers and elements. Hence, it was not sensible to consider individual barriers within the bounds of a single category. To that end, the choice was made to introduce an extension to this framework that would enable a more justified analysis of the barriers. This extension of the framework enabled a more comprehensive analysis of the institutional, economic and social factors of these barriers.

Although the conceptual framework provides the possibility to include dimensions of elements, it has an inherently qualitative nature. Consequently, the findings of this study are primarily derived from the interpretation of a non-calculative analysis. On the one hand, the qualitative approach enables the researcher to identify nuances that cannot be found with purely numerical analysis. On the other hand, the framework limits the researcher in determining the magnitude of barriers and the required strength of possible solutions to these barriers.

It would have been possible to choose a more quantitative approach, a modelling study, for example. However, such an approach is likely to be less helpful in recommending non-numerical policy measures. The reason is that many of the barriers and elements encountered in this study are not measurable. It would be possible to construct some type of scale for these variables. However, interpreting a numerical value for a non-measurable variable, like social acceptance might not be justifiable.

On the contrary, with the current conceptual framework, it has proven to be challenging to compare the barriers between countries. Since the elements are non-numerical, the comparison could change based on a misinterpretation of textual information.

Finally, the initially constructed framework, with the literature's and interviews' barriers and elements, required multiple revisions and adjustments. Part of these followed from new insights on the influence of elements on specific barriers. Another reason for the revisions was adding or removing elements to avoid unnecessary complexity. Although a comprehensive set of barriers and elements has been analysed, some elements or barriers have possibly not been identified. Hence, these have not been part of the analyses. It is, however, unlikely that the influence of these unknown elements or barriers would have changed the outcomes of this study. The reason is that any other important barriers would have come up during the interviews with experts since the variety of experts allowed the researcher to identify barriers over a broad view.

8.2.2. Research methods

The research methods that have been used for this study have been described in Chapter 4. The research methods seemed appropriate for this type of study, as they have allowed the researcher to answer the research questions. on the other hand, it would be interesting to see if the use of different research methods would result in alternative findings.

Energy statistics analysis

During this study, several types of energy statistics have been presented and used in calculations. Throughout the research process, the researcher aimed to utilise data from the same sources as much as possible. This was done to ensure that the used data sets had been collected and processed in a uniform way, increasing the reliability of the comparison. In cases where data from different sources was used, the assumptions under which the data was collected were checked to determine the alignment of data. Nevertheless, there is a small chance that some of the data used in this report was not completely reliable.

Some differences between data sources have been observed. These are mainly related to the installed capacity of geothermal district heating. Most of the observed differences are only minor. Hence, they are unlikely to have impacted the conclusions of this study. Additionally, for the Netherlands, there is no information on geothermal district heating since there is no operational installation yet.

Consequently, the expected installed capacity had to be determined by identifying planned systems or systems under construction. However, the actual production capacity of the installations could deviate from the planned capacity. Hence, the estimations for the Netherlands might be slightly off. This will not have significantly affected the study's conclusion since the current developments are overseeable and relatively small in number.

Document analysis

Document analysis has played a central role in this study. Various scientific articles and reports were used to analyse developments and answer the research questions. As mentioned in Chapter 4, this study focused on the developments in the past decade and the possibilities for the coming decades. Hence, only documents published in the past decade have been used to perform the analyses. This enabled the researcher to get a close-up view of the recent developments regarding geothermal district heating.

Nevertheless, there is a chance that a reproduction of this study might result in different findings for several reasons. First of all, there is a chance that the researcher has not been able to find or access all available documents that could be used. Hence, other researchers that may reproduce this study may find or access documents that result in other insights. Although some documents have not been available for use or have not been found, the impact on the results of this study is expected to be minimal. Various data sources have been used, allowing the researcher to cross-check any inconsistencies. In the case of unclear or uncertain information, the experts have been consulted to clarify or to confirm findings.

In addition to that, the time at which the study was conducted plays a significant role. New information will likely become available in the future, leading to alternative insights. This means that this report should only be seen as a snapshot of the current situation concerning geothermal district heating.

Also, differences in reporting structure between the countries was observed. To start, not all documents have been available in English. Hence, there is a possibility that some information has been lost in translation. However, that will not have influenced the results of this study significantly since the core of the documents was leading.

Finally, a large variety of available data has been encountered. For Hungary, many government documents do not include clearly specified targets for every energy source. This made it challenging to determine the expected growth in the coming years. Considering the speed of previous development, a reasonable estimation was made. Additionally, the pricing methods and subsidy for natural gas were not available in clear figures. Therefore, the subsidy scheme for geothermal district heating has to be derived from the other two countries. This may have resulted in a slightly less reliable estimation of the required subsidy scheme. However, the result does appear to be in line with the observations from Germany and the Netherlands. Hence, the recommended subsidy seems reasonable.

Interviews

Semi-structured interviews have been conducted to gather first-hand hand experiences. The objective was to allow the researcher to control the conversation without risking the loss of valuable (background) information. It would be interesting to know if using structured interviews would result in significantly different findings. In the case of structured interviews, the answers given by the interviewees would have been likely to be more to the point. This could potentially result in the possibility to make a measurable comparison between the answers provided by the interviewees. This type of interview could also result in a loss of valuable information that would help to differentiate the root cause of the barriers for every country. Similarly, conducting open interviews could result in much more information on the background of geothermal heat in district heating. However, the answers by the interviewees might not lead to the identification of specific barriers for the investigated countries, or the interpretation of the interviews could be more challenging.

Occasionally, the experts were not familiar with the barriers presented by the researcher. In those cases, the researcher briefly explained the idea behind a barrier by giving examples or describing a situation. It was essential that the interviewees to understood the barriers and the questions, and made their interpretation within the context of their country. Nevertheless, the researcher may have influenced the view of the interviewees on certain barriers, which, in turn, may have influenced their answers to the questions. It is unlikely that the researcher has limited their view on the barriers, since they indicated their unfamiliarity with some concepts. However, the researcher may have directed their perception of the barriers. Although, it cannot be measured to what extent this may have influenced the findings of this study, it is important to note this issue.

The interviews were approached as objectively as possible. Nevertheless, bias may have played a role. Considering the interviews were conducted with three different types of experts, the statements from the different experts could have varied significantly. Some interviewees may have provided answers that supported or reflected their opinion instead of the facts. Consequently, it became apparent that several interviewees have exaggerated some barriers. From all the interviews, it seemed that the developers of geothermal district heating, in particular, were convinced that government support could hardly be sufficient.

Besides that, the government was blamed for a barrier in various interviews. In Hungary specifically, the government was blamed for some barriers. In one or two instances, this appeared to be justified to some extent. However, in most other cases, a combination of factors was more likely to have caused a barrier. Despite several attempts to contact various policymakers in Hungary, it turned out not to be possible to interview this type of expert. In a sense, this may support the statement made by one of the other experts, saying that government officials are unreceptive to converse about geothermal district heating. On the other hand, this is unfortunate since the government's view had to be extracted solely from policy documents. This may have affected the findings of Chapter 7 to some extent, since current government plans remained unknown. However, for the general conclusion, the impact is minor.

Considering the discussion of the research methods, it becomes clear that several factors may have influenced the results of this study to some extent. In most cases, the level of influence appears to be negligible. Additionally, uncertainties of the study's results have been discussed. Overall, the influence of the discussed factors on the conclusion is minimal since the study aims to identify a broad set of requirements for European countries to reach accelerated upscaling of geothermal district heating. These requirements are the result of the analyses of all three countries combined. Hence, it is unlikely that minor influences in the individual analyses have affected the conclusion substantially.

8.3. Reflection on scientific and societal value

8.3.1. Reflection on Scientific value

The scientific value of this research is predominantly in the iterative application of the combined conceptual framework, independent of predefined categories. First, it was used to decompose and analyse barriers to geothermal district heating, followed by an iteration to determine the effect of previous barrier-mitigating measures. A final iteration was performed to formulate additional requirements to accelerate the upscaling of geothermal district heating.

The primary use of the conceptual framework by Painuly (2001) is to analyse the causes of barriers to renewable energy technology penetration. The framework was extended to include the interactions between institutional, economic, and technical factors by building upon this basis. This combined conceptual framework was subsequently used to propose policy measures to mitigate barriers. However, the initial decomposition of the barriers is highly standardised by the creator of this basic framework. Hence, for this study, a slightly different approach was chosen. This enabled the identification of barriers and elements specific to the upscaling of geothermal district heating. This approach was chosen to ensure a comprehensive analysis of the upscaling possibilities of geothermal district heating in Europe.

Besides that, this study showed that it is possible to use this framework to formulate a coherent set of policy measures that enable the accelerated upscaling of geothermal district heating. Furthermore, it became clear that the physical environment in which the technology is implemented strongly influences its use and upscaling possibilities.

Looking back on this study, other framework designs could prove more effective in determining the magnitude of barriers. Additionally, the estimated effects of previous actions and recommended actions have been based primarily on interpreted data. As mentioned previously, the analysis was approached with objectivity. Nevertheless, the inability to measure the effects might have influenced the robustness of the analysis.

8.3.2. Reflection on Societal value

Geothermal district heating could provide a near-endless source of emission-free heat. Despite being a mature technology, ready to be implemented on a large scale, multiple forces prevent the accelerated upscaling of geothermal district heating. Since this technology can play a pivotal role in the energy transition, it is crucial to establish conditions that enable widespread implementation. This study aims to provide tools for mitigating barriers to the accelerated upscaling of geothermal district heating.

As mentioned earlier, various studies have already been conducted on the barriers to geothermal energy in general. Additionally, there is much literature on the potential and applications of geothermal energy. However, there has been no specific research into the barriers of geothermal district heating in Europe. Furthermore, most studies limited their scope to identifying and analysing drivers and barriers to geothermal energy without recommending specific policy measures to mitigate barriers. This study's objective is to fill part of that void.

This study first identified and decomposed barriers by using the conceptual framework. Then, an in-depth investigation was performed for Germany, the Netherlands and Hungary. By using literature and interviews with experts, not only the barriers were determined. The selected approach also allowed to formulate a prognosis for the future development of geothermal district heating under the current conditions.

Besides that, barriers to geothermal district heating were used to determine the conditions for accelerated upscaling of the technology, while considering the investigated countries' economic, institutional and social context.

Hence the societal contribution of this study is characterised by the following:

- The barriers specific to the upscaling of geothermal district heating in Europe have been identified, and a prognosis for the future under the assumption of constant conditions is presented.
- The study recommends specific policy measures that assist in the mitigation of the most important barriers to the governments of Germany, Hungary and the Netherlands.
- Generalised conditions that enable accelerated upscaling of geothermal district heating in European countries are presented.

9

Conclusion & recommendations

9.1. Conclusion

Despite the sizeable geothermal potential in Europe, accelerated upscaling of geothermal district heating has not been achieved yet. Through the use of a conceptual framework, barriers to the accelerated upscaling of geothermal district heating have been decomposed. This study's sub-questions have been answered in the Chapters 5 to 7. First, European developments have been studied and three European countries, being Germany, Hungary, and the Netherlands have been selected for in-depth analysis. Second, the presence of the barriers has been tested for these countries. Next, previous actions to mitigate these barriers have been found, after which a prognosis for upscaling until 2030 was presented. Finally, requirements for accelerated upscaling before 2030 are recommended to the governments of the countries.

9.1.1. Answers to the sub-questions

1. *How has geothermal district heating developed itself in the European context over the past decade?*.

The use of geothermal district heating has increased in several countries over the past decade. In 2012, the share of geothermal district heating in the households, commercial and public services heat sector of the European countries presented in Table 5.1 was 1.1%, whereas, in 2019, that share has grown to 1.7%. Countries like France and Hungary were found to have high shares of geothermal heat in their district heating sector. In some countries, the development was concentrated to a specific region with known geothermal resources, while in other countries, new, previously unknown resources were tapped into. At the same time, the Netherlands, for example, does not yet have operational geothermal district heating systems. Nevertheless, the Dutch government has ambitious plans for implementing this technology.

2. *Why have certain countries achieved a high degree of geothermal district heat use while others have not?*

One of the main reasons geothermal district heat use has not reached high levels in certain countries is that conventional heat sources, like natural gas, are sometimes preferred over less conventional ones. In some countries, this translates into government policies that enable price reductions on natural gas heating or into price caps for (district) heating, dependent on natural gas prices.

Additionally, renewable energy technology promotion policies significantly influenced the upscaling of geothermal district heating. Some renewable energy technology promotion policies were not very advantageous to geothermal district heating since they prioritised specific renewable energy sources over others. The SDE++ renewable energy technology subsidy scheme in the Netherlands, for example.

Finally, poor insulation of buildings was found to affect the suitability to use low and medium-temperature district heating systems. These district heating systems are particularly suitable for geothermal district heat input. It became clear that a prerequisite for geothermal district heating is medium to high energy efficiency levels in the building stock.

3. *What actions have been taken to achieve further upscaling of geothermal district heating, and why have the actions taken been (un)successful in the investigated countries?*

From the analyses it was found that countries have tried to remove legislative and regulatory barriers to geothermal district heating. Though, some actions were found to be unsuccessful, delayed or even have adverse effects. For example the restructured licensing procedures in Hungary.

The analysis showed that all three countries have taken actions to increase the economic viability of geothermal district heating. Tax incentives and subsidy schemes were most prevalent. However, tax incentives were primarily beneficial for development of the consumer base of district heating in general, while subsidy schemes were found to be insufficient or unavailable due to competition with other sustainable energy products and applications.

Additionally, actions to mitigate a lack of social acceptance have been taken, most of which have been successful. Nevertheless, a lack of social acceptance and public opposition is pointed out as a barrier that needs continued efforts in the future.

4. *What is the future perspective for the investigated countries concerning geothermal district heating up to 2030?*

The use of geothermal district heating is expected to keep growing in all three countries in up to 2030. A basic prognosis for the countries' share of geothermal district heating was made. This resulted in the insight that, if the governments follow the path that they are currently on, the share of geothermal district heating will increase in all three countries. For Germany, that would mean an increase in the share from 1.6% to 2.6%. In Hungary, the share is likely to have increased from 3.9% to 5.4%. And for the Netherlands, it is expected to increase from the current 0% to approximately 4% in 2030.

5. *What additional actions are required to achieve accelerated upscaling of geothermal district heating systems deployment in European countries?*

Several actions are recommended to reach a 10% share of geothermal district heating by 2030. In some countries, achieving this target will be more challenging than other countries. The primary action is for governments to provide a subsidy for geothermal district heating. The necessary government funds that need to be allocated to geothermal district heating until 2030 were estimated to be about €1 billion in Germany, €102 million in Hungary, and €305 million in the Netherlands, all annually. Moreover, it is expected that substantial subsidies still need to be provided post-2030.

Additionally, several legislative changes are recommended to provide better legal conditions for upscaling geothermal district heating. These include restructuring heat market regulation and establishing legal boundary temperatures for low and medium-temperature district heating systems.

Besides that, government incentives for energy efficiency improvements in buildings should be provided to allow the use of low and medium-temperature district heating systems suitable for geothermal heat input.

9.1.2. Answer to the main research question

Following from the results of the sub-questions, the main research question of this study can be answered. To recap, this question is:

"How can the implementation of geothermal district heating in European countries be accelerated within this decade?"

It has become clear that, under current conditions, only a possible doubling of geothermal district heat use in Europe can be achieved before 2030. To accelerate the upscaling of geothermal district heating, a combination of conditions should be met. Notwithstanding the relatively suitable geology in Europe, it has become apparent that essential issues need to be addressed for geothermal district heating to become a widely implemented technology. Nevertheless, geothermal installations could provide a significant share of the heat production in the district heating sector in the future.

First of all, the economic viability of geothermal district heating should be secured. This condition can be met by implementing various measures focused on the upscaling of this technology. In some countries, this would require restructuring the regulation schemes of heat markets and reducing subsidies for conventional heating. Besides that, governments are recommended to reserve substantial subsidy funds for geothermal district heating systems to accelerate upscaling of this application directly. The accelerated upscaling of this geothermal energy application will not come cheap for governments as the estimated subsidies range between one hundred million to a billion Euros until 2030, depending on the demand of a country's residential, commercial and public services heat sector.

The second condition is to establish high energy efficiencies in buildings. Hence, the governments are recommended to provide incentives for energy efficiency improvements. Several forms of incentives are possible, like subsidies and tax discounts. special attention should be paid to communal residential buildings, which generally have a substantial heat demand. That would enable the implementation of district heating systems that have low or medium operational temperatures, which are suitable for geothermal heat input. Besides that, this condition also serves other purposes that favour the development of geothermal district heating. Since high energy efficiency reduces the heat demands of individual spaces or buildings, it enables further expansion of (geothermal) district heating systems. Accordingly, as the number of consumers grows, this allows for the development of higher-capacity geothermal district heating installations where geologically possible.

Finally, governments are recommended to create clear legislative and regulatory conditions for geothermal district heating. Examples of recommended actions are establishing legal boundary standards for district heating system temperatures and adjusting heat price regulation schemes to enable profitable supply for geothermal district heating. Clear legal and regulatory arrangements for geothermal district heating are essential for accelerated upscaling for two reasons: One, it will result in the efficient development of geothermal district heating since licensing procedures and regulations are unambiguous. Two, it provides a more stable environment for financial institutions to invest since business cases are less uncertain than under the current conditions.

By meeting the requirements described above, governments of European countries can improve the conditions for achieving accelerated deployment of geothermal district heating before 2030. Assuming that the recommended actions are taken, European countries are expected to cover a substantial share of their residential, commercial and public services heat demand with geothermal heat. Whether these recommendations will definitively result in the desired 10% share of geothermal district heating, indicated in this report, is uncertain since the focus of this study has not been on numerical evaluations. Nevertheless, the recommendations provide a basis for governments to accelerate the development of geothermal district heating.

At the same time, it is not implied that the recommended actions are the only ones that will result in the accelerated deployment of geothermal district heating in Europe. Since the recommendations are a generalised extract from the analysis of three countries, the study provides a relatively robust set of proposed actions for application in other European countries. Nonetheless, differences in other European countries' legislative, economic or geological conditions might require a different approach.

9.2. Recommendations for further research

Following this thesis, recommendations for further research can be formulated for several parts of this study. This study aimed to compare the barriers to and the development of geothermal district heating in three countries. One of the final objectives was to generalise the findings to indicate the conditions under which geothermal district heating can reach accelerated upscaling in the wider context of European countries. It was found that these generalised conditions only provide a stepping stone to the accelerated upscaling of geothermal district heating in European countries.

In order to formulate specific and effective measures, it is recommended to perform a more extensive study into one particular region or perhaps even one city. This could lead to valuable insights for policymakers and the geothermal sector on achieving further upscaling of the technology.

Another recommendation is to study the magnitude of the barriers to the upscaling of geothermal district heating. As mentioned in the discussion, this study primarily aimed at answering the questions *why and how*, not necessarily *to what extent* the barriers play a role. Hence, a study into the numerical effects of the barriers could generate findings that benefit the sector and simultaneously grow the knowledge base on the subject. A system dynamics approach, in particular, could yield valuable insights.

Since the requirements have been proposed to accelerate the upscaling of geothermal district heating specifically, their effects on the use of other heat sources and the heat sector are generally less considered. Therefore, specific research into the impact of accelerated upscaling of geothermal district heating on the heating sector is recommended.

Finally, an ex-post analysis of a geothermal district heating system, in the form of a case study. It could result in insights that are valuable for both developers and policymakers. This would not only result in a more detailed identification of barriers or enablers, but it could also mainly serve as a great learning opportunity for future development.

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A

Appendices

A.1. Literature review table

Table A.1: An overview of the literature used for this review in table-format. The columns present the article's geographic area of focus, the type of research article, the research objective and the cited article, respectively.

Geographic area	Study type	Research objective	Cited article
Europe, Spain, Canary Islands	Case study	Analysis of barriers for implementation of geothermal energy.	(Colmenar-Santos et al., 2018)
Europe	Method development	Expansion of model for analysis of geothermal heat pumps.	(Dalla Longa et al., 2020)
13 countries	Case study	Numerical analysis of governance of shallow geothermal energy	(García-Gil et al., 2020)
Germany, Europe in general	Identification of issue	Sustainability analysis of policies on shallow geothermal energy.	(Hähnlein et al., 2013)
European Union	Journal article	EU-policy analysis for geothermal energy.	(Karlsdottir et al., 2020)
United States, China	Comparative study	Comparison of heat pump status between the US and China.	(Liu et al., 2015)
Global	Overview	Update status of direct use geothermal.	(Lund and Boyd, 2016)
Global	Overview	Update status of direct use geothermal.	(Lund and Toth, 2021)
Global	Technology review	Identify developments in geothermal power plants and direct use applications.	(Moya et al., 2018)
Italy	Case study	Analysis of public opinion and stakeholder engagement in geothermal policy processes.	(Pellizzone et al., 2017)
Western Australia	Research	Review 20 years of direct use geothermal energy in Western Australia.	(Pujol et al., 2015)
Canada, Global	Desk research	Status review of geothermal heat pumps.	(Self et al., 2013)
Global	Technology review	Review of the evolution of geothermal energy	(Soltani et al., 2019)
Global	Technology review	Impact analysis of environmental, economic and social factors on geothermal energy.	(Soltani et al., 2021)
Germany, the EU	Journal article	Analysis of the political economy of renewable energy policies	(Strunz et al., 2016)
United States, Iceland	Comparative study, current status	Analysis of the barriers and enablers of geothermal district heating in the US, compared to Iceland.	(Thorsteinsson and Tester, 2010)
Fourteen European countries	Case study	Review of legal framework in European countries.	(Tsagarakis et al., 2020)

A.2. Interview protocol

Goal of the interview

The goal of the interviews is to get a first-hand insight into the specific challenges and opportunities that are encountered when developing deep geothermal heating systems in particular countries. This way, The researcher aims to get a deeper understanding of underlying (social-) structures that determine the success of implementing deep geothermal heating in certain locations.

Structure of the interview

The interviews will be semi-structured. This structure is chosen for two reasons. The first reason is, that this structure lets the researcher keep control over the conversation, while simultaneously allowing for deviations when potentially valuable insights may arise. The second reason is, that this structure enables to have a conversation-based interview, in which the interviewee is invited to provide more in-depth answers. To ensure that the conversation stays on-topic, the conceptual framework is used as a guide during the interviews.

Interview guide

Introduction topic

This interview is part of a qualitative research project into the possibilities for upscaling of deep geothermal heating systems in the European Union. These possibilities are explored by identifying the opportunities and the challenges that are currently experienced, and from there, finding the underlying issues that prevent further upscaling of this technology.

Before the interview

The boundaries of interviewee's field of expertise regarding deep geothermal heating systems is determined. If this cannot be established before the interview, the interviewee is asked to elaborate on their perspective and field of knowledge.

Interview Questions

First the interviewee is asked which of the identified barriers have played a role in their country. The interviewees are invited to elaborate on their answer and to specify their statements if required. The conceptual framework is used as a guide to assist the interviewee in answering the questions.

Q1: *Which of the barriers have been of influence in in your country, and to what extent have these barriers played a role in the geothermal district heating sector?*

Now, The interviewee is asked which barriers have been overcome and how these barriers have been overcome.

Q2: *Which barriers have been overcome, and how was that achieved?*

Following that, the interviewee is given the opportunity to go into detail about other factors that may have played a role in the introduction of deep geothermal heating in their country.

Q3: *Are there any factors in your country, that still play a big role in deep geothermal heat development, and why?*

Now, we discuss the advantages (if present) for the introduction of deep geothermal heating of their country.

Q4: *For your country specifically, what do you consider to be advantageous conditions for the development of deep geothermal heat from a policy, legislative and regulatory perspective?*

Finally, work towards the solutions to the barriers and try to find out what the interviewee thinks is necessary to accelerate the implementation of geothermal district heating before 2030.

Q5: *'What actions are required to reach a level of 10% geothermal district heating in the residential and commercial heating sector in your country by 2030?'*

A.3. list of interviewees

For this research project, anonymous interviews with experts from the field of research were held. Table A.2 below provides a description of the interviewees and their reference number used in this report.

Table A.2: Interviewee description table.

Interviewee-ID	**Country**	**Interviewee description** (profession, years of experience)	**Date of interview**
DE-1	Germany	Geoscientist, 30 years	30-09-2021
DE-2	Germany	Developer/operator, 15+ years	15-10-2021
DE-3	Germany	Policy advisor/geoscientist, 20+ years	19-10-2021
HU-1	Hungary	Geoscientist, 15+ years	10-08-2021
HU-2	Hungary	Developer, 30+ years	09-10-2021
NL-1	The Netherlands	Developer, 10+ years	30-08-2021
NL-2	The Netherlands	Developer, 10+ years	23-09-2021
NL-3	The Netherlands	Heat network developer, 5+ years	29-09-2021
NL-4	The Netherlands	Geoscientist, 10+ years	06-10-2021
NL-5	The Netherlands	Policy maker, 5+ years	08-10-2021

A.4. Declaration of the Hungarian Geothermal Association

Courtesy of the president of the Hungarian Geothermal Association

HUNGARIAN GEOTHERMAL ASSOCIATION

Address: 1021 Budapest, Ötvös János u. 3. e-mail: info@mgte.hu
Tel. (+36-1)-224 0424 Web: www.mgte.hu

DECLARATION

of the Hungarian Geothermal Association
on the current situation of geothermal energy utilization in Hungary

The Hungarian Geothermal Association is seriously concerned about the current state of geothermal energy utilization and its handling by the Hungarian Government.

During the last 6 decades the geothermal utilisation of thermal water, although with a periodically varying rate, has steadily increased. Our country gaining full membership of the EU, funds becoming available for the geothermal sector, have boosted its development. Several successful projects have been set up and innovation has been started. This development was blocked by the lack of calls for new tenders, and that since the beginning of 2013 there have been no meaningful tenders launched, nor have the submitted applications been evaluated. At the same time, it can be observed that some projects are still receiving significant non-refundable funds, however, their preparation, planning, risk assessment, evaluation and handling are not appropriate. This erroneous grant practice has often led to unsuccessful exploitation of thermal water, and also resulted in not- or non-well-functioning equipment, for example at Kiskunhalas and Nagyszénás.

Being not rich enough, Hungary can't afford the luxury of supporting inappropriately prepared high risk projects, often poorly planned and implemented, when there is ample opportunity to exploit thermal water without risk, as well as to apply 21st century surface technology.

Besides the uncertain regulatory framework (Mining Law Act vs. Act of Water Management) and stagnating concessional harnessing of geothermal energy, the reason for its decline of utilisation is inappropriate governmental management.

Budapest, 3rd May, 2017

Gábor Szita
President