The Role of Geothermal Energy in the Energy Transition of Frisia, the Netherlands

A case study on the effect of Market Based Instruments on geothermal energy in Frisia.

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Abstract

Climate change is one of the greatest challenges humanity faces today. One major contributor to the changing climate is the energy sector, which has led to a transition from fossil fuels to sustainable fuels. Sustainable methods like wind and solar energy have increased in popularity significantly in the last few decades, while other methods seem to lag behind. One of these methods is geothermal energy. This paper aims to find out why geothermal energy is lagging behind, which it does through the lens of Market Based Instruments, a set of tools which promote the private sector to invest. The case of Frisia is chosen, as this area in the Netherlands is relatively suitable for geothermal energy. To find whether geothermal energy can have a significant impact on the energy transition of Frisia through the use of MBIs, a series of in-depth interviews, a case study on MBIs in other European nations and a comparison study between geothermal, wind and solar have been conducted. The interviews covered the opinion of the Frisian population, as well as the risks of earthquakes. The interviews indicated that the people would not mind geothermal instead of another sustainable method. Then the MBIs in Germany, France and Finland were studied, which indicated that the growth of geothermal energy, and especially deep geothermal energy, were correlated with the availability of MBIs. However, although geothermal energy grew significantly over a few years, the share of total energy remains negligible. Finally, the comparison study showed that financially, geothermal energy could compete with solar and wind energy, while the institutions of geothermal are more complicated and demanding than that of wind and especially solar. It also showed that geothermal energy requires more time to be constructed, and more planning. Overall, it is clear that geothermal energy is more complicated as a technology than wind and solar energy. To stimulate the growth of geothermal energy, financial measures therefore seem to not be adequate, and additional measures to reduce complexity are required.

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1. Introduction

1.1 Climate change and the energy transition

Since the agreements made in Paris, the focus on the energy transition has increased worldwide. Article 2 of the Paris agreements states that all parties will make an effort to reduce global temperature rise to well below 2 degrees Celsius, aiming at 1,5 degrees Celsius compared to pre-Industrial revolution levels, as such an effort could limit the impact of climate change significantly (UNFCCC, 2015). To achieve this, United Nations member states are required to take action. The energy sector is one of the most important fields in dealing with climate change, accounting for about 25% to 35% of total emissions (Bergamo Dos Santos, 2016). Additionally, transition to a sustainable energy sector would account for 90% of decarbonisation required to meet the Paris agreements (IRENA, 2017). Thus, a transition from fossil fuel-based energy generation to sustainable methods for energy generation is required. Sustainable methods need investment to be developed and researched, to improve the known and applied methods of sustainable energy and to discover or develop new methods. In 2021, the most used sustainable method for energy generation globally was hydro energy with 38.4% of total sustainable energy generation, followed by solar energy with 27.5% and wind energy with 26.9% (25.1% onshore, 1.8% offshore), as depicted in figure 1 below. These methods are followed by other measures such as biofuel, biogas, renewable waste and finally, with only 0.5% of global sustainable energy generation, geothermal. In the last two decades, wind and solar energy especially have grown in popularity. Figure 1 shows that in the last two decades wind energy and in the last decade solar energy have increased significantly in prominence. In 2001 for instance, solar energy accounted for only 0.1% of all sustainable energy, while onshore wind energy accounted for 3.1%. In 2011, this had increased to 5.4% and 16.3% respectively (IRENA, 2022a). Geothermal however, did not increase in this time. In fact, the share of geothermal energy declined from 1.1% in 2000 to 0.5% in 2021.

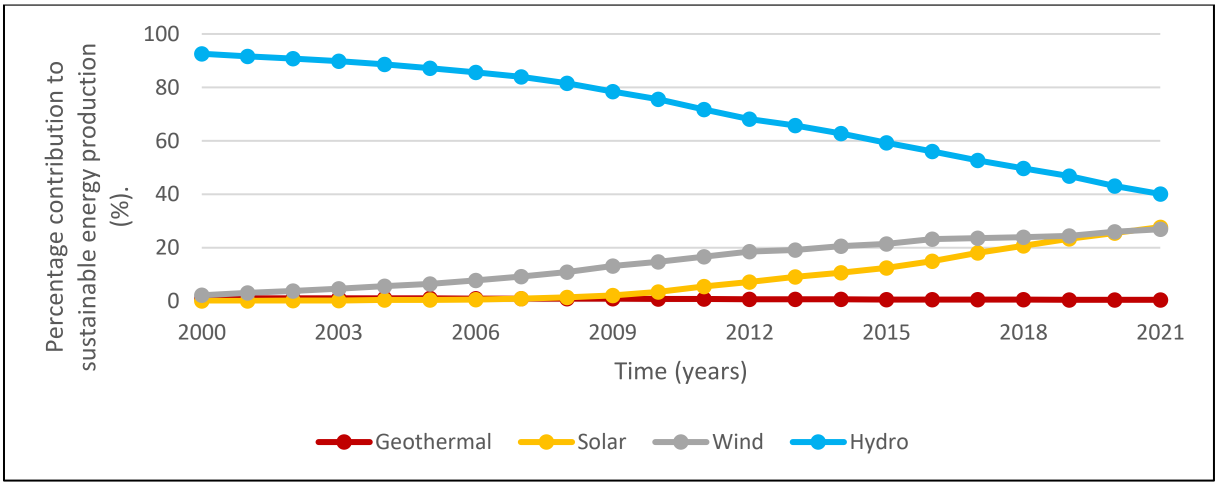

Figure 1: The share of geothermal, solar, wind and hydro energy as a percentage of total sustainable energy production worldwide, since 2000 (Author's own, based on data from IRENA, 2022a).

Hydro energy is a sustainable energy method which was applied extensively even before the energy transition. As a consequence of climate change it gained even more traction (IHA, 2022). Since hydro-energy was established already, it has been well-developed, and therefore relatively easy and cheap to produce compared to less-developed methods, while resulting in reliable and controllable energy output. However, the most general type of hydro-energy, making use of dams, requires both a river and suitable geomorphology (Azarpour et al., 2013). Over the last two decades, major investments have been made especially in solar and wind energy, as depicted in figure 2 below. (Henze, 2019). In comparison, geothermal energy has received little investment (Clauser & Ewert, 2018; Henze, 2019). Consequently, the share of geothermal energy also has not increased significantly over the last two decades (IRENA, 2022b). The level on investment depicted in figure 2 correlates with the share of each technology in figure 1. Heavy investments in solar energy lead to a growing share, while the low investment in hydro and geothermal leads to their relative decline.

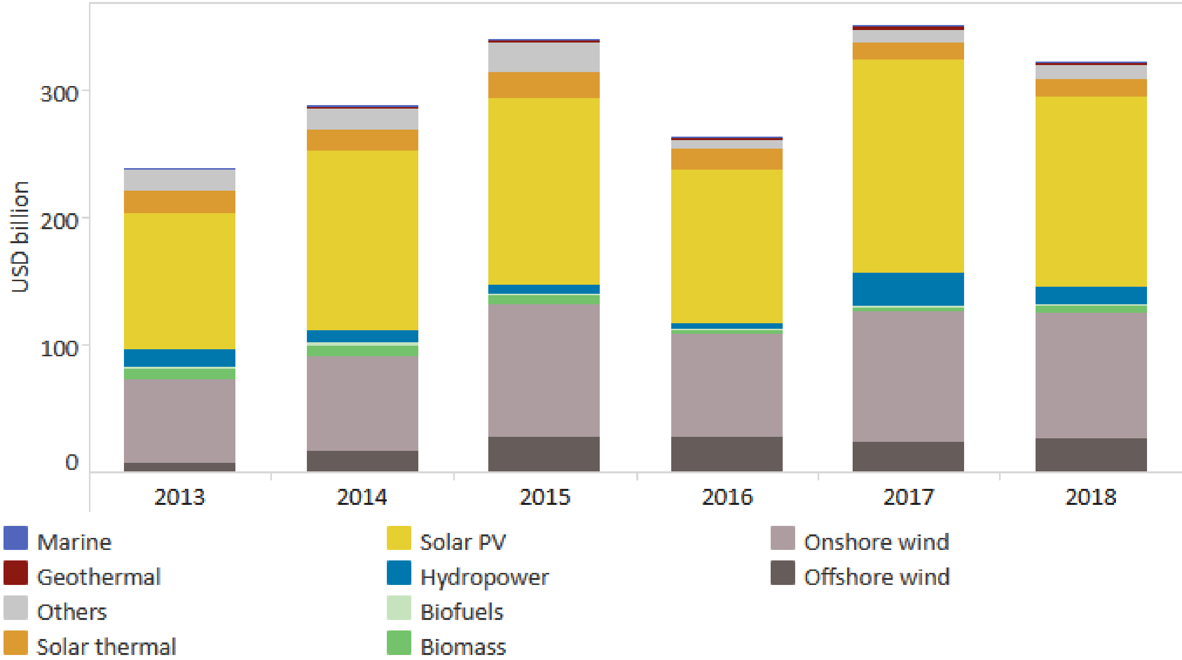

Figure 2: Investments made in sustainable energy types between 2013 and 2018. (IRENA, 2022b)

The reason why geothermal energy is less popular and has had fewer investments in the past two decades compared to wind and solar energy is most likely due to geothermal energy reaching capacity without major technological developments (Moriarty & Honnery, 2011). This means that with current technology, there are few suitable locations for geothermal power extraction. Additionally, negative impacts of geothermal energy on the environment may be a deterring factor. For instance, geothermal energy harvesting may lead to pollution of air and water near a power plant, affecting wildlife, while also risking seismic activity (Moriarty & Honnery, 2011, Azarpour et al., 2013). Geothermal energy is not the only renewable energy which has disadvantages however. In fact, each energy generation has its own advantages and disadvantages (Azarpour et al., 2013), the most important of which will be covered in the next section.

The main benefit of geothermal compared to wind and solar energy however is the reliability and controllability of its energy generation levels. Wind and solar energy are both intermittent, because they depend on weather conditions on the short term and climate on the long term for high efficiency, and as a result can vary in efficiency (Azarpour et al., 2013, Sayed et al., 2021).

Although it is possible, it is difficult to reach 100% energy neutrality using only solar and/or wind energy. Due to their intermittent nature, they cannot produce energy on demand. To overcome this issue, either energy storage needs to be sophisticated enough to cover this trough storing energy when supply is higher than demand and releasing energy when supply is lower than demand. Alternatively, a mix of methods including methods which can produce sustainable energy on demand can cover this issue. Geothermal energy could be one of such methods and therefore deserves consideration.

Since geothermal energy generation has various benefits over some other methods, this paper will attempt to identify why geothermal energy, compared to wind/solar energy, has such low presence in both investment rates and production share. Additionally, the value of exploiting geothermal sources compared to wind and solar energy is studied.

1.2 The case of Frisia

To further analyse the potential for geothermal energy in the energy transition, the case of Frisia is selected. Frisia is the northernmost province in the Netherlands. Frisia spans 3335 km^2 of land surface. With 659,612 inhabitants, that results in a population density of about 198 inhabitants per kilometre squared. This density is mostly focussed in the bigger towns and cities around the province, with mostly farmlands in between. As a part of the Netherlands, Frisia is required to take action towards the Paris agreement. To live up to the Paris agreement, the Dutch government split the nation into 30 energy regions (RES, 2022). Each of these regions has developed their own strategy for transitioning to renewable energy and heating, suited to their region. The entire province of Frisia is one of these Regional Energy Strategy (RES) regions. Frisia has high potential for geothermal energy at first glance, due to the high sub-surface temperature.

The goal for all RES regions is a 50% reduction of carbon dioxide emissions compared to 1990. In the RES for Frisia, there is no mention of geothermal energy for 2030 or 2050 (RES Fryslân, 2021). The focus is very clearly on wind- and solar energy to provide clean electricity. More recently, an exploratory research by RES Fryslân, in collaboration with regional parties, considered geothermal energy generation, but more specifically for heating. This 'System Study Frisia' had developed 5 strategies, the first of which was the strategy for 2030, similar to the RES above (RES Fryslân, 2022). The other 4 strategies are aimed at 2050 and they are based on the level of government involved: regional, national, European and international. Depending on where the pressure for development would lie, the strategy planned what the result might be in each case. Each strategy still has a focus on local energy generation, where heating is partly done through geothermal heating within heating networks. The strategy focusses on heating networks more so than geothermal heating, even though it recognizes that Frisia has a high potential for geothermal heat (RES Fryslân, 2022). The estimated potential for geothermal heating is estimated to be 1.6 PJ in 2050. However, in this document there is no mention of power being generated through geothermal energy. So even though the potential for geothermal is acknowledged, the impact of geothermal stays limited. The Noord-Oost polder, part of the Flevoland RES region, has slightly higher temperatures. Still, this region also does not mention geothermal as more than a possibility for district heating (FEA, 2023). The province of Zuid-Holland however has many more geothermal projects than either Frisia or the Noord-Oost polder, even though the subsurface temperature would suggest otherwise. This is mostly because the province is more energy intensive and especially heat intensive, due to greenhouses, industry and a higher population density. This province is also split into 7 different RES regions (RES, 2022).

1.3 Market Based Instruments

Market Based Instruments (MBI) are a set of tools within the Neo-liberal approach in planning. MBIs are considered opposite to Command-and-Control instruments (Du Toit, 2014). Command-and-Control instruments are more regulatory, often using obligations and restrictions. Instead, MBIs are economic incentives, often aimed at solving environmental issues. With those incentives, the goal is for the solutions to the problems to become economically viable to such an extent that private investors and entrepreneurs solve the issue, as it could be a profitable business. Instruments like specific taxes, which aim to make certain processes more expensive, or subsidies, which make the target more economically viable are options. However, more common are Emission Trading and Energy Efficiency Obligations.

Emission trading can happen when a government restricts the emission of (usually) CO_2 in an area, but allows emission permits to be traded (Felli, 2015). This means some actors within the market can buy permits, which allow their emissions to be higher, while other actors can sell their permits for additional profit as an incentive to lower emissions. This process therefore incentivizes companies to innovate in energy. Energy Efficiency Obligations (EEO) are another tool within the MBI toolset, one that is even mandatory within the European Union (ECEEE, n.d.). In the EU this means that energy companies are required to save 1,5% of their yearly income by raising efficiency. These two common MBIs therefore focus on energy efficiency, instead of on renewable energy.

A study by Rosenow et al. (2019) shows that MBIs are used for energy efficiency globally, albeit more commonly in Europe and North America. Their research shows that MBIs can contribute in the energy field, and have a positive impact when it comes to the price of energy, which in the case of the aforementioned study was lower than average energy costs. González-Eguino (2011) however found that although in many cases MBIs results in a decrease in emissions, a decrease in costs was uncommon, in fact, in most cases costs increased. Another study, by Mazaheri et al. (2022) again showed that MBIs are not always a success. In their research, Mazaheri et al. compared the use of MBIs in Europe and east Asia, where east Asia showed more positive results, while Europe showed more negative results. They found that geographical factors have a significant impact on the success of MBIs, while the distinction between east Asia and Europe may also have to do with the political climate and the level of technological development.

MBIs for renewable energy are not focussed on energy efficiency however. Renewable energy generally has high initial costs, which prevents new renewable energy production to be established (Du Toit, 2014). Therefore measures like subsidies or reduced taxes on renewable energy, or increased taxes emissions can create a stronger incentive for renewable energy, such as geothermal energy, and circumvent the high initial costs barrier. As such, subsidies may incentivize the market to invest more in geothermal as an alternative energy source.

1.4 Research questions

There is little attention spent on geothermal as a source of energy in the regional plans for Frisia, even though the potential for it is acknowledged. There is a lack of investment into this source of renewable energy, which might be improved by using MBIs. This paper aims to find why geothermal is not considered as a viable option and why it does not receive the investments necessary to make a significant contribution to energy production within Frisia.

The main research question for this research then is as follows:

- 'What effect can Market Based Instruments have on the contribution of geothermal energy to the energy transition of Frisia?'

This research is written in the context of spatial planning. Sustainable energy, including geothermal, are important subjects within the planning discipline. When making plans for the built environment, a suitable location needs to be found for energy as well. What makes a location suitable is dependent on many aspects, such as finances & local support, which are taken into account by the planner. Therefore this paper also will discuss multiple aspects of geothermal energy, which are taken into account for answering the sub questions. These questions are:

- Why is geothermal energy not as common as wind or solar energy?
- What role does geothermal energy play in Frisia?
- Do the people of Frisia support geothermal energy?
- What are Market-Based Instruments and how can they affect renewable energy?

The first question is aimed at finding why geothermal is not as commonly used as compared to solar and wind energy. This encompasses finding out what the advantages and disadvantages of geothermal, wind & solar energy are, so they can be compared. An important part of this comparison is the finances involved: What are the initial costs & the operational costs and what are their profit projections. Besides, this question also aims to find other reasons for the unpopularity of geothermal energy. The second question is asked to find the state of geothermal energy in Frisia. Is geothermal already being used and if so, to what extent? As well as if geothermal is a part of any plans to reach climate goals. This question will show if and how there is more to gain from geothermal in Frisia. The third question is aimed at the local inhabitants, to find their view on geothermal energy as an alternative source of energy. If their support is weak or non-existent, additional measures like campaigns would be required, or geothermal might not be feasible at all. Finally, the fourth question is on what the effects of MBIs on geothermal energy can be. How do MBIs affect other renewable energy and can this be used on geothermal energy as well?

These questions are answered initially through researching literature for a theoretical basis, after which several in-depth interviews will be held with experts in the field, to provide insight and answer questions specific to this study, while building upon the theory and connecting it to the case of Frisia. Besides, a case study and comparative study will be conducted to compare the use of MBIs in geothermal energy in Frisia with MBIs outside of Frisia, while also comparing geothermal to solar & wind. The result should therefore be an overview of the potential geothermal energy can play in the energy transition of Frisia, specifically compared to wind and solar energy, which may then be applied to cases elsewhere in the world.

2. Theoretical framework

This chapter of the paper is concerned with creating a theoretical foundation on which the questions posed in the last chapter can be answered. This foundation includes literature on geothermal energy, expanding on what has already been mentioned in the previous chapter. The information gathered in this chapter will culminate in the conceptual model, which will be visually represented at the end of the chapter.

2.1 What is geothermal energy?

The most important word to define in this research is geothermal energy. The word geothermal is a combination of the Greek words 'geo' and 'thermos', which mean earth and heat respectively. The earth's core is around 5000 degrees Celsius (Alfè et al., 2007), due to radioactive decay. This heat is dissipated towards the surface through radiation. This kind of temperature is not accessible, but drilling down from the surface, the temperature increases by about 30 degrees each kilometre on average (Barbier, 2002). However, this number can vary depending on the location. In some locations, like hot springs, geothermal energy can be exploited on the surface. Many of these locations have used geothermal energy for hundreds of years, like in Bath (Barbier, 2002). As in these hot springs, the extraction of geothermal energy often relies on water. This is because water is a great carrier of heat, but other liquids are also possible, like CO_2 for example (Okoroafor et al., 2022; Singh et al., 2023). In most geothermal systems, an underground source of water, an aquifer, is the carrier for heating and energy extraction. If however these aquifers are not available, a technique called fracking is used to create cracks in the layer where energy is extracted from, in which a heat carrier is inserted, to serve as an artificial aquifer.

The difference between geothermal heating and geothermal power

It is important to distinguish between geothermal heating and geothermal power. This paper is concerned with both geothermal power, the end product of which is electricity and geothermal heating, which is the direct application of heat. This process may also play an important role in the energy transition, since direct heating can replace conventional heating systems, which use fossil fuels. The potential for geothermal heating is big worldwide, while only a fraction is being exploited (Limberger et al., 2018).

Geothermal power on the other hand is generated through a turbine, attached to a generator. Although different types of geothermal power plants work slightly differently, the general process is the same: The liquid in the subsurface aquifer reaches a high temperature and pressure. The resulting vaporised liquid is brought trough to the surface and circulated through the turbine, where it generates power. The vapor condenses into a liquid, after which it is led to the subsurface for warming to repeat the process (Fallah et al. 2018).

Ideally, both methods are used, since they both help reduce fossil fuel usage and thereby carbon dioxide emissions, and therefore help towards reaching the climate accord committed to in the Paris agreement. In most literature, geothermal energy is simply referred to as energy, without the distinction of power or heating. Generating geothermal heat is significantly easier than generating geothermal power, which is why oftentimes geothermal energy refers to heating instead of power.

What does a location need to be suitable for geothermal energy extraction?

For a location to be suitable for geothermal energy extraction there are a few relevant factors. First of all is the depth at which the critical temperature levels are reached. Next is the availability of an underground water reservoir or aquifer, which, as mentioned before, serves as the conduit for temperature exchange. A third factor is soil composition and its permeability (Limberger et al., 2018).

The temperature of the extraction determines the energy potential of the extracted fluids. The temperature required in these cases is around 150 to 200 degrees Celsius for geothermal power (Fridleifsson et al., 2008). The depth at which this temperature is reached varies from place to place, which means that geothermal energy is not equally suitable everywhere. On average, suitable temperature are reached at a depth of around five to seven kilometres. Generating energy from these depths is currently difficult and expensive, since it is a relatively new concept. Technologies like Enhanced Geothermal Systems (EGS) and Ultra-Deep Geothermal (UDG) are likely to improve those conditions. In contrast, with geothermal heating, the temperature requirement is much lower than with geothermal energy for electricity generation. The second requirement is the existence of underground fluids at an optimal depth. This is because fluids are the carriers of heat energy which the geothermal energy plant harnesses on the surface. These underground fluids may exist naturally, in the form of an aquifer, which would be the ideal scenario. The third requirement is for soil at the extraction depth to be permeable, to allow for fluid to move. It is quite rare that these conditions are met, and most locations where it is the case, geothermal energy is already harnessed (Sayed et al., 2021).

It is clear that temperature, which decides energy potential, is most important to determine how suitable a location is for geothermal energy extraction, since other requirements can be created artificially, though if all conditions are met naturally, the entire process will be more efficient and economically viable. In fact, if conditions for geothermal energy extraction are right, that is if the subsurface contains steam or hot water aquifers, it is one of the cheapest forms of sustainable energy (Clauser & Ewert, 2018).

Fracking

If the rock is not sufficiently permeable, it can be made so artificially, although the technology for doing this is underdeveloped (Sayed et al., 2021). The technology for fracturing the subsurface is called fracking or hydraulic fracturing and it can induce earthquakes with a magnitude of 4,4 on the Richter scale (Mitchell & Green, 2017), although the majority of earthquakes are imperceptible by humans (Moska et al., 2021). Induced seismic activity is different from natural, tectonic earthquakes. The epicentre for induced earthquakes is closer to the surface compared to tectonic earthquakes. However, the effect of the earthquake becomes weaker more quickly by distance in the case of induced earthquakes compared to tectonic earthquakes. This means that the potential for damaging earthquakes is an issue when fracking is required for geothermal energy production. There are other factors that influence the chance and magnitude of a potential earthquake however. For example, the fluid balance within the system and the change in temperature caused by the fluids. The risk of earthquakes is context dependant, but a risk that should not be overlooked.

Besides, the negative public perception of fracking is a risk when it comes to public acceptance of newly implemented geothermal energy. This negative association with fracking comes from the usage of the technology in fossil fuel industry, and this negative perception is carried over to geothermal energy. (Westlake et al., 2023)

Geothermal potential in Frisia

The geothermal potential in Frisia, as mentioned by the RES Frisia (2021) is due to volcanic activity in the late Jurassic period, about 160 to 148 million years ago. The so-called Zuidwal volcano is covered by about 2 kilometres of sediment, and has been extinct for almost 150 million years, which means there is no risk of an eruption (GeoGraphixs, 2022). However, the remnants of this volcanic activity does mean that the temperature of the ground around the area is relatively high, as can be seen in figure 3 below. At a depth of 2 kilometres, relevant for geothermal heating, the temperature is between 60 to 100 degrees Celsius. While at a depth of 5 kilometres, the temperature is around 150 to 180 degrees Celsius, increasing to 180 to 200 degrees Celsius at 6 kilometres depth, which means it is potentially suitable for geothermal energy production. The high temperature of the subsurface is why the RES Frisia considers the potential for geothermal energy as great enough to contribute to the region's energy plans, albeit only as heating: their plans do not consider geothermal as an option for power generation, next to wind and solar energy.

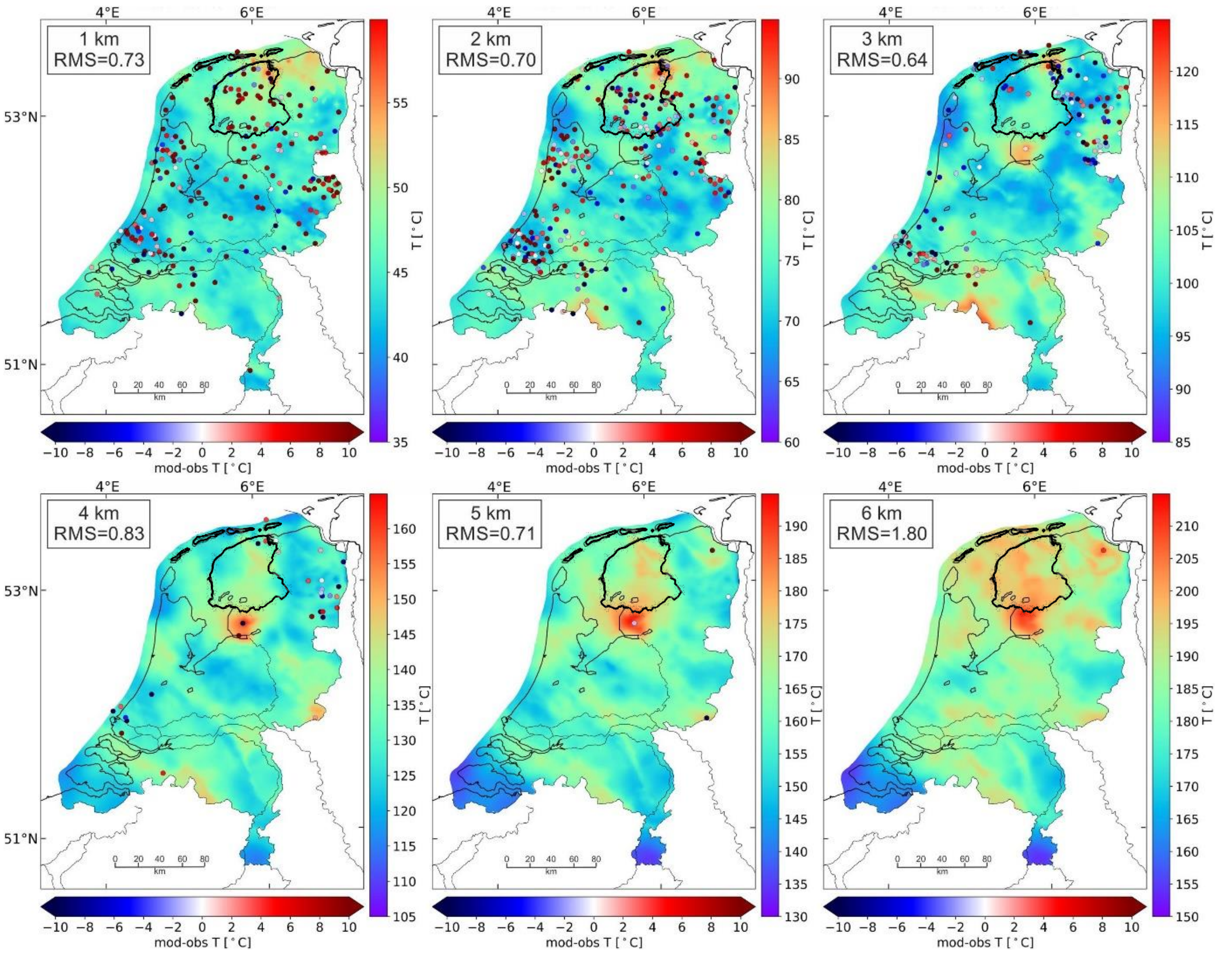

Figure 3: Temperature of the soil in the Netherlands at depths from 1km to 6km. Outlined in black is the province of Frisia. Source: Békési et al., 2020.

Spatial relevance

Geothermal heating and especially geothermal energy plants cannot be built everywhere. Just like most sustainable methods, geothermal energy is more efficient at some specific locations compared to others. At suitable places, the necessary heat level is closer to the surface compared to other places, which means that the infrastructure in the form of pipes has to be less deep as well. Since deeper infrastructure means exponentially higher costs, the right location means the cheap location, while deeper infrastructure also comes with additional challenges, making it increasingly difficult to implement the deeper it is.

Geothermal energy does not have a major impact on the physical space, since most of the relevant infrastructure is below ground. The turbine attached to such an energy plant would be similar looking to other power plants, though without direct danger for the environment from emissions. Residences could therefore be constructed relatively close to such a plant, compared to other energy types.

Frisia has few densely populated urban areas, which negatively affects the opportunity for geothermal as a heating source (CE Delft, 2018). A heating network is more cost effective if it can reach a lot of homes without having to travel major distances. Since Frisia has only few such opportunities, adjustments have to be made. Higher temperatures means the heating can cover larger distances. Industrial buildings and greenhouses require a lot of heating as well, which makes geothermal heating near those structures more effective as well.

2.2 Advantages, disadvantages and risks of geothermal energy

Globally, solar and wind energy have gained prominence as the two main sustainable forms of energy for the future, while other methods, including geothermal, have taken a background role (IRENA, 2022a). As mentioned before, the province of Frisia also wants to almost fully rely on wind and solar energy for its electricity in 2050 (RES Fryslân, 2021). In this section of the paper, the advantages and disadvantages of geothermal energy are compared to those of wind and solar energy.

Wind energy is relatively effective in Frisia, especially near the coast, as shown in figure 4 below. Solar is relatively ineffective however, as seen in figure 5, due to the high latitude of Frisia. From a purely energy efficiency perspective, investment in wind energy therefore makes sense, while solar energy should see lower levels of investment. The reason why relying on solar and wind energy is an issue, is that they have their disadvantages, as do all forms of sustainable energy (Azarpour et al., 2013). Among other things, solar and wind energy are both inconsistent: their rates of energy production fluctuate based on weather and climate conditions.

Conventional geothermal energy, that is geothermal energy which does not require deep drilling, but instead makes use of natural high temperature soil, is nearing its potential (Moriarty & Honnery, 2011). In other words, places where geothermal energy is easy and cheap to implement with current technology are nearing full capacity. This means there is a need for technological developments in geothermal energy for it to be potentially extracted in different places. Later in this chapter the paper will cover EGS and UDG as potential technological advancements to this end. In any case, geothermal also comes with the disadvantage of a chance of minor seismic activity, in both conventional geothermal and EGS (Azarpour et al., 2013), the risk of which is substantially increased by fracking as mentioned before. There are also environmental concerns, including land subsidence, as well as land and water pollution, noise and odour pollution and high demand & waste of water (Azarpour et al., 2013, Sayed et al., 2021). These also impact wildlife, as their potential habitat is affected. There is also a chance of emitting some harmful (greenhouse) gases from reservoirs in the soil to the atmosphere, although these can be contained in principle (Moriarty & Honnery, 2011).

Wind energy

Wind energy is intermittent, meaning that the energy potential is inconsistent, because of unpredictable weather conditions (Azarpour et al., 2013). Wind turbines cannot operate if wind speeds are too low nor when they are too high (Moriarty & Honnery, 2011). The average level of wind is also different per location, meaning that just like conventional geothermal energy, the resource is not equally distributed across the planet. Wind energy can provide greater yields when built on high altitudes or offshore, but each of these requires more technological development and both are more expensive than onshore wind turbines. Even then, there are places where there is no to barely any potential for wind energy. Besides, wind turbines affect wildlife, especially birds and bats, killing around one each year on average due to collisions. Furthermore, there is loss of habitat and disturbance to wildlife due to turbines in nature areas (Moriarty & Honnery, 2011). Wind turbines also cause noise and visual pollution (Sayed et al., 2021). Again, offshore and high altitude wind could circumvent some of those issues.

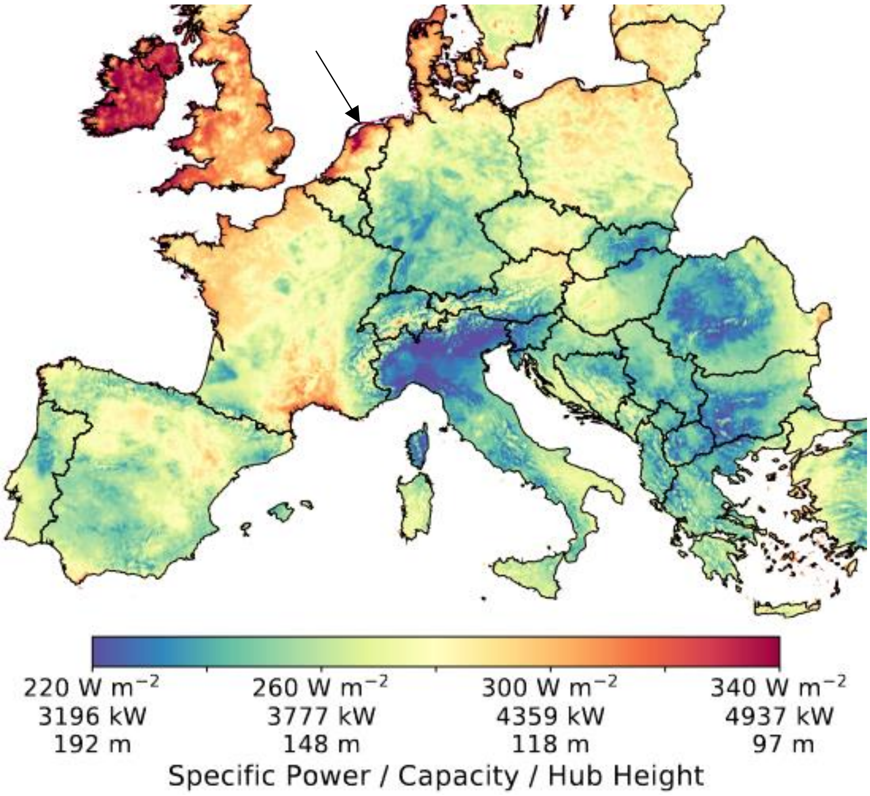

Figure 4: Wind power potential in Europe. The location of Frisia is indicated by the arrow. Source: Ryberg et al., 2019

Solar energy

Solar energy is also intermittent (Azarpour et al., 2013), based on weather and climate effects, mostly related to the frequency of clouds blocking sunlight, but also water vapor, dust or smoke, which can reduce energy from 10 up to 100% (Azarpour et al., 2013). Additionally, the distance from the equator impacts solar potential in two ways: First, the distance from the equator determines the day-night cycle of a location. At night, solar potential is much lower than during the day. Secondly, the farther from the equator, the longer the winter period, which has a weaker sun, meaning less energy potential (Moriarty & Honnery, 2011). Even in deserts, the areas on the world with least clouds, there are moments in the year with less potential, since they are not on the equator. Even countries like Mexico or Australia, at a distance of 35 degrees in latitude from the equator, may have around 50% reduced solar power potential during the winter. This decreased efficiency becomes worse with increasing latitudes. Besides, solar cells contain chemicals which can be harmful to human health (Azarpour et al., 2013). There are technological developments which can overcome these issues, including Satellite Power Systems, but these are again very expensive and often require specific materials that can be quite rare (Moriarty & Honnery, 2011).

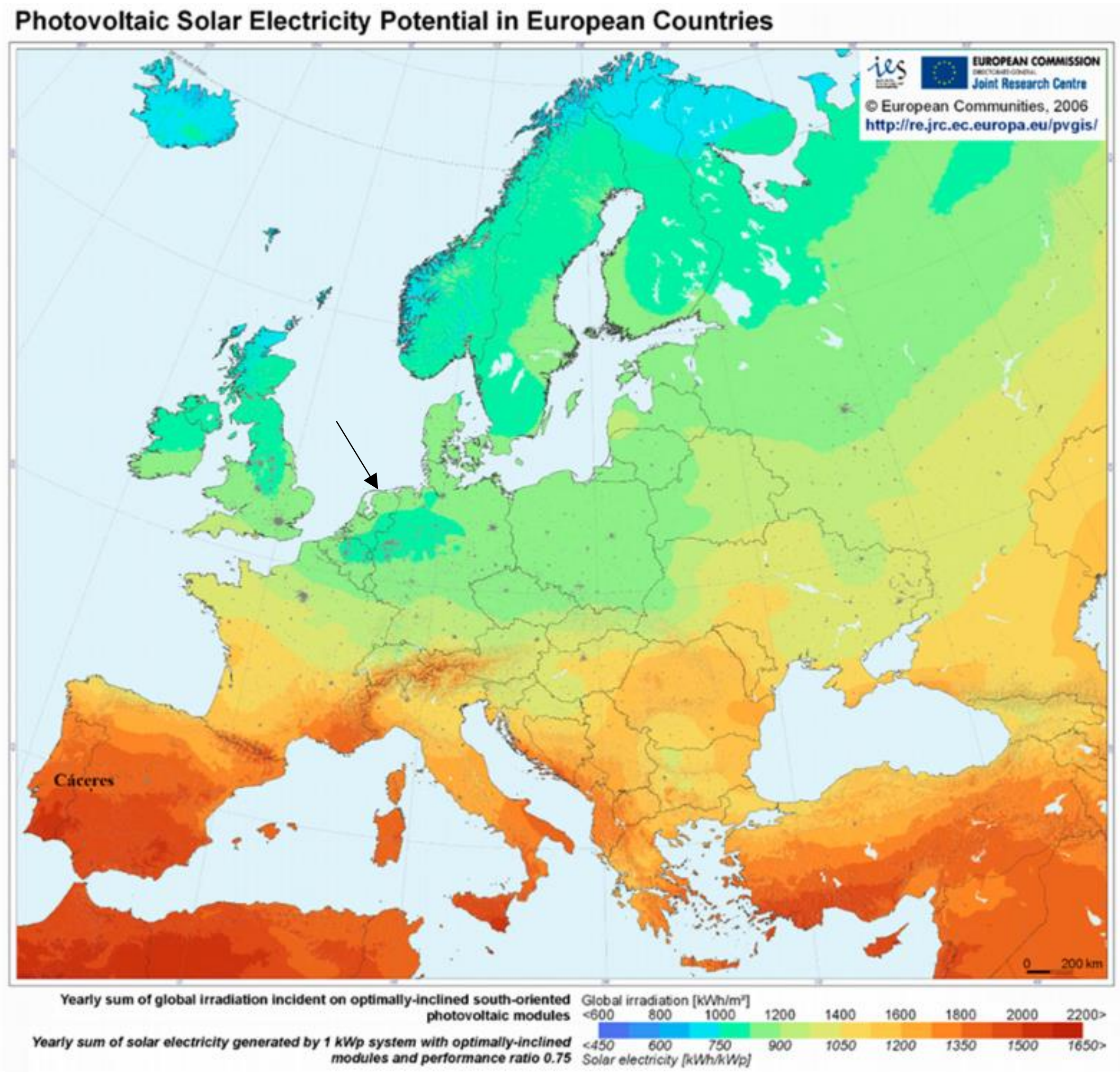

Figure 5: PV solar electricity potential in Europe (Source: http://re.jrc.ec.europa.eu/pvgis/).

In short, comparing the three, conventional geothermal is nearing its peak production, while wind and solar energy are developing pretty well. Each of them could be more effective in the future, but each would also require technological developments, which costs money and time. The main benefits of putting this time and money into geothermal is that the source of its energy is widespread, and available everywhere, which is something wind and solar have difficulties of overcoming, while also being continuous, something wind and solar can achieve for example via storage (Azarpour et al., 2013) or other technological developments (Moriarty & Honnery, 2011).

2.3 Different types of geothermal energy

There are multiple types of geothermal energy plants. The three most common types are dry steam, flash steam and binary systems, the latter two also having subtypes. Within the literature, the amount of different plants being discussed differs from paper to paper. This paper uses the distinction made by Fallah et al. (2018), but uses information for other literature, which do not necessarily follow the same distinctions.

Dry steam

The dry steam cycle is the most straightforward of the cycles. The geothermal source for this type requires steam from the production well, which is pumped up into the system. This steam is lead through the turbine, which generates power, after which the steam runs through a condenser, which then returns the steam in fluid state towards the production well. This type of geothermal power plant is the most common worldwide, but its requirements mean that it can only be placed on conventional, non-deep geothermal sources. This means that this type of system is unsuitable at most places on earth.

Flash steam

The flash steam cycle differentiates itself from the dry steam in that it contains an extra step within the system (the separator) before the turbine, where liquid is separated from steam. This means that the flash steam cycle does not need steam in the reservoir, and as such is more widely applicable compared to the dry steam cycle (Fallah et al. 2018).

Within the flash steam cycle there are three common variations, single flash, double flash and triple flash, the numeral referring to the amount of flash turbines the cycle contains (Fallah et al. 2018). With each step, the total power generated from a single resource, or total efficiency is higher. However, this increase in power is less than the relative increase in cost, meaning that the double, and especially triple flash steam cycle are not as cost-efficient as the single flash cycle (Fallah et al. 2018).

Binary cycle

Then finally there is the binary cycle, which does not generate electricity by using steam, but rather through a secondary material in liquid state (Fridleifsson et al., 2008). This secondary fluid remains in liquid state, even with higher temperatures, unlike water in the other plants. Besides this difference, the fluid is still passed through a turbine, as the steam plants in the other categories. The binary cycle is most effective with low temperature reservoirs and is also effective in combination with direct heating applications (Fridleifsson et al., 2008).

Within the binary cycle, two variations are mentioned: the Organic Rankine cycle (ORC) and the Kalina cycle (KC). The difference between the two is in the secondary fluid used. The ORC uses an organic fluid, while the KC uses a mixture of ammonia and water as its secondary fluid (Campos Rodríguez et al., 2013).

Efficiency and enthalpy

Zarrouk & Moon (2014) calculated and compared the efficiency levels and enthalpy of 94 geothermal plants of different types. Efficiency refers to the percentage of energy retrieved from the reservoirs is converted to electricity. Enthalpy is the sum of the internal energy within a reservoir and the pressure multiplied with the volume of said reservoir. The results of this analysis shows that the efficiency of single flash & dry steam plants is highest, followed by double flash and finally binary systems. Binary systems however have a higher efficiency level at low enthalpy levels, around 750–850 kJ/kg (Zarrouk & Moon, 2014).

2.4 Technological advancements

As mentioned before, conventional geothermal energy has reached its potential. Most, if not all places which are naturally suitable for relatively shallow geothermal energy with a high enough temperature to generate power are already being exploited. Thus, if there is to be more geothermal energy production, new production wells have to be created. Ultra Deep Geothermal (UDG) refers to geothermal energy wells, created at a very deep level, usually between 5 and 7 kilometres deep. The depth is necessary, since only at those depths are temperatures high enough for geothermal power. The great benefit of UDG is that geothermal energy can theoretically be generated everywhere, instead of being restricted to natural conditions. However, there are a few disadvantages compared to conventional geothermal energy. First, the deeper a well has to reach for suitable temperatures, the more expensive the well becomes. This cost increases exponentially with depth (Beckers et al, 2013). Since a lot of the cost of geothermal is up-front, this high cost can be a significant hurdle to overcome. Besides, if a well turns out to be unsuitable for exploitation after exploratory drilling there is no return on investment, which means the high costs become even more of an obstacle.

Secondly, the layout of the subsurface at depths below 4 kilometres is relatively unknown (Békési et al., 2020). The layers above are more clear, due to drilling for fossil fuels (Platform Geothermie, 2018). The most suitable layer for electricity production with UDG would be the Carboniferous Limestone Group, which in Frisia is located at a depth of around 5 to 6 kilometres (Békési et al., 2020). How thick this layer is however remains unclear, as is the composition of the subsurface below that point.

Another term used is EGS, which stands for Enhanced Geothermal Systems. EGS aims to improve geothermal energy in multiple ways, expanding is applicability and efficiency (Fridleifsson et al., 2008). This is done for example through improved exploration methods, improved drilling methods and by improving thermodynamic cycles to allow for electricity production at lower temperatures.

Combining multiple methods

Although one method may be better in certain aspects than other methods, this does not mean the optimal energy production for a given location should be solely from that particular source. Good potential for geothermal energy in Frisia can and should mean a considerable share of total energy production, but unlikely a dominant share. This is because combining methods can be beneficial. For example, the baseline production that geothermal energy can provide, unlike solar and wind, is an aforementioned advantage, and it is the way geothermal is typically used (Basosi et al., 2020; Millstein et al., 2020). However, geothermal could combine its advantages with solar and wind more, by having a flexible production, instead of a baseline (Millstein et al., 2020). This would allow the geothermal production to produce more during low production moments from wind and solar, for example during the night or the winter. This flexibility can make a system more robust, while also providing more cost effective power. Secondly, since all of these technologies are constantly being developed, investing in more than one spreads the chances of being able to take advantage of significant breakthroughs within one of those technologies Besides, the flexibility of geothermal also means it can support a more stable power grid, like hydro energy can (IRENA, 2022c).

2.5 Transition

As demonstrated in the theory so far, geothermal energy can technically be generated in Frisia. The requirements for geothermal are met sufficiently to make a significant contribution towards energy transition in the area. The reason for the lack of geothermal energy can therefore be assumed not to be technical in nature, but another issue must exist. This transition in geothermal energy is intertwined with other transitions, as with other transitions (Martens & Rotmans, 2005). In order for the entire system to work, each individual transition must also be effective, as visualized in figure 6 below. One gear being halted may cause the entire system to be stopped. Of course, the technical aspect is very important, since if the requirements are not met, geothermal is not possible in the first place. The other transitions are also important however, which if dysfunctional could prevent geothermal from contributing a significant share in energy. Besides the technical aspect, another big cog in the system is finances, since the financial situation is an important factor in energy transition, and therefore in geothermal as well. If geothermal is more expensive up-front and during operation than other energy, whether they are green or grey, this transition is slow or non-existent. The third cog represents the institutions. The laws and regulations determine the energy transition to some extent as well. Among other things, this may determine the economic viability of geothermal energy. Time is also a factor in this transition, both because geothermal has two distinct phases (exploration and exploitation) and because geothermal energy takes relatively long to implement, compared to other sustainable methods. During such a long instalment process, plenty of things can go wrong and therefore be an obstacle to successful geothermal drilling. A minor but notable gear is that of local support, which represents the cooperation and acceptance of inhabitants of the area around a geothermal energy plant. In the remainder of this chapter the aspects represented as gears in the figure are discussed further.

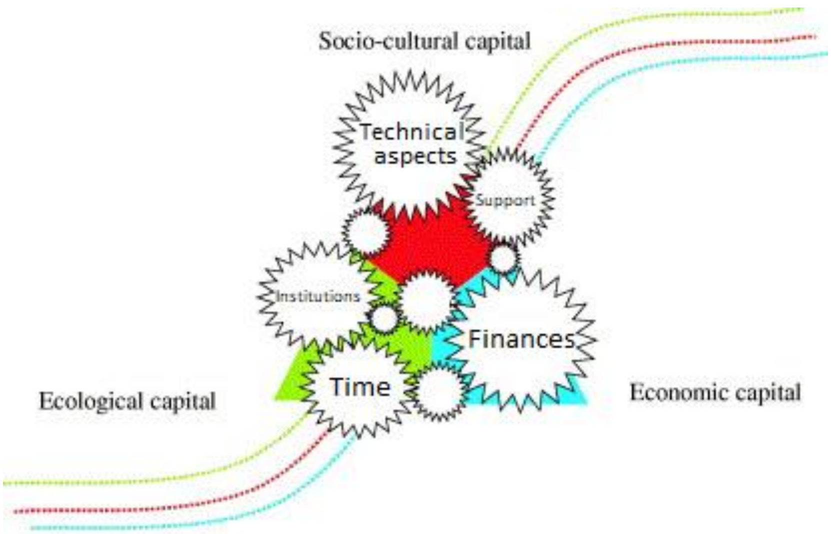

Figure 6: Adapted from Martens & Rotmans, 2005. A transition is the result of developments in several domains.

2.6 Finances and investment levels

One of the major factors for geothermal energy being a considerable source of energy is its cost. The question is whether geothermal energy can compete with fossil fuels and, more importantly, with various sustainable methods. IRENA publishes data of this nature each year. In their report, the most recent prices of various energy types has been expressed in US dollars per kWh, the result of which are represented in table 1. In the table, 5 technologies are included: Geothermal, Solar Photovoltaic, Concentrated Solar Power, Onshore Wind, and Offshore Wind. Solar Photovoltaic refers to standard solar panels, while Concentrated Solar Power is essentially a solar power plant. In 2010, geothermal was the cheapest of these technologies, while in 2021 it was the 3rd cheapest. The percentage change shows that all technologies besides geothermal have undergone significant decreases in Levelized cost, while geothermal increased in cost. This is because of the aforementioned reached peak of capacity of geothermal energy, which forces more expensive Ultra Deep Geothermal in order to exploit the resource. Still, geothermal remains cheaper than CSP and offshore wind, of which the up-front cost is more similar to geothermal energy than to Solar PV or onshore wind (IRENA, 2022c).

However, even if in theory geothermal energy could compete when the average cost is taken over a longer period of time. A major issue this technology faces is that a significant portion of the costs is up-front (IRENA, 2022c). The operational costs are also relatively high, but these are compensated for through the high capacity of geothermal. The power plant itself has a high cost (dependent on which type), as well as the (exploratory) drilling. Even more so, the drilling can yield no result, if the chosen location turns out to be less suitable than expected, which means there is a significant risk in this investment (IRENA, 2022c). Compared to other methods, like wind and solar, the risk of investment and the time it takes before it yields results make the geothermal field less attractive as an investment opportunity, which might be one of the reasons why investment levels have been lacking within the geothermal field. The rate of success, or the amount of drilling operations leading to exploitation, has increased in recent years however, likely due to improved geothermal resource mapping (IRENA, 2022c).

High investment levels with no guarantee on payoff means a high risk on investment. This means that in order to increase geothermal investment, an MBI which increases security on this payoff could provide investors with the level of security needed to make that investment.

	2021 USD/kWh	*2021 USD/kWh*	*2021 USD/kWh*
Year	2010	2021	Percent change
Geothermal	0.050	0.068	34%
Solar PV	0.417	0.048	-88%
Concentrating Solar	0.358	0.114	-68%
Onshore wind	0.102	0.033	-68%
Offshore wind	0.188	0.075	-60%

Table 1: Levelized cost of electricity of geothermal, solar and wind energy in 2010 and 2021. Based on IRENA, 2022c.

Actors on the market

Besides the producer of the geothermal energy and the consumer there are other actors involved. The two most important, which may have a significant impact on the implementation of geothermal energy, are discussed. These are actors involved with the electric grid. In recent years, issues concerning the grid capacity have become more common, and there are concerns the grid operators cannot expand their grids fast enough to keep up with higher demand. (Liander, n.d., & TenneT, 2022) This higher demand is caused by both an increase in energy usage, as well as an increase in energy deliverers, due to the increase of wind mills, but mostly due to the increase in solar panels. The relative impact of geothermal on the grid would be lower compared to wind & solar (IRENA, 2022c).

The high voltage network, which is also connected internationally, is operated by TenneT, which does so for the entire Netherlands (Energievergelijk, n.d.). TenneT has reached grid capacity in Frisia (TenneT, 2022). To solve this issue, TenneT has two solutions: Firstly, the grid will be reinforced and expanded, resulting in higher maximum capacity. Secondly, TenneT has developed a strategy which promotes more flexibility in usage of the grid, which TenneT compares with rush hour avoidance. This means that outside the peaks, TenneT charges less.

Then there is the operator of the electrical grid. The grid in Frisia is operated by Liander, the biggest of six grid operators in the Netherlands (Energievergelijk, n.d.). The prices of these different operators varies, but the consumer cannot choose their operator. To accommodate the growth of both production and consumption, Liander has outlined a plan for the expansion of the grid (Liander, n.d.).

If a geothermal plant is constructed in Frisia, cooperation with TenneT and Liander is required. Besides a connection to the grid itself, there needs to be enough capacity on the grid for a geothermal plant to work with 100% efficiency.

Heating networks are as of yet very rare: Only two exist in Frisia, and those use mostly natural gas and a bit of biogas (Ennatuurlijk, n.d.). In the long term, this can however be replaced with geothermal, as the owner of the heating network is working on that as well. The opportunities for heating networks in Frisia are estimated to be slim (CE Delft, 2018). Only the urban centres provide opportunity for heating networks.

Market Based Instruments & the Neo-liberal approach

To promote the use of geothermal as a source of renewable energy, the aforementioned financial issues need to be resolved. Market Based Instruments can provide such a solution. In the introduction it is mentioned that MBIs often involve either EEOs or permit trading. EEOs are not aimed at sustainable sources, as they involve energy efficiency, limiting the emissions of fossil fuel based energy plants. Permit trading however is an option. An issue of emission permit trading however is that it is not a sustainable business itself. For example, a geothermal plant can make additional profits, due to being able to sell these permits, as they themselves don't emit any greenhouse gasses. However, as more sustainable energy is being generated, more of these permits will enter the market, making them in turn less valuable. This then means that the profit for sustainable energy producers will be lowered, which makes investment in sustainable energy less favourable. Since the higher investment costs and risks are the financial issue, common among renewable energy, a preferred instrument would be subsidies (Du Toit, 2014).

Subsidies & risk prevention

An effective way to solve the issues geothermal energy faces when it comes to financial restraints is the combination of subsidies & risk prevention. The Dutch government identified these financial issues as being a major reason for the slow increase of geothermal as an energy source in the Netherlands, and as a result implemented policy in 2013 to solve these issues (Mijnlieff et al., 2013). Both the issue of the risk being too great for investment to be reliable enough and the issue of geothermal energy not turning a high enough profit are tackled. The first measure of the Dutch government is in the form of subsidies. As mentioned in the MBI section, subsidies are an instrument which allows the government to influence the economic viability of, in this case, geothermal energy. By doing so, geothermal energy becomes a more attractive investment opportunity for investors, as the profit margin is increased. The subsidy is designed to level the costs between renewable energy and conventional energy. Since 2012, geothermal also has become part of this subsidy, to also level the costs between the various renewable methods (Mijnlieff et al., 2013).

The second measure is one of risk prevention. As established, the risk of geothermal energy is high, since before the first energy is harvested, exploratory drilling needs to take place. This can however return no results, while being expensive. Especially the transmissivity of aquifers is very difficult to predict (Mijnlieff et al., 2013). The measure of the Dutch government is aimed at alleviating the costs of failed exploratory drilling. This measure is based on the probability of success within a geothermal project and gives subsidies to the P90 point. This means that for 90% of geothermal projects the value higher than this point (Mijnlieff et al., 2013). Although these measures are aimed at one of, if not the biggest obstacle to geothermal energy, not much has changed. The share of geothermal energy is still very low, even though these measures have existed for 10 years. This means that either these MBIs had little effect, were too small or there are other external factors which affect the success of geothermal energy.

2.7 Institutions

Institutions in this research are viewed as the rules and laws which dictate geothermal policy. Salet (2018) describes 5 different typologies of institutions from a planning perspective. In this paper, with an eye on MBIs, the Regime perspective by Salet will be discussed shortly. This perspective is concerned with the relations between parties, on different levels, scales and topics. It views institutions being created during and by action, unlike some of the other perspectives. This is in line with the view this paper has on markets and liberal thinking, where markets are seen as being able to solve issues trough innovation due to competition on the market (Salet, 2018).

Institutions are another issue preventing geothermal from being a significant contributor. More specifically, the rules and laws concerning geothermal energy. The first institution concerning geothermal energy is the Mijnbouwwet (Mining Act) of 2002, which states that all minerals in the sub-surface at a depth of over 100 meters are property of the state. Besides stating the rules around fossil fuels and other minable materials, this act also concerns geothermal energy. Namely, it includes geothermal heat, meaning that all the heat is property of the state as well, although only over a depth of 500 meters. Furthermore, this law states that any drilling or exploitation of geothermal resources requires permission from the Minister of Economic Affairs and Climate Policy. This permission will only be granted to one operator at a time, meaning that in a single region, no more than one geothermal project can exist at a time (art. 7, lid 1, Mijnbouwwet 2002). Another section of the law mentions that permission for exploitation of geothermal energy will only be granted if it is economically viable (art. 8, lid 1, Mijnbouwwet 2002). There are more stipulations in the law, such as the economic and technical capability of the applicant, as well as environmental reasons, like nature preserves and drinking water supply (art. 9, lid 1, Mijnbouwwet 2002).

2.8 Time & geothermal phases

One factor which seems to impact the availability of geothermal energy in Frisia is time. The time spend on development of geothermal projects is around 6 years on average (ThinkGeoEnergy, n.d & Aragón-Aguilar et al., 2019), although construction of the relevant infrastructure can start at about 3 to 4 years into the project. The development of a geothermal project can be identified as consisting of two distinct stages: exploration and exploitation (Aragón-Aguilar et al., 2019). Frisia is mostly in the exploration stage, but some individual projects are in the exploitation stage.

Exploration

Within the exploration stage, Aragón-Aguilar et al. recognize three phases, each spanning roughly a year: Recognition, Exploration and Exploratory drilling. These initial steps are about reconnaissance of the area. Here the three necessities discussed earlier in the chapter (high temperature, availability of water & suitable ground) are studied. Besides, the surface is scouted for possible advantages or disadvantages like availability of an electric grid, population density in the area or the existence of protected areas like nature reserves. In this initial step the area covered is large, over 1000 km^2, which is reduced with each step.

Exploitation

In this stage there are also three phases: Feasibility, Field development and Construction. In this stage the risk is low, since there is a lot more certainty because of the steps taken in the previous phases. In this step high investment is required. In this stage the geothermal plant is designed and analysed for financial prospects, after which infrastructure like pipes and connections to the grid are planned, and finally the plant is constructed & tested, after which it is ready for operation.

2.9 Conceptual model & Hypothesis

The main concepts used in this section are summarized in the conceptual model below. To summarize, the question what the potential of geothermal power is in Frisia and whether it can contribute to the energy transition askes about viability of the technology in general. The geothermal potential is based on the cost of geothermal energy and its advantages over other methods, as well as the degree to which the requirements for geothermal energy are met. These requirements are the temperature of the subsurface, the soil type and the availability of a water reservoir within the soil. Finally, geothermal potential is also dependent on its complexity relative to other methods. Besides, the views and opinions of the local inhabitants are important to the contribution of geothermal to the energy transition of Frisia. The effect MBIs have on this transition is the last part of the model.

The expectation set forth by the theory is that geothermal energy can make a minor contribution to the energy transition in Frisia. This is because the requirements for geothermal energy are likely met, although some information is missing here. Besides, geothermal has clear advantages over other methods, including solar and wind power. The cost of geothermal is expected to be higher than those methods however. The uncertainty of the soil and therefore the uncertainty of success in drilling means that investing in geothermal may be risky, especially on a large scale. Combined with the benefits of having multiple sustainable methods at a time, this means geothermal could play a minor part within the energy transition of Frisia.

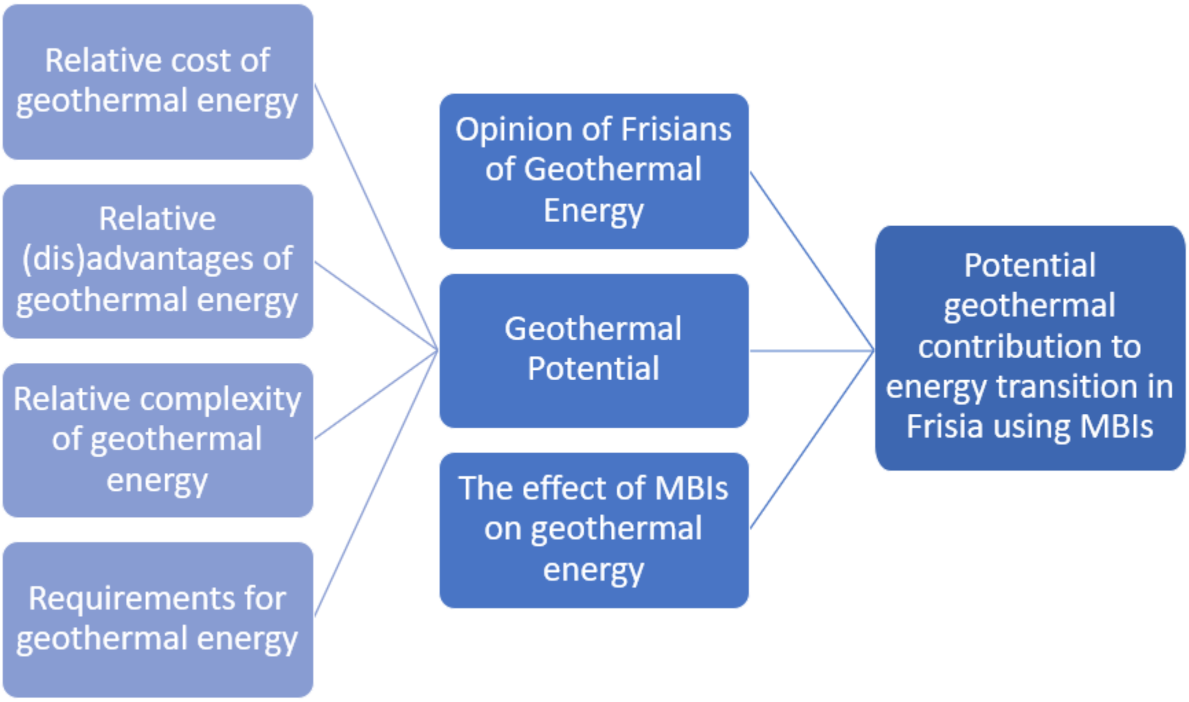

Figure 7: Conceptual model.

3. Methodology

3.1 Ontology, epistemology & research paradigm

This paper aims to find why geothermal is not considered as a viable option and why it does not receive the investments necessary to make a significant contribution to energy production within Frisia. This research is a case study on the case of Frisia. The choice for a case study was made because geothermal energy is context and location dependant. The expectation of this paper is that geothermal energy will have a small role to fulfil within the energy production of the province. How big this role is however is dependent on both unchangeable conditions and changeable conditions. Some conditions, like whether we need sustainable energy at all, or the temperature of the subsurface are relatively stable, while factors like costs, weather changes and public opinion are subject to change. In other words, the answers to the questions in this paper are context dependent.

Research methods

To answer the questions raised in this paper and fill the conceptual model, a mix of methods is required. Previously, a literature study has been conducted. This basis is required to answer the questions of this paper, and to be able to find out whether geothermal energy can contribute to the energy transition of Frisia.

To answer the questions in this paper, three different methods have been chosen in order to reach a satisfactory answer: First, in-depth interview with local experts whom can provide information and context regarding the support the local population has towards geothermal energy. This also includes the questions concerning the small yet possible danger of earthquakes. Besides, they can shed light on the specifics of the case with regards to geothermal energy. Secondly, a case study is conducted which compares the MBI's used in other regions and countries which have geothermal energy with varying degrees of success, in order to try to find a causal relation between certain MBI's and policies and geothermal success. Finally, a comparison between wind, solar and geothermal energy is conducted on the difficulty of each technology in certain categories. The categories are those mentioned in the previous chapter, namely finances, institutions and time. The idea here is that geothermal overall seems to be more complicated across the board, which would explain the higher barrier geothermal seems to have over wind and solar energy. Together, these methods can answer the questions posed in the paper.

3.2 Interviews

The chosen interview format is semi-structured, meaning that each interview has a set of questions in order, though the interviewer can deviate from this structure to ask more in depth questions about specific interests or topics. It also encourages the interviewee to expand more about their specific field of expertise and their interests surrounding the overarching topic. This method is chosen because the questions in the paper require at least some structure to be answered, since these questions concern specific topics, while not every interviewee will be able to talk in length about each of these specific topics. This requires a degree of flexibility a fully structured interview does not offer, and a degree of certainty which a unstructured interview does not offer. The question for the interviews to answer is the sub question: "D*o the people of Frisia support geothermal energy?"* The interview format is chosen to find an answer to this somewhat subjective question. Besides, the interviews also will include some questions on wind & solar compared to geothermal, as well as the role of geothermal energy in Frisia. These questions will help answer two of the other sub questions. Market Based Instruments are not a part of the interviews.

The experts preferably meet two criteria: first they are involved in geothermal energy project and/or have expertise on the subject. Secondly, they are involved in projects and/or have expertise in Frisia. Unfortunately, there are only few people who meet both criteria. As such, the interviews also involve respondents who are less experienced in geothermal energy, but are involved in geothermal heating, which Frisia has more of. Individuals who were involved in such projects may be able to give their perspective on the questions raised in this paper. Even though they may be somewhat lacking in the technical aspects, the main goal of the interviews is to learn the perspective of the people of Frisia, which these experts can still answer. In total, seven interviews were conducted. Out of these seven interviewees, one is an expert on energy from a non-commercial organisation which develops energy projects for local and regional governments, including geothermal projects. The other six are municipal or provincial experts with knowledge and specialization on either spatial planning or sustainability & energy. All seven interviewees are from Frisia and as such know the area. With their expertise and local knowledge, they are able to answer the questions of the interview in order to reach an answer for the sub questions of this paper.

The interview form can be found in appendix 1. Below is a summary of the interview form and the reasoning behind it. Some of the questions are more relevant to the topic and goal of the research than other questions. Therefore, the answers to some of the questions below is given in appendix 2. In the next chapter the findings of the interview are given, which are also verified with the information of the previous chapter.

Questions before the interview

The first question asked to the interviewee is whether the interviewee agrees with the interview being recorded. This recording is made to make analysis of the interview easier, while also allowing the interviewer more time during the interview itself, since their time is not spent writing. The second question is regarding the anonymity of the interview. The interviewees are assured their anonymity is preserved within the research process and the result.

Introduction

To stimulate the interviewee to be more open and ready to talk, the interviewer first introduces themselves. This also includes the reason why the topic Geothermal Energy is chosen. After this, the interviewee is asked to introduce themselves as well, with some emphasis on their relation to geothermal energy. After the introductions, both the interviewer and the interviewee can better understand each other's point of view and knowledge of the subject.

Questions regarding geothermal energy

The first topical questions in this interview are on the distinction between geothermal heating and geothermal power. As geothermal power is a fairly unknown and underutilized resource within Frisia, while geothermal heating is relatively much more developed, the interviewees are expected to be less informed about geothermal power compared to geothermal heating, since geothermal power is less developed in Frisia compared to geothermal heating.

Have you considered geothermal energy as an alternative source of power?

This question is asked to find the level of commitment the interviewee and their colleagues have towards geothermal energy for power production versus geothermal for heating applications only.

Most municipalities in Frisia have at least some goals regarding geothermal heating, though geothermal power is much more rare.

Do you think geothermal energy has potential to be a contributor to the energy in your region?

This question is asked to find if there are differences between different regions within Frisia on their attitude towards deep geothermal.

What do you think are the biggest hurdles to overcome with regards to successful geothermal application?

The aim of this question is to find what specific issue the interviewee would consider the greatest obstacle for geothermal energy, and therefore the most important reason for why geothermal energy is not implemented as of yet.

What could the benefit of geothermal be, compared to other methods?

Since this paper also includes a comparison between geothermal and solar & wind as sustainable energy sources, this question is posed to find out whether the interviewees identify specific benefits of geothermal energy, be it due to geothermal strengths or weaknesses of alternatives.

Questions regarding Frisia

In this section, the focus is on the province of Frisia and its inhabitants. The interviewees are asked if the people of Frisia are inclined to accept geothermal energy as an alternative to fossil fuels, as well as other sustainable methods. This encompasses economic and environmental advantages and disadvantages. Besides this, the interviewees are also asked about earthquakes: whether they believe earthquakes are a risk, and whether they think the people would agree with that belief. This question is asked, since the province bordering Frisia to the east has had earthquakes in recent years, caused by gas extraction from the subsurface. This lead to resistance from locals and, after a while, the government promised to scale down and eventually stop extraction altogether. With this political and social issue fresh in mind, the people of Frisia may also be opposed to geothermal in Frisia, as there is also a risk of earthquakes. The public perception and support is vital, but may therefore be influenced by this risk.

What (do you expect) is the public perception towards geothermal energy?

In this question the interviewee is asked to consider how the local inhabitants of their municipality or region view geothermal energy. Oftentimes municipalities and other parties whom push for such new facilities organize moments in which locals are invited and asked to participate, give feedback and share their opinions. The doubts or criticisms voiced during such times can helpful to determine the public perception, which in turn is an important factor towards eventual successful implementation of geothermal energy.

Does the risk of earthquakes involved with geothermal pose an obstacle in Frisia?

One specific point of attention concerning the public perception is the risk of earthquakes. Although only a minor risk, this is an issue that could prevent geothermal energy as a source of energy. The province neighboring Frisia to the east, Groningen, has issues with earthquakes caused by the extraction of natural gas from the subsurface. Due to the similarities in technologies, a fear of this happening in Frisia as well may be a deterring factor for geothermal in Frisia.

Other energy questions

The focus in this section of the interview is on the comparison between geothermal and other sustainable methods, especially solar and wind energy. The interviewees are asked what they believe the reason is for the focus on solar and wind energy over any other methods. Besides, they are also asked if there are any other methods that have been seriously considered within their conversations or discussion with relevant boards or meetings concerning energy transition.

Why do you think the focus of the energy transition lies mostly on solar and wind power?

In a previous question, the interviewee was asked about the benefits of geothermal compared to solar and wind. If the benefits of solar and wind over geothermal were not discussed, they can be discussed here instead. Besides, other arguments or reasons can be given in this section, to find why solar and wind have such popularity.

Have there been other methods of power generation which you have considered?

Besides geothermal, solar and wind there are many more methods of generating energy sustainably. It may well be that the interviewee has considered more options, of which some may also have been tested or even implemented. Either way, exploring another option means that the interviewee had previously identified a reason for its exploration, which may give some insight into whether geothermal could be or have been a choice instead.

Conclusions

Finally, the interviewee is asked if there is anything they would like to add to the interview. This is done because of the loose nature of the semi-structured interview sometimes leading to certain topics being skipped, even though the interviewee would consider it important to the subject. The interviewee is thanked for their participation and this concludes the interview.

3.3 Case Study MBIs

Based on the theory in chapter 2, the MBIs in the Netherlands do not seem to have a significant impact on the development of geothermal energy in Frisia. To find whether MBIs can have such an impact, a case study is carried out next to the interviews, in which a few cases of MBIs being used in renewable energy and geothermal energy projects are researched. The goal is to find which MBIs are used, to what extent and the effect they have on the viability of geothermal or another renewable energy. If geothermal is successful in other cases, then either the existence or absence of MBIs in those cases may have had an effect on that success. In each of these cases, support schemes and other MBIs are identified in these regions, whether they are similar to the Dutch support scheme, different to the Dutch scheme or non-existent.

The top 10 nations which produce the most geothermal energy around the world are all producing that energy in areas with high volcanic activity (ThinkGeoEnergy, 2022), meaning that often no deep geothermal is required. Since there are no such temperatures in the Frisian subsurface, these cases are not suitable to compare.

Instead, three European nations are compared to the Netherlands: Germany, France and Finland. Germany and France are chosen as they are close to the Netherlands, therefore having similar conditions. Besides, Germany and France have made some progress with deep geothermal energy as well. Finland is added as a nation which has a significant share of geothermal heating, but dissimilar conditions as the Netherlands.

Germany

The first case in which MBIs are analysed is Germany. Germany has also invested in geothermal energy in the last decades (Ganz et al., 2013). Similarly to Frisia and the Netherlands however, these investments have not resulted in a significant share of geothermal in the national energy production. There are support schemes in place which are similar to those in the Netherlands.

France

France has made progress with regards to geothermal energy. In fact, France wants to be a leading producer of geothermal energy. France has similar risk prevention schemes to mitigate the high investment risk of especially deep geothermal projects (Boissavy et al., 2019). France also has a few deep geothermal wells for electricity generation, which will be expanded in the future.

Finland

Finland has fairly poor conditions for geothermal energy, but the demand for heat is high (Kukkonen, 2000). As a result, heat pumps are very common in Finland, and have been for a few decades already. Recently however there has been an increase in investment in deeper geothermal projects. 100 degrees Celsius is reached at 6 to 8 kilometres depth in Finland, and as such geothermal power is relative to Frisia and the aforementioned cases unsuitable.

3.4 Comparison

Finally, this study covers a comparison between geothermal, wind and solar energy. This comparison will find certain aspects relevant to each of the technologies and compare them in difficulty between the technologies. This is done to find if there are more struggles for geothermal than already identified within the last chapter, as well as to find if these struggles exist for wind and solar as well, and to what extent. The reason for this is that geothermal energy is insignificant in contribution compared to solar and wind in the Netherlands, even though investment and subsidies are available. Based on the theory there is the expectation that geothermal energy is not only unsuccessful because of the finances, but is also more complicated in general. The subjects of comparison are finance, institutions & time, as discussed in the last chapter and as shown in figure 6. The financial aspect will compare the finances of geothermal with solar and wind, both on investment & profit margins. The institutional aspect includes the comparison between the rules and laws of geothermal energy and wind & solar energy. The aspect of time is about how much time is needed for geothermal to be implemented as compared to wind & solar.

Finances

The financial situation of solar, wind and geothermal have been discussed shortly in the previous chapter. From the overview, it became clear that solar energy especially has become cheaper, wind energy not far behind, while geothermal has increased in cost (table 1). To dive deeper into this topic, this paper will research how expensive each of the technologies are per kWh, both in the cost of installation and in the operation & maintenance cost. Together, these categories decide most of the investment cost and the cost of one unit of energy per unit of time.

Installation cost

Installation cost entails the totality of costs from the first day of the project until the first day of operation. Installation of a single solar panel cannot be compared to the cost of a single geothermal plant. To make this comparison more linear, the amount of solar panels that produces a similar amount of average power as a single geothermal power plant is compared to one another. This amount of solar panels is not likely to be installed in one place however, but more likely to be spread across different areas & buildings, by multiple different contractors. This does mean that the result of the comparison will not show fact, but instead give an indication.

Operation & Maintenance cost

The operation and maintenance costs are continuous costs. These costs include the costs related to upkeeping the power productions at a high level. This cost includes cleaning & repairs for all three technologies, as well as any costs due to the power plant, turbine or panels being active. As with the installation cost, the O&M cost is equalised between the three technologies, to better compare them to each other.

Institutions

In this section the institutions of solar, wind and geothermal are compared. As mentioned in the second chapter, the institutional paradigm of this paper is the Regime paradigm (Salet, 2018). Since the institutions are not expressed in a quantitative format, like the finances are, the comparison is not simply based on numerical values. Instead, a value is given in for each technology in each of the subjects below, from - - to + +, implying the complexity of each technology on that specific topic relative to each other.

Permits

In the permit section the technologies are compared to each other on the difficulty of obtaining a permit, or multiple permits. The easiest in this case would be no permit requirement for a technology, while the most difficult would require multiple permits. If no permits are required for a technology, this would likely make that technology more favourable, compared to other technologies which require permits, since obtaining a permit may be a long & tedious process.

Laws & Regulation

The laws and regulation section adds on that by focussing more on the rules which each technology has to follow and take into account before project development and operation. The lack of rules entirely would in this case be the easiest technology, while having to meet many rules would be more difficult. Having a lack of laws to worry about would make a specific technology more favourable, since it is easier to develop from an institutional perspective.

Time

The final comparison is made on the topic of time. Two sections are discussed here as well. First, the development time: The time spent from the initial step to operation, which is compared between wind, solar and geothermal. Second is the operation time, the life cycle, which is the amount of time a technology can remain operational after development is complete. These two factors show first whether one technology is a more significant time investment than the others, while also showing if that time investment pays off in more operation time.

Development time

The time spent on development of a project from start to finish. This includes the construction of the plant, panel or turbine itself, but also includes, for example, exploratory research, obtaining permits, temporary infrastructure and transportation. Like the finances, the development time is again equalised between the three technologies to allow for better comparison.

Operation time

The amount of time a geothermal plant, turbine or panel can remain operational. Operation time starts when the development is complete. How long an individual panel, turbine or plant can operate depends on the circumstances of that specific unit. Therefore, the operation time in this paper is an average expected lifetime of each technology. A key difference between geothermal and wind & solar here however is that lifetime does not mean optimal productivity for the latter two, since they will not be operational all the time.

4. Findings

The data collected through the methods outlined in the last chapter is presented in this section. In the last chapter, three different research methods were applied, each aimed at answering certain questions and a specific part of the conceptual model. In this chapter, the same three parts are presented independently. In these sections, the findings of the applied method are given, but no conclusions are drawn. In the following chapter, chapter 5, the conclusions are given.

4.1 Interviews

In the last section, the methods for data collection have been discussed. Because the interviews were semi-structured, data is qualitative in nature. Although quantifying the data is an option, the goal of the interviews was to gain qualitative data. Besides, conducting quantitative analysis on qualitative data weakens the result (Boyce & Neale, 2006). This however does mean that from this data no definitive conclusions can be drawn, but instead suggestions are made.

Below, the data is presented in a general analysis of what the respondents answered on the questions asked, sorted by category. Since the interviews were semi-structured, the questions varied from interview to interview, as the questions were adapted based on the interview itself. However, in each interview the questions asked were based on a predetermined set of questions, as outlined in the previous chapter. Some of the results are not relevant for answering the research questions of this paper. The complete written results are found within appendix 2.

Questions regarding geothermal energy

Have you considered geothermal energy as an alternative source of power?

The interviewees had varying degrees of involvement of geothermal energy within their plans for energy transition. Each of the interviewees did mention at least considering geothermal heating as an option within the energy framework of their respective region, while all but one had plans with geothermal heating. However, geothermal power was not as prevalent. Between the respondents there was a varying degree of experience and knowledge on geothermal power. None of the respondents had geothermal power as a component of their plans for energy within their region, although two of them were in the process of conducting research to find if geothermal power is an option for them.

Do you think geothermal energy has potential to be a contributor to the energy in your region?

Six out of seven interviewees considered geothermal as a potential option, but primarily in heating. Only one of the respondents did consider geothermal power as an option, and was actively researching the viability of geothermal power in their region. Other respondents either had not considered geothermal power as an option, or dismissed it due to it being too expensive.

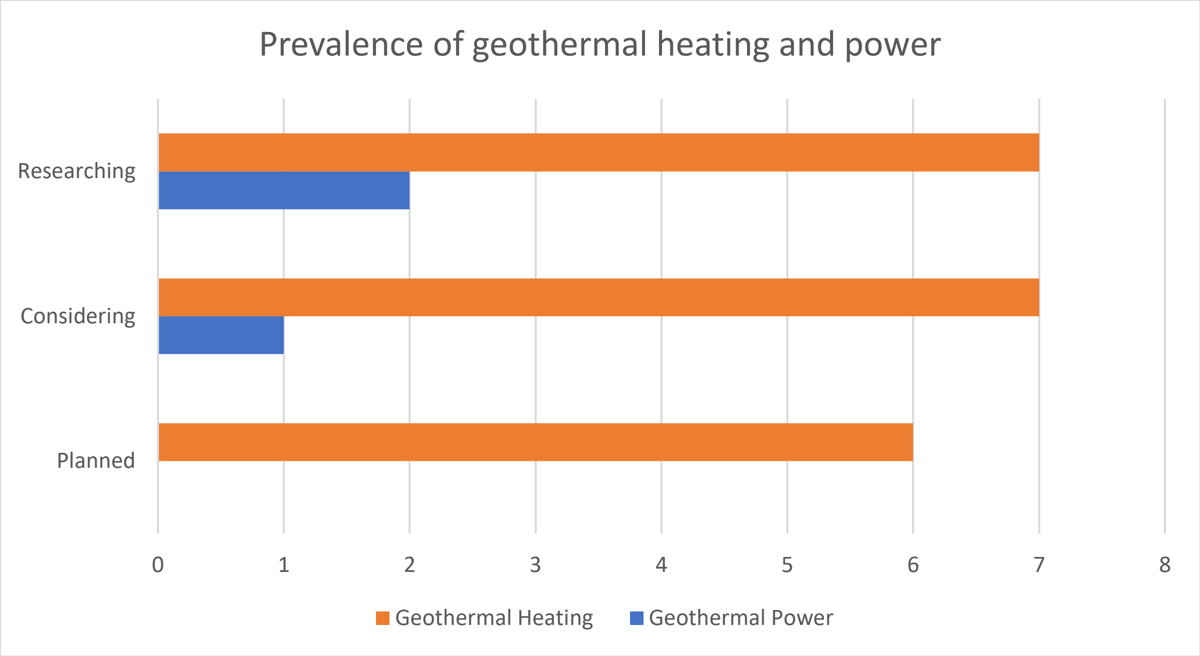

Figure 8: The number of interviewees who researched, considered and/or planned geothermal heating and power

What do you think are the biggest hurdles to overcome with regards to successful geothermal application?

The answer to this question was clear in all seven interviews: The cost. More specifically, the high up-front investment levels, combined with relatively high risk of the investment not paying off due to uncertainties involving the drilling process. Besides, this process takes a few years. The interviewees considered solar and wind preferable since they require smaller investments with much more certainty of their yield. The response of the interviewees shows that they all believe that geothermal energy is too expensive and too risky of an endeavor, and therefore not worth doing. This result is what is initially shown as the main hurdle for geothermal energy in this paper as well, which is the issue that MBIs attempt to overcome. Therefore, MBIs are either not substantial enough for these Frisian experts to consider geothermal power, or they do not know about the MBIs.

What could the benefit of geothermal be, compared to other methods?

The respondents agreed that the reliability of geothermal energy could definitely outweigh the benefits of solar and wind energy, since those methods are dependent on weather, among other factors. This is also one of the benefits mentioned in chapter 2.2 of this paper. One interviewee also mentioned the added benefit of combining geothermal heating with geothermal power, which would combine well, especially in urban or industrial areas where the need for both is higher. This is potentially an efficient combination, as geothermal power could produce heat as a side product, which could also be applied directly as heating.

Questions regarding Frisia

What (do you expect) is the public perception towards geothermal energy?

Three interviewees shared they had held gatherings with locals about their energy plans. In those gatherings, information was shared and opinions of the local inhabitants where shared as well. In two of the meetings, the topic of geothermal energy did come up, and the people were largely positive about the technology. Therefore these interviewees would consider the public perception to be positive. The other interviewees did agree with this idea, stating that most people agree with innovations if the benefits outweigh the costs.

Does the risk of earthquakes involved with geothermal pose an obstacle in Frisia?

Most interviewees expected this question, as the risk of earthquakes is an important topic in the neighbouring province. Five interviewees had not talked about it, since with geothermal heating specifically, there is no risk of earthquakes. However, one interviewee did talk about this during one of the aforementioned gatherings, and explained what the risk was. The public were convinced that the risk of earthquakes was minimal, and thus this would not be an obstacle. In fact, the public was more interested in the best option with regards to energy security and cost. The other interviewees also expected this fear to not be an issue, as the risk is considerably lower than in Groningen. Besides, one interviewee added, earthquakes in geothermal can be prevented by careful planning and by not taking unnecessary risks.

Other energy questions

Why do you think the focus of the energy transition lies mostly on solar and wind power?

All seven interviewees made use of solar and wind as well, or had the ambition to do so. Scalability was the main benefit mentioned by 4 of the interviewees since it allows them to increase sustainable energy shares step by step. Another benefit that was mentioned twice is that solar wind energy have a variety of uses. For example, windmills can be placed in a wind park, where multiple windmills are close to each other and far away from housing, but windmills can also be placed individually at industrial sites or farms. Similarly for solar, where many solar panels can be placed together on a field, but they can also be placed on individual buildings. Besides, one interviewee added that there was much more experience on solar and wind energy. They had multiple partners associated with those technologies, which make them more accessible.

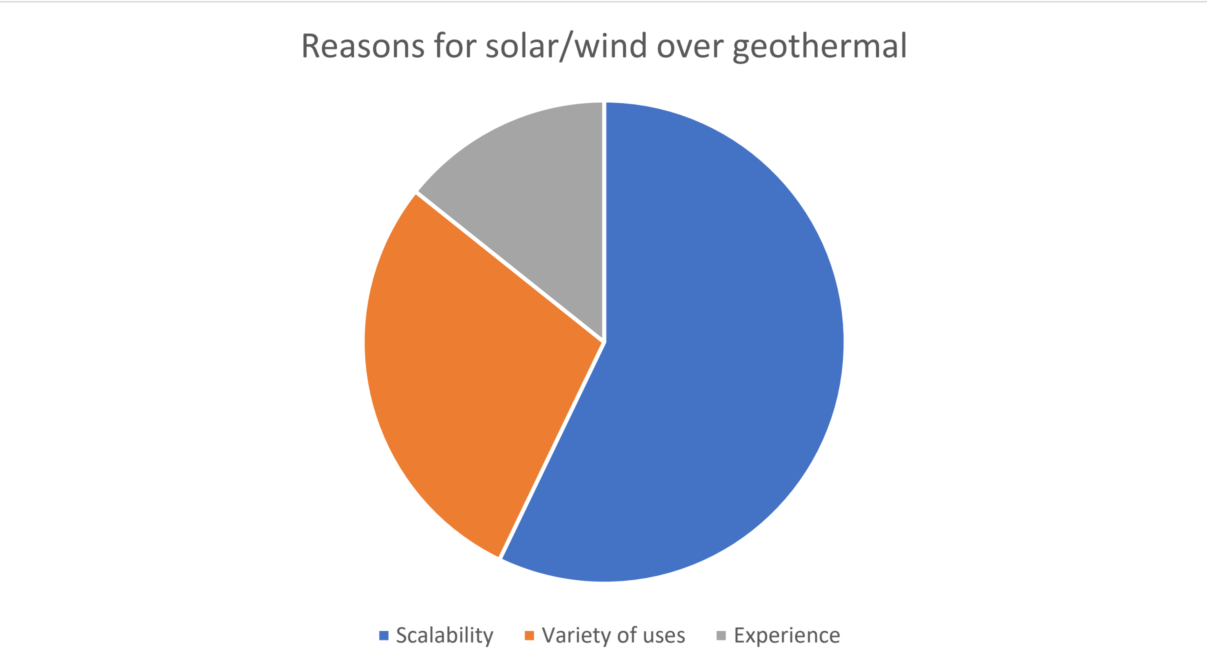

Figure 9: The reason for the focus on solar and win over geothermal, according to the interviewees.

4.2 Case studies

Germany

The German MBI support scheme for geothermal energy is similar to that of the Netherlands (Ganz et al., 2013). There are three parts to the support scheme: First, a loan from the KFW, a banking group, with low interest. This loan can help alleviate the risk of exploration, financing anywhere up to 80% of the costs of the exploratory drilling, as well as fully covering the risk of an unsuccessful exploration. Second, a feed in tariff which is set at 25 eurocents per kWh, or 30 eurocents per kWh for EGS systems in 2013. This is done in the EEG, the energy sources act. This feed in tariff has been increased in recent years. Third, the MAP, is a similar solution as that of the KFW, although meant for smaller projects, like heat pumps. However, from 2012 onwards, the MAP is only granted in existing buildings, in which the cost of heat pumps is higher than the support given, and as such the number of projects funded by the MAP has reduced drastically. The energy generated by geothermal has increased from 0,2 to 28 GWh from 2005 to 2010, and by 350% to 2014, to 98 GWh (BMWK, 2021). Still, the total energy produced in 2014 was 161,379 GWh, of which 27% renewable, and only 0.06% geothermal.

France

The ambitions of France are to be a leader in geothermal energy production. In order to achieve this, France also has a few MBIs in place (Boissavy et al., 2019). A risk mitigation scheme, called the SAF Environment scheme, has existed for 40 years and has proven successful in achieving its goal. This scheme supports not only the exploratory drilling, but also the first 10 years of exploitation. And even if the drills are successful, there still is financial support. For heating, a different scheme exists: The Renewable Heat Fund. Still, in 2015, the share of geothermal energy of total renewable electric energy was only 0.10%, and this percentage is expected to drop, as other renewables expand more quickly (Victanis, 2019).

Finland

Finland has a different support scheme than the Netherlands, in that it is focused on different things. Since deep geothermal is less efficient in Finland, there are fewer MBIs (Kukkonen, 2000). Although the MBIs are different in Finland, their share of geothermal energy, especially by heat, is larger than in the Netherlands. This is mostly due to a higher necessity, since there are few alternatives. There are about 10,000 heat pumps in Finland. These are more expensive to install in a home compared to oil or gas heaters, but their operational cost is lower. There are some larger projects in Finland, which focus on heating for a larger area. The funding for these projects is sometimes done by outside parties like Kiilto Ventures or by the state funded Climate Fund. The Climate Fund does however not give grants. In most cases, they give out loans, and sometimes they invest in the project.

4.3 Comparison

In this section, the findings of the comparison of geothermal energy with wind & solar based on the categories of finance, institutions and time are given. Each section has their own methods to make accurate comparisons on specific points between the different technologies.

Finances

Installation cost

The cost of a geothermal power plant depends on the location and type of power plant. Since the conditions of water reservoirs in the subsurface of Frisia are unknown, there are two likely candidates for the best possible power plant type. These are the double-flash steam type or the binary type. Research on which type is the most cost-efficient was done for CERN in Geneva, Switzerland (El Haj Assad, 2017). In that research, binary, single flash and dual flash type geothermal plants were compared for 80% of contribution to total energy production for CERN. The results show that a binary plant has a cost of 625 million USD, about 593.75 million euros, for 632 thousand MWh annually. Dual flash shows a 612 thousand MWh annually at a cost of 776 million USD, or about 737.2 million euros.

In 2021 the Windpark Fryslân was completed. This park consists of 89 wind turbines built just offshore on the Ijsselmeer, the largest lake of the Netherlands (Windpark Fryslân, n.d.). Each of these turbines produces 4.3 MW, which makes the total power 382.7 MW. Converted to MWh, this results in about 3,354,748.2 MWh at maximum capacity, however, the real MWh is about 1,500,000 MWh. The total costs of the project were 850 million euros.

In a research on the profitability of solar panels on farmlands in the Netherlands, estimated numbers were proposed for a hectare of farmland filled with solar panels (Spruijt, 2015). The estimated cost for a hectare of solar panels is about 650 thousand euros. One hectare has an estimated output of 0.65 MWp. The annual output would be around 500 MWh.

To make the comparison, these number are equalized on power output. When the investment cost is divided by the power output for each of the three technologies, the results are as they are shown in figure 10 below. As mentioned before, the efficiency of each of these technologies depends a lot on external factors. Additionally, scaling each of the technologies to the same number ignores one of the main reasons why one of them is chosen over another. Even if for example solar is more expensive comparatively, often it is more convenient for funding if investments are required in smaller numbers. These numbers are not enough to definitively state geothermal is cheaper than wind and solar, it does show that it can be.

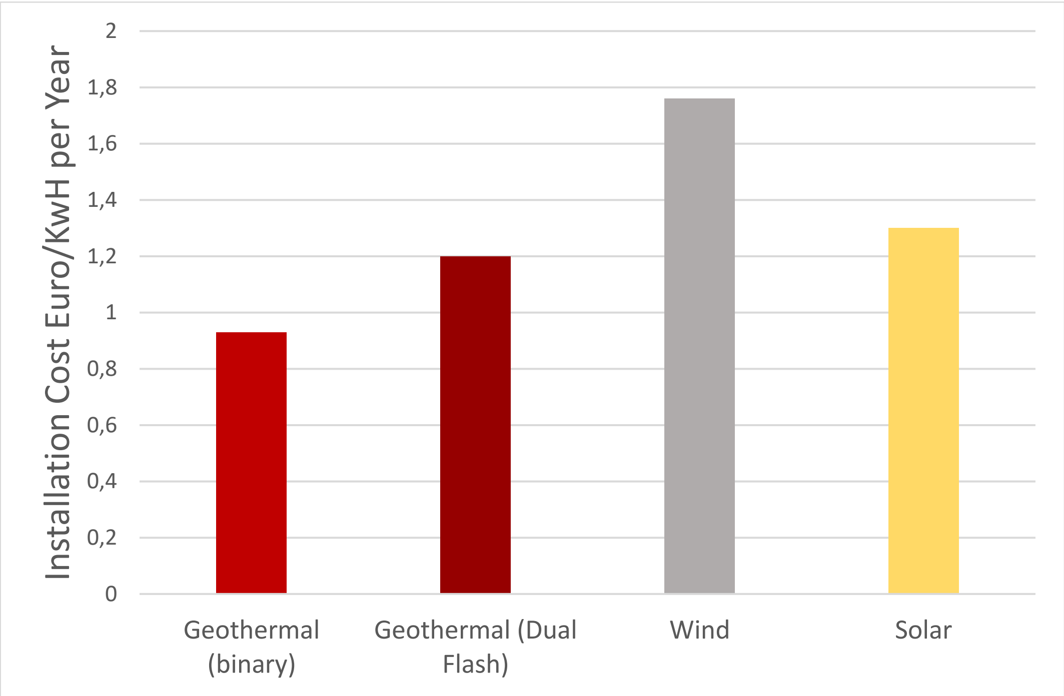

Figure 10: Installation cost of each technology in the comparison.

Operation & maintenance cost

The operation and maintenance cost of solar panels is relatively low. Most of the maintenance is aimed at cleaning the solar panels, in order to keep their energy production as high as possible. There is also the possibility that certain parts of the panels malfunction, which then require repairs. IRENA showed that European solar O&M costs constituted about 9 to 10 USD/kW per year.

For wind energy, the operational cost has been thoroughly researched in 2009 by experts from Europe, financed by the Intelligent Energy Europe Programme (IEE), part of the European Commission (Wind Energy – The Facts, 2009). The operation and maintenance costs are divided in six categories: insurance, regular maintenance, repair, spare parts, administration and miscellaneous. The research shows that repairs constitute the largest share of these categories. Another result was that newer and larger turbines had lower O&M costs/kWh compared to older and smaller turbines. IRENA also shared O&M costs of onshore wind in different countries. The costs in 2019 were about 44 USD/kW per year in Denmark & 47 USD/kW per year in Germany (IRENA, 2022c). The expected O&M cost in the Netherlands and Frisia therefore is around the same value.

For geothermal energy, IRENA estimates the O&M cost to be significantly higher, at about 115 USD/kW per year. This is because geothermal wells usually lose pressure over time, which requires the need for either re-injection or new wells. Since this is an expensive process, the O&M costs are raised significantly.

The O&M costs are converted to be expressed in euros/kWh, which has given the results expressed in figure 11. For solar and wind two values were given above, the graph shows the average of those numbers.

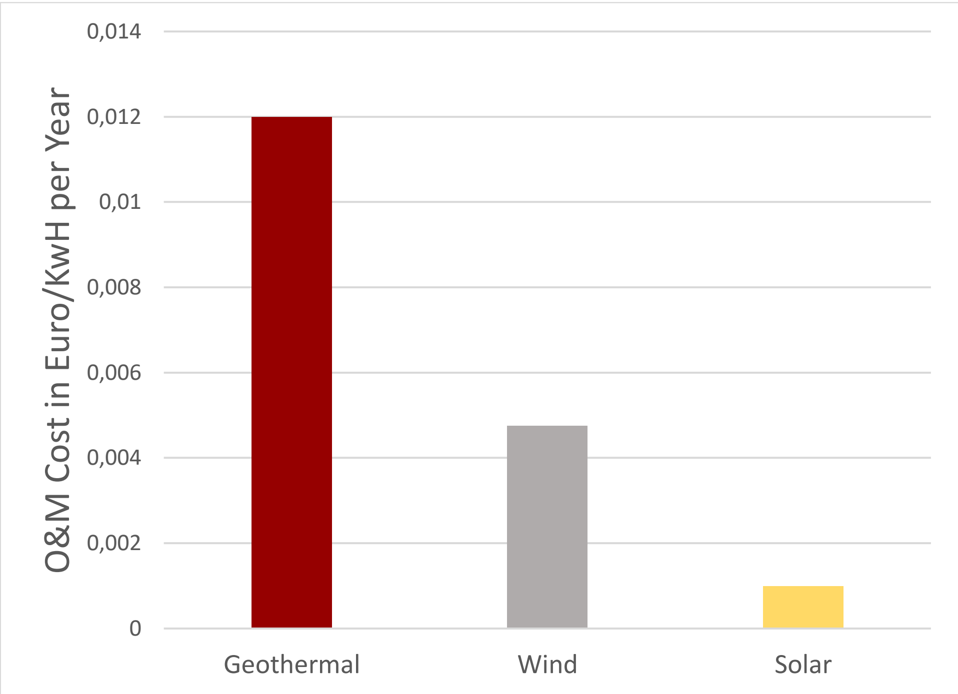

Figure 11: Operation & Maintenance cost of each technology in the comparison.

Institutions

In this section the difficulty or complexity of wind, solar and geothermal energy are compared to each other on the subject of intuitions: the rules and laws for each technology. Since these are qualitative and somewhat subjective data, these are expressed from very complicated to very straightforward, expressed by - - to + +, in five steps, as shown in the table below.

Obtaining a permit

When it comes to solar energy, the rules are the most straightforward. If an individual want to place a few solar panels on their own property, in most cases no permit is required. In some cases, there are certain restrictions, like when the solar panels are visible from outside the property, since this is part of the zoning plan. Overall, the rules here are quite straightforward (Rijksoverheid, n.d.). A field of solar panels does require a permit. A smaller scale solar farm, for example ones placed by and exclusively used by a single business or company, only has minimal requirements to meet. These requirements are concerned with the zoning plan, again mostly because of visibility. For large scale solar farms the permits are more difficult to obtain, since certain areas have limits on size, power output and orientation. The request for this kind of permit is complicated enough that generally an expert on spatial planning is required (Zonnestroom Nederland, n.d).

Wind turbines have more rules to contend with (RVO, 2021). Wind turbines disturb the environment more than solar panels. As such, before an investor can place wind turbines, several permits are required, based on the amount of turbines and/or their power output. In all cases a MER, an Environmental Impact Report, is required, since even a single turbine can have impact on the environment. With the MER, a 'sign up note' is added, which includes the reasons for the construction. Besides the MER, a omgevingsvergunning, an environment permit, is required. This permit shows what is necessary for construction of the turbine(s). Sometimes this also involves deforestation of the area and the construction of temporary infrastructure. Besides, the municipality decides in this step if they oppose the project based on the zoning plan. In wind parks which contain three or more wind turbines, the omgevingsvergunning and MER can be combined. Then permits are required which are concerned with nature conservation, water conservation and other potential permits, dependent on the specific location. All of these can be coordinated together by municipalities, allowing for significant time savings. Together, all these permits mean that wind turbines require more time and effort from an institutional perspective than solar panels. Most permits can be done by the initiator of the project in cooperation with the municipality, while sometimes the province and Rijkswaterstaat (Department of Waterways and Public Works) are involved.

For geothermal there is a distinction based on the depth. As mentioned before, the 500 meter depth range is the dividing factor. Any projects in above that point require only few permits. For example, a type of geothermal heating called a heat-cold storage system requires only a single permit. This type of heat storage below large buildings allows them to use their stored heat from the summer in the winter and the stored cold of the winter in the summer (RVO, 2021). Any project at a depth of more than 500 meters requires a few more permits. First, the exploration of an area for geothermal energy requires two permits. The exploitation an additional three permits, one of which again is an omgevingsvergunning, and one concerns the water in the area (Geothermie Nederland, n.d.).

Laws and regulation

As mentioned in the institution section in chapter 2, the heat in the subsurface below 500 meters of depth is property of the state (Mijnbouwwet, 2002). Wind and solar radiation however are common resources however, and are therefore free to be exploited.

Solar panels have a limited effect on their surroundings, especially when placed on buildings. In those cases, only the aforementioned rules apply, where solar panels may not affect the scenery of the living space too much. Solar farms have more impact on their surroundings, although no major environmental impact, like wind or geothermal energy can have. Solar farms impact the area in which they are built in that there is no other use for the land. Recently however, the Dutch minister of public housing stated that placing solar panels on existing buildings is preferred over solar panels in fields, as this is deemed a waste of space, a scarce commodity in the Netherlands (Peer, 2023). This suggests that solar farms may receive more strict regulation in the future.

Wind turbines have a greater effect on their surroundings. Due to their height, some turbines are equipped with red blinking lights, which serve as a signal to aircraft. As such, even at night pilots can identify where wind turbines are. Recently, these lights can detect aircrafts, and as such they only turn on when an aircraft is nearby (RVO, 2023). Another effect turbines have is on birds and bats, which are killed by the blades of the wind turbines. An innovation here allows the wind turbines to turn off under ideal conditions for birds and bats, limiting the number of casualties. Another example is that of the shadows, caused by de blades of the turbine, which may only occur for a few hours a year in houses. The solution for this problem was found in calculating the shadow by measuring the position of the sun and the rotation of the turbine, and then automatically turning the turbine off when its shadows are reaching residential homes (RVO, 2023). These examples show that wind turbines have an impact on their environment in different ways, but there are usually solutions for those issues. Those solutions however may lead to reduced productivity of the turbines.

Geothermal energy affects their surroundings somewhat aboveground, but the larger limitations are below ground. For geothermal heating, the environmental impact is not as great, and can be produced within the scope of the permits, which protect the environment enough (Jharap et al., 2020). Geothermal energy at greater depths has a larger impact however. The risks include groundwater contamination, increased seismic activity, and other environmental damage. Uncontrolled flow during drilling may contaminate the water and damage the environment even further. With UDG, there even is a chance of increased natural radioactivity (Jharap et al., 2020). These risks mean that the Dutch State Supervisor of Mines might make the involvement of a geo-mechanical expert and a radiation expert on UDG projects mandatory.

Level of difficulty	- -	-	+ -	+	+ +
Permits	Geothermal (power)	Wind	Geothermal (heating)	Solar (farm)	Solar (individual)
Laws & regulation	Geothermal (power)	Wind	Geothermal (heating)		Solar

Table 2: Difficulty levels of each technology on the topics of permits and on laws & regulation, with the easiest being + + on the left and the most difficult - - on the right.

Development time

For each of the technologies the development time is correlated with the scale of the project. Since a lot of development time is dependent on economies of scale, this section compares three large scale projects, one for each technology. In addition, another figure is presented which equalizes the build time based on power output.

Solar development time is relatively short. Especially small scale solar projects, which do not require permits. In these projects, only the installation itself is required, a process which can be done within a day. The larger solar farms require a bit more planning, as permits are required and requests need to be approved. A solar farm of 12 Megawatt, just over 100,000 MWh/year, took about 6 months to develop (NAM, 2020).

Wind energy requires more time to develop. The wind turbine itself is a more challenging structure to place & transport, which makes the development take longer. Besides, the aforementioned regulations of wind energy make the process of finding an appropriate location and obtaining a permit a more time consuming process as compared to solar energy. The entire project of Windpark Fryslân took about two and a half years, which included creating an artificial island (Windpark Fryslân, n.d.).

Geothermal energy requires even more time. As mentioned in chapter 2.8, the time spend on development of geothermal projects is around 6 years on average (ThinkGeoEnergy, n.d & Aragón-Aguilar et al., 2019). The values of each of the technologies is visualized in the figure below.

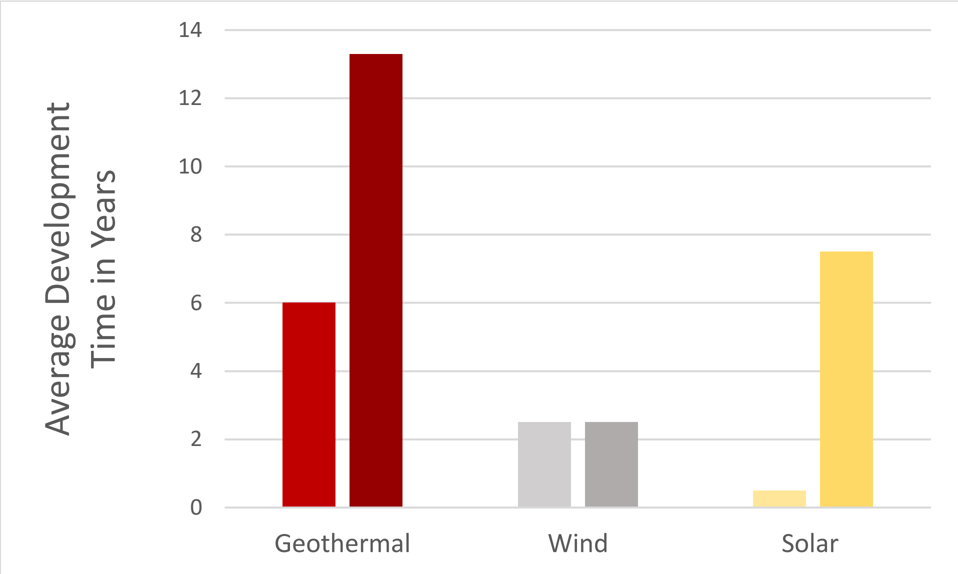

Figure 12: Development time of a project for each technology. The values on the left are the real values, and on the right are the corrected values, which show equalized development time based the same output, in this case that of Windpark Fryslân.

Operation time

Solar panels have a life cycle of about 25-30 years, depending on the type and circumstances (Contreras-Lisperguer et al., 2007 & Basosi et al., 2020). The life cycle of wind turbines is generally considered to be lower, namely 20 years (Martínez et al., 2009). However, there are cases which last longer, up to 30 years (Basosi et al., 2020). Similar to solar energy, geothermal power plants have a life cycle of 25-30 years (Basosi et al., 2020). Thus, solar and geothermal energy about equal life cycles, while the life cycle of wind energy is somewhat shorter. As mentioned in the methods section, the lifetime of wind and solar take their intermittent power production into account.

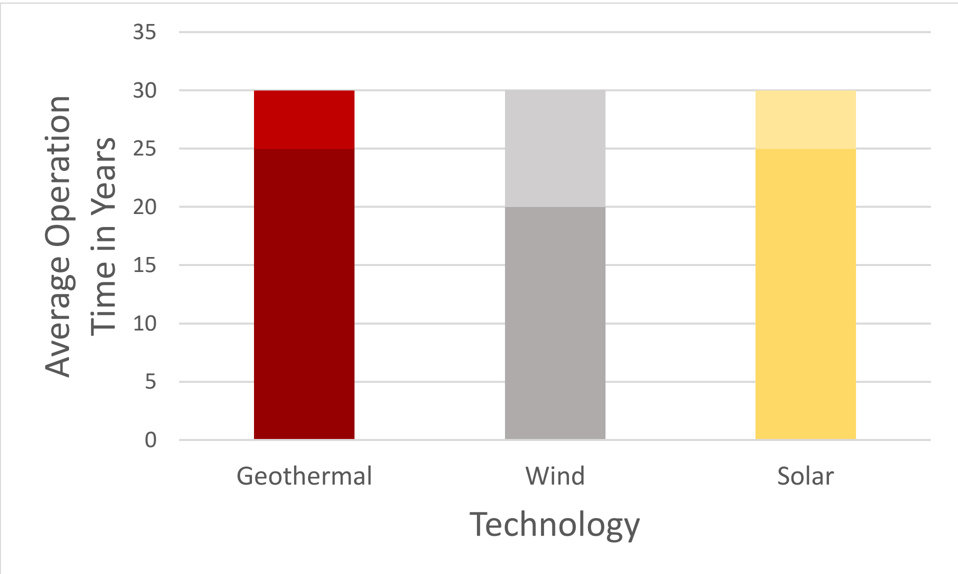

Figure 13: The minimum and maximum average operation time in years for each of the three technologies.

5. Conclusion & Reflection

The main research question of this paper was: '*What effect can Market Based Instruments have on the contribution of geothermal energy to the energy transition of Frisia?'.* This question is answered by dividing the question in three parts in the conceptual model. First, the interviews, which focussed on Frisia. The analysis of the interviews indicate that both the Frisian population and the local experts would not mind geothermal energy to be a part of their regional energy plans. The main concern however remained financial. Second, the effect of MBIs on geothermal energy. In the case study it was found that MBIs have likely had a positive impact on the development of geothermal energy, as it has in other nations as well. This development however was too slow to have a significant share of sustainable energy production. Therefore, it seems that MBIs alone are not enough to increase the share of geothermal energy significantly. Finally, the comparison study indicated that finances might not be the main issue for geothermal energy. In fact, an example was given of a geothermal plant that was cheaper than solar and wind alternatives. However, the institutions were more complex for geothermal energy compared to wind energy, and even more complex compared to solar energy. Besides, the time scale of geothermal makes it even less attractive as an option for investors.

So even though geothermal energy is a viable option for Frisia and other regions to overcome the shortcomings of solar and wind energy, it seems unlikely that MBIs specifically would improve geothermal shares significantly. Those shortcomings mainly being the relative impact on the energy grid and the disadvantages of solar and wind being such that 100% sustainable energy cannot be reached with just these two technologies. They need either energy storage or consistent and reliable energy like geothermal, the energy output of which can be upscaled or downscaled on demand, to cover for fluctuations in weather. Therefore the goal of becoming climate neutral in the long term requires more than just the short term expansion of solar and wind power. This paper has shown that geothermal is a viable option to fill the gaps of solar and wind and therefore an option to reach climate neutrality.

This paper has looked at the lack of geothermal energy in Frisia from different perspectives, due to the nature of the spatial planning discipline. The recommendation of this paper also is from two perspectives: One from the perspective of investors and one from the governments perspective.

- As it stands, investors are saver to invest in large wind parks, since they are less complex, both in theoretical knowledge and in its institutions, while providing a more certain cost-benefit. The aforementioned benefits of geothermal are not a concern for the private investor, and therefore are not arguments in favour of geothermal from their perspective. Instead, the cost-benefit of geothermal should outweigh that of solar and wind, in the combination of finances, institutions and time. Geothermal needs to become less complicated and more streamlined for investors, which will allow the market to invest more in geothermal energy.

- Investing in geothermal could create significant benefits for the energy security in the long term. Since the benefits do not concern the market, MBIs might not be the right approach to increasing the share of geothermal energy. Instead, the government could opt for a more hands-on approach, and could make these investments themselves. Although it is possible for the market to create geothermal projects, it is usually reserved for relatively large investments, due to its scale. Due to the difficulties of geothermal, it also requires a lot of knowledge, expertise and time, which makes it unappealing for the average investor. The MBIs may cover some of the financial constraints, but they do not make geothermal appealing on their own.

Either of the perspectives could reach the outcome in which Frisia has a significant share of geothermal energy to meet the climate goals set in Paris, but each with a different approach. The recommendation for Frisian spatial planners is then to identify which perspective has their preference and to solve the issues geothermal energy has from that point of view, if they wish to see more geothermal energy in their region.

Reflection

A weakness of the research is the number of interviews conducted. Since few people within Frisia are involved in projects concerning geothermal power, the level of expertise on the subject is relatively low, which in turn means that any answers given by the respondent are given within a frame of relatively little information, which lowers the validity. Besides, the lack of expertise also meant that there were few respondents at all, which also negatively affects the validity of the research. In the comparative study and MBI case study, the cases and examples were not in large enough quantity to give definitive answers, just indications. Besides, the measure of complexity in the institution section is somewhat subjective.

Another factor that is limiting for this research is the gap of information on the subsurface of Frisia. The layer in which geothermal power is most likely to be harvested is lacking in information. This information can prove helpful in determining the cost efficiency of specific locations, as the ground layer is important for estimates about aquifers and permeability. Little consistent information is available on the deep ground layers, which are most relevant for ultra deep geothermal.

The outcomes of the research are convincing, as they reflect the issues any sustainable development struggles with: Risk in development, high cost and uncertainty of returns on investment, combined with more difficult technologies and institutions make geothermal power plants uninviting projects to tackle. Due to the benefits geothermal has, especially in combination with other sustainable methods like wind and solar, there is considerable reason to make geothermal more attractive. Governments, including that of the province of Frisia, should consider how they would reach climate neutrality and whether geothermal could have a place in that.

In Frisia there is uncertainty around the applicability of geothermal as a source of power. Policy within Frisia therefore rarely includes geothermal power. By shedding some light on the conditions geothermal power requires, the benefits of geothermal and the risks involved, this paper has aimed to aid the spatial planners and policymakers of Frisia in their decision-making when it comes to the energy transition of their respective domain. In this it hopefully aided making geothermal less complex for investors, and has shown that for any (local) government wishing to reach climate neutrality geothermal is an option to be considered.

6. References

Alfè, D., Gillan, M. J., & Price, G. D. (2007). Temperature and composition of the Earth's core. *Contemporary Physics*, *48*(2), 63–80. https://doi.org/10.1080/00107510701529653

Aragón-Aguilar, A., Izquierdo-Montalvo, G., Octavio Aragón-Gaspar, D., & Barreto-Rivera, D. N. (2019). Stages of an Integrated Geothermal Project. *Renewable Geothermal Energy Explorations.* https://doi.org/10.5772/intechopen.81017

Azarpour, A., Suhaimi, S., Zahedi, G., & Bahadori, A. (2013). A review on the drawbacks of renewable energy as a promising energy source of the future. *Arabian Journal for Science and Engineering*, *38*(2), 317–328. https://doi.org/10.1007/s13369-012-0436-6

Barbier, E. (2002). Geothermal energy technology and current status: an overview. *Renewable And Sustainable Energy Reviews*, *6*(1-2), 3-65. doi: 10.1016/s1364-0321(02)00002-3

Basosi R, Bonciani R, Frosali D, Manfrida G, Parisi ML, Sansone F. (2020). Life Cycle Analysis of a Geothermal Power Plant: Comparison of the Environmental Performance with Other Renewable Energy Systems. *Sustainability*, 12(7):2786. https://doi.org/10.3390/su12072786

Beckers, K., Lukawski, M., Anderson, B., Moore, M., Beckers, K. F., Lukawski, M. Z., Reber, T. J., Anderson, B. J., Moore, M. C., & Tester, J. W. (2013). Introducing GEOPHIRES v1.0: Software package for estimating levelized cost of electricity and/or heat from enhanced geothermal systems. Thirty-Eighth Workshop on Geothermal Reservoir engineering, Stanford CA. Available at: https://www.researchgate.net/publication/265998371

Békési, E., Struijk, M., Bonté, D., Veldkamp, H., Limberger, J., Fokker, P. A., Vrijlandt, M., & van Wees, J. D. (2020). An updated geothermal model of the Dutch subsurface based on inversion of temperature data. *Geothermics*, *88*. https://doi.org/10.1016/j.geothermics.2020.101880

BMWK (2021). *Renewable energy sources in figures.* [online] Federal Ministry for Economic Affairs and Energy. Available at: <https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/renewable-energy-sources-in-figures-2020.pdf?__blob=publicationFile&v=4/> [Accessed 7 November 2023].

Boissavy, C., Henry, L., Genter, A., Pomart, A., Rocher, P., & Schmidlé-Bloch, V. (2019, June 11-14). Geothermal Energy Use, Country Update for France. European Geothermal Congress 2019 Den Haag.

Boyce, C. & Neale, P. (2006). Conducting In-depth Interviews: A Guide for Designing and Conducting In-Depth Interviews for Evaluation Input. *Pathfinder International Tool Series, Monitoring and Evaluation-2.*

Campos Rodríguez, C. E., Escobar Palacio, J. C., Venturini, O. J., Silva Lora, E. E., Cobas, V. M., Marques Dos Santos, D., Lofrano Dotto, F. R., & Gialluca, V. (2013). Exergetic and economic comparison of ORC and Kalina cycle for low temperature enhanced geothermal system in Brazil. *Applied Thermal Engineering*, *52*(1), 109–119. https://doi.org/10.1016/j.applthermaleng.2012.11.012

CE Delft (2018). *Warmtekaart provincie Fryslân.* [online] CE Delft. Available at: <https://www.noardeast-fryslan.nl/sites/default/files/2019-04/Warmtekaard%20provincie%20Frysl%C3%A2n.pdf/> [Accessed 28 September 2023].

Clauser, C., Ewert, M. (2018). The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy – Review and case study. *Renewable & Sustainable energy reviews,* 82 (3), 3683-3693. https://doi.org/10.1016/j.rser.2017.10.095.

Climate Fund (n.d.) *Interested in funding?* [online] Climate Fund. Available at: <https://www.ilmastorahasto.fi/en/interested-in-funding/> [Accessed 11 November 2023].

Contreras-Lisperguer, R., Muñoz-Cerón, E., Aguilera, J., & de la Casa, J. (2017). Cradle-to-cradle approach in the life cycle of silicon solar photovoltaic panels. *Journal of Cleaner Production*, 168. 51-59. https://doi.org/10.1016/j.jclepro.2017.08.206.

Du Toit, L. (2014). Promoting renewable energy in South Africa through the inclusion of market-based instruments in South Africa's legal and policy framework with particular reference to the feed-in tariff. (Thesis). University of Cape Town, Faculty of Law, Department of Public Law. Retrieved from http://hdl.handle.net/11427/8717

ECEEE (n.d.). *Energy Efficiency Obligations.* [online] European Council for an Energy Efficient Economy. Available at: <https://www.eceee.org/policy-areas/EE-directive/energy-efficiency-obligations/> [Accessed 28 June 2023].

El Haj Assad, M., Bani-Hani, E., & Khalil, M. (2017). Performance of geothermal power plants (single, dual, and binary) to compensate for LHC-CERN power consumption: comparative study. *Geothermal Energy*, *5*(17). https://doi.org/10.1186/s40517-017-0074-z

Energievergelijk (n.d.). *Netbeheerders Nederland (stroom en gas)*. [online] Energievergelijk. Available at: <https://www.energievergelijk.nl/onderwerpen/netbeheerders/> [Accessed 28 September 2023].

Ennatuurlijk (n.d.). *Warmtenet Leeuwarden*. [online] Ennatuurlijk. Available at: <https://ennatuurlijk.nl/thuis/in-jouw-buurt/warmtenet-leeuwarden/> [Accessed 29 September 2023].

Bergamo Dos Santos, P. E. (2016). Urbanization and climate change - Buildings and GHG. https://doi.org/10.13140/RG.2.1.2147.3686

Fallah, M., Ghiasi, R. A., & Mokarram, N. H. (2018). A comprehensive comparison among different types of geothermal plants from exergy and thermoeconomic points of view. *Thermal Science and Engineering Progress*, 5, 15–24. https://doi.org/10.1016/j.tsep.2017.10.017

FEA (2023). *Regionale Energie Strategie Flevoland*. [online] Flevolandse Energieagenda. Available at: <https://fea.nl/over-res/> [Accessed 26 September 2023].

Felli, R. (2015). Environment, not planning: the neoliberal depoliticisation of environmental policy by means of emissions trading. *Environmental Politics*, 24(5), 641–660. https://doi.org/10.1080/09644016.2015.1051323

Fridleifsson, I.B., Bertani, R., Huenges, E., Lund, J.W., Ragnarsson, Á., & Rybach, L. (2008). The possible role and contribution of geothermal energy to the mitigation of climate change. *IPCC scoping meeting on renewable energy sources: Proceedings,* 59-80. *Https*://www.researchgate.net/publication/284685252

Ganz, B., Schellschmidt, R., Schulz, R., & Sanner, B. (2013). Geothermal Energy Use in Germany. *European Geothermal Congress 2013 Pisa, Italy.* Available at: http://www.geothermal-energy.org/pdf/IGAstandard/EGC/2013/EGC2013_CUR-13.pdf

GeoGraphixs (n.d.). *De Zuidwal Vulkaan*. [online] GeoGraphixs. Available at: <https://www.geographixs.com/zuidwal-vulkaan.html/> [Accessed 16 June 2022].

Geothermie Nederland. (n.d.). *Wetgeving en vergunningen*. [online] Geothermie Nederland. Available at: <https://geothermie.nl/themas/wetgeving-en-vergunningen/> [Accessed 2 November 2023].

González-Eguino, M. (2011). The importance of the design of market-based instruments for CO2 mitigation: An AGE analysis for Spain. *Ecological Economics 70(12).* 2292-2302. https://doi.org/10.1016/j.ecolecon.2011.05.023

Henze, V. (2019). *Clean Energy Investment Exceeded $300 Billion Once Again in 2018*. [online] BloombergNEF. Available at: <https://about.bnef.com/blog/clean-energy-investment-exceeded-300-billion-2018/> [Accessed 26 May 2022].

IHA. (2022). *A brief history of hydropower*. [online] International Hydropower Association. Available at: <https://www.hydropower.org/iha/discover-history-of-hydropower/> [Accessed 14 July 2022].

IRENA. (2017). *Renewable energy: A key climate solution*. [online] International Renewable Energy Agency. Available at: <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_A_key_climate_solution_2017.pdf?la=en&hash=A9561C1518629886361D12EFA11A051E004C5C98/> [Accessed 16 May 2022].

IRENA. (2022a). *Technologies*. [online] International Renewable Energy Agency. Available at: <https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Technologies/> [Accessed 22 May 2022].

IRENA. (2022b). *Investment trends*. [online] International Renewable Energy Agency. Available at: <https://www.irena.org/Data/View-data-by-topic/Finance-and-Investment/Investment-trends/> [Accessed 22 May 2022].

IRENA (2022c). *Renewable Power Generation Costs in 2021*. [online] International Renewable Energy Agency. Available at: <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8/> [Accessed 26 May 2022].

Jharap, G., van Leeuwen, L., Mout, R., van der Zee, W., Roos, F., & Muntendam-Bos, A. (2020). Ensuring safe growth of the geothermal energy sector in the Netherlands by proactively addressing risks and hazards. *Netherlands Journal Of Geosciences*, *99*. https://doi.org/10.1017/njg.2020.3

Kiilto Ventures (n.d.) *We invest in early-stage startups that future-proof the built environment.* [online] Kiilto Ventures. Available at: <https://kiiltoventures.com/> [Accessed 11 November 2023].

Kukkonen, I. T. (2000). Geothermal Energy in Finland. *Proceedings World Geothermal Congress 2000, Kyushu.* Available at: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2000/R0778.PDF.

Liander. (n.d). *Liander investeert in Friesland*. [online] Liander. Available at: <https://www.liander.nl/capaciteit-stroomnet/investeringfriesland/> [Accessed 28 September 2023].

Limberger, J., Boxem, T., Pluymaekers, M., Bruhn, D., Manzella, A., Calcagno, P., Beekman, F., Cloetingh, S., & van Wees, J. D. (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renewable and Sustainable Energy Reviews* 82, pp. 961–975). https://doi.org/10.1016/j.rser.2017.09.084

Mazaheri, M., Bonnín Roca, J., Markus, A. & Walrave, B. (2022). Market-based instruments and sustainable innovation: A systematic literature review and critique. *Journal of Cleaner Production 373*. 133947. https://doi.org/10.1016/j.jclepro.2022.133947.

Martens, P., & Rotmans, J. (2005). Transitions in a globalising world. *Futures*, *37*(10), 1133–1144. https://doi.org/10.1016/j.futures.2005.02.010

Martínez, E., Sanz, F., Pellegrini, S., Jiménez, E. & Blanco, J. (2009) Life cycle assessment of a multi-megawatt wind turbine. *Renewable Energy*, 34(3). 667-673. https://doi.org/10.1016/j.renene.2008.05.020.

Mijnbouwwet (2002). *Mijnbouwwet*. [online]. Overheid Wettenbank. Available at: <https://wetten.overheid.nl/BWBR0014168/2022-03-05/> [Accessed 16 Oktober 2023].

Mijnlieff, H., Ramsak, P., Lako, P., in 't Groen, B., Smeets, J., & Veldkamp, H. (2013). *Geothermal energy and support schemes in The Netherlands.* [online]. TNO Utrecht. Available at: <https://www.nlog.nl/sites/default/files/egc-2013%20geothermal%20energy%20and%20support%20schemes%20in%20the%20netherlands.pdf/> [Accessed 11 Oktober 2023].

Millstein, D., Dobson, P., and Jeong, S. (2020). The Potential to Improve the Value of U.S. Geothermal Electricity Generation Through Flexible Operations.. *Journal of Energy Resources Technology, 143(1):* 010905. https://doi.org/10.1115/1.4048981

Mitchell, J. K., & Green, R. A. (2017). Some induced seismicity considerations in geo-energy resource development. *Geomechanics for Energy and the Environment*, *10*, 3–11. https://doi.org/10.1016/j.gete.2017.01.001

Moriarty, P., Honnery, D. (2011). Renewable Energy: Too Little, Too Late? *Rise and Fall of the Carbon Civilisation.* 79-101. https://doi.org/10.1007/978-1-84996-483-8_5

Moska, R., Labus, K., & Kasza, P. (2021). Hydraulic fracturing in enhanced geothermal systems—field, tectonic and rock mechanics conditions—a review. In *Energies* 14 (18). 5725 https://doi.org/10.3390/en14185725

NAM (2020). *Mijlpaal: start bouw van het zonnepark.* [online] NAM. Available at: <https://www.nam.nl/nieuws/2020/mijlpaal-start-bouw-van-het-zonnepark.html/> [Accessed 21 November 2023].

Okoroafor, E. R., Williams, M. J., Gossuin, J., Keshinro, O., & Horne, R. N. (2022). Fracture roughness considerations in comparing CO2 and water as enhanced geothermal system working fluids. *Geothermics*, *106*. 102578 https://doi.org/10.1016/j.geothermics.2022.102578

Peer, W. (2023). *Minister De Jonge maakt einde aan volplanten van weilanden met zonnepanelen: 'Dat moet je echt niet willen'.* [online] Algemeen Dagblad. Available at: <https://www.ad.nl/politiek/minister-de-jonge-maakt-einde-aan-volplanten-van-weilanden-met-zonnepanelen-dat-moet-je-echt-niet-willen~a64a89e11/> [Accessed 27 November 2023].

Platform Geothermie (2018). *Master Plan Geothermal Energy in the Netherlands: A broad foundation for sustainable heat supply*. [online] Platform Geothermie. Available at: <https://geothermie.nl/images/bestanden/Masterplan_Aardwarmte_in_Nederland_ENG.pdf /> [Accessed 21 June 2022].

RES (2022). *Nationaal Programma Regionale Energiestrategie - Regionale Energiestrategie*. [online] Regionale Energiestrategie. Available at: <https://www.regionale-energiestrategie.nl/home/default.aspx> [Accessed 2 June 2022].

RES Fryslân (2021). *Regionale energie strategie Fryslân.* [online] RES Fryslân. Available at: <https://www.resfryslan.frl/wp-content/uploads/2021/04/RES-1.0_RES-FRYSLÂN_NL_DEF_digitaal.pdf> [Accessed 2 June 2022].

RES Fryslân (2022). *Systeemstudie Fryslan* [online] RES Fryslân. Available at: <https://www.resfryslan.frl/wp-content/uploads/2022/05/Rapport-Systeemstudie-Frysl%C3%A2n.pdf/> [Accessed 12 November 2023].

Rosenow, J., Cowart, R., & Thomas, S. (2019). Market-based instruments for energy efficiency: a global review. *Energy Efficiency*, *12*(5), 1379–1398. https://doi.org/10.1007/s12053-018-9766-x

RVO (2021). *Ondiepe bodemenergie - open systemen*. [online] Rijksdienst Voor Ondernemend Nederland. Available at: < https://www.rvo.nl/onderwerpen/bodemenergie-aardwarmte/open-systemen/> [Accessed 31 Oktober 2023].

RVO (2023). *Windenergie op land.* [online] Rijksdienst voor Ondernemend Nederland. Available at: <https://www.rvo.nl/onderwerpen/windenergie-op-land/> [Accessed 27 November 2023].

Rijksoverheid (n.d.). *Heb ik een vergunning nodig om zonnepanelen op mijn dak te plaatsen?*. [online] Rijksoverheid. Available at: <https://www.rijksoverheid.nl/onderwerpen/energie-thuis/vraag-en-antwoord/heb-ik-een-vergunning-nodig-om-zonnepanelen-op-mijn-dak-te-plaatsen/> [Accessed 7 November 2023].

Salet, W. G. M. (2018) Five Paradigms of Institutional Planning. In: Public Norms and Aspirations: The Turn to Institutions in Action (1st ed.). *Routledge*. https://doi.org/10.4324/9781315111599

Sayed, E., Wilberforce, T., Elsaid, K., Rabaia, M., Abdelkareem, M., Chae, K., & Olabi, A. (2021). A critical review on environmental impacts of renewable energy systems and mitigation strategies: Wind, hydro, biomass and geothermal. *Science Of The Total Environment*, *766*, 144505. https://doi.org/10.1016/j.scitotenv.2020.144505

Ryberg, D. S., Caglayan, D. G., Schmitt, S., Linßen, J., Stolten, D., & Robinius, M. (2019). The future of European onshore wind energy potential: Detailed distribution and simulation of advanced turbine designs. *Energy*, 182, 1222–1238. https://doi.org/10.1016/j.energy.2019.06.052

Singh, M., Mahmoodpour, S., Ershadnia, R., Soltanian, M. R., & Sass, I. (2023). Comparative study on heat extraction from Soultz-sous-Forêts geothermal field using supercritical carbon dioxide and water as the working fluid. *Energy*, *266*. https://doi.org/10.1016/j.energy.2022.126388

Spruijt, J. (2015). *Wat levert een Zonneweide per ha op*? [online] Application Center for Renewable Resources. Available at: <https://edepot.wur.nl/336567/> [Accessed 12 November 2023].

TenneT (2022). *TenneT biedt extra ruimte voor windparken en zonneweides in vier provincies*. [online] TenneT. Available at: < https://www.tennet.eu/nl/nieuws/tennet-biedt-extra-ruimte-voor-windparken-en-zonneweides-vier-provincies /> [Accessed 28 September 2023].

ThinkGeoEnergy (n.d.). *What is Geothermal Energy?*. [online] ThinkGeoEnergy. Available at: <https://www.thinkgeoenergy.com/geothermal/what-is-geothermal-energy//> [Accessed 21 September 2023].

ThinkGeoEnergy (2022). *ThinkGeoEnergy's Top 10 Geothermal Countries 2022 – Power Generation Capacity (MW)?*. [online] ThinkGeoEnergy. Available at: <https://www.thinkgeoenergy.com/thinkgeoenergys-top-10-geothermal-countries-2022-power-generation-capacity-mw//> [Accessed 11 November 2023].

UNFCCC (2015). *Paris agreement.* [online] United Nations. Available at: <https://unfccc.int/sites/default/files/english_paris_agreement.pdf/> [Accessed 7 May 2022].

Victanis (2019). *Market Review of Renewable Energy in France*. [online] Victanis. Available at: <https://www.victanis.com/renewable-energy-france-market-review//> [Accessed 9 November 2023].

Westlake, S., John, C. H. D., & Cox, E. (2023). Perception spillover from fracking onto public perceptions of novel energy technologies. *Nature Energy, 8*. 149-158. https://doi.org/10.1038/s41560-022-01178-4

Wind Energy – The Facts (2009). *Operation and Maintenance Costs of Wind Generated Power.* [online] Wind Energy – The Facts. Available at: < https://www.wind-energy-the-facts.org/operation-and-maintenance-costs-of-wind-generated-power.html/> [Accessed 8 November 2023].

Windpark Fryslân (n.d.) *Energy for 500,000 Households.* [online] Windpark Fryslân. Available at: <https://www.windparkfryslan.nl/the-wind-farm/> [Accessed 7 November 2023].

Zarrouk, S. J., & Moon, H. (2014). Efficiency of geothermal power plants: A worldwide review. *Geothermics, 51*. 142–153. https://doi.org/10.1016/j.geothermics.2013.11.001

Zonnestroom Nederland (n.d.). *Zonneveld of zonneweide aanleggen: hoe zit het met de vergunning?* [online] Zonnestroom Nederland. Available at: <https://www.zonnestroomnederland.nl/kennisbank/zonneveld-of-zonneweide-aanleggen-hoe-zit-het-met-de-vergunning/> [Accessed 7 November 2023].

Appendix 1: Interview form

Questions before the interview	- **Is it okay if the interview is recorded?** - **If your name is mentioned, permission will be asked before posting the thesis, else the interview is anonymous.**
Introduction	- **The interviewer introduces themselves and the thesis** - **The interviewee is asked to introduce themselves, with emphasis on their relation to geothermal energy.**
Questions regarding geothermal energy	- **Have you considered geothermal energy as an alternative source of power?** - **Do you think geothermal energy has potential to be a contributor to the energy in your region?** - **What do you think are the biggest hurdles to overcome with regards to successful geothermal application?** - **What could the benefit of geothermal be, compared to other methods?**
Questions regarding Frisia	- **What (do you expect) is the public perception towards geothermal energy?** - **Does the risk of earthquakes involved with geothermal pose an obstacle in Frisia?**
Other energy questions	- **Why do you think the focus of the energy transition lies mostly on solar and wind power?** - **Have there been other methods of power generation which you have considered?**
Conclusions	- **Is there anything you would like to add?** - **Thank you.**

Appendix 2: Full Interview Results

Questions regarding geothermal energy

Have you considered geothermal energy as an alternative source of power?

The interviewees had varying degrees of involvement of geothermal energy within their plans for energy transition. Each of the interviewees did mention at least considering geothermal heating as an option within the energy framework of their respective region. However, geothermal power was not as prevalent. Between the respondents there was a varying degree of experience and knowledge on geothermal power. None of the respondents had geothermal power as a component of their plans for energy within their region, although two of them were in the process of conducting research to find if geothermal power is an option for them.

Do you think geothermal energy has potential to be a contributor to the energy in your region?

Six out of seven interviewees considered geothermal as a potential option, but primarily in heating. Only one of the respondents did consider geothermal power as an option, and was actively researching the viability of geothermal power in their region. Other respondents either had not considered geothermal power as an option, or dismissed it due to it being too expensive.

What do you think are the biggest hurdles to overcome with regards to successful geothermal application?

The answer to this question was clear in all seven interviews: The cost. More specifically, the high up-front investment levels, combined with relatively high risk of the investment not paying off due to uncertainties involving the drilling process. Besides, this process takes a few years. The interviewees considered solar and wind preferable since they require smaller investments with much more certainty of their yield.

What could the benefit of geothermal be, compared to other methods?

The respondents agreed that the reliability of geothermal energy could definitely outweigh the benefits of solar and wind energy, since those methods are dependent on weather, among other factors. One interviewee also mentioned the added benefit of combining geothermal heating with geothermal power, which would combine well, especially in urban or industrial areas where the need for both is higher.

Questions regarding Frisia

In the province bordering Frisia to the east there have been earthquakes in recent years. These earthquakes are caused by gas extraction in the region. This lead to resistance from locals and, after a while, the government promised to scale down and eventually stop extraction altogether. With this political and social issue fresh in mind, the people of Frisia may also be opposed to geothermal in Frisia, as there is also a risk of earthquakes. The public perception and support is vital, but may therefore be influenced by this risk.

What (do you expect) is the public perception towards geothermal energy?

Three interviewees shared they had held gatherings with locals about their energy plans. In those gatherings, information was shared and opinions of the local inhabitants where shared as well. In two of the meetings, the topic of geothermal energy did come up, and the people were largely positive about the technology. Therefore these interviewees would consider the public perception to be positive. The other interviewees did agree with this idea, stating that most people agree with innovations if the benefits outweigh the costs.

Does the risk of earthquakes involved with geothermal pose an obstacle in Frisia?

Most interviewees expected this question, as the risk of earthquakes is an important topic in the neighbouring province. Five interviewees had not talked about it, since with geothermal heating specifically, there is no risk of earthquakes. However, one interviewee did talk about this during one of the aforementioned gatherings, and explained what the risk was. The public were convinced that the risk of earthquakes was minimal, and thus this would not be an obstacle. In fact, the public was more interested in the best option with regards to energy security and cost. The other interviewees also expected this fear to not be an issue, as the risk is considerably lower than in Groningen. Besides, one interviewee added, earthquakes in geothermal can be prevented by careful planning and by not taking unnecessary risks.

Other energy questions

Most of the respondents answered that they worked mostly with solar and wind energy as well, since these sources are easy to access and scalable, allowing them to expand in smaller steps, which makes transition easier. Besides there is a lot more expertise on these sources compared to any other method, including regional expertise, which adds another factor benefitting the locals. Besides wind and solar energy, some interviewees said they used geothermal heating, especially in urban areas. Another common method seemed to be hydrogen gas, although that was still based in plans.

Why do you think the focus of the energy transition lies mostly on solar and wind power?

All seven interviewees made use of solar and wind as well, or had the ambition to do so. As the two biggest benefits they gave the scalability of wind and solar, but especially solar, and the variety of uses. Scalability is a benefit since it allows them to increase sustainable energy shares step by step. Another benefit that was mentioned is that solar wind energy have a variety of uses. For example, windmills can be placed in a wind park, where multiple windmills are close to each other and far away from housing, but windmills can also be placed individually at industrial sites or farms. Similarly for solar, where many solar panels can be placed together on a field, but they can also be placed on individual buildings. Besides, one interviewee added that there was much more experience on solar and wind energy. They had multiple partners associated with those technologies, which make them more accessible.

Have there been other methods of power generation which you have considered?

Besides wind, solar and geothermal, a few respondents were interested in hydrogen gas as a source of power. Although this was in all cases in an exploratory phase, the interest was mostly its similarity to natural gas. This could potentially allow for the same infrastructure that is used for natural gas now to be used for hydrogen gas. Another interesting option that was brought up was the Tidal Kite, a device which used the energy in tides, as a kind of underwater wind energy. Since Frisia has a relatively sizable coastline, tidal power could also have a place in the future.

Conclusions

Finally, the interviewees were asked if they themselves had anything to add, something which they hadn't felt the right question for or something they think is interesting or relevant to the topic.

All of the interviewees also expressed their interest in the technology and its development, which shows that the representatives of energy governing in Frisia are looking for ways to reduce their impact on climate change.