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Drivers and barriers to deep geothermal energy in the Netherlands: what are the implications of government policy?

Dissertation for the completion of MSc Integrated Resource Management

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Abstract

This dissertation looks into the drivers and barriers to geothermal energy and what the influence is of the governmental support for geothermal energy in the Netherlands. The main drivers of geothermal energy are its independence from fossil fuels and with that its environmental friendliness. However, the existence of natural gas as an established and less costly fuel and the high investment costs combined with the risk profile for geothermal energy constrain the growth of this energy source. The government has introduced different policy measures, such as the SDE+ subsidy scheme, the SEI guarantee scheme, and the licencing structure for exploration and production that have an influence on the growth geothermal energy. The implications of these policies for the geothermal industry will be discussed. Based on the remaining barriers to geothermal energy the potential effect of possible new policies aimed at lowering those barriers will be studied. The policies considered are building plants with public money, the set up of a research fund, a change in the way gas is currently priced for industrial consumers and the introduction of a long term guarantee scheme. As the geothermal energy industry is still in the infancy stage, it remains to be seen whether the existing and possible future policy measures can help overcome the barriers to geothermal energy.

Acknowledgements

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A special thanks to Victor van Heekeren of Platform Geothermie for all his insights in the Dutch geothermal industry, his help with the content of my work and who introduced me to ECN.
Then I'd like to thank Sander Lensink of ECN for inviting me to several meetings which gave me a deeper understanding of the SDE+ subsidy scheme and who was willing to gave his insights on that chapter.
Furthermore, a thank you to the operators of geothermal plants and others related to the industry that were willing to share information with me.
The personal contact with all of these people provided valuable information that led to an understanding that could not have been gained if written documentation alone would have been used, for which I am very grateful.

Carolien Kraan

Statement of Originality

I hereby delare that this dissertation has been composed by me and is based on my own work.

Carolien Kraan

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1 Introduction

1.1 A description of geothermal energy in the Netherlands

Definition of geothermal energy The adjective geothermal is derived from the Greek nouns $\gamma\eta$ (*ge*) meaning *Earth* and $\theta\epsilon\rho\mu\eta$ (*therme*) meaning *heat*, as geothermal energy is energy derived from the heat that is stored in the interior of the Earth. Our planet is generally modelled as a sphere made up of a rocky mantle around a hot iron core and covered by a thin crust, see figure 1.1. While the crust is relatively cool, the temperature at the core has been estimated to reach approximately 5700 K [87][7]. The heat stored in the Earth has two sources; part of it is the primordial heat that is left over from the planet's formation, and the other part is caused by ongoing radioactive decay of the unstable isotopes ^{40}K (potassium), ^{232}Th (thorium), ^{235}U and ^{238}U (uranium). The relative share of each of these heat sources is hard to determine and quite controversial, with the percentage of decay heat estimated to be ranging from 18% to 80% [44].

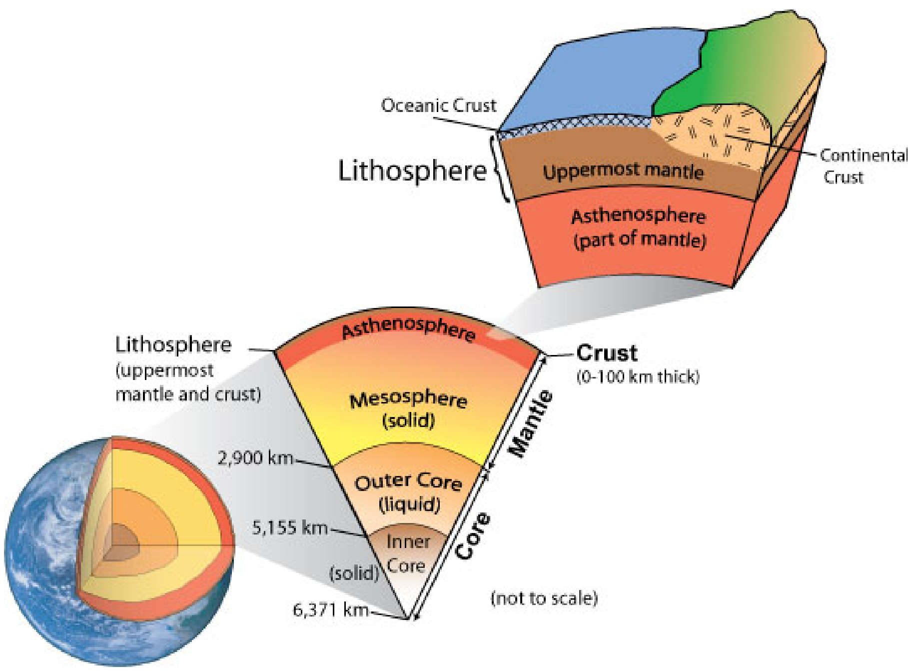

Fig. 1.1. Model of the interior of the Earth including the core, the mantle, and the crust. Source: [80]

Convection and conduction in the mantle and crust enable heat transfer to allow planetary cooling. The Earth's crust is between 5 and 10 km thick underneath the oceans, while under the continental shelves it reaches a depth of 30 to 50 km. Thus far, it has not yet been possible to reach the mantle, because of the high temperatures and pressures deep within the crust. In fact, the deepest artificial point on Earth can be found at the bottom of the Kola Superdeep Borehole in Russia, which has a depth of 12,262 m, but reaches down no further than a third of the Baltic continental crust [11].

Worldwide the geothermal gradient has an average of 25° C/km, meaning that for every km depth the measured temperatures will be 25° C higher. This world average can be much higher in hotspot areas though, such as Iceland where geothermal gradients of 200° C/km have been measured [46]. In such high enthalpy (temperature) areas, geothermal energy has been used for the generation of electricity and the direct application of heat for a long time. Because in such places higher temperatures can be found closer to the surface, extracting the heat is easier and economically more attractive there. This is because drilling makes up a considerable share of the total costs of a geothermal well. However, over the last few decades geothermal energy has also been explored in low enthalpy (temperature) regions, such as Australia, Germany, Austria and France. More recently, it has also been extracted in the Netherlands.

Geothermal energy technologies The European Union (EU) Renewable Energy Directive defines geothermal energy as the "energy stored in the form of heat beneath the surface of the solid earth" [16][1]. In order to extract the energy from the underground, a fluid is used that takes the heat up to the surface, where it can be used for electricity generation or heating purposes. In the more conventional case, a well is drilled into an underground aquifer and the hot brine is pumped towards the surface. In many cases not one but two wells are drilled: one for production and one for reinjection, see figure 1.2. Though this significantly increases the costs of the overall project, the drilling being a major expense, it carries several advantages as well.

First of all it allows for a direct discharge of the waste water. Draining the effluent has two major problems: first of all there is the sheer quantity of it, and secondly the water from aquifers is often contaminated with salts and other pollutants, and can therefore not be discharged on surface waters without treatment. A major advantage of the reinjection well is that it allows for the replenishment of the aquifer. By maintaining the water table and pressure within the underground water body the lifetime of the geothermal well can be significantly prolonged.

Though in low enthalpy regions the water temperatures will generally be lower, the same technology has been used as in many high enthalpy regions. This method of geothermal energy extraction is well established, but very dependent upon the local geology. Not only is there the requirement of the presence of an aquifer, it's depth, temperature, thickness, porosity and permeability[2] determine whether it is suitable as a geothermal energy resource. Furthermore, the aquifer must be "sufficiently continuous horizontally" [40]. The specific combination of these characteristics will determine whether the energy is commercially exploitable.

If the limiting factor is the low permeability of the aquifer, it may be possible to stimulate the well by hydraulic stimulation. In this process water under high pressure is forced into the well to enhance existing fractures in the rock, thereby improving the permeability. This is not unlike the hydraulic fracturing, or *fracking* used for the extraction of shale gas.

[1] This is not limited to planetary heat, but includes geothermal, or ground source, heat pumps. These operate at shallow depths, where the subsurface temperature is highly dependent upon the seasons, instead making use of indirect solar energy.

[2] "Permeability is the easy with which the water can pass (or be pumped) through an aquifer" [40].

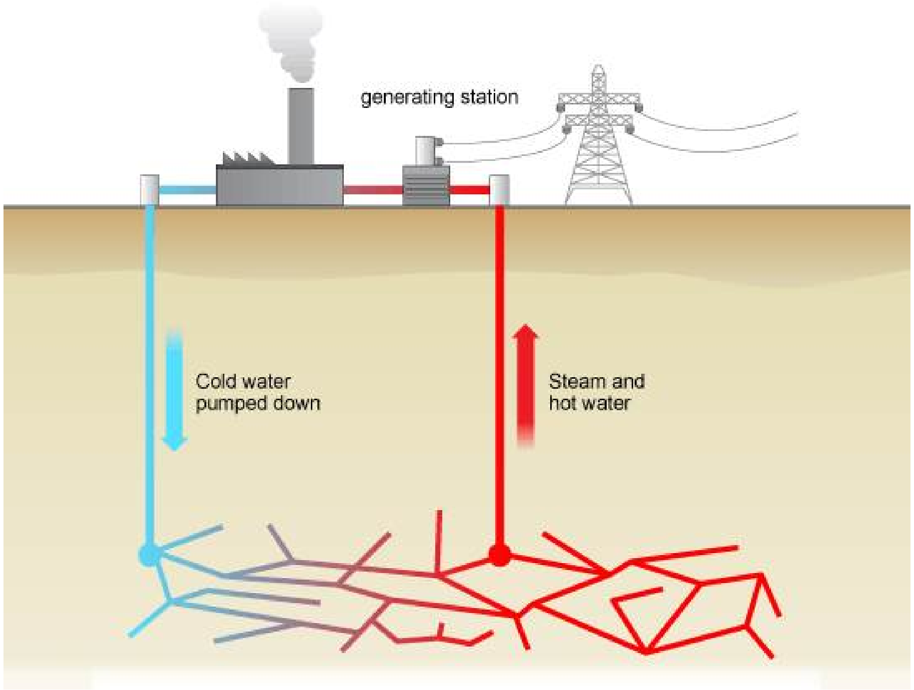

Fig. 1.2. A geothermal doublet. Turbines are used for electricity generation and heat exchangers to transfer the energy to the heat distribution network. Source: [10]

Geothermal plants making use of hydraulic stimulation are called Enhanced Geothermal Systems (EGS).

Also included in the category EGS plants are those where no aquifer is available, but where the energy comes from the Hot Dry Rock (HDR). With HDR, not only the permeability must be artificially improved, also the fluid carrying the heat must be supplied from external sources. The advantage of this technology is that the extraction of geothermal energy does not place many conditions on the characteristics of the subsurface and seems to be feasible anywhere in the world. However, EGS plants are still in the development and testing phase and seismic activity as a result of the fracturing of the rocks has resulted in a loss of public support. This happened in Basel, Switzerland, where the induced seismisity resulted in the preliminary shut-down of the plant [63].

Geothermal energy in the Netherlands In the Netherlands most of the potential for deep geothermal energy can be found in the west and north of the country. There is also considerable potential in the province of Brabant, and local conditions elsewhere could be supportive of geothermal energy as well. For a map of the temperature distribution at 2 km depth and the regions considered most suitable for geothermal energy, see figure 1.3. More information on the regions which are suitable for geothermal energy can be found in [45]. Geothermal energy is considered to be *deep* if it has well depths of more than 500 m; the boundary from which the Mining Act is applicable.

As stated before, the Netherlands is a country of low-enthalpy geothermal energy, which implies the well produces water of relatively low temperature. In the Netherlands, the surface temperature has an annual average of 10° C and the geothermal gradient finds itself between 25° C/km and 40° C/km [47]. The average thermal gradient in the Netherlands is 31.3° C/km [12], slightly higher than the world average[3]. Because the Netherlands is a country of low enthalpy, though a well depth of 500 m is enough to give it the name geothermal energy, in practice economically attractive extraction will take place from aquifers between 1500 and 4000 meters deep, where the temperature ranges from 50°C to 150°C.

Until now, because of these moderate water temperatures the energy is not converted into electricity, but the heat is used directly. Because of the high, very localised heat demand in greenhouses, most of the completed projects are providing heat for the cultivation of plants, flowers, vegetables and fruit. However, the geothermal heat is also suitable for district heating, as is done in Heerlen and The Hague. Currently nine doublets have been drilled; a doublet is the system consisting of a production and reinjection well. Eight of these doublets have a depth between 1600 and 2900 m and withdraw water from sandstone aquifers [82]. The ninth, in Heerlen, is a special mine water project, where water is pumped up from a system of old coal mines with a maximum depth of 750 m to serve as district heating of offices, shops, schools, homes, etc. [60].

Last year the annual production of geothermal energy is estimated to lie around 1 Petajoule (PJ)[4]. However, different studies have shown that because of the presence of many sedimentary layers containing hot water and having good potential flow properties the potential for geothermal energy is much bigger than that [72]. According to [45] the total techno-economical potential reaches up to 85,000 PJ, which compares to about 70% of the ultimate recoverable energy from the Slochteren gas field in Groningen. The geothermal energy production in 2020 has the potential to be 10 to 15 Petajoule (PJ) [48] [19]. Furthermore, though EGS technology will most likely not play a role in the next few years, it is expected that in 2050 it should be possible to provide 20% of total energy from geothermal energy sources deeper than 4 km where no aquifers are present [41].

[3] More information on the temperature at different depths in the subsurface can be found in [12].
[4] Victor van Heekeren, personal communication, August 2013

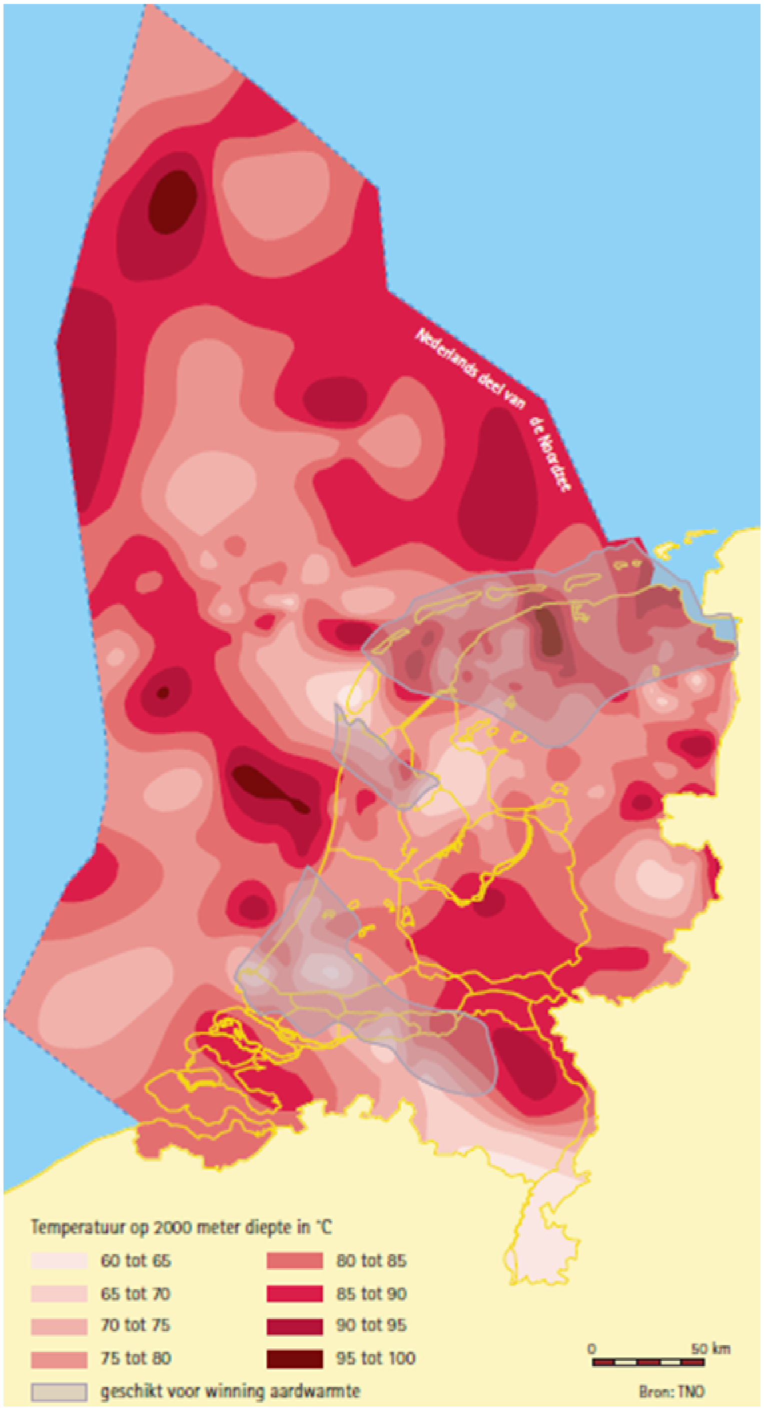

Fig. 1.3. This map shows the temperature of the subsurface at a depth of 2000 m in the Netherlands and the Dutch Exclusive Economic Zone (EEZ) of the North Sea. The grey areas are those that are generally perceived to be most suitable for geothermal energy. Source: [65]

1.2 My research

Research question The first purpose of this research is to determine what the driving forces behind geothermal energy are and how they influence the industry. These drivers and barriers can be subdivided in several categories. First of all there are the advantages and disadvantages that are intrinsic to geothermal energy production and usage. In addition there are driving forces that are caused by local circumstances, such as the geology and the market; those that influence the Dutch situation will be discussed. The third source of drivers is artificial; these are caused by policy that aims to promote geothermal energy. Not only existing policy will be analysed, also possible future policies will be examined. This is done to achieve the second aim of this research: to analyse the impact of new policies that have the potential to promote geothermal energy.

In order to come to any conclusions about the geothermal energy industry and what influences it, the following question must be answered:

What are the implications of government policies meant to encourage geothermal energy in the Netherlands?

In order to answer this question, the following subquestion will be addressed:

- **What are the intrinsic advantages and disadvantages of geothermal energy?**
- **What drives the demand for geothermal energy in the Netherlands?**
- **What influences the Dutch production of geothermal energy?**
- **How do exisiting policies influence the geothermal energy industry?**
- **How could possible future policies affect geothermal energy?**

This research concerns deep geothermal energy in the Netherlands over the next few years. Both the conventional technology and EGS will be included for the production of both geothermal heat and electricity, but the focus will lie on the current applications, as EGS is not yet established and there are not yet clear plans for its use. The policies included are those which are meant to have a direct effect on the production of geothermal energy.

This is a qualitative research which focusses on the different kinds of impacts the drivers have on this energy source. Its purpose is not to quantify the impact of these drivers and barriers. Instead, it is meant to define those factors that play the most important roles, and determine *how* they influence the growth of the geothermal energy industry as a whole.

Methodology This research focusses on the multitude of drivers in the geothermal energy industry and what influence they have. It is important to have this knowledge before new policies that aim to promote geothermal energy are designed, so as to have an understanding of the different ways in which geothermal energy could be encouraged. For finding and analysing these driving forces, it is important to know what environment geothermal energy finds itself in the Netherlands. This means taking into consideration, among others, the environmental, economical, social, political, technological, and legal aspects of the geothermal energy industry.

A desk study was done to gather most of the necessary information. Most of the academic research done on geothermal energy in the Netherlands is directly related to the geology of the underground[5]. However, more recently two other master's students have finished their dissertation on other aspects concerning geothermal energy; Gonzalez [37] has written on the sustainability of Dutch geothermal systems and Straathof [88] has modelled the cost of geothermal energy in the Netherlands. The main sources of information where therefore sought outside of academia; instead reports from research institutions, as well as written documentation from the government and government agencies were predominantly used.

In order to gain a deeper understanding of the geothermal industry, different (key) players in the Dutch geothermal energy industry have been contacted. This happened on a multitude of occasions and in a variety of ways. On April 17 I attended Geothermal Update 2013 in Amsterdam, a conference organised by T&A Survey, a company specialised in subsurface research. There were national and international speakers that covered a variety of topics, such as individual projects, financing, and insurance of geothermal systems. Furthermore, at the invitation of the Energieonderzoek Centrum Nederland (ECN; *Energy Research Centre of the Netherlands*) I attended multiple meetings concerning the subsidy scheme SDE+.

These doors were opened after a telephone conversation with Victor van Heekeren, chair of Platform Geothermie (*Geothermal Energy Platform*), a non-profit organisation which objective it is "to foster the development of geothermal energy in the Netherlands" [71]. After this initial call, several more telephone conversations have been held with both Mr. van Heekeren and Mr. Lensink from ECN. Other people contacted for information were operators of geothermal plants. Most contact has been informal in nature, only with the operators semi-structured interviews were held for the purpose of understanding their experiences with geothermal energy.

Structure The results of this research will be presented below in a report that has been split in three parts. The first part concerns the driving forces that influence the geothermal energy industry, and that are independent from government policy. The intrinsic drivers of geothermal energy, as well as those that characterise the Dutch situation will be examined, answering the first three of the subquestions posed earlier:

- What are the intrinsic advantages and disadvantages of geothermal energy?

[5] See for example The Netherlands Journal of Geosciences, which has dedicated a large share of the December 2012 issue to geothermal energy.

- What drives the demand for geothermal energy in the Netherlands?
- What influences the Dutch production of geothermal energy?

In the second part three different policies that are currently in effect will be analysed for their inflluence on the Dutch geothermal energy industry. These policies are the subsidy scheme SDE+, the issuance of exploration and production licences, and the SEI guarantee scheme. These are the most important policies affecting the geothermal industry, and this will answer the fourth subquestion:

- How do exisiting policies influence the geothermal energy industry?

The third part addresses a range of different policies that could potentially lead to a higher demand and a higher production of geothermal energy in the Netherlands, and what implications these policies carry. They include the building of plants with public money, the creation of a public fund for research, the abolition of the degressive gas pricing system for large industrial consumers, and the introduction of a long term guarantee scheme. This will answer the last subquestion:

- How could possible future policies affect geothermal energy?

The last section will then combine the main points that have been discussed in these three parts in order to reach an overall conclusion regarding the effects of government policy on the geothermal industry in the Netherlands.

2 Part I: The drivers of and barriers to geothermal energy

2.1 What are the advantages and disadvantages of geothermal energy?

Environmental Friendliness A very important driver of geothermal energy is that it is considered to be an environmentally friendly and sustainable energy source, see for example [93][79]. The production of geothermal energy does not require the burning of a fuel other than for the (electric) pumps in the wells. This means that the production of geothermal energy emits very little CO_2 and other greenhouse gases compared to fossil fuels. Much of the total lifetime emissions of a geothermal well will have been emitted in the construction phase. Not only does the drilling require the use of fossil fuel driven drilling rigs, there are also emissions related to the construction of the well casings, the aboveground installation, and infrastructure for heat transportation. However, as Gonzalez has shown, a geothermal system in a Dutch greenhouse can become a net carbon saver within two months of production [37]. In a world that is more and more concerned about the effects of these gases on the climate, this is a major advantage.

The production of geothermal energy also has only a limited effect on other natural resources and the environment. The space requirement aboveground is modest, and consists mainly of the wellheads, the heat exchanger and if necessary, a hydrocarbon separator. Furthermore, next to being clean in use, the close environment of the geothermal installation is hardly affected by noise and visual pollution. The system is silent in operation and does not require a lot of both horizontal and vertical space, see fig 2.1, something that does constrain the use of photovoltaic cells and wind turbines. It is only during the drilling phase, which lasts a couple of months, that the drilling rig can cause visual and audible disturbance to the closely surrounding environment.

Technology Planetary cooling is a stable and continuous process, and as a consequence geothermal energy is a very reliable energy source that can be harvested year round. This makes geothermal energy suitable to serve as a baseload energy source, something that does not apply to many other renewable energy technologies. Furthermore, as the well requires pumps to transport the hot brine to the surface, there is even a certain degree of control in the output of the energy plant.

The technology for the conventional production of geothermal energy can be considered mature; there is a lot of experience with drilling to similar depths from the oil and gas industry and high enthalpy geothermal energy has been exploited for a long time. However, at the same time there is little experience with low enthalpy geothermal energy in the Netherlands. This means that although solutions to issues have been found elsewhere, they could be not applicable due to a different geological structure of the aquifer or they need revision in order to fall within the Dutch laws and regulations. An example of the latter are the new wellheads that needed to be designed for wells where hydrocarbons were dissolved in the water, see section 3.4.

On the other hand the EGS technology is not yet mature. Hydraulic fracturing is a much used method for extracting shale gas in the US, but is considered a controversial

Fig. 2.1. This aerial photograph of the construction site and greenhouses at Van Wijnen Square Crops in Californië, Limburg. Source: [96]

practice in Europe. According to Romain Vernier, the head of the geothermal divison of the French Bureau de Recherches Géologiques et Minières (BRGM; *Geology and Mining Research Agency*), the hydraulic stimulation needed for the production of geothermal energy bears only modest resemblance to fracking; instead of creating new fissures it will reopen those that are clogged by mineral deposits and uses water and acid instead of a mixture of water, sand and chemicals as is done in the shale gas industry[6] [70]. The EGS pilot project in Soultz-sous-Fôrests, which produces sustainable energy drawing on heat sources 4500 to 5000 m deep [14], also made use of this stimulation inducing seismicity with a magnitude of 2.9, which could be felt aboveground [70].

Hydraulic stimulation of the well only needs to happen at the onset and will not have to be repeated during the production phase, according to Vernier [70]. Nevertheless, this practice could lead to public resistance and reduce the social support for geothermal energy. In Groningen, where most of the Dutch onshore gas production takes place, induced seismicity is not uncommon. The last heavier earthquake happened on July 3 of this year. It had a magnitude of 3.0 and within a few hours resulted in more than 260 complaints, mostly of cracks in walls and loose plaster [64]. In a country as densely populated as the Netherlands, it is unlikely that induced seismicity of that scale will not affect citizens. The Nederlandse Aardolie Maatschappij (NAM, *Dutch Oil Company*), the operator of the Slochteren gas field, has the resources to compensate for this damage [61], but it is unlikely that EGS operators are willing to take this risk.

[6] For more information on the use of hydraulic stimulation for geothermal energy versus shale gas, see [32]

2.2 Cost and risk

Improvements of the technology are expected to lead to a cost reduction of approximately 60% for low temperature geothermal energy before the year 2030 [33]. However for now, although less costly than other renewable energy sources, geothermal energy in the Netherlands is still more expensive than if fossil fuels would have been used. As will be discussed later in section 3.2 on the subsidy scheme, ECN advises the government on the tariffs for the different energy technologies based on their exploitation costs. From their calculations it turns out that in the Netherlands geothermal heat installations are among the cheaper technologies [20]. On the other hand, geothermal electricity production still falls in the middle range of costs for energy production.

Other than the costs per unit of energy that a geothermal energy plant will make, it is important to realise *when* these costs have to be made. There are many uncertainties surrounding the construction of a geothermal plant, especially in the preparatory phases, see figure 2.2. As can be seen in the table, many of the characteristics important for the economic viability of the geothermal well are quite uncertain in the early stages and will only become more certain once deep exploration has taken place, i.e. when the well has been drilled.

		Reconnaissance		Surface Exploration		Deep Exploration	
Category	**Parameter**	Uncertainty	Impact	Uncertainty	Impact	Uncertainty	Impact
Resource characteristics	Temperature	Medium	High	Low	Medium	Low	Low
	Flow rate	High	High	High	High	Low	Medium
	Depth	Medium	High	Low	Medium	Low	Low
	Volume	Medium	High	Low	Medium	Low	Low
	Recovery factor	Medium	Medium	Medium	Medium	Low	Low
	Chemistry	Medium	High	Medium	High	Low	Low
Technology	Energy conversion costs	Medium	Medium	Medium	Medium	Low	Low
	Drilling costs	Medium	High	Medium	Medium	Low	Low
	Plant costs	Medium	Medium	Medium	Medium	Low	Low
	Operational costs	Medium	High	Medium	Medium	Low	Low
Logistics	Grid connection costs	Low	Low	Low	Low	Low	Low
	Access roads and supplies	Low	Low	Low	Low	Low	Low
Environmental & social	Reserved areas	Medium	High	Low	High	Medium	High
	Acceptance of exploration	High	High	High	High	Low	Medium
	Acceptance of production	High	High	High	High	Medium	Medium
Market	Energy prices	Medium	High	Medium	High	Medium	High
	Tax and regulations	Low	Medium	Low	Medium	Low	Medium

Low Medium High

Fig. 2.2. This table shows the uncertainties and their impacts in the early stages of construction. Source: [90]

When taking all costs over the lifetime of the geothermal plant in consideration, we can see that a significant share of those costs have to be made in the construction phase. Generally, initial investment costs for geothermal energy are high, whereas the variable costs that come with the actual production of the energy are relatively low. The drilling of the doublet takes up a considerable share of the total project costs. However, as has been shown in figure 2.2, many of the high impact properties of the well are highly uncertain at that stage. This has been a reason for concern within the geothermal energy industry since its beginning [89]. This has also been recognised as an issue in other countries. The French Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME; *Environment and Energy Management Agency*), has summarised this situation in figure 2.3. It shows that approximately half of the costs over the lifetime of the project will have been made before drilling has been finished; it is also until this stage that the project has a moderate to high risk of failure.

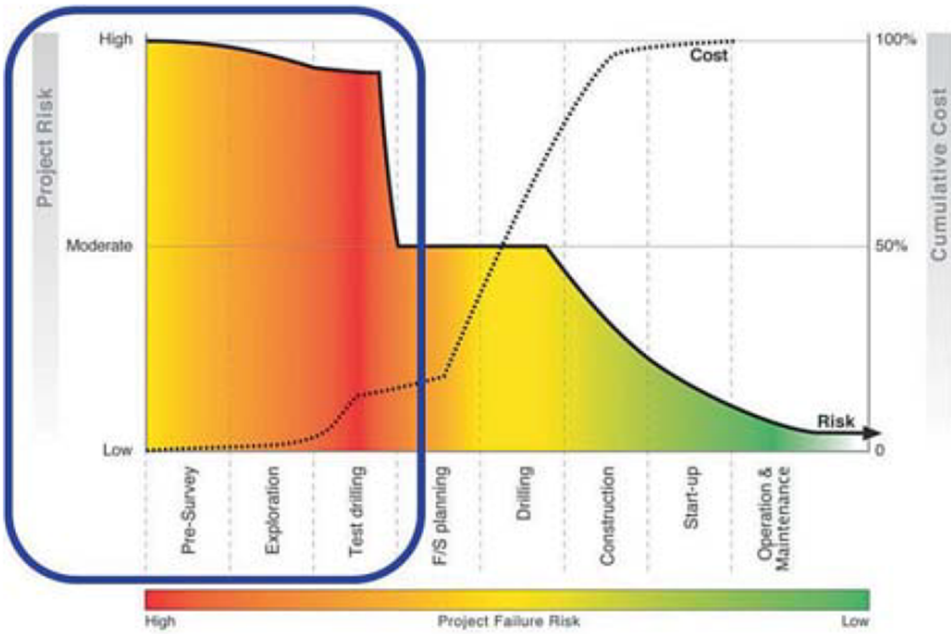

Fig. 2.3. This graph shows the structure of the costs versus the risk during the construction phase of the project. Source: [1]

Because it remains unclear what the true capacity of the well is before drilling has finished, the investment in a geothermal well is a high risk one. This is clearly a disadvantage for the investors, as they will have to put resources into the construction of the well before they know whether this investment will pay off. Furthermore, other than oil and gas, which have high profit rates, the return on investment of geothermal well is much lower. This might make investors unwilling to contribute to such a high risk project.

2.3 What influences the demand for geothermal energy?

In the Netherlands there are three different purposes for geothermal energy: heat production for the horticultural industry, heat production for district heating, and power generation. The first two of these are already in production, but thus far there is no electricity generation from geothermal energy. In this section the factors influencing the demand for geothermal energy for these three types of projects will be described. However, when considering the demand for geothermal energy, it is very important to see what alternatives are available, so first other possible energy sources will be discussed.

Alternatives to geothermal energy The single most important fuel in the Netherlands is natural gas with 47.1% of the Total Primary Energy Supply (TPES) [42]. The gas industry started with the discovery of a gas field near Slochteren in the northern province of Groningen. In the 1970s when offshore production commenced, the industry went through a rapid expansion. There have been times when gas production was twice as big as domestic demand, and still approximately 40% of the volume produced is being exported [31], making the Netherlands the second largest producer of natural gas within the European Union.

Natural gas fuels 60% of Dutch electricity production and virtually all heating [42] [81]. Not only is gas used as the main fuel for high temperature industrial applications, also for low temperature purposes gas is used. In households the use of gas fuels 90% of all heating, the rest being waste heat (6%; mostly via district heating systems), oil (1%), wood stoves and ground source heat pumps [62]. One of the reasons for this is the existence of an extensive gas grid in the Netherlands with 12,000 km of transport pipelines and 123,000 km of distribution pipelines [39], making it the densest gas network in the world, with connections to 95% of all homes [97].

With a cumulative production of 3.2 trillion cubic meter (tcm) and remaining reserves of 1.3 tcm the Netherlands still has a third of its reserves left [42]. However, inevitably there will be an end to the large Dutch gas production in the future. According to the Energy Report of the Dutch Ministry of Economic Affairs "[c]urrent data suggests that Dutch gas production could remain at its present level until approximately 2030, after which it will decline" [49]. However, other sources project the gas production to remain stable only until 2020 and quickly diminish after that, see figure 2.4, such that the Netherlands would become a net importer between 2020 and 2025 [54] [38].

The gas sector plays an important role within the Dutch economy with annual revenues of €12 billion in 2011 and 70,000 full time employees (fte) [51]. The exisiting infrastructure is not only important for the domestic market, but also includes interconnectors with Norway, Germany, Belgium and the UK. The government aims to make the Netherlands a gas hub, or 'roundabout', within Europe [49], such that even though production declines, the industry as a whole will remain important. This will make it likely that gas will remain in the position that it has today, namely being the *default* fuel, as it is cheap, reliable and, because its use hardly ever gives trouble, people trust it. This is a large barrier for geothermal energy.

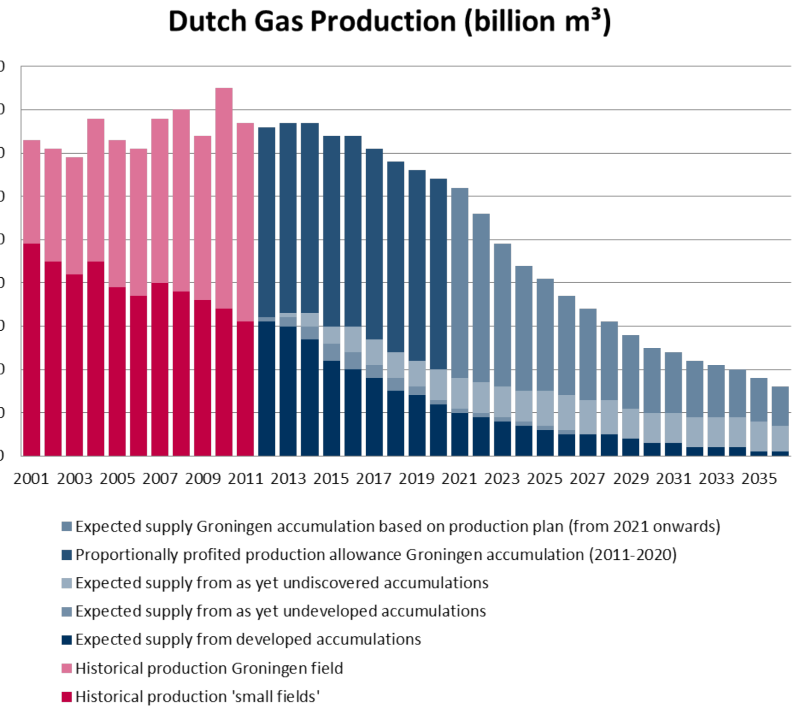

Fig. 2.4. This diagrams shows the historical gas production over the last twelve years and the predicted gas production until 2036. Source: [54]

Gas has been seen as the main alternative to geothermal energy for a long time. Already in 1995 Walter [97] spoke about the negative effect of the large scale natural gas production in the Netherlands on the economic attractiveness of geothermal energy as the most important barrier. There are also other renewable alternatives to geothermal energy, but these only play a role on a much smaller scale. For example, other forms of renewable heating that could be used as alternatives for geothermal energy, are ground source heat pumps and the usage of waste heat. The first is mainly used for individual homes. The second might be an alternative option in district heating, however, this is highly dependent on the presence of a large heat source in close vicinity. In greenhouses also biomass-fired combined heat and power (CHP) plants are used, though also on a relatively small scale. The main renewable alternative to geothermal power is green electricity from biomass burning, which is mainly co-fired in thermal power plants using coal.

Greenhouses Currently heating in the horticultural industry is fuelled by natural gas. Horticulturalists need a lot of gas for space heating of the greenhouses, and their profits are strongly linked to the price of gas [98]. Many horticulturalists own a CHP installation that uses the gas to produce electricity, which is then either used or sold to the grid, after which the waste heat is used for increasing the temperature in the greenhouse. Though this is energetically efficient and financially attractive, it has been described by a horticulturalist as "a game of roulette" ("*een roulettespel*")[7].

[7] Ted Duijvestijn, personal communication, June 2013

Increasing gas prices in 2006 and 2007, see 2.5, where reasons for horticulturalist Ammerlaan to look into altenatives[8]. The further increase of gas prices in 2008 and 2009, a result of political instability that caused Russia to limit its gas supply to Europe, was the trigger for horticulturalist Duijvestijn to start geothermal exploration. The expectation of higher gas prices in the future convinced him that geothermal energy was a smart strategic decision[9]. A (long term) increase in gas prices could thus lead to a higher demand in geothermal energy.

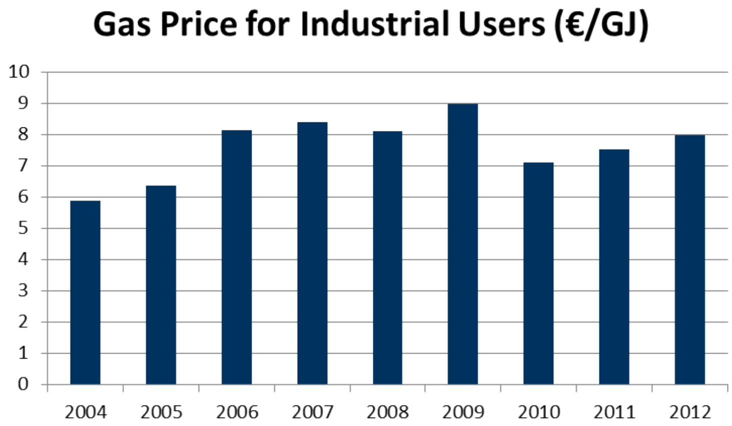

Fig. 2.5. This graph shows the average annual gas price for industrial users from 2004 to 2012. Although the absolute price differences may seem marginal, for an industry which profits is highly dependent on the price of gas, this has a significant effect. Source: [34]

Though sustainability is becoming more and more important also in the horticultural industry, a major drawback for this industry is that consumers do not differentiate between sustainably and unsustainably produced goods. Therefore, it is impossible for horticulturalists to internalise the external (environmental) costs of production and thus they cannot increase their prices when goods become more expensive due to environmentally friendly measures, such as a geothermal energy supply. This is an important barrier for them, as the production of geothermal energy is currently still more expensive than heating using natural gas.

Another characteristic of geothermal energy in this industry is that it creates an independence from energy companies, which is considered to be a positive point according to Platform Geothermie[10]. However, with this freedom comes the responsibility for a well, which is something horticulturalists are not specialised or experienced in. Although information and knowledge is shared intensely within the geothermal industry, the industry is still immature resulting in each new operator facing new problems, such as with hydrocarbons or injectivity.

8 Leon Ammerlaan, personal communication, June 2013
9 Ted Duijvestijn, personal communication, June 2013
10 Victor van Heekeren, personal communication, 2013

A last drawback is that most greenhouses make use of the natural gas emissions as a CO_2 source to improve plant growth. Some horticulturalists are connected to a grid that supplies carbon dioxide to the greenhouses, others use techniques that require no addition of CO_2 to the air. Nevertheless, this is something a horticulturalist should take into account when considering geothermal energy.

District heating In this case of a horticulturalist the consumer and producer are the same person or group of persons[11]. In the district heating area, however, there is a clear distinction to be made between an energy company that produces the geothermal energy and the consumers that will make use of the geothermal energy.

The use of geothermal energy in district heating systems poses an advantage over gas powered CHP installations in that it may reduce local air pollution, as no greenhouse gases are emitted. Furthermore, it might give home owners a sense of pride in living in a more environmentally friendly home. Similarly to this, offices can claim the use of sustainable heating as part of their Corporate Social Responsibility (CSR).

Buildings connected to a district heating system cannot choose a supplier. The Heat Act (*Warmtewet*) states that energy companies are not allowed to charge more than if the same space was heated with natural gas in a high efficiency boiler (*HR ketel*), the most widely used heating source for space heating; approximately 86% of homes used this high efficiency boiler in 2008 [15]. The Heat Act protects the consumer from a monopoly position of the energy company. However, some people are uncomfortable with this lack of freedom.

Electricity production Also for electricity production there is a separate group of consumers and a producer of the energy. However, since end users cannot make a distinction between the different sources of electricity at the point of use, they have no specific demand for it. The reason why an electricity company would want to exploit geothermal energy are given in the next section.

[11] Note that there are also instances where the operator is a horticulturalist and sells his heat to external parties. Although this might be an important aspect of the business case, it is not the leading motivation for committing to a geothermal project.

2.4 What drives the production of geothermal energy?

Now that has been discussed what influences the demand for geothermal energy, this section will focus on what aspects of the Dutch economy, society and environment affect the production of geothermal energy. Similarly to the last section, the situation for the three purposes will be sketched, however, as some of the aspects have similar effects on all three, these will be discussed first.

As was explained in the last section, the price of gas is an important factor in the demand for geothermal energy, especially for horticulturalists. The price of gas varies widely over time and the stable costs for geothermal energy could give them a sense of continuity[12]. However, at the same time the price for the geothermal well will increase as fossil prices rise. This has two reasons; first of all the competition for drilling rigs will increase, as the oil and gas industry will try to increase supply, and secondly drilling a well requires a lot of (fossil) energy, which will then be more expensive. Since the drilling of the well takes up a significant share of the total project costs, this means that when gas prices rise, also the costs for geothermal energy increases. Within the geothermal industry this has been referred to as the *gas paradox*.

A lot of research has been done into the subsurface of the Netherlands by the oil and gas industry. This information is now publicly available[13] in easily accessible formats, such as WarmteAtlas (*HeatAtlas*) and ThermoGIS, an online GIS software available in two versions; for laymen and experts [91]. The fact that a lot of information is known about the subsurface and that this information is readily available makes investers more inclined to consider the option of geothermal energy.

However, though it is known where the most favourable conditions for geothermal energy can be found, there is still a geological risk to drilling for geothermal energy, as has been elaborated upon before. Because of the high investment costs, many operators will try to insure against a lower than expected capacity. However, currently there is only one German insurance company that is willing to privately insure against this risk [48]. Because of the little experience with geothermal energy in the Netherlands, no other (Dutch) companies have yet been willing to provide this insurance for operators.

There are a number of barriers to production of geothermal energy other than the current insurance market that are linked to the fact that although the technology is mature, the geothermal industry in the Netherlands is still in the infancy stage. Because of the small size and the recency of the growth of the geothermal industry, there is still a learning curve that needs to be passed through. Especially regarding standards and regulations, and technical improvements. One advantage, however, is that contrary to the oil and gas industry, the geothermal industry is more transparant. There are regular meetings between operators and other related parties, organised by Platform Geothermie, which allow operators to know exactly what is going on with other projects and learn from each

[12] Ted Duijvestijn, personal communcation, June 2013

[13] The Mining Act states that after five years borehole and other geological data should be published and accessible [43].

other[14]. Also individual operators are willing to share their knowledge. Duijvestijn, one of the operators in Pijnacker, for example, has approximately 1200 visitors a year[15].

Greenhouses Horticulturalists that are operators of geothermal wells are unlikely to not make use of their installation themselves and thus their role as consumer is more important than their role as producer. However, they are not necessarily the only consumers of the heat the well produces. Different wells (some initially drilled to supply heat only for their own business), have now expanded the heating system by including other greenhouses or public buildings, such as schools or swimming pools[16]. Although it might be early to speak of a trend, it also seems that more wells are now drilled in cooperation of different parties. This happened in the Koekoekspolder in Kampen and with the project of Green Well Westland [74].

District heating In district heating the operator of the well would be an energy company. District heating systems in modern neighbourhoods require a water temperature of 60° C, while older district heating systems require water temperatures of 80° C. This makes the newer district heating systems more suitable for geothermal energy. Many of these systems are now powered by natural gas (heat only or CHP) installations [15], however, another sustainable alternative to this would be making use of waste heat from industrial sources, although this option seems to suffer from a poor match in demand [21].

A disadvantage to district heating systems is that they are hard to put in place after the homes have been built. Furthermore, connecting new homes to an (existing) district heating system is far more expensive than connecting new homes to the gas grid [39], which can make it hard to adjust the demand. Especially with the geological risk in mind, this might be an important disadvantage to geothermal energy, as energy companies have to make sure to either have a source large enough to cover the demand in the worst case scenario or install a back-up (natural gas) heat source.

Electricity production Currently no geothermal power plants exist in the Netherlands, one of the reasons for this is that higher temperatures are necessary than those found in current installations. Those make use of water of temperatures between 60° C and 80° C, wheras temperatures of at least 100° C are necessary for electricity production [18]. As mentioned before, the oil and gas industry have left a heritage of very detailed information about the Dutch subsurface. However, the higher required temperatures will be found at higher depths (more than 3000 m) of which little is known. This greatly increases the risk of the investment. Furthermore, at such depths there are less aquifers present and they generally have lower porosity and permeability. This means that the aquifer might need hydraulic stimulation before the well can be used, which adds to the cost and complexity of the project.

[14] Leon Ammerlaan, personal communication, June 2013
[15] Ted Duijvestijn, personal communication, June 2013
[16] For example Ammerlaan. Duijvestijn has plans to connect to a district heating system in the future.

On the other hand, geothermal electricity production provides a very stable supply of non-CO_2 emitting energy. Because of the stability of the energy production, geothermal energy is one of the few renewable energy sources that can be used as a baseload energy source. However, it is unlikely that electricity production will be financially attractive if the heat cannot be sold as well. This causes a location dependence, as the heat will need to be transported to a (group of) clients near by the geothermal power station. Fortunately, geothermal power systems do have a large influence on the surroundings in terms of pollution, space and noise levels, such that they can be build close to built environments and industrial areas with a high (density) heat demand. However, possible induced seismicity because of the hydraulic stimulation is a high barrier to this.

3 Part II: The effects and limits of existing policy

3.1 What policies regarding geothermal energy exist?

Part I has shown that there are a number of different drivers and constraints to the production of geothermal energy. In this section the policies that are designed to help overcome the barriers to geothermal energy will be elaborated upon. First of all some arguments for why the government would want to promote geothermal energy will be given. After this, a short overview of the different policies in place will serve as an introduction to the rest of Part II, which are the discussions about the relevant policies currently in place.

Reasons for governmental support There are a number of reasons why the government would want to invest in geothermal energy in order to stimulate the growth of the industry. The high potential of geothermal energy could be a reason to invest in it, as there is the possibility that it could take over a considerable share of the heat production. In a country with a relatively large demand for heat[17], supporting the transition towards a more sustainable heat supply could help reach binding policy targets, such as the EU Renewable Energy Directive, which states the Netherlands should have 14% renewable energy by 2020 [76].

The European Commission issued in Directive 2009/28/EC on Renewable Energy. Article four of this Directive states that Member States had to submit a National Renewable Energy Action Plan (NREAP) by June 2010. In this plan the Member State has to give a detailed roadmap of how the binding target of renewable energy share in their final energy consumption will be met. The plans are a combination of (non-binding) targets for different technologies and policies that support these aims. For geothermal energy this plan includes a target production capacity of 11 PJ (or 0.26 Mtoe) in 2020 and a guarantee scheme to cover the geological risks (the same scheme that will be discussed in section 3.3)[18].

Another political advantage to geothermal energy could be that it makes use of a local energy source. Currently natural gas is the most important energy source for the Netherlands. Although it has been a net gas exporter for a long time, domestic production is declining, as was shown in section 2.3 . It has been predicted that the Dutch will become natural gas importers between 2020 and 2025 [54][38]. As gas is used for virtually all heating, replacing part of this by geothermal energy could make the Netherlands less dependent on foreign gas and with a more diverse energy supply a better energy security can be achieved.

One thing that the government needs to keep in mind when supporting geothermal energy is that it competes with other uses of the underground. The Dutch subsurface is a busy place, at more shallow depths, there are a lot of cables and pipelines. At depts similar

[17] In the Netherlands, approximately 40% of the total energy consumption is used for heating [6] [81].

[18] It is interesting to note that no mention is made yet of including renewable heat in a feed-in-tariff (FIT) subsidy scheme, but instead geothermal energy can apply for the innovation subsidy grant.

to those from which geothermal energy is extracted, also other mining activities take place, such as oil and gas production, rock salt extraction and (potentially) CO_2 storage [43].

Although the geothermal energy target itself is non-binding, it still has an influence on the energy industry; it created a political vision for this energy source. A year after the submission of the NREAP, the Ministry of Economic Affairs published Actieplan Aardwarmte (*Action Plan Geothermal Heat*). This document elaborates how the target of 11 PJ of geothermal energy can be reached and describes the market situation at that time and which measures need to be taken to support the growth of the geothermal industry. In order to put together this action plan, the advice many operators and other people related to or with an interest in geothermal energy was taken into account.

Current policy measures There are a multitude of different policies in place in the Netherlands that aim to support geothermal energy either by lowering the barriers or by enhancing the drivers. Because the most significant barrier is the relative cost of renewable energy in comparison with that of gas, and perhaps also the most easily measurable, most of the policies in place aim to lower the cost of producing energy from more sustainable sources than fossil fuels. In order to lower the barrier of higher costs for renewable energy compared to fossil fuels, there are multiple subsidies and fiscal incentives that operators of sustainable technologies can apply for.

Examples are the Stimulering Duurzame Energie Plus (SDE+; *Stimulating Sustainable Energy Plus*), a feed-in tariff that brigdes the financial gap (*onrendabele top*) between production costs of renewable energy in comparison with conventional energy sources; the Energie Investeringsaftrek (EIA; *Energy Investment Reduction*), which allows firms to subtract up to 41.5% of the investment costs from the fiscal profit; the Subsidieregeling Energie en Innovatie: Risico's dekken voor Aardwarmte guarantee scheme (SEI Aardwarmte; *Subsidy Scheme Energy and Innovation: Covering Risks for Geothermal Energy*), which is technically speaking a subsidy, covers the geological risk in exchange for a premium; the Unieke Kansen Regeling/Unieke Kansen Programma (UKR/UKP; *Unique Opportunity Scheme/Unique Opportunity Programme*), which subsidised innovative projects aimed to reduce energy demand and make supply more sustainable; and the Marktintroductie Energie-innovaties (MEI; *Market Introduction Energy Innovations*), which subsidised geothermal energy in the horticultural industry before the SDE+. Note that the support from the UKR/UKP and MEI programmes were aimed at innovative technologies and have been terminated (for geothermal energy).

The most important of these schemes for geothermal energy are the SDE+ and the SEI guarantee scheme, which are specifically aimed to lower barriers every operator of a geothermal well will face: the higher production cost of geothermal energy compared to using gas, and the geological risk of only being able to extract a lower than expected amount of energy from the well, either because of disappointing water temperatures or volumes. The impacts of policies like these on the geothermal industry will be analysed in separate sections below.

Another policy that has a substantial influence on the geothermal energy industry stems from the very sophisiticated Dutch Mining Act, which governs all that happens at depths more than 500 m below the surface. Exploration licenses must be granted before any drilling is done at such depths and once the wells are finished, production licenses are necessary to provide proof of safe working. A third section below will elaborate upon the implications of this policy.

3.2 SDE+

The subsidy scheme Stimulering Duurzame Energie Plus (SDE+; *Stimulation Sustainable Energy Plus*) is the most important policy measure supporting the increase of the share of renewable energy sources in the Netherlands. It works as a FIT that covers the financial gap (*onrendabele top*) between the cost of producing energy using sustainable sources compared to the cost of using conventional sources. The aim of this subsidy is to lower the cost for operators of renewable energy plants, such that they become more financially attractive. A subsidy covering the difference in cost between conventional energy sources and geothermal technologies will lower the barrier of higher prices for geothermal energy.

The SDE+ came into place in 2012 as the successor of the SDE subsidy scheme. Within the SDE different technologies each had their own separate budget, such that more costly, but potentially promising technologies could also be supported. This changed as the Minister of Economic Affairs set the goal of the SDE+ to produce renewable energy as cost-efficiently as possible [50]. Furthermore, not only did the SDE+ include electricity and biogas, also renewable heat was included. Because of the little experience with geothermal energy and the subsidy, it is difficult to draw solid conclusions on the effectiveness of the subsidy scheme. However, possible and observed effects of the SDE+ on the development of the geothermal industry will be discussed below.

Calculation of the subsidy amount The amount of subsidy that an operator of a renewable energy plant receives depends upon two things: the production cost of energy for that technology and the cost of energy using conventional energy sources. These are reflected in the base rate (*basisbedrag*) and the correction rate (*correctiebedrag*) respectively; subtracting the second from the first results in the amount of subsidy to be received by the sustainable energy producer [5].

- The base rate is the cost that is assumed to be made per unit of electricy, biogas or heat. These are recalculated each year to reflect current prices. However, for an accepted application the give base rate of the year it was submitted will remain fixed for the 15 year duration of the subsidy contract.
- The correction rate is the cost of conventional energy production. Depending on the technology, this is the average price of electricity or gas over a year. The applicable correction rates are recalculated annually.
- The subsidy rate that a producer of renewable energy receives is then equal to the base rate minus the correction rate. Because of the annual recalculation of the correction rate, this will vary over the years, depending on the price of conventional energy sources.

The main argument for a fixed base rate is that for many renewable technologies the initial investment is high in comparison with the variable production costs. This is true also for geothermal energy, where the construction of the well can amount up the majority of the total lifetime project costs. At the same time, a yearly adjustment of the base rates allows the government to determine what the current costs for renewable energy production are.

This prevents oversubsidisation of technologies as they become cheaper over the years. The main reason for keeping a fixed base rate for accepted projects for the duration of the SDE+ contract is that despite the fact that costs for renewable energy technologies may fall in the future, the investment has to be made today the subsidy must reflect the *actual* costs made by the producer in order to be effective.

Although the base rate is fixed for an operator once the subsidy contract has been signed, the correction rate, which is the average of *conventional* energy price over a year, is recalculated annualy. As a result, the received subsidy amount per unit of energy is different each year as well. The Dutch government focusses in the SDE+ scheme on cost-effectiveness and as part of that the SDE+ only covers the financial gap between energy sources. In the case of horticulturalists that operate geothermal well, this means that they (theoretically) will not pay more than what they would have paid if they would have used natural gas to heat the greenhouses.

As has been elaborated upon before, an (expected) increase in gas prices will increase the demand for geothermal energy. Although it might seem that this driver is weakened by the fact that the subsidy takes into account the actual energy prices, this is not entirely the case, because it is likely that many geothermal wells will produce heat for longer than the subsidy contract. It is expected that most wells will be producing energy for more than thirty years[19] [48].

Reference cases The base rate for renewable energy differs per type and technology of energy production. In 2012 there were two categories for geothermal energy, heat production and cogeneration, each with different base rates. In the 2013 version of the SDE+, the heat production was subdivided into two categories, with a well depth of 2700 m as the differentiating factor. In the draft advice for the scheme in 2014 it is proposed this be at 3300 m [23]. Because different technologies have different costs, even if they belong to the same energy source, this is reflected in their base rates in order to prevent oversubsidisation of cheaper technologies and undersubsidisation for more expensive technologies.

However, caution must be taken: too few categories and the subsidy level will not be accurate, but too many categories and the process of applying for the subsidy will become too complex, reducing the effectiveness of the scheme. This is why Platform Geothermie calls for not extend the number of categories without checking if these could be part of another existing category[20].

In order to calculate the base rates for the SDE+, ECN makes use of reference cases for each different technology. The costs calculated for this model are not those of an average installation, rather the parameters are chosen in such a way that the base rate will be enough to cover the financial gap in 80% of the cases [19]. For the projects with well depths less than 2700 m there seems to be little variability in energy prices (€ /GJ).

[19] The predicted temperature loss of the aquifer is at only .5° Cfor one well. This supports the idea that the well can be used for much longer than the duration of the subsidy contract (Anonymous, personal communication, 2013).

[20] Victor van Heekeren, personal communication, August 2013

However, for projects deeper than that there is a higher unpredictability in costs, making it harder to correctly model the costs [24]. The difficulty in calculating the reference cases for this deeper category and the cogeneration plant also arises from the fact that such projects have not yet been built in the Netherlands[21]; i.e. it is impossible to verify whether they are correct.

Because the SDE+ subsidy scheme is meant for all renewable energy technologies, calculations for the base rates are standardised in order to allow for clear comparison between technologies. The calculations for the project costs are based upon the cashflow of the operator and can be found on the website of ECN [25]. They all make use of the same model, which makes it easy to compare the different costs between differen technologies. One model for calculating project costs does give a unique comparison of the relative costs of each technology, but it also has some limitations. Some parameters are set to be equal for all projects, such as return on equity, interest rates, and the proportion of equity versus debt share. However, because of the high risk investment in geothermal energy compared to other technologies, these do not necessarily reflect the reality.

First of all investors in high risk projects are likely to demand a higher return on investment. This is true for operators that are likely to construct only one geothermal well, such as horticulturalists, but also for those that could invest in more than one well, such as energy companies and also financial institutions. It is therefore likely that they will demand higher rates of return on equity and higher interest rates.

Secondly, the high level of uncertainty regarding the successful production of the initially estimated capacity leaves financial institutions unwilling to invest in geothermal projects if the shart of equity invested is not at least 30% of total costs, especially in the current economic situation. Other criticisms on the SDE+ scheme in 2013 were that the operation and maintenance (O&M) and health, safety and environment (HSE) costs were estimated too low. These have been upwardly adjusted after a discussion between ECN, Platform Geothermie and several other parties on August 6, 2013[22].

Budget and phases The SDE+ scheme has a solid budget it adheres to. As wil be explained in the next section, there is also a maximum amount of subsidy a single project can get. In 2003 the Milieukwaliteit Energieproductie (MEP; *Environmental Quality Energy Production*) scheme, the predecessor of the SDE and SDE+ schemes, was introduced. This was also a FIT that covered the financial gap between energy costs, and was based on the same calculations. However, this subsidy scheme had no fixed budget and an unexpectedly high demand for subsidy for sustainable energy projects lead to unanticipated high costs. This lead to the partial freezing of the scheme in May 2005, and finally the scheme was ended in August 2006 as the Ministry of Economic Affairs expected that the target share of renewable energy for 2010 would be reached without any further stimulation [8].

[21] The one exception to this being the Green Well Westland project that withdraws water from a source 2900 m deep.

[22] Victor van Heekeren, personal communication, August 2013

When this turned out not to be the case, the successor of the MEP, the SDE scheme was introduced in 2009. This scheme was given a budget for every different technology. With the SDE+ this has changed into one budget for all renewable energy technologies together. Until 2012 the subsidy was paid for by the treasury, but starting in 2013 it will be paid for by a premium that is raised on energy bills; over this year this would amount to approximately €9 for an average household [78]. Having a budget will allow the government to control the spending and protect the consumers from unreasonable increases in their energy bills. However, at the same time it increases the pressure of competition for the subsidy between operators. Because of the fixed amount of financial resources available for the FIT the subsidy is a privilege rather than a right for the operator.

Applications for the SDE+ scheme cannot be handed in at any time during the year. Instead there is a new round of applications with a new budget every year. Applications for the subsidy are then organised in six successive phases, with incremental maximum bas rates, see [77]. A project can apply for subsidy in a phase when the base rate for that technology is lower than the maximum base rate for that phase. If the base rate of a technology is higher than that of the current phase, it can still apply within that phase, but then only for a subsidy equal to the maximum base rate of that phase (*vrije categorie*).

With one budget for all renewable energy resources together, they have to compete with each other for financial support. In the SDE+ 2013 each phase lasts around one month (only the third phase lasts 3 months over the summer), with the first phase opening on April 4 and the sixth phase opening on November 5. The SDE+ works on a *first come, first serve*-basis, such that the cheaper technologies called for in the earlier phases have an advantage over those in later phases. This supports the goal of the SDE+ to produce as much renewable energy as cost-effectively as possible.

Both categories of geotermal heat production fall in the first phase, but geothermal cogeneration requires a higher base rate and falls in the third phase. For the promotion of geothermal energy, the SDE+ method has both advantages and disadvantages. With the relatively low subsidy that is required for geothermal heat production, these two technology categories have a large probability of being supported by the SDE+, even though there are much more applications than can be accepted. In 2012 the total budget was €1.7 million, while the amount of budget applied for at its maximum reached an astonishing €4.24 billion, or about 2.5 times the budget [77]. Nevertheless, within the geothermal heat category many applications were successful and 30 projects were awarded €829 million in total. Although in 2013 the budget was nearly doubled in comparison with the year before (to €3 billion) the claimed amount was already more than the budget on May 16, only two days after the second phase had started. This has as result that projects within technologies that are called for in later phases have virtually no chance of obtaining the subsidy.

Subsidising only the least expensive technologies is the most cost-effective way to increase the production of renewable energy. However, currently within the SDE+ scheme the more expensive technologies are (in practice) not supported. They do not get a chance to pass through a learning curve and reduce cost. The fact that the budget is often exhausted before the third phase starts, is a barrier to potential operators of geothermal CHP plants. The mere uncertainty of whether or not they will have a chance of getting subsidised will have a negative impact, as their business case is most likely not financially viable without the subsidy. A high uncertainty regarding the allocation of the subsidy due to the high demand for it in combination with high investments in (geological) research which have to be done before applications for the subsidy are made are an unfortunate combination for this geothermal technology.

Payment The SDE+ does not guarantee the operators a fixed amount of subsidy for every unit of energy produced over a certain time. Instead, as said before, the actual amount of subsidy differs each year depending on the average price of electricity, heat or gas during that year. Furthermore, there is a maximum to amount of subsidy the plant operator can receive. The number of full load hours (*vollasturen*) over a year and the capacity of the plant determine the maximum energy output of a plant that will be subsidised. The number of full load hours that will be accepted for subsidy depends on the technology; for geothermal heat production this is 5500 hours a year. Thus, a geothermal well with a capacity of 10 Megawatt thermal (MW_{th}) will only receive subsidy for the first

$$5500(hours) * 60(minutes) * 60(seconds) * 10 * 10^6(power) = 198,000GJ$$

of energy it produces[23]. This way there is a limit on the total amount of subsidy a project can receive, which will prevent overreservation of the budget and overstimulation of the well-performing renewable energy systems.

The FIT nature of the SDE+ scheme also has some disadvantages for geothermal well operators. Most of the costs for a geothermal project have to be made before the energy production can begin. Therefore, subsidising only the output of the well increases the risks for the operator and investors, since the actual production is not known until the costs have been made. A FIT might be more appropriate for an energy producer with high variable costs, since the investment into geothermal energy has to be made regardless of the final output of the well. From a government perspective subsidising the output rather than the investment does incentivise the operator to use the well to produce the amount of energy that was indicated in the application. However, at the same time, because of the limit on subsidy available for each project operators are not incentivised to produce more than the amount eligible for subsidy.

The disadvantage of the subsidy depending on the production of the plant is stronger, if the operator of the well is not the user of the energy that is produced. Because the success of the project then depends on the heat consumption of other parties, which the operator has no control over, an output dependent subsidy might be less efficient than an investment subsidy that is made at once at the beginning of a project when the majority of the costs are made[24].

[23] Note, however, that the subsidy depends on the amount of energy that is *actually* produced, which can be less than 198,000 GJ for a 10 MW_{th} well

[24] Anonymous, personal communication, 2013

On the other hand, the spread payment of the SDE+ also has an advantage. The continuous income from the scheme helps lower the risks for financial institutions, which might be more willing to invest in a geothermal project if they know the operator has a steady income. Furthermore, many geothermal projects are launched under a parent company, and the predictable income from the subsidy scheme increases the value of the parent company[25].

The capacity maximum When in 2012 geothermal energy was first allowed to apply for subsidy in the SDE+ scheme, a large number of applications were sent in. Because of the *first come, first serve*-basis of the application rounds and the low base rate for geothermal heat production, a lot of geothermal projects were granted subsidy. In total these projects were appointed € 829 million, this meant that out of a total budget of € 1.7 billion, half was reserved for geothermal energy. After the experience with geothermal energy in the SDE+ 2012, the Minster of Economic Affairs decided to place a maximum on the size (capacity) of the geothermal plants in the SDE+ 2013; 12.4 MW for wells with a maximum depth of 2700 m, 18.0 MW for deeper projects, and 11.9 MW for CHP plants. Reasons given for the necessity of the cap were prevention of overstimulation and overreservation of the budget [53], but it remains unanswered why these are a problem and how the capacity maximum would solve the issue.

It is also unclear where the idea for the maximisation of geothermal plant size originates from. According to ECN the Ministry of Economic Affairs specifically demanded to be informed on suitable maximum production capacities of geothermal wells and the desirability of making the maximum amount of subsidy dependent on this capacity [19]. The Ministry replied to have copied the advice of ECN about the capacity maximum one-to-one ("*één-op-één*"), but does not confirm whether they have demanded this capacity maximum [58]. Platform Geothermie suspects that the strong lobby for wind energy in the Netherlands was fearing for a take-over of the SDE+ budget by the geothermal energy industry and presented the idea to the Ministry [73].

The capacity limit for geothermal installation caused a lot of discussion within the geothermal energy industry in the Netherlands as soon as it was announced. As the representing body of the geothermal industry in the Netherlands, Platform Geothermie wrote a letter to the Minister about why this measure would impair the growth of the geothermal energy industry. They argued that this maximisation of the size of geothermal power plants created an atrificial barrier to wells with a depth of more than 3000 m, since wells this deep need to have a higher capacity to be profitable. Such plants currently do not exist in the Netherlands, but plans for a plant with a depth up to 4000 m had been announced[26] [27].

Plants with a depth of more than 3000 m are recognised by ECN as an important share of the potential capacity for the 2020 target of 11 PJ [19]. The cap could hinder the realisation of these deeper projects. Some potential operators might downscale the plant size to fit within the eligible capacity for the SDE+ subsidy, resulting in a loss of realised

[25] Ted Duijvestijn, personal communication, June 2013

[26] In June of this year it became clear that due to financial issues and problems with the SDE+ this project is cancelled [28].

geothermal potential. An even larger decrease in produced geothermal energy would occur if there is no option for downscaling, for exampe if no aquifer is present at shallower depth or if there is mainly a demand for higher temperature heating, for example for industrial applications.

According to ECN, which advices the Ministry of Economic Affairs on the limits for the cap, even with these maximum production capacities in place 80% of the geothermal projects could still be realised [19]. They do note that the capacity cap could have an effect on the design of future projects. However, they also state that they have not been able to find proof that any of the possible effects of the capacity cap, such as downscaling and discouragement of applying for subsidy, have occured [19]. On the other hand, Platform Geothermie has described the capacity maximisation as a guillotine against an emerging headache ("*een guillotine tegen een opkomende hoofdpijn*") [73]. They claim that it has a noticeable effect ("*merkbaar effect*") in that those projects that are in the planning stage are now sometimes downscaled and may forgo the option to sell geothermal energy to neighbouring heat consumers.

Alternatives It has been argued that due to economies of scale bigger geothermal projects would be overstimulated. However, it is actually more likely that the opposite happens for higher capacity projects. The capacity depends upon the water temperature and the amount of water that can be extracted from the well at any given time. This, however, requires deeper or wider wells, which increases drilling costs. For the depth, however, ECN has shown that drilling costs are proportionally higher for deeper projects [19].

The issue with overreservation was due to the overstatement of well capacities in the application forms. This happened on a very large schale. The 32 projects that had applied initially claimed €1.161 billion of the budget. However, as the Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO; *Netherlands Organisation for Applied Scientific Research*) did a check of the indicated capacities and concluded that many of those were overestimated. As the amount of subsidy a project receives depends upon the size of the project, this meant that the production capacities in the application forms had to be adjusted. As a result the final claim by the 32 projects was €877 million, meaning the initial claim was overestimated by a quarter. Although (downward) adjustments for other categories have also been made, for none the technologies had claim adjustments this rigorous [4].

The reasons the initial capacities were overestimated was partly due to the opportunism on the side of the operators. The way the SDE+ works if the well would produce less than the declared capacity, the subsidy would automatically be adjusted downward, whereas if the capacity of the well would turn out to be more than intially claimed, there would be no upward adjustment. Therefore, it is beneficial for the operators to overstate the capacity of the well. However, there were other reasons, such as unsuitable application forms and communication issues [27].

[27] Victor van Heekeren, personal communication, August 2013

Because capacity overestimation seems to be causing the most issues, alternatives to the capacity maximum could perhaps be more suitable. Even though it was not specifically requested, ECN has been given the freedom by the Ministry to investigate any alternative options to the maximisation of the production capacity eligible for geothermal energy. A possible[28] solution that ECN has come up with that would reduce the overreservation of the budget due to opportunism on the side of the operators, is to have the capacity with which they apply for the subsidy checked by an accredited institution. The operators would have to pay a fee proportional to the capacity of the well for this but in return they do get a much clearer analysis of the capacity, which might make getting financing easier [29]. Platform Geothermie has agreed that their opinion towards this plan is predominantly positive ("*overwegend positief*")[30].

Another option that is mentiond would be to use portfolio management to avoid overreservation by projects that will not be realised or will turn out smaller than expected, but this requires a fundamentally different way of budgetting the SDE+ and is not feasible in the short term[31], among others because the short history of the SDE+ means there is only limited knowledge regarding the success rate of projects.

Conclusion Althought it is too early to draw any conclusions about the effectiveness of the SDE+ subsidy scheme for the geothermal energy industry, many applications for subsidy have been submitted and accepted, which looks promising. Generally there seems to be a willingness to provide renewable energy if financial support is given, as the high number of claims made during the 2012 and 2013 rounds showed.

The fact that the SDE+ scheme has one budget for different renewable energy technolgies combined, does pose some limitations on the specific support that can be given to geothermal energy. The heat production plants require a relatively low level of subsidy and thus have an advantage over many other technologies. However, on the other hand this same system disadvantages the geothermal CHP plant, that is more expensive and has, with the current high demand for subsidy, virtually no chance at being financially supported.

Also the design of the scheme poses some limitations on the effectiveness of the support for geothermal energy. However, this is inherent to the type of subsidy mechanism and can never be fully overcome. The fact that the SDE+ is a type of FIT rather than an investment subsidy that is granted in full at the start of the project realisation, is not ideal as most of the costs for geothermal energy will be made in the construction phase. This effect is felt stronger in case the producer is not also the main consumer of the geothermal energy produced.

The maximisation of the production capacity eligible for subsidy is quite controversial and caused some heated discussions. Proof of its effect is hard to find, but the possibility that

[28] This alternative option is still in an early phase of development.
[29] Sander Lensink & Victor van Heekeren, personal contact, June 2013
[30] Sander Lensink & Victor van Heekeren, personal contact, June 2013
[31] Sander Lensink & Victor van Heekeren, personal contact, June 2013

is might deter potential operators from considering geothermal energy is not fortunate for an industry still in its infancy stage.

Furthermore, though some changes could benefit geothermal energy more, creating a reliable and predictable subsidy scheme creates stability within the field of renewable energy and will be most effective in lowering the barrier of higher costs for renewables. The flexibility of the SDE+ scheme to make yearly changes, however, is a major advantage for a growing industry as it can be adapted to new experience and advancing insights ("*De SDE+ kan van jaar op jaar aangepast worden aan nieuwe ervaringen en voortschrijdende inzichten*") [22].

3.3 Guarantee scheme

In 2009 the Dutch government introduced the Stimuleringsregeling Energie en Innovatie Risico's dekken voor aardwarmte (SEI Aardwarmte; *Stimulation Energy and Innovation Risk cover for geothermal energy*). This guarantee scheme is technically a subsidy, but works as an insurance for unsatisfactory well performance. The main reason for the introduction of this public guarantee scheme is the absence of a competitive market of insurance companies willing to cover the geological risk associated with drilling a geothermal well.

The demand for insuring against this risk exists, because although the probability of an unsuccessful drilling may be small, the high investment costs can have serious financial consequences ("*aangezien een boring zeer kostbaar is, kan een misboring grote financiële gevolgen hebben*") [3]. This is especially the case if this risk is carried by one investor only. It has been possible to privately insure against this risk with a German insurance company via one drilling company [26], but no other private insurers are willing to cover the risk against reasonable cost, because of the inexperience with geothermal wells in the Netherlands, the relatively small market, and the type of risk to cover [86].

Not all operators decide to insure against this geological risk. For example, in The Hague the geological risk of underperformance was carried by the six investors that set up the project themselves [48]. Other large scale investors might accept the risk as part of their line-of-business. However, entrepreneurs and municipalities are not likely to be owners of more than one, perhaps two wells. Most of them might want insurance not because the *probability* of failure is so high, but because the *impact* of performace failure is so serious [26]. Moreover, the guarantee scheme can also help with financing the project, as it lowers the risk for financial institutions. In France, financial organisations sometimes even refused to invest without a formal insurance or guarantee [13].

Because of the geological uncertainties, the size of the well is generally estimated by assigning probabilities to the expected production capacities. The preparatory geological research is used to create a graph of exceedance, as can be seen in figure 3.1. This graph gives the range of possible well capacities and the relating probabilities that the well will perform better than that. Two important capacities used are the P50 and P90 capacities. With a P50 capacity, there is a fifty-fifty chance that the *true* capacity of the resource will be either larger or smaller. The P90 capacity of the well is the minimal capacity that will be gotten 90% of the time. There is thus a nine out of ten chance that the actual capacity of the well will be higher than this, and a one in ten chance that it will be lower[32]. The P50 capacity is thus always higher than the P90 capacity, as can also be seen in the graph below.

Because the actual production capacity cannot be known without certainty before the well has been drilled, these P90 and P50 capacities play an important role in planning for the project. Not only do they determine what equipment would be necessary for the construction of the geothermal plant, such as the heat exchangers, wellheads and the heat distribution infrastructure, they are also important for the financial aspect of the

[32] In more mathematical terms, in a cumulative probabilty graph this is the 10th percentile with 90% probability

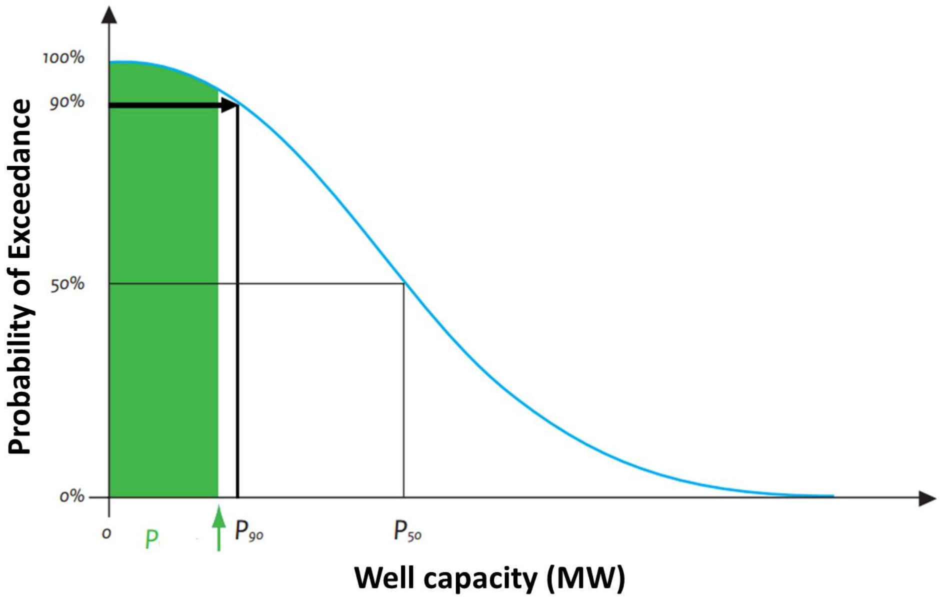

Fig. 3.1. This diagram shows the probability of exceedance of the well capacity. The expected P90 and P50 capacities are those that have a 90% or 50% chance of being exceeded by the actual capacity of the well. The green P is an example of a project with a capacity lower than P90; this project is eligible for compensation under the guarantee scheme. Source: [3]

planning. Generally the business case of the project is based upon the P90 capacity of the well[33], and is thus also used when applying for loans at financial institutions, etc[34]. It is also the defining capacity for the guarantee scheme.

In 2013 the government reserved approximately € 43 million for this scheme. Against a premium of 7% of the investment costs the operator can have the (deep) geothemal well insured against failure, with a maximum compensation of € 7,225,000 or € 12,750,000 for projects shallower or deeper than 3500 m, respectively [3]. Failure is described as the situation where the well produces less than the P90 capacity. In this case up to 85% of the investment can be reimbursed. The determining factors for the capacity are the temperature of the water and the flow of the well[35]. It is important to realise that only the performance of the finished well is insured; other factors that could lead to higher costs and/or project failure, but which are related to the drilling itself are not covered by this scheme.

The guarantee scheme is not open to applications year round. Instead different rounds, lasting a few months each, have been organised in 2009, 2010 and 2013. This has both advantages and disadvantages for operators. On the one hand this discontinuity can cause uncertainty among potential operators, as it is unclear whether the scheme will open another round next year and whether the conditions will have changed. The scheme

[33] Anonymous, personal communication, 2013
[34] Note that for the SDE+ subsidy application the P50 capacity is used.
[35] The flow is the amount of water that can be extracted from the well in a certain amount of time.

demands that the project will be started in the six months after the guarantee has been given. As it takes a long time to prepare for a geothermal project, this might be too soon for some operators, especially if they will need proof of the guarantee for the financing of the well.

However, on the other hand it allows for flexibility in the scheme. After the first round, which lasted from autumn 2009 to spring 2010, there had only been two applications [48] and at the symposium Update Geothermie 2010 which took place end of March, when the first application round came to its end, it was concluded that the scheme was not effective ("*werkt niet*")[89]. Reasons for this were its complexity, the high proven probability of succes and a low maximum compensation [26]. An operator said that he chose not to make use of the SEI scheme as the exact conditions were unclear ("*zag er niet duidelijk uit*")[36].

For the next round of the subsidy scheme, which opened half a year later, it was decided that the maximum compensation would be increased from €5,950,000 to €7,225,000. Furthermore, the conditions for receiving compensation were relaxed [2]. The probability of succes refers to the condition that the well is only eligible for compensation if its capacity is less than the P90 capacity. Though this was also a point of criticism, it has not been adapted. Another adjustment that has not been made is the percentage of coverage, which remained at 85% of the investment costs. This means still 15% of the investment is carried by the operator, which was deemed as too high. However, Rabobank, a Dutch bank, has designed an arrangement where the bank is a guarantor of another 10%, leaving only five percent of the investment as a loss for the operator in case of unsatisfactory results [89].

For the 2013 round more adjustments were made. These were so extensive in nature that it was decided that the SEI scheme had to be newly established, rather than simply adapted [86]. One of the changes is that a second category was added for deeper projects, with a higher maximum compensation. This removes the barrier for deeper projects to insure with the guarantee scheme, as before they would have been limited by a relatively low maximum, which meant that they would receive proportionally less compensation in case of a complete failure than a smaller project would. Other changes are the possibility to insure half a doublet, or one well instead of two; coverage of costs for research that might lead to better perfomances, if those were unsatisfatory to begin with; and the dismissal of the condition that the temperature difference between production and reinjection is more than 35° C. Unfortunately, at the time of writing it was not published whether these changes, combined with the many projects that were accepted for the SDE+ subsidy in 2012, has yet resulted in an increase of applications.

Guarantee schemes are considered to be one of the most cost-effective forms of renewable energy support, where the successful projects carrying the burden of unsuccesful projects. Because the compensation is not needed in 90% of the cases, the scheme is not expensive for the goverment [30]. Especially because there has not yet developed a market for private insurance companies that cover the geological risk, while the demand for such insurance is high among the operators. After the first round, in which only two applications for

[36] Anonymous, personal communication, 2013

the SEI scheme were granted, six operators applied for the public insurance against performance failure in the second round. So far out of these eight projects one claim has been made.

Although it is not explicitly mentioned, it seems as if the goal of the SEI scheme is to provide a formal guarantee as long as there are no private insurance carriers and that it will be terminated if private insurance companies enter the market. The government recognises that there are currently no private parties doing this [86], and that it remains unclear whether the scheme will exist as soon as next year again. This gives the impression that the government wants to revoke the scheme whenever it feels the industry is ready. Multiple projects in areas where a lot of subsurface research has been done and where multiple geothermal projects are located close together have been insured with the private insurer. A project in an area of which was initially said that geothermal energy was impossible ("*niet mogelijk*") made use of the guarantee scheme of the government [96]. *If* the goal is to simply bridge the gap between the demand and supply of private insurances, this is a good sign. The experience obtained with the SEI scheme (in more unknown areas) could then trigger more insurance companies to enter the market.

3.4 Licences

In the Netherlands mining activities in the underground at depths more than 500 m are governed by the Mining Act. This requires operators to apply to exploration and production licences at the Ministry of Economic Affairs. An operator should have obtained an exploration licence before any drilling can take place. Once drilling has taken place and the economic viability of the resources has been proven, a production licence must be issued before actual mining may start. The first exploration licence for geothermal energy was issued in 2005. After this, the demand grew rapidly to approximately 75 exploration licences mid 2013. An overview of all geothermal licences issued and applied for can be found in figure 3.2.

It is the Minister of Economic Affairs that grants the licences. For this, however, the support of Staatstoezicht op de Mijnen (SodM; *State Supervision of Mines*) is required. SodM is a governmental service (*rijksinspectiedienst*) that inspects whether the Mining Act is correctly adhered to, this means that it is the supervisor of all licences and whether drilling and extraction of the geothermal energy happens safely and in a socially acceptable manner[37]. Platform Geothermie has been given the role as main communicator within the geothermal energy industry and is also the first contact for licence holders [17].

The deep subsurface in the Netherlands can be used for many purposes, such as, the extraction of oil and gas, rock salt mining, CO_2 storage, and geothermal energy production. The issuance of licences for the use of the Dutch subsurface allows the government not only to know and control which activities take place, but more imporantly, to pose conditions on *how* these are carried out.

Exploration Licence There is no fee that the operator needs to pay before applying for a geothermal exploration licence. However, several documents need to be provided, such as a description of the area, a geological report, and general, technical, and financial data of the operator[38]. This geological report will consist of the information gathered at the *quick scan* that the operator will have had carried out. This quick scan of the subsurface is a desk study carried out by a geological consultant and uses information from earlier boreholes drilled in the area.

The major advantage of the exploration licence for the operator is that exclusivity of the resource is guaranteed. Both the quick scan and the more extensive geological research that needs to be carried out before the well can be drilled are quite expensive (total costs in the range of €26,000 to €32,000 [94]). With this licence in place the operator knows that the research he carries out, and which will lead to the drilling design of the well,

[37] The formal definition of supervision is: the collection of information about whether an act or business satisfies the necessary requirements, then make up a judgement about this, and if necessary intervene (*De definitie van toezicht (uit KVoT 2001), Tweede Kamer, nr. 27831: het verzamelen van informatie over de vraag of een handeling of zaak voldoet aan de daaraan gestelde eisen, het zich daarna vormen van een oordeel daarover en het eventueel naar aanleiding daarvan interveniren* [83]).

[38] For more information regarding the necessary documentation and a time schedule, see [66].

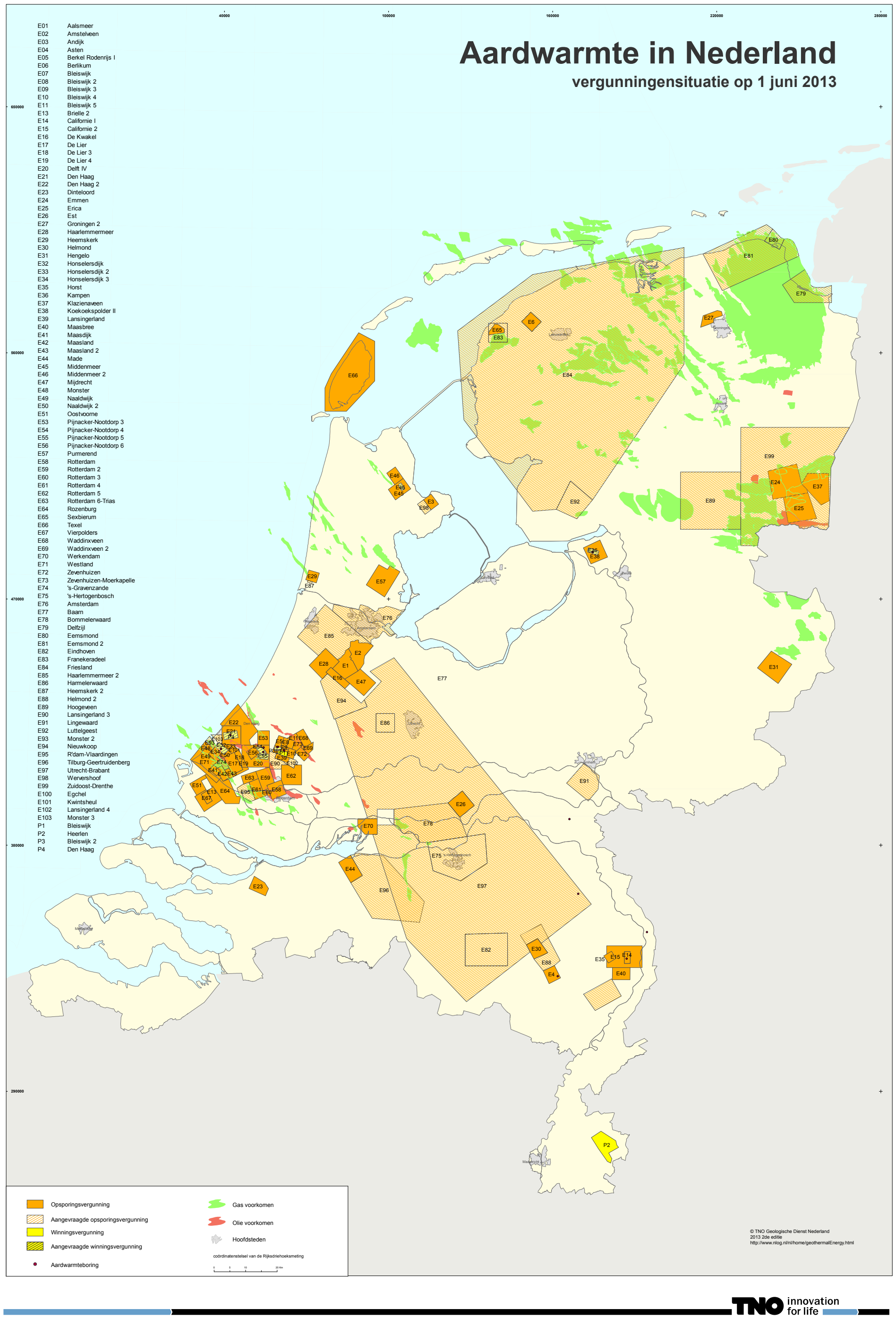

Fig. 3.2. This map shows the spatial distribution of geothermal licences in the Netherlands as of June 1, 2013. Exploration licences are orange; production licences yellow. Licences applied for but not yet granted are striped. Green and red areas indicate gas and oil fields, respectively. Source: [65]

will not become fruitless due to a competitive drilling nearby. It is possible for multiple users to make use of the same aquifer, however, this needs to be well coordinated.

Once the operator has applied for an exploration licence, this will be published in the Staatscourant (the Dutch legal gazette), after which there is a six week period in which other parties can object. This happened, for example, when the technical university (TU) in Delft applied for an exploration licence that included the area around the town Pijnacker, where two horticulturalists wanted to apply for exploration licences as well. In the end they decided to cooperate and share the costs of the large geological research, to make a design that could hold all three wells within the same sandstone aquifer. Both horticulturalists have finished the well and are currently producing geothermal energy for a number of greenhouses, a school, a sports centre, and a swimming pool[39] [40].

Obtaining an exploration licence that allows for the drilling of a geothermal well is not only one of the first steps that need to be taken by the operator; it is also key for the growth of the industry that these are issued, since without them no geothermal energy plants can be constructed. SodM states in its five year strategy plan 2012-2016 that it wishes to encourage the growth of geothermal energy [83]. However, at the same time it has learnt from the first handful of projects that the operators (mostly horticulturalists) had insufficient knowledge and experience with geothermal wells. Secondly, it concluded that four of the wells also produced oil and/or gas, which had not been expected. Although the well is a closed loop system, these need to be separated out from the water before injection can take place. Furthermore, SodM has been increasingly strict since the 2010 *Deepwater Horizon*, or *Macondo*, oil spill in the Gulf of Mexico. These findings, combined with the lower number of licences issued, make it seem as if they are more hesitant with giving out exploration licences.

In the diagram below, see figure 3.3, the number of exploration licences issued is shown. According to Platform Geothermie, the geothermal energy industry requires more exploration licences to be issued if the target of 16 PJ produced geothermal energy in 2020 is to be achieved. Assuming an average size of 11 MW per project, a good thirty licences will need to be issued each year in order to reach that target [95]. However, as the diagram shows, this number has only been reached in 2009 and is very unlikely to be met this year. One should note, however, that although there are still 28 applications pending [56], the number of applications has also decreased; in 2012 only eight applications were submitted. Nevertheless it remains vital for the industry that serious applications will be granted exploration licences such that the inertia in the growth of the geothermal industry is not slowed down.

Production Licence It is only after the wells have been drilled and tested, that the operator can apply for a production licence. Although nine wells have been drilled successfully, only two of those currently hold a production licence; the 2005 project in Bleiswijk and the 2006 project in Heerlen, which hold the exclusive right of usage of the geothermal resource for 30 and 35 years, respectively [84] [85]. Two of the other wells have applied for

[39] The TU has not yet started drilling.
[40] Ted Duijvestijn & Leon Ammerlaan, personal communication, June 2013

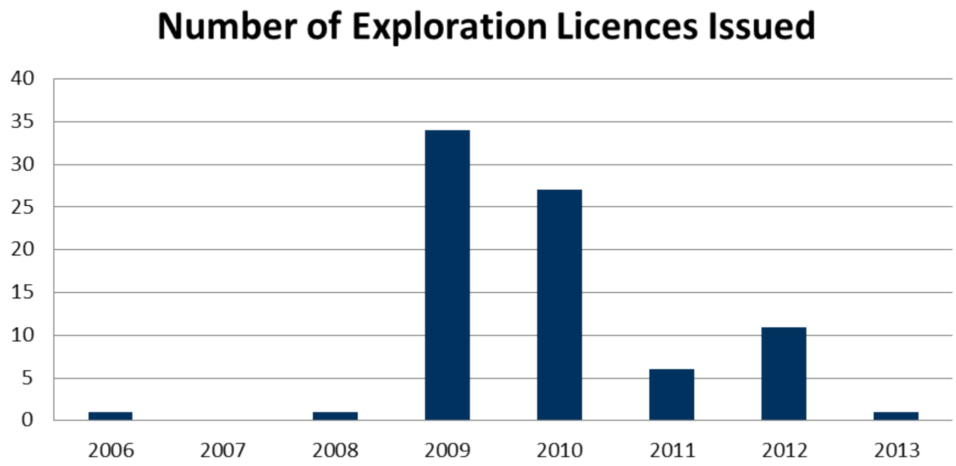

Fig. 3.3. Diagram showing the number of exploration licences for geothermal energy that have been inssued each year. Note that the number of granted licences for 2013 are only those issued before July 1. Source: [95][56]

this licence in 2011 [54], the others earlier this year [56]. Although applications for production licences have been submitted, these are still pending and licences have not been granted yet. The production licence grants the owner the right to use the geothermal well for heat production, but will only be issued after it has been proven that this will happen in line with health, safety and environmental (HSE) regulations. These conditions are based on the Mining Act, but interpretations of this act differ between oil and gas wells, and geothermal wells.

Due to the long history of oil and gas drilling in the Netherlands and on the Dutch continental shelf, the Mining Act is a sophisticated piece of legislature. However, although the application of the law is very clear for these mining activities, the inexperience with geothermal energy means that the interpretation of the law for this mining activity is less clear. This became apparent when unexpectedly hydrocarbons were found dissolved in the water in two wells in Pijnacker. The presence of oil can clog up the wells and the presence gas could lead to the well flowing independently; both these cases could not only damage the geothermal installation, but with that also lead to situations where safety and the environment are compromised. This made it necessary to intensify the relatively loose interpretation of the Mining Act for geothermal wells, see [52].

Although it is known that oil and gas fiels are present in the area, the probability of finding these fuels dissolved in the aquifer was considered virtually zero and no geological expert had expected it to happen [59]. Therefore, no precautions were taken to deal with this bycatch.

The two horticulturalists decided to commence in a joint study on how to solve this issue. They tried to find solutions in the oil and gas industry[41], and as it turned out a new wellhead that could resist more pressure had to be designed. This process was partly

[41] Ted Duijvestijn, personal communication, June 2013

funded by the MEI subsidy and grants and loans from other parties[42], but the majority of the costs had to be carried by the operators. Not only was it costly, it was also a great inconvenience to them, because the wells had to be closed for more than a year.

As explained before the role of SodM is that of supervisor; it is not a club of advisors ("*adviesclub*"[43]). The role of SodM was to give general directions and confirming whether the actions taken to improve the HSE situation were acceptable or not[44]. This implies that SodM checks whether mining activities are carried out safely and if regulations are adhered to, but that they do not set the standards. In a study summarising how the process of solving this hydrocarbon problem went, the authors concluded that one issue for the operators was that they didn't know which standards the new wellheads, etc. needed to conform to ("*probleem daarbij was dat SODM vooraf niet aangaf hoe streng deze eisen moesten zijn, maar Ammerlaan en Duijvestijn moesten zelf met voorstellen komen*" [59]).

The uncertainty regarding the regulations can lead operators to come up with creative solutions. For example, after the bycatch of gas was caught, the operators decided to install a CHP installation. This allowed them to bring the initially unwelcome substance to good use. In fact, one operator has called it a fortunate side effect ("*gunstige bijkomstigheid*")[45].

At the same time it can also be a frustrating process. Especially as earlier accepted aspects were later declined [59]. According to the report on their study and the results, part of this problem is because SodM has a theoretical way of thinking; they accept only those installations that could withstand the most extreme cases and the biggest risks. The horticultural industry on the other hand, is known to have a more practical mindset [59]. As a result of the research done by the two horticulturalists though, new wellheads were developed that were accepted by SodM. Because of the extensive investment in the design of the new wellheads, these have since been used by other wells as well, and seem to become the standard wellheads for geothermal wells.

Although this issues seems to have been solved, it could leave a negative impact on the geothermal industry as a whole. Clearly safety is of utmost importance, but as the interpretation of the law remains unclear, causing delays in obtaining production licences, future operators could be discouraged. However, it simply requires experience and research to come to the 'best' interpretation of the law.

Conclusion The exploration and production licences for geothermal energy allow the operator to become the sole user of the geothermal resource in an area at a certain depth. This protects the operator from competition from others that want to make use of the same resource and reduces the chance of the well producing less than expected due to interference with other wells that could potentially be drilled in the area.

[42] Ted Duijvestijn, personal communication, June 2013
[43] Ted Duijvestijn, personal communication, June 2013
[44] Again, SodM is a supervisor and does not explicitly state their approval ("*zegt geen ja en geen nee*"), as this will make them liable. Instead they simply stop intervening. (Anonymous, personal communication, 2013)
[45] Leon Ammerlaan, personal communication, June 2013

Conditions for the licences are changing as the industry is growing and more and different problems are faced. The inexperience of the industry is the main reason for this and as the industry reaches maturity, it is likely that clearer standards and interpretations of the law will be established. For now, however, it is key that there is an opportunity within this uncertainy for creative solutions such that the growth of the industry is not hindered.

During a meeting with the Second Chamber on June 26, 2013 (a so-called "*Rondetafelgesprek*") it became clear that there is a wish among some to be granted a 'light' exploration licence. This start licence would not allow drilling, but buy the operator some time for desk study ("*bureau activiteiten*") [36], such that the investment in this research is not wasted by being done by multiple parties in one area. This licence would then not require all the organisational conditions that need to be met for the exploration licence. This could possibly further enhance the reduction of the risk factor associated with the competition for one source. However, on the other hand it could also slow down the growth, as after the start licence is obtained, and one operator will do research in the area, after which for some reason he will cancel the project, while other potential operators do not get a chance at persuing their plans.

3.5 The effect of existing policy on barriers

The most important barriers in place are the high price of geothermal enegy compared to conventional energy sources and the geological risk which directly affects the output of the geothermal plant. The most imporant driver is the fact that geothermal energy is considered to be sustainable and does not emit CO_2. The SDE+ subsidy scheme, the SEI guarantee scheme and the system in place for licencing exploration and production of geothermal energy are the three most important policies in place that directly influence the growth of the geothermal energy industry.

The SDE+ scheme lowers the barrier of price by covering the financial gap between the cost of producing geothermal and fossil energy. It has a promising potential effectiveness, as thus far 47 projects have been granted the subsidy, some of which are already in or have finished construction. Because the way the scheme is set up, it is most effective for geothermal heat only plants that are owned by single or small groups of operators that will also make use of (part of) the heat themselves. This is appropriate, as the likeliest market to adopt is horticulture; most of the current and planned projects are mainly aimed at heating greenhouses.

A guarantee scheme is a very cost-effecitve way to support geothermal energy. In the past this scheme as received considerable criticism. A significant number of adaptations have been made, which should hopefully increase the effectiveness of the scheme. It is quite important that such a scheme exists when no private insurance carriers are willing to cover the risk, as the financial effect an underperforming well can have on entrepreneurs, which is what most horticulturalists are, is very large. The uncertainty of when the scheme will be relaunched weakens the effect though.

Although there is always a long term geological risk involved with the performance of the aquifer, it is very important that the operator is able to make the most of the well for a long time, especially since geothermal energy projects have high investment costs and long payback times. In the Netherlands, there are regulations on licencing hydrothermal sources, such that for a certain amount of time the operator is the exclusive user of the resource, allowing him to earn his expenses back. Without the certainty that the well performance will not be affected by other drillings into the same aquifer (unless they have specifically chosen to do so from the start, as happened in Pijnacker), the risk that the investment will not be returned is too high.

Although these major barriers have been lowered for geothermal energy, there are other constraints that have not been taken away. This is mostly due to the immature state of the industry and the little experience with geothermal energy in the Netherlands, which has led to a number of complications with the wells, and which has affected and is still affecting the effectiveness of the policies in place. This, however, is a phase that every industry has to go through, and it is of utmost importance that support in this phase will lead to a healthy and mature industry in the future.

4 Part III: The implications of supporting policy

4.1 What policies could potentially increase the growth of geothermal energy?

In this third section a number of possible other supporting policies for geothermal energy will be shortly discussed. It needs to be noted that these are suggestive policy measures that have not (yet) been introduced in the Netherlands. They might have been introduced in other countries, but due to the reliance on local conditions, such as the market, the geology and public opinion towards geothermal energy, it is hard to transfer the effects to the Dutch geothermal energy industry. It is by no means the goal of this section to predict whether these policies have the potential to be introduced in the Netherlands and will be successful in supporting deep geothermal energy. Instead their possible outcomes and the barriers for implementing these policy measures will be discussed; This section has a more *exploratory* nature.

Government builds plants Although several geothermal heat applications have already been constructed and are currently in the energy production phase, this is not the case for geothermal power or CHP. Barriers to starting such projects, however, are the fact that this is currently an expensive energy source, and also because of the lack of experience with it in the Netherlands.

In 2003 the German government started with the construction of geothermal power plants. The first plant constructed was in Neustatdt-Glewe and makes use of fluids with a temperature less than 100° C. Germany has three regions that are suitable for the production of geothermal energy, the Northern-German Sedimentary Basin, and in the South the the Bavarian Molasse Basin and the Upper Rhine Rift. In each of these areas, pilot project power plants have been set up for research purposes. They make use of different technologies, such as Kalina and Organic Rankine cycles, and make use of different water temperatures [75].

Five geothermal CHP plants have been constructed, and the government hopes that with the research and experience that can be gained from those, costs for geothermal power will decrease and the technology becomes more established. This will make geothermal power more attractive for private investors; the first privately financed geothermal power plant (Dürrnhaar) is in the planning stage. In a foresight by the renewable energy agency in 2009 it was predicted that between 2010 and 2020 the installed capacity will increase with an astonishing 5000%. This is believed to be (at least partly) due to the pilot plants that have been installed so far [75].

An important barrier to the construction of publicly funded geothermal plants is that they are expensive. Furthermore, it can also be a politically sensitive topic. When projects will not be as successfull as was hoped for, the government will be blamed for wasting public money. After all of the partners of the district heating project in The Hague left the cooperation, a municipal executive (*wethouder*) stated that he still believed in the project and that he wanted to find other investors to continue the project[46]. This plan was criticised by other municipal executives, who did not want any more public money spend on this [69].

Fund for research The geological risk that arises at the start of every hydrothermal energy project is not the only risk that affects the outcome of a geothermal project. Because of the little experience that exists with low enthalpy geothermal energy in the Netherlands, only some solutions to the problems that have occured so far have been found, and more problems can be expected as the geothermal systems age and more, deeper wells (also in less known geologies) are drilled. As one operator said, we have now encountered thirty problems and found ten solutions, but in a few years this will have become eighty problems with seventy solutions[47].

This means that all those first projects that are currently either constructing a hydrothermal energy system or producing geothermal energy are all pioneers that will be the ones that will experience these problems for the first time. With all things new, it might take some time before the (right) solution to the problem is found, meaning that those pioneers will most likely have to devote extra resources to finding new answers, rather than being able to implement known solutions.

In order to find ways to tackle these problems, individual operators or a group of operators experiencing the same issue, have to invest in research that will result in a solution. Depending on the size of the problem, this can be an expensive task. If the government would create a fund that could support for such investigations, this would reduce risk for the operator, as it will not have to face unexpected high costs related to issues that will (most likely) already influence the performance of the well. At the moment there are innovation subsidies available that can help pay for these costs; subsidies that helped fund earlier research was done by with the MEI and UKR subsidies.

However, these only subsidised a minor share of the costs. Ammerlaan, one of the operators which faced the problem with hydrocarbon bycatch said that he had expected more help financially ("*financiëel meer verwacht*"). The availability of funds for research was also one of the recommendations by the GeoThermal Regulation - Heat study of 2009 [29]. This made the operator(s) of the problematic well(s) responsible for finding solutions to problems that might arise in other wells, too. This is exactly what happend with the gas found in the wells; since it was discovered by the two wells in Pijnacker, two newer wells have experienced the same problems.

There is € 2 million available for geological research [57], but this does not include technological problems with the wells themselves, and this is not publicly available. It is very likely granted to research institution TNO[48]. This year € 400,000 has been reserved by the government for the stimulation of research and the development of knowledge in the geothermal industry [57], but it is unclear whether this will be used for such issues.

[46] July 27th, 2013 it became official that the project will be terminated and will file for bankruptcy [67].
[47] Leon Ammerlaan, personal communication, June 2013
[48] Victor van Heekeren, personal communication, July 2013

The discovery of dissolved oil and gas in the brine is one of the more serious issues that have occured in the short history of geothermal energy in the Netherlands. Another major problem that has been experienced by multiple operators is with the injectivity of the geothermal fluid. A short study into this has been done by TNO, however, this has not yet resulted in proper solutions. As the report concluded, not one “serial killer”, but instead a “series of killers” has been found [92]. It seems that at least some of them can or could have been resolved with the use of information and knowledge from the large oil and gas industry that exists in the Netherlands. For others, however, technical solutions will need to be found in order to have the wells working in the best possible condition. These solutions could be worked into a standard for the industry that will prevent the same issues from arising in future wells too.

A constraint to this policy measure is that it will lead to higher expenses for the government. Also, although they will lower the risk for future operators a bit, investors might still be wary of the immaturity of the geothermal energy industry in the Netherlands and the continuous changes that have taken, and will, in the near future, take place regarding standards for drilling and operation of the well.

Gas pricing system As gas is the most important alternative for geothermally produced heat, the price of gas plays a large role as a driver for geothermal energy. This can go both ways: if prices are expected to rise, the demand for geothermal energy will likely increase, whereas when fossil energy prices are expected to remain at current (low) levels, this could hinder the growth of the industry.

The way the gas pricing in the Netherlands is organised is counterconstructive for the geothermal industry. There exists a degressive gas pricing structure, which means that with increasing volumes of consumption, the unit price of gas goes down, see figure 4.1. These low prices for large consumers are a barrier to geothermal energy. The degressive market structure has existed since the gas production started and was the cause of an increase in gas consumption, which then resulted in the extensive grid present nowadays. However, what was used then in order to promote the gas industry, is now counteracting the environmental movement by reducing incentives to use less gas or using it more efficiently.

Creating a new system of gas prices, with either stable prices or increasing prices with increasing volumes consumed, could lead to a higher demand in alternatives for gas, of which geothermal energy is one. However, it will very likely lead to a storm of protest if this change would be implemented, as for many bulk consumers the costs for energy will go up, resulting in serious economic consequences for many sectors. The current low prices for industrial users in the Netherlands compared to other European countries, see figure 4.2 make the Netherlands a favourable location for industrial companies with high gas demands. An increase in prices could lead these firms to relocate to places where their energy costs will be lower.

The horticultural sector accounts for 10% of the total gas consumption in the Netherlands [68]. Although generally speaking this sector is very suitable for using geothermal power, not all of them will be able to switch over to geothermal energy. For example, because no

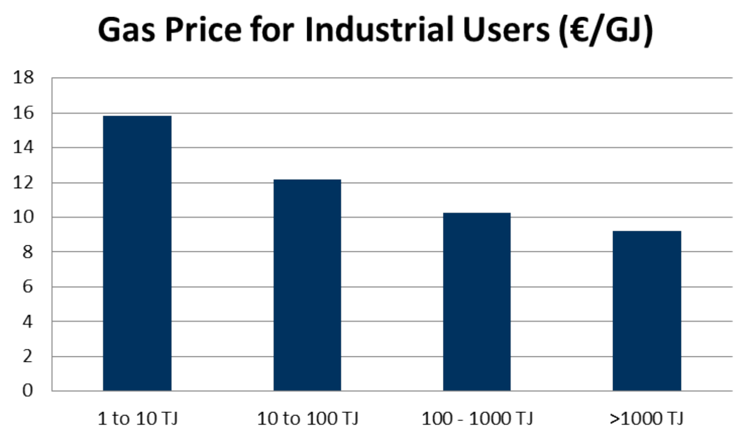

Fig. 4.1. Diagram showing the prices for gas for industrial consumers in the Netherlands. Source: [34]

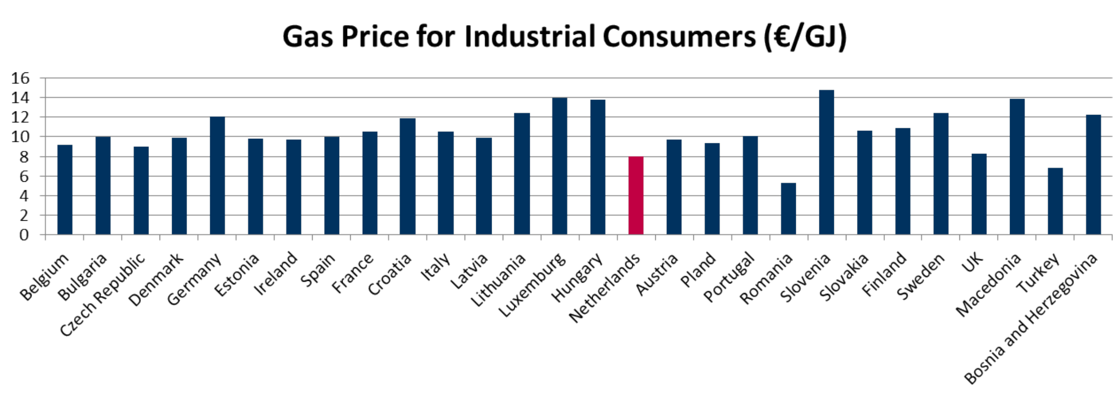

Fig. 4.2. Diagram showing the prices for gas for industrial consumers in different European countries. As can be seen, the Netherlands has one of the lowest prices, only after Romania and Turkey. Source: [34]

suitable aquifers are present in the area, or the aquifers present are already being fully used by others.

The effect of the price of gas is very complex and has a very wide range. It will therefore never be adjusted *for* the geothermal industry. However, its change could have significant consequences for this renewable energy source, as the gas price is one of the most important barriers to the geothermal industry. However, it is not at all certain whether such a change would be helpful for the geothermal industry. It is also possible that other alternatives are preferred.

Long term guarantee scheme Although there is a guarantee scheme in the Netherlands for when the capacity of the well is lower than expected right after drilling, there is no equivalent for if the performance of the well decreases during the production phase. With geothermal projects the investment done up front needs to be earned back by the production of energy during the lifetime of the well. For this to happen, it is key that the capacity of the well remains stable during production.

In France, however, they do have a scheme like this. With this long term guarantee scheme, the operator can insure the well against problems that result in a reduction in capacity. Geothermal energy requires a high initial investment and has a long payback time (> 15 years), but is is generally assumed that the well will be providing heat for a timespan of around 30 years. If the production, however, unexpectedly decreases over time, the payback time of the well could become much longer and the profitability of the well may suffer.

The necessity of this scheme came about when at a well in Meileray, France, the first borehole, the production well had a good performance, but the second well, which would be used for reinjection “presented many difficulties” [9]. This is not a situation that is unheard of in the Netherlands, even in the short history of deep geothermal energy. Because all the water that is pumped up must also be pumped back into the aquifer, injectivity and production are equally important. The injectivity, however, has given trouble with some of the wells. One of the operators has recently installed new, bigger pumps in order to be able to reinject the water and started research this summer into the well to see how the injectivity can be improved[49].

It is hard to predict whether there is a demand for such a guarantee scheme in the Netherlands. In France, operators have to pay a downpayment which is a certain percentage of the initial investment costs, and then a yearly fee of €12,500 [35]. This makes the scheme quite expensive and leads to long term mandatory expenses for the operator, something that might deter him from making use of it.

Because the scheme is, just like the well performance SEI scheme, relatively inexpensive for the government, as the successful projects help pay for those which have unsatisfactory results. Money will need to be reserved on the budget as long as not that many operators make use of it, just as with the SEI right now, to make sure that there is the financial

[49] Anonymous, personal communication, 2013

possibility of compensation. This is a barrier for the government to implementing this scheme, especially in the current economic situation.

5 Conclusion

The most important barrier that still exists is the availability of gas as an alternative, because in the Netherlands gas (for large non-residential) users is relatively inexpensive, reliable and the (psychological) default fuel. Furthermore, investment into geothermal energy is being seen as a high risk investment, not only because of the geological risks, but also because of problems that have arised in existing projects. This is partly a consequence of the immaturity of the geothermal industry, because of the little experience problems are dealt with reactively, instead of being prevented by proactive action.

Currently the geothermal energy industry is still in its infancy stage, with only nine wells running since its start in 2005. Only if the industry successfully runs through a learning curve, and thus makes it a less risky investment, geothermal energy could fulfill its large potential. However, until that time, the industry has to become more mature and create a (stable) set of standards regarding technology and policy. Over the next few years the changes in the geothermal industry as it is growing quickly should be monitored and studied closely, such that policy can adapt in order to remain effective in stimulating this energy source. As Ammerlaan said: first we were born, then we started crawling, now we have just slowly started to walk, but we're not yet in the pub drinking a beer ("*we zijn eerst geboren, daarna zijn we gaan kruipen, we zijn nu voorzichtig aan het lopen, maar we zitten nog niet in de kroeg bier te drinken*")[50].

The GeoThermal Regulation - Heat study by the EC in 2009 identified a number of requirements for geothermal regulation [30]:

- The necessity of sound and enduring legal structures for ownership and licensing of geothermal heat exploration & production
- The presence of a level playing field for incentives for geothermal energy compared to other renewable energy options
- Appropriate organisational structures to develop a vision on geothermal energy potential and the roadmaps to implement this potential

And it seems that although the application of the policies in place might still need some adaptations to reach their full potential, and will need continuous reassessment over the next few years as the geothermal energy industry is evolving and growing, a solid basis for each of these points has been set in the form of the exploration and production licences, the SDE+ subsidy scheme and documents such as Actieplan Aardwarmte and Stappenplan Aardwarmte voor de Glastuinbouw. Also when comparing the Dutch geothermal policy situation with the suggested regulations from the GTRH project, many things of their points are reflected in the Dutch laws and regulations guiding the geothermal energy industry.

If the geothermal energy proves to be a successful energy source in the Netherlands and the industry will be able to reach maturity, then the future dependency on (foreign) gas could be reduced, and the heat and electricity could be provided with a clean, safe,

[50] Ammerlaan, personal communication, June 2013

reliable, easily controlled, and environmentally friendly source of energy. It is important to note that although most of this work was about all that could or has gone wrong within the first few years of geothermal energy as a heat provider, there have also been many successes, such as a geothermal installation in an area where little was known of the geology or aquifers where the temperature or flow turned out higher than expected.

6 Nomenclature

ADEME - Agence de l'Environnement et de la Maîtrise de l'Énergie - Environment and Energy Management Agency
BRGM - Bureau de Recherches Géologiques et Minières - Geology and Mining Research Agency
CHP - Combined Heat and Power
CSR - Corporate Social Responsibility
EC - European Commssion
ECN - Energie Centrum Nederland - Energy Research Centre of the Netherlands
EEZ - Exclusive Economic Zone
EGS - Enhanced Geothermal Systems
EU - European Union
FIT - Feed in Tariff
fte - full time employee
GJ - Giga Joule (10^9 Joule)
HDR - Hot Dry Rock
K - Kelvin
Mtoe - Mega tonnes of oil equivalent (10^6 toe)
MW_{th} - Megawatt thermal (10^6 Watt thermal)
NAM - Nederlandse Aardolie Maatschappij - Dutch Oil Company
NREAP - National Renewable Energy Action Plan
PJ - Peta Joule (10^{15} Joule)
tcm - trillion cubic meter
TNO - Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek - Netherlands Organisation for Applied Scientific Research
TPES - Total Primary Energy Supply

References

1. ADEME. French know-how in the field of geothermal energy, August 2012.
2. Agentschap NL. Handleiding sei risico's dekken voor aardwarmte, September 2010.
3. Agentschap NL. Handleiding sei risico's dekken voor aardwarmte, November 2012.
4. Agentschap NL. Tabellen stand van zaken sde+ 2012, 10 December 2012.
5. Agentschap NL. Berekening stimulering duurzame energieproductie (sde+), June 2013.
6. Agentschap NL. National expertisecentrum warmte, April 2013.
7. D. Alfe, M. Gillan, and G. Price. Thermodynamics from first principles: temperature and composition of the earth's core. *Mineral Mag*, 67(1):113 – 123, 2003.
8. Algemene Rekenkamer. Subsidieregelingen duurzame energieprenergie (mep & sde) - terugblik 2010, March 2010.
9. W. Bank. Geothermal risk mitigation instrument and incentive program, September 2007. UPI Number: 00253607.
10. BBC. Gcse bitesize geothermal energy. www.bbc.co.uk/schools/gscebitesize/science.
11. BBC. The kola superdeep borehole. http://howbigreally.com/dimension/depths/kola-superdeep-borehole.
12. D. Bont, J.-D. van Wees, and J. Verwij. Subsurface temperature of the onshore netherlands: new temperature dataset and modelling. *Netherlands Journal of Geosciences*, 91(4):491–515, December 2012.
13. BRGM. The french geothermal risk guarantee system, November 2008. https://pangea.stanford.edu/ERE/pdf/IGAstandard/GeoFund/Germany2008/Bezelgues-Courtade.pdf.
14. BRGM. Deep geothermal energy: the soultz-sous-forts site has reached the sustainable production phase, July 2012.
15. CE Delft. Warmtenetten in nederland, October 2009.
16. E. Commission. Directive 2009/28/ec on renewable energy systems, 2009.
17. J. de Groot. Letter may 7, 2013, platform geothermie, May 2013.
18. Duurzame Energiebronnen. Geothermische energie.
19. ECN. Aanvullend advies geothermie sde+ 2013, December 2012.
20. ECN. Basisbedragen in de sde+ 2013 eindadvies, September 2012.
21. ECN. Dutch industrial waste heat in district heating: wasted effort?, September 2012.
22. ECN. Bijdrage ten behoeve van rondetafelgesprek, 26 June 2013.

23. ECN. Conceptadvies basisbedragen sde+ 2014 voor marktconsultatie, May 2013.

24. ECN. Conceptadvies sde+ 2013. Presentation by Sander Lensink, 13 May 2013. The Hague.

25. ECN. Stimuleristimulering duurzame energie 2014, 2013.

26. Energeia. Commercile verzekeraars duiken in geothermisch gat dat de overheid laat vallen, April 2010.

27. Energiek2020.nl. Floraholland gaat aardwarmte van 4 km diep oppompen, June 2011.

28. Energiek2020.nl. Diepe aardwarmte westland gaat niet door, June 2013.

29. European Commision. Geothermal regulation framework, November 2009.

30. European Commission. Geothermal regulation - heat - final publishable report, December 2009.

31. European Commission. Primary production of natural gas. Graph by Eurostat, 2013.

32. European Geothermal Energy Council. Fact eheet on enhanced geothermal systems: why it is different to shale gas, June 2013.

33. European Geothermal Energy Council. Financing geothermal energy, July 2013.

34. Eurostat. Gas prices for industrial consumers, June 2013.

35. GEOFAR. The geothermal risk guarantee system. http://www.energia.gr/geofar/articlefiles/factsheets/France-FactsheetJune 2009.

36. P. Geothermie. Samenvatting ronde tafelgesprek tweede kamer over geothermie, July 2013.

37. L. Gonzalez. Aardwarmte - de duurzaamheid van geothermie. Master's thesis, The Hague University of Applied Science, January 2013.

38. Government of the Netherlands. Energy, 2013.

39. Grontmij Nederland BV. Waardebepaling kleine ondergrondse infrastructuur. Technical report, Stichting Pipeliner, Houten, October 2005.

40. J. Heederik and A. Huurdeman. Geothermal study of the central graben (north brabant): evaluation of the results of an exploratory geothermal well in asten. *TNO Communication on Hydrological Research*, pages 77–95, 1988.

41. IF Technology, Ecofys and TNO. Diepe geothermie in 2050. Technical report, Agentschap NL, March 2011.

42. International Energy Agency. Oil and gas security - the netherlands, 2012.

43. H. Kombrink, J. van Veen, and M. Geluk. Exploration in the netherlands, 1987 - 2012. *Netherlands Journal of Geosciences*, 91(4):403–418, December 2012.

44. J. Korenaga. Clairvoyant geoneutrinos. *Nature Geoscience*, 4:581–582, September 2011.

45. L. Kramers, J.-D. van Wees, M. Pluymaekers, A. Kronimus, and T. Boxem. Direct heat resource assessment and subsurface information systems for geothermal aquifers; the dutch perspective. *Netherlands Journal of Geosciences*, 91(4):637–649, December 2012.

46. K. Kranz. Geothermal energy in iceland. Seminar Geology Technische Universitt Freiberg, January 2007.

47. A. Lokhorst and T. E. Wong. Geothermal energy. *Royal Netherlands Academy of Arts and Sciences*, pages 341–346, 2007.

48. Ministry of Economic Affairs. Actieplan aardwarmte, 2011.

49. Ministry of Economic Affairs. Energy report 2011. Policy report, The Hague, June 2011.

50. Ministry of Economic Affairs. Letter antwoorden op schriftelijke vragen over de sde+, 16 May 2011.

51. Ministry of Economic Affairs. Energy and the economy. Infographic, 2012.

52. Ministry of Economic Affairs. Letter 31 january, 2012, opsporing en winning aardwarmte, January 2012.

53. Ministry of Economic Affairs. Letter minister kamp - openstelling sde+ 2013, 10 December 2012.

54. Ministry of Economic Affairs. Natural resources and geothermal energy in the netherlands. Annual review 2011, May 2012.

55. Ministry of Economic Affairs. Aardwarmte vergunningen per 1 juli 2013, July 2013.

56. Ministry of Economic Affairs. Aardwarmte vergunningen per 1 juli 2103, July 2013.

57. Ministry of Economic Affairs. Geothermal energy in the netherlands. Presentation by H. Kal, 28 March 2013.

58. Ministry of Economic Affairs. Letter minister kamp - reactie sde+ 2013, 10 April 2013.

59. Ministry of Economic Affairs and Productschap Tuinbouw. Verslaglegging ontwikkeling voorwaarden en aanpassing van technische installaties gvoor geothermiebronnen met olie en/of gas, 2013.

60. Municipality Heerlen. Mijnwater: basis duurzaam energie-netwerk, May 2012.

61. NAM. Aardbevingen.

62. Nationaal Expertisecentrum Warmte. Warmte en koude in nederland. Commissioned by: Ministry of Economic Affairs, January 2013.

63. New York Times. Quake threat leads swiss to close geothermal project, December 2009.

64. R. Nieuws. Aardbeving groningen, July 2013.

65. NLOG. Geothermie. http://www.nlog.nl/nl/geothermalEnergy/geothermalEnergy.html.

66. NLOG. Olie, gas en aardwarmte in nederland, November 2007.

67. Omroep West. Aardwarmteplan den haag is failiet. Online newspaper article, July 2013.

68. Omroep West. Twee procent minder gas door aardwarmte in de tuinbouw. Online newspaper article, July 2013.

69. Omroep West. Wethouder zet aardwarmteproject door. Online newspaper article, May 2013.

70. T. Patel. Le fracking for geothermal drawing ire of french oil. bloomberg.com, April 2013.

71. Platform Geothermie. Information in english.

72. Platform Geothermie. Technisch/economisch potentieel van geothermie in nederland.

73. Platform Geothermie. Faq's en ffact over aftopping van het subsidiabele vermogen van aardwarmteprojecten, May 2013.

74. Platform Geothermie. Projecten, August 2013.

75. H. Quick, J. Michael, U. Arslan, and H. Huber. Geothermal application in low-enthalpy regions. *Renewable Energy*, 49:133–136, January 2013.

76. Rijksoverheid. Nationaal actieplan voor energie uit hernieuwbare bronnen, June 2010. Also available as National Renewable Energy Action Plan (English translation).

77. Rijksoverheid. Overzicht van de openstelling sde+ in fases. Attachement to Openstelling Stimuleringsregeling Duurzame Energie+ 2013, December 2012.

78. Rijksoverheid. Stimulering duurzame energie (sde+), 2013.

79. L. Rybach. Geothermal energy: sustainability and the environment. *Geothermics*, 32(4-6):463–470, 2003. Selected Papers from the European Geothermal Conference 2003.

80. Sattelite Applications for Geoscience Education. Fundamental geologic concepts.

81. B. Schepers, J. Benner, and D. Bennink. 200-200 in 2020 - overzicht van het warmtepotentieel in nederland. Technical report, CE Delft, Delft, August 2010.

82. SodM. Aardwarmte, July 2012.

83. SodM. Strategie & programma 2012 - 2016, 2012.

84. Staatscourant. Winningsvergunning aardwarmte gebied bleiswijk, November 2008.

85. Staatscourant. Winningsvergunning aardwarmte heerlen, October 2009.

86. Staatscourant. Regeling van de minister van economische zaken van 13 februari 2013, nr. wjz/12043892, tot wijziging van de subsidieregeling energie en innovatie ter

wijziging van de voorwaarden in het programma risico's dekken voor aardwarmte - toelichting, February 2013.

87. G. Steinle-Neumann, L. Stixrude, and R. Cohen. New understanding of earth's inner core. News Release, September 2001.

88. D. Straathof. Cost of deep geothermal energy in the netherlands. Master's thesis, University of Utrecht, June 2012.

89. T&A Survey. Geothermie: veelbelovend maar zekerheid is nodig - summary geothermal update 2010.

90. TNO. Geothermal energy.

91. TNO. Thermogis. www.thermogis.nl.

92. TNO. Bia geothermal - tno umbrella report into the causes and solutions to poor well performance in dutch geothermal projects. Technical report, 2012.

93. US DOE Geothermal Technologies Office. Geothermal faqs, June 2013.

94. R. van den Bosch and B. Flipse. Winning aardwartme voor glastuinbouw. Kas als Energiebron, November 2010.

95. V. van Heekeren. Update geothermie 2013: Van heekeren gaat rupdate, April 2013.

96. P. van Wijnen. Update geothermie 2013: Eigenwijsheid is soms niet verkeerd, April 2013.

97. F. Walter. The status of geothermal energy in the netherlands. In *World Geothermal Congress*, pages 279–281. Delft University of Technology, 1995.

98. H. H. Westland. Rabobank investeert in aardwarmte, October 2011.