Research sustainability
Geothermal Wells in the Netherlands

Energy pay-back time, Life cycle analysis and social cost benefit analysis

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Preface

First and foremost, I would like to thank Victor van Heekeren for his support during this research. What would have been a short project, turned out to be quite a journey that took longer than anticipated. I was glad we were able to talk things over every time something new emerged that needed a solution. Without his help, I wouldn't have been able to gather all the required data. I would also like to thank everyone who contributed with data or feedback. The data has been fundamental and without feedback, the result wouldn't be what it is now. Finally, I would like to thank de Kennisagenda Aardwarmte for their patience with the delays in this study.
After 1,5 years of research, I am happy to be able to present this report.

Sincerely, Larissa Gonzalez

Summary

The first geothermal well in the Netherlands was realised in 2008. By 2014 the total amount of operational doublets had grown to 10. In this period of time a lot of experience was gained, making it possible to learn from the various issues that surfaced while extracting geothermal energy. These experiences helped the geothermal society to improve the various processes, making geothermal energy more efficient and sustainable along the way. While these developments continue, it remains necessary to gather data for the evaluation of this energy-source and for arguments in national and international discussions. This report on the sustainability of geothermal energy in the Netherlands is a response to this need. Back in 2012/2013 a first research was done on this subject which included just one geothermal well, namely Green Well Westland (GWW). This new research includes all wells operational in 2014, making the view on the sustainability of the extraction of geothermal energy in the Netherlands more complete.

This research consists of two parts, a Life Cycle Analysis (LCA) including the Energy Payback Time (EPBT) and an exploratory Social Cost-Benefit Analysis (SCBA).

LCA

Based on the data from 2014, it takes about 2-3 months of production to compensate the amount of energy that was needed and CO_2 that was emitted while drilling the well. Assuming that a geothermal well has a lifetime of 30 years it will produce a net amount of energy of 5,5 million GJ (1,5 million MWh). The amount of natural gas that will be saved in this period by using geothermal energy instead, is 174 million m^3, while saving the emission of 297.000 tonnes CO_2. That is the same as consumed by 3.625 households. The COP of the average of the wells is 21,9.
When looking back at the previous research on the sustainability of geothermal energy in the Netherlands of 2012/2013, which only included one well, it can be concluded that the sustainability of GWW is in line with the other wells. When taking a brief look at 2015, 2016 and the near future, it can be expected that the results will get better as the trend for geothermal doublets is to become deeper with higher capacities and production rates, making them more efficient and sustainable.
As for other environmental effects that are harder to quantify it can be stated that the risks are very low. These are among others: the auditory and visual nuisance for the surroundings, the decommissioning of a well, seismic activity and the possible implications of naturally occurring radiative materials (NORM). For these risks guidelines and industrial standards are or will be established by DAGO, the Dutch Association Geothermal Operators. Also various developments are taking place on this account, for example in studies of the Kennisagenda Aardwarmte. These results and the industrial standards will make it easier to share experiences on the extraction of geothermal energy in the Netherlands, thus reducing risks and possible negative environmental effects.

SCBA

The exploratory SCBA shows that the current forms of geothermal energy in the Netherlands – the supply of heat to greenhouses – have a positive SCBA balance. Even though a lot of aspects of the SCBA were subject to uncertainties, it is clear that geothermal energy is a favourable option to achieve high emission reductions and will have a positive social balance when the government of the Netherlands decides on a strict climate policy for the future. Therefore we can conclude that the extraction of geothermal energy in the Netherlands has a positive effect on the welfare of our society.

Nederlandse samenvatting

De eerste geothermische bron in Nederland is in 2008 gerealiseerd. In 2014 was het totaal aantal operationele bronnen gestegen tot 10. In deze periode is veel ervaring opgedaan waardoor geleerd kon worden van de verschillende issues die naar boven kwamen bij het winnen van geothermische energie. Deze ervaringen hielpen de geothermische sector om de processen te verbeteren, waardoor geothermie efficiënter en duurzamer werd. Terwijl deze ontwikkelingen plaatsvinden blijft het noodzakelijk om data te verzamelen voor het evalueren van deze energiebron en voor argumentatie in nationale en internationale discussies. Dit rapport over de duurzaamheid van geothermie in Nederland speelt in op deze behoefte. In 2012/2013 is een eerste onderzoek gedaan naar dit onderwerp waarbij naar slechts één geothermische bron gekeken is, namelijk Green Well Westland (GWW). Dit nieuwe onderzoek neemt alle bronnen mee die operationeel waren in 2014, wat het beeld van de duurzaamheid van geothermie in Nederland meer compleet maakt.

Dit onderzoek bestaat uit twee gedeelten, een Life Cycle Analysis (LCA) met hierin de Energetische Terugverdientijd (Energy Payback Time – EPBT) en een verkennende Maatschappelijke Kosten-Baten analyse (Social Cost-Benefit Analysis – SCBA).

LCA

Gebaseerd op de data uit 2014, duurt het ongeveer 2-3 maanden aan productie voordat de hoeveelheid energie die nodig is voor de boring van de bron gecompenseerd is. Hetzelfde geldt voor de hoeveelheid CO_2 die hierbij is uitgestoten. Bij de aanname dat een geothermische bron een levensduur heeft van 30 jaar, zal hij een netto hoeveelheid energie produceren van 5,5 miljoen GJ (1,5 miljoen MWh). Door gebruik te maken van geothermische energie in plaats van aardgas, wordt in deze periode bron 174 miljoen m^3 aardgas bespaard, waarbij 297.000 ton CO_2 minder wordt uitgestoten. Dat is dezelfde hoeveelheid als gebruikt door 3.625 huishoudens. De COP van het gemiddelde van de bronnen is 21,9. Terugkijkend op het eerdere onderzoek naar de duurzaamheid van geothermie in Nederland uit 2012/2013, waarbij slechts gekeken is naar één geothermische bron, kan worden geconcludeerd dat de duurzaamheid van GWW ongeveer overeenkomt met de andere bronnen. Wanneer we een snelle blik werpen op 2015 met een doorkijk naar 2016 en de nabije toekomst, is de verwachting dat de resultaten nog zullen verbeteren aangezien er een trend te zien is naar steeds diepere geothermische doubletten met hogere capaciteit en productie, waardoor ze efficiënter en duurzamer worden.
Voor overige milieueffecten die lastiger te kwantificeren zijn, geldt dat eventuele risico's erg laag zijn, zoals voor onder andere geluid en visueel overlast voor de omgeving, het ontmantelen van een bron, seismische activiteit en de mogelijke effecten van natuurlijk voorkomende radioactieve materialen (NORM). Voor deze risico's zijn of worden richtlijnen en industriële standaarden opgesteld door DAGO, de Nederlandse Vereniging voor Geothermische Operators. Daarnaast vinden er verscheidene ontwikkelingen plaats, zoals studies op dit gebied door de Kennisagenda Aardwarmte. Deze resultaten en industriële standaarden zullen het makkelijker maken om ervaringen uit te wisselen over het winnen van geothermische energie in Nederland, waardoor risico's en de kans op mogelijke negatieve effecten verder zullen afnemen.

SCBA

De verkennende maatschappelijke kosten-baten analyse (MKBA) laat zien dat de bestaande geothermische bronnen in Nederland – die warmte leveren aan kassen – een positieve MKBA balans hebben. Ondanks dat veel van de aspecten uit de MKBA onderwerp waren van onzekerheden, is het duidelijk dat geothermische energie een gunstige optie is om grote emissie reducties te behalen en dat het winnen ervan een positieve maatschappelijke balans zal hebben wanneer de Nederlandse overheid besluit tot een strikt klimaatbeleid. Het winnen van geothermische energie heeft dus een positief effect op de welvaart van onze maatschappij.

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1. Introduction

In recent years geothermal energy in the Netherlands has been subject to a great deal of development. From 2008 till 2014 several geothermal wells have been drilled, most of them with success and to ones satisfaction. However, it remains a complex business in which not everything turns out the way it is at first hoped for or expected. This raises questions as to the efficiency, feasibility and also sustainability of geothermal energy in the Netherlands.
On this last subject there has been research in 2012 on the sustainability of one well, namely Green Well Westland (Gonzalez, 2013). The results have proven to be of great value for the Geothermal Platform in the Netherlands in their communication with several authorities. This was not in the last place because the results were very opportune, with the main result being that the amount of energy needed to drill the well, was 'paid back' in less than 3 months of production. However, as the results were based upon solely one well they could be considered biased or one-sided, as this well in particular was thought to be one of the best at the time.

In the context of discussions like STRONG ('structuurvisie van de ondergrond') and the SER-agreement, but also with provinces, there is an increasing demand for analyses in which it is examined what the effects of these kind of energy sources are on the environment. Therefore there is a need for a more general and broader view on the sustainability of geothermal energy in the Netherlands. That is why the ministry of Economic Affairs and LTO Glaskracht Nederland – through the program 'Kas als energiebron' and with support of the Geothermal Platform – have decided on this extension of the research on all operational wells in the Netherlands in 2014. With the results in this report one can proactively answer questions on the effects of geothermal wells on the environment. Hereby it is prevented that third parties with little knowledge of deep geothermal energy, will make unsubstantiated assumptions and thus decisions. Additionally the results will be used in national and international discussions on the matter.

This study consists of two parts. Firstly an exploratory Life Cycle Analysis including the Energy Payback Time in which it is examined when a geothermal well will produce net (sustainable) energy, considering the amount of energy it costs to realise a well, what effects it has on the environment during its 'lifetime' and also what decommissioning will imply. Secondly the geothermal part of the exploratory Social Cost-Benefit Analysis of CE Delft is described. This chapter gives an indication of the social costs and benefits that geothermal energy has and will have on the welfare of our society. In chapter 2 it is illustrated what methodologies are used for each of these parts. Chapter 3 commences on the results of the LCA and the SCBA. In chapter 4 these results are discussed in current perspective and finally chapter 5 will present the conclusions.

When starting this research in 2015, only the data of 2014 was available. However, due to circumstances the SCBA-part took longer than originally planned, causing a delay in the publication of this report till the beginning of 2017. During this time data of 2015 became available, which could have been used for the LCA and EPBT. This part was already finished though, and even though it was not possible to redo this part of the research, it was still considered very important to somehow include it to keep the final report actual. Therefore an update is written at the end of the analysis in chapter 3.1.1, describing the 2015 data compared to 2014, and what the expected differences would have been in the results.

2. Methodology

At the time of the first research on the sustainability of Green Well Westland in 2012, there had not been any other similar research. It has been investigated again if this has changed over the last years, but this is (as far as the author has discovered) not the case. Also, it was taken into consideration to collaborate with students from for example the TU Delft, or to cooperate with an institute in Utrecht. This way the research could be more extensive and if they were doing research on the same subject we could help each other. Unfortunately, beforehand it appeared to be too hard to make this work, as it would have taken more time than was available to set up such a cooperation.[1]

When it was decided that a cooperation was not possible, the process was continued the way it was originally thought of. In the beginning this research consisted of three different parts:

- The Energy Payback Time (EPBT)
- An exploratory Life Cycle Analysis (LCA)
- An exploratory Social Cost-Benefit Analysis (SCBA)

During the research however it became clear that the first and the second part (EPBT and LCA) were inextricably linked and could not be separately assessed. Therefore the results in this report will contain only two chapters:

- LCA (including the EPBT)
- SCBA

The methods used in each of these two parts are explained below.

2.1 Life Cycle Analysis

In a life cycle analysis the complete lifespan of a material or energy source is assessed in terms of environmental impact. In this case research is done on the lifespan of geothermal wells in the Netherlands. As mentioned above this LCA is an exploratory analysis, taking into account the most important components of the life cycle of a general geothermal well in the Netherlands as known in 2014/2015. No official LCA tool or software is used, but this report is a description of the elements of geothermal wells that have the greatest impact on the environment, either positive or negative, describing also the delimitations that had to be made and their impact on the accuracy of the results.

The research includes:

- Drilling and Production
  - The amount of energy needed and greenhouse gases emitted by manufacturing the steel and cement for the casings.
  - The amount of energy needed to drill a well
  - The amount of natural gas (and energy) that is saved by using geothermal heat instead of natural gas (per year and lifetime).

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[1] Halfway a cooperation between CE Delft was established for the second part of this research, as explained in chapter 2.2.

    - The amount of CO_2 that is not emitted into the air because geothermal heat is used instead of natural gas (per year and lifetime).

- Additional environmental impact
    - Auditory and visual nuisance
    - Maintenance
    - Naturally Occurring Radioactive Materials / Low Specific Activity (NORM / LSA)
    - Risk on seismic activity
    - Groundwater pollution
    - Decommission
    - Other emissions

The 'Drilling and Production' calculations are performed using the same method as for the research in 2012/2013. Back then the research was done solely on Green Well Westland. This time all the operational geothermal wells in 2014 have been taken into account, in order to determine a 'general' well in the Netherlands in 2014. The participating wells are, in order of completion[2] the following 10:

- A+G van den Bosch (2x, locations Bleiswijk and Lansingerland)
- Ammerlaan
- Duijvestijn
- Greenhouse Geopower
- Green Well Westland
- Wijnen Square Crops
- ECW/Agriport A7 (2x)
- VoF Geothermie de Lier

Over time it has become clear that regular maintenance of the geothermal wells is needed. The availability of the geothermal energy depends on this and on the occasions of occurring malfunctioning due to technical reasons. As these events will happen more often during the lifetime of a geothermal well, these have been included in the assessments.
Other wells however have not been able to perform all the time from January-December because their doublets were not yet completed and thus were not operational in the first months. These wells are compensated for that part of 2014 in which they did not yet have any production.

Some wells in The Netherlands coproduce minor quantities of natural gas, which is mostly used for heating as well. This gas fully replaces an equivalent amount of natural gas otherwise to be obtained from the gas grid. The total effect on emissions is therefore zero and the coproduction is thus not included in the calculations (zero sum game).

For the research on production data the operators were asked to confirm and complement the data obtained from the Geothermal Platform. Unfortunately not all data was provided, thus an estimation had to be made for some of them. This however does not affect the accuracy of the calculations, as it concerns less than 5% of the data. Other data could be obtained through other parties like Well Engineering Partners and Daldrup.

[2] When referred to individual doublets in this research, numbers are used instead of names to warrant each operators privacy. These numbers do not represent the operators in the same order as mentioned here.

The obtained data is used as input in the Excel sheet that was created in the earlier research in 2012/2013. Some minor changes were made in the calculations and also the indicators were checked and adapted if necessary.[3] With the results the payback time could also be calculated as mentioned before. This is part of the Excel tool.

Until here the calculations have been specifically over the year 2014. To know the effects on the complete lifetime however we need to determine how many years a geothermal well 'lives'. Commonly this is assumed to be 30 years. This assumption is quite controversial, as it states only the period of time after which the temperature of the produced water will (slowly) start to decrease. The efficiency will decline, but it will take some years more before this process has advanced as much for the well to become inefficient. Nonetheless 30 years will be maintained in this research to be consistent with other research. The possible errors due to this assumption will at most cause a slightly less positive result, but certainly no overestimation.[4]

In this analysis the (average) capacity and COP of a geothermal well will also be taken into account. In the geothermal world they are important factors and often used to compare the wells with each other. Even more, the decision to drill a geothermal well is generally based on estimates of these data made by geothermal research agencies.

2.2 Social cost-benefit analysis

While doing research for the social cost-benefit analysis (SCBA) part of this study, it was found that CE Delft was also doing an SCBA on several underground functions in the Netherlands, including the extraction of geothermal energy. In this study in 2015-2016 CE Delft has analysed what the effects of the implementation of these functions would be on the welfare of our society. This study is done in the context of the mandatory 'PlanMER' (Environmental Impact Assessment) to support the formation of the 'structuurvisie van de ondergrond' (STRONG) which is a structural plan for the underground in the Netherlands.

Soon it became clear that it would be useful to await the results of the study of CE Delft and avoid double work by cooperating, thus making a SCBA on geothermal energy based on real data from existing geothermal wells. It was agreed that by providing CE Delft with these data, the results of their study could be used for this research on the sustainability of geothermal energy.

In general an SCBA determines the costs and benefits for an entire society. The calculation includes the financial costs needed for the realisation of a certain operation, but also external effects like air pollution and the effects on the climate. If the effects are non-financial, they will be monetised using key figures, thus making it possible to compile them and create an approximate image of the social costs and benefits. This will be set out over a certain period of time, including calculations concerning the discount rate. Next the results will be compared to a situation without the realisation of that specific operation, also called a 'reference alternative', thereby discovering what the differences would be over time when carrying out the operation.

[3] The indicators used in the Excel tool are justified in Appendix I.
[4] In Appendix II the general sustainability of geothermal energy is discussed, expanding more on the subject of decrease of the production.

In their study CE Delft has determined the effects of the implementation of several underground functions on the welfare of our society, including the extraction of geothermal energy. These implementations were the operations as explained above. The reference alternative would be at first heating with natural gas instead of geothermal energy and secondly a situation without the STRONG regulations on the underground, thus continuing a 'business as usual' scenario.
For this study on the sustainability of geothermal energy, only that part of the CE Delft SCBA is used in which the implementation of geothermal wells in the Netherlands is examined. For this purpose they selected two applications: on the one hand a geothermal doublet heating existing greenhouses, on the other hand a doublet plus new district heating grid serving existing houses. The output of both applications was kept identical at 200.000 GJ per year. In their study CE Delft composed scenarios including both the greenhouses and residential houses application, assuming that their development will proceed quite equally. The situation in The Netherlands in 2016 however, is that 15 out of the 16 existing geothermal installations are (or will be) serving greenhouses; only one – not yet operational – installation will supply heat to a new district heating grid for a residential area. According to the Geothermal Platform it is thus not likely that in coming years the use of geothermal energy in residential areas will develop equally to its use for greenhouses. This research on the sustainability of geothermal energy in the Netherlands focuses therefore on the greenhouse application of the CE Delft study.

The intention of the study of CE Delft was to make the SCBA mainly quantitative. During the process however it became clear that STRONG would become quite abstract, and the PlanMER was thus also going to be more qualitative than originally intended. CE Delft accordingly decided to make the SCBA more exploratory, calling their research an 'exploration on welfare effects' rather than a SCBA. The results will serve mostly to identify under which circumstances a scenario will have a positive or negative influence on our society compared to a situation without STRONG.

In chapter 3.2 the results of the exploration on welfare effects of CE Delft are presented. The exploration will consistently be referred to as the SCBA of CE Delft.

3. Results

As explained in the previous chapter, the operators of all producing wells in 2014 were asked for their production data of that year. Firstly, with this data the average characteristics of the currently operational geothermal wells could be determined.

Average characteristics	
Depth [m]	2.230
T high [°C]	77
T low [°C]	33
Capacity [MWth]	9,6
Flowrate [m3/h]	195
Production [GJ/yr]	190.000
Consumption [MWh/yr]	3.000
COP	21,9
Weighted average COP [5]	25,6

Table 3.1 - Average characteristics of geothermal wells in the Netherlands (2014)

The results as presented below are based upon (all) the data of the operators.

3.1 Life Cycle Analysis

The LCA research is an extension of the Energy payback research, analysing not only the start-up phase of a geothermal well, but also its lifetime and decommission, as explained in chapter 2.1.

3.1.1 Drilling and production

Realisation of the well

After having retrieved all data from the operators, the excel tool from the previous research of 2012/2013 is used to determine the amount of energy used and CO_2 emitted while drilling the well. Therefore the amount of steel and cement needed for the casings is taken into account, plus their manufacturing processes, and also the amount of electricity used for the drilling itself.
With their production data it is then determined how much net energy they produced, by subtracting the amount of energy needed for the pumps from their production in 2014 (see also below).
Comparing the net production with the realisation-calculations, it was then possible to determine the energy and CO_2 payback times. For the results of all individual doublets, see Appendix III. Tabel 3.2 shows the average results.

	Energy [months]	CO_2 [months]
Average payback time	1,8	3,2

Table 3.2 – average payback times

[5] In the production weighted average COP wells with a high production contribute correspondingly more than wells with a low production. By taking this into account the weighted average COP for the total group is calculated.

These results are very close to the original calculations of the GWW research in which was determined that their payback times were about 2 months.

Lifetime

The lifetime of a geothermal well is assumed to be 30 years (see chapter 2.1). During its lifespan a great amount of energy and gas is saved by using geothermal heat instead of gas to warm the greenhouses. Also, by not combusting this gas, a fair amount of CO_2-emission is avoided. In Table 3.3 the amount of energy is presented that is produced by an average geothermal well in the year 2014, calculated out of the data from the Geothermal Platform (corresponding to the CBS data). This is not the same amount as in table 3.1, as in this calculation the wells that have only been able to perform a part of 2014 are compensated.

Production in 2014	GJ	MWh
Average	204.373	56.770

Table 3.3 – average production (gross)

For this production a certain amount of electricity was needed for the pumps to create the geothermal water flow. The Excel tool takes this into account and calculates the net produced energy, also including the energy it costs to produce the electricity that is needed. In other words, the primary energy.
This total amount is then expressed in gas and CO_2-emission (see table 3.4).

Saved in 2014	Net energy production		Gas [million m^3]	CO_2 [1000 tonne]
	[GJ]	[MWh]		
Average	183.354	50.932	5,8	9,9

Table 3.4 – saved in 2014

Both table 3.3 and 3.4 show only the average results, in Appendix III the results are presented of the savings of each individual well in 2014.

When assuming that a geothermal well has a lifetime of 30 years and an average production rate as stated above, the total amount of energy produced, and gas and CO_2 saved will be as shown in Table 3.5.

To put things into perspective

An average household in the Netherlands consumes about 1.600 m^3 gas a year. This means that one geothermal well saves as much gas as needed for approximately 3.625 households.

Produced in 30 years				Saved in 30 years	
Gross		Net		Gas [million m^3]	CO_2 [1000 tonne]
GJ	MWh	GJ	MWh		
6.131.190	1.703.100	5.500.620	1.527.960	174	297

Table 3.5 – results over a period of 30 years

Update for 2015

In the results above, only data over 2014 is used, as the analysis was finished before the data over 2015 came available (in april 2016). Another thorough analysis over this new dataset was not possible, but still it was considered important to include a review on it in this research to make the analysis complete and keep the final report as actual as possible. Therefore the data of 2015 has been compared to 2014 with a short analysis done by the Geothermal Platform.

The total amount of operational wells in 2015 was 11, one more than in 2014 as Floricultura has been taken into operation too. The wells that were new in 2014 have been operational in all of 2015 and the data of this year shows that their production was even better than expected in the calculations above. Furthermore, almost all of the wells had a higher production than the year before (except two). This resulted in a total production of around 2,4 PJ in 2015, about 0,5 PJ more than in 2014. The average production temperature stayed the same at 77°C and the injection temperature decreased with 1°C to 32°C. The average capacity and flowrate were a bit lower with 171 m^3/h (195 m^3/h in 2014) and 8,9 MWth (9,6 MWth in 2014). The electricity consumption stayed more or less the same (2950 MWh) and the COP was slightly lower, around 21.

Overview through the years, past and near future

Figure 3.1 shows the production through the years of all geothermal wells in the Netherlands in GWh/yr (1.000 GWh = 3,6 PJ). Especially the increase between 2014 and 2015 is evident, which is about 60%. In the last two years the production has even more than doubled.

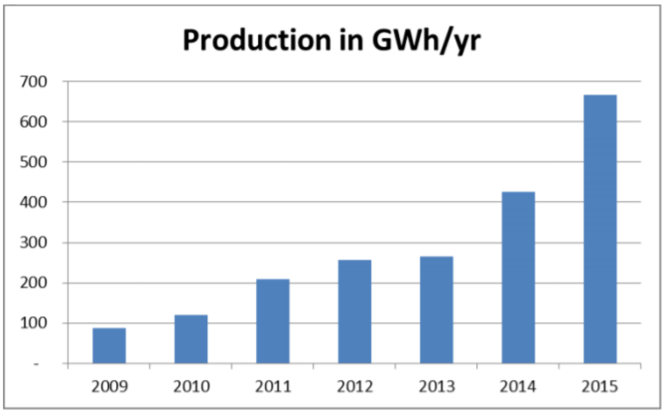

Figure 3.1 – Total production through the years of all geothermal wells in the Netherlands in GWh/yr (source: Geothermal Platform)

The Dutch Geothermal Platform has also made an overview on the amount of wells and the total and average capacity in MWth through the years. Figure 3.2, 3.3 and 3.4 show these developments.

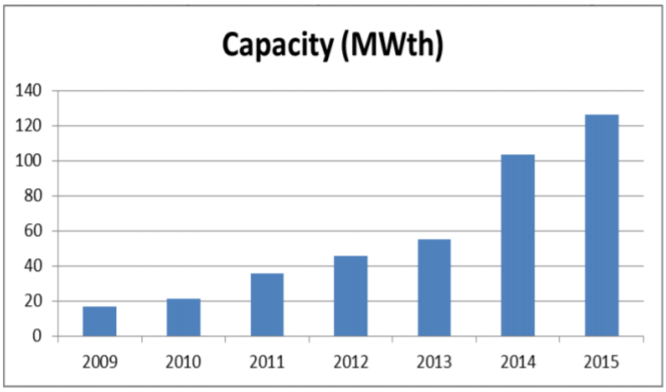

Figure 3.2 – Total capacity through the years of all geothermal wells in the Netherlands in MWth (source: Geothermal Platform)

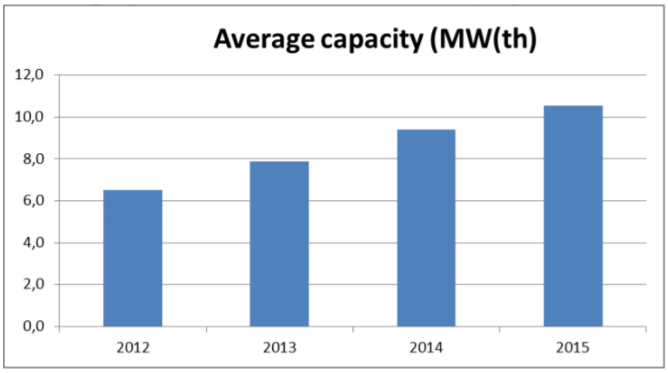

Figure 3.3 – Average capacity through the years of all geothermal wells in the Netherlands in MWth (source: Geothermal Platform)

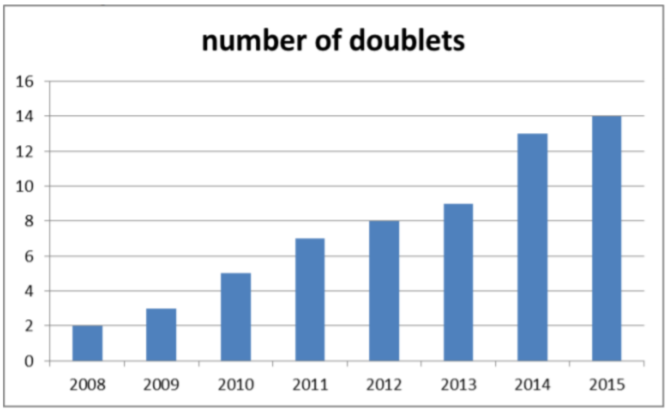

Figure 3.4 – Number of realised geothermal doublets in the Netherlands through the years[6] (source: Geothermal Platform)

In 2016 again one new geothermal well has been taken into operation, namely Vierpolders, and the prospects for 2017 are good: three more geothermal doublets are under construction. The website of the Dutch Geothermal Platform states that for the coming two years 6-10 new initiatives will start drilling. Also the only well in the Netherlands that hasn't been taken into operation after realisation

[6] The number of wells in this figure include the wells that were realised but not yet operational in the year of completion. The research in this report does not inlcude these doublets, hence the difference between the amount of wells in 2014: 10 wells as stated in chapter 2.1, and 13 wells according to figure 3.2.

(Aardwarmte Den Haag) will have a restart in the near future under the new name Haagse Aardwarmte Leyweg.

Considering the new data and information, it is evident that the LCA and EPBT as calculated above (based on data of 2014) is rather conservative and still improving every year, making geothermal energy in the Netherlands even more sustainable.

3.1.2 Additional environmental impact

Due to the direct data obtained from the operators, the effects on the environment of the energy production and CO_2-emissions could be calculated quantitatively. For other effects however the data to do the same are not as straightforward. Therefore these will be described qualitatively below, looking at the various occurring events and proceedings during its lifespan. Sometimes a quantitative approximation is possible, if so this will be noted.

As the geothermal industry in the Netherlands is still quite young, lots of developments are still taking place. Along with this study, the Kennisagenda Aardwarmte commissioned several other studies on subjects like well integrity and QHSE (quality, health, safety and environment). Some of these results, like on the risk on seismic activity, is already included below. Other research is still work in progress. DAGO, the Dutch Association of Geothermal Operators, cooperates in several of these studies to set up industrial standards. In the coming years more results and standards will become available, making it easier to share experiences on the extraction of geothermal energy in the Netherlands, thus reducing risks and possible negative environmental effects.

Auditory and visual nuisance

Firstly we consider the auditory and visual nuisance caused by a geothermal well. During the drilling period these will be quite significant. The drilling rig will occupy around 3000 to 4000 m^2 and cause nuisance for its surroundings, both auditory and visual. Depending on the location of the geothermal well it is possible that neighbours experience inconvenience around their properties, like traffic. This situation will last for several months, 24 hours a day. The duration of the drilling activities depends on depth and specific conditions and usually average about 100 days.
When the drilling is done however, most of the nuisance will be over also. When the drilling rig is removed and the finishing activities are done, what is left is a small building containing the heat exchangers near the production and injection well. Thanks to the insulation almost no noise will escape from this place, reducing the nuisance to almost none.

Maintenance

With the ongoing developments a lot of experience will continue to be gained on the subject of maintenance. Nevertheless, the experiences in these 8 years have taught us a lot already.
Below the known components of maintenance are described. In general the costs of maintenance are held at 3% of the investment. This can also be said of the CO_2 and energy costs of the maintenance, as a well-educated guess. The described components are all part of this 3%.

Replacement of accessories

- Pumps

  The pumps used to be replaced once every 3 to 5 years, though it now seems that a higher capacity and flow rate may cause the pumps to wear out faster. Regarding the environmental impact of manufacturing the pumps – fabricating the steel itself costs the most energy and even though the quality of the steel is higher, the amount of steel needed for a pump is nothing compared to the kilometres of casing needed underground. Even if the pump replacements take place often this won't change.

- Filters
  These need to be changed very often, sometimes a few times per month. As to the CO_2-emissions and energy costs, for these goes the same as for the pumps.

Impact of temporary shutdown

During malfunctioning, failures or maintenance like changing the pumps or inspection, the production is temporarily stopped. There is usually a yearly production stop for normal maintenance and inspection. The impact of these shutdowns on the production is already taken into account in the calculations above, over the year 2014, in which there were many maintenance stops.

Naturally Occurring Radioactive Materials / Low Specific Activity (NORM / LSA)

It is possible that with the water originating from deep in the underground, some radioactive material will be transported along and deposited in small amounts on the inside of the geothermal installation. These naturally occurring radioactive materials have no effect when the system is closed. When it has to be opened however precautions are taken to prevent contamination with the radioactive material by following specific guidelines. In line with these guidelines protective clothes are worn and a radiation expert is present as a supervisor who provides information and takes control measurements when a geothermal system is opened. When these guidelines are adhered to, it is safe to work with an open geothermal installation. DAGO is actively involved in (re)defining the guidelines.

Risk on seismic activity

The risk of vibrations caused by the winning of geothermal energy is very small. This is because the pressure underground at the reservoir level is kept the same: water is extracted from a specific earth layer, but also pumped back into the same formation – only the heat is extracted from the water, but no substance will remain aboveground. This opposite to oil and gas wells where substance is taken away, leaving 'empty' spaces, thus changing the pressure and increasing the chance on soil subsidence (which is the major contributor to seismic activities in the Netherlands context). (Platform Geothermie 2016) Subsidence could take place because of the cooling of the reservoir underground. P.A. Fokker and J.D. van Wees have investigated this (Fokker et al., 2014), concluding a possible decline of 17 mm per 100 years. This is so small that to measure this would be almost impossible, as other effects (like the settling of peat and deposition) would soon become much bigger and could thus easily interfere with the measurements.
Q-Con and IF Technology have done research on induced seismicity. (Kennisagenda Aardwarmte, 2016) They analysed the various possible forms of seismicity and the way to signalise and minimalise this. Their report contains a protocol for the assessment of seismic hazards and risks associated with geothermal systems in the Netherlands. The protocol aims to assist project developers in understanding and mitigating these seismicity risks.

Sometimes the concern is expressed that geothermal energy is much like the winning of shale gas, where fracking is needed. Firstly, the extraction of geothermal energy is not the same as the winning of (shale) gas as explained above. Secondly for the doublets like those in the Netherlands there is often no need for fracking – not one of the wells in the Netherlands has placed a frack during its lifetime. When in the future geothermal wells will be realised that are deeper, it might be possible that these wells need some stimulation. As to possible vibrations during this fracking, CE Delft has performed an exploratory research on shale gas (CE Delft, 2015), concluding that even during fracking the micro seismic vibrations are not sensible for humans and have no effect on buildings or infrastructure. Stating this, for geothermal energy the risk is negligible. More information on hydraulic stimulation for the extraction of geothermal energy will be published by the Geothermal Platform in 2017.

Groundwater pollution

When drilling a geothermal well different layers will be pierced, including groundwater. During the lifetime of a well it may happen that liquids migrate through covering layers in the underground. In the shale gas report from CE Delft it is stated that based on data from the US and SODM, more or less 3% of the wells experience well integrity problems. However, US drilling methods differ greatly (negatively) from the Dutch standards. Well integrity is considered important in the Netherlands and both preventive and monitoring measures are applied to secure well integrity. Also not all of these problems involve groundwater. A well is approximately 2-2,5 km deep, of which the groundwater is only some hundred meters which is also a very small percentage. The risk of pollution of the groundwater is therefore very small. More extensive research on well integrity is currently conducted, as said before. These will result in guidelines specifically for the geothermal industry in the Netherlands.

Decommission

As momentarily there are no geothermal wells in the Netherlands that have reached the end of their lifetime, and are thus taken out of operation, an estimation had to be made at this point. A geothermal well is in principle much like an oil and gas well. Because of the similarities and the absence of an abandoned geothermal well, for this research it is investigated what happens when decommissioning an oil/gas well, assuming that more or less the same procedure will take place when decommissioning a geothermal well. Obviously this will only result in an indication and estimation of the procedure that will in time take place with geothermal wells, as there are also many differences. For one, it is not known what a lifetime of production will do to the casings of a geothermal well in the Netherlands. It is possible that some of the steel of the well has to be removed because it is more severely damaged than with an oil/gas well: a geothermal well is perhaps more exposed to corrosion due to the circulation of very salty water with traces of oxygen entrained etc.[7]

Following the mining legislation, a well that is no longer in operation must be abandoned. This means that it must be plugged so nothing can enter or leave the opening of the well. Commonly this is done by sealing it with a number of cement plugs. Depending on the well it is possible that more ‘barriers’ need to be installed, meaning that critical cap rocks in the well must be restored, assuring that every possible path of the water is sealed and no water can escape its formation. This prevents a potential pollution of shallow water layers in the future. The number of plugs will vary with every well; commonly at least two barriers are installed. For now we will assume that three plugs are needed, closing the well at the entrance and in two cap rocks. An approximation for what is needed to follow this procedure is described below:

[7] According to Nogepa, WEP assumes there will be no difference between oil/gas wells and geothermal wells.

- Per plug ca. 10 m^3 of cement is needed, which is about 15 tonne.[8] The total amount of cement needed for three plugs is then ± 45 tonne.
- It takes more or less 7 days to complete the procedure, in which 15.000 liters of diesel is needed, corresponding with 65 MWh (235 GJ).[9]
- The location must be cleared completely. This is obligatory by law.

The above is based on the combined information from WEP and Nogepa, with the explicit note that it's only an indication and that decommissioning a well depends on the circumstances of every single well, which are not yet known for geothermal. (WEP, 2015) (Nogepa, 2015)

When continuing the calculations with the data above, we get the following:
Approximately 40 tonne of CO_2 is emitted by using 15.000 L of diesel.[10] To produce the cement that is needed for the plug more or less 40 tonne CO_2 is emitted too, adding up to ± 80 tonne CO_2. The production of the cement costs about 200 GJ, which brings the total amount of energy needed on more or less 435 GJ (120 MWh). (See appendix I for constants used in these calculations.)

To resume: in total the process of decommissioning a well emits approximately 80 tonne CO_2, and needs 435 GJ of energy. This is respectively about 3,5% and 1,8% of the total amount needed for the realisation of a well.

Other emissions

This research has its focus on energy and CO_2. Apart from CO_2 there are also other emissions that will be reduced, like NO_x, PM_{10} and SO_2, but these are harder to track down and have less impact on the environment. Furthermore, CO_2 is a good and even the most common indicator for impact on the environment. Therefore other emissions are not taken into account in this research.

3.2 Social cost-benefit analysis

As is mentioned in chapter 2, CE Delft has performed an SCBA determining the effects of the implementation of several underground functions on the welfare of our society, including the use of geothermal energy. The other underground functions are not listed here, but can be found in the original publication of the SCBA of CE Delft (CE Delft, 2016).

The SCBA is performed in two phases. The first phase will be explained below. The second phase is mostly a comparison of Dutch scenario's including other underground functions which is not part of this research. Only the scenario in which geothermal energy is included will hereby be explained later on.
In the first phase a 'model operation' was determined of the various underground functions, calculating the effects of an example operation as it could be implemented according to STRONG. In the case of geothermal energy this was an 'average geothermal well' with a production of 0,2 PJ per year, used for the heating of residential houses or greenhouses. This is more or less the same

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[8] This amount is based on a well with a diameter of 13 3/8 inch, assuming that 100 meters are needed for 1 barrier, and that 1 m^3 of cement is about 1,50 tonne.
[9] Based on a light mining facility, using 0,235 liter to produce 1 kWh.
[10] Assuming an emission of 2,640 kg CO_2/L of diesel

amount as is calculated in this study for an average geothermal well (190.000 GJ). In the SCBA it is assumed that if there was no geothermal energy to be used (the reference alternative), the heating would have been done by the use of natural gas.

3.2.1 Direct, external and environmental effects

The social effects that were taken into account in the SCBA are direct, external, and environmental effects. The indirect effects were not taken into account as in practice these effects (like the effect on the labour market) are negligible. The direct effects include investments and exploitation costs, electricity purchase, grants and taxes and CO_2. The external effects are supply security, environmental benefits and climate benefits. Both the direct and external effects are monetised and included in the model operation (see also table 3.8).

The most important costs when extracting geothermal energy from the underground are the costs for the drilling, the realisation of the heating network and the connection of the (green)houses to the network. In addition there will be maintenance costs, electricity costs and replacement investments of certain components. On the other hand, when using geothermal energy there will be no costs for gas usage. By investing in geothermal energy the profit will be the avoided gas costs.
External effects include additional environmental impacts as already discussed in chapter 3.1.2.
The environmental effects are hard to monetise because there is no market for them as for the other effects. These are therefore included as 'PM' in the model operation as described later on (table 3.8). In the Dutch PlanMER these effects are described and assessed as shown in Table 3.6.

Environmental effects		**Risk**
Deterioration of the quality of the water layer due to		
	the mixing of groundwater of different qualities	Very low
	the leaking of substances into the groundwater by or along the drilling hole	Low
	or through a migration route	Very low
Damage and casualties in case of a blow-out		Very low
Damage on buildings and vital infrastructure caused by induced earthquakes		Very low

Table 3.6 – Description and assessment of environmental effects in the Dutch PlanMER

3.2.2 Scenario's for the future

In the SCBA of CE Delft the project effects are estimated by three scenarios for the future, high, low and 2°C. These scenarios have different developments from now till 2050, each having different effects on society.
In 'high' there will be fast technological developments. Greenhouse gas emission will slowly reduce till 2025, after which the reduction will accelerate because of the introduction of a worldwide emission system in 2030. The demand for fossil fuels will decrease because of strict climate policies, which will put the prices under pressure. Additional climate policies will slowly be phased out. There are no geopolitical tensions and the price of fossil fuels is in line with the production costs.
In 'low' the developments will go more slowly. Geopolitical tensions will increase which will cause higher oil prices and it is harder to make international climate agreements. The prices are higher due to these tensions than you would expect based on production costs.

The 2°C scenario is an extra scenario which is a variant on ‘high’. In this scenario a stricter climate policy is conducted, resulting in a greater reduction in greenhouse gas emissions and thus a limited increase in temperature.
In table 3.7 you see the relative differences between the scenario’s.

	Low	**High**	**2°C**
Relative population + economic growth	Moderate	High	High
Relative oil/gas/coal prices	High	Low	Low
Relative greenhouse gas reduction (<1990)	40%	65%	80/95%
Relative CO_2 price	Low	High	Very high
Relative electricity price	Low	High	High
Temperature increase	3,5 - 4°C	2,5 - 3°C	2°C

Table 3.7 – Relative differences between the three scenarios

In the geothermal model operation the distinction was made between greenhouses and residential houses. The main difference between these two is that the operational and investment costs are relatively high for a geothermal scenario with residential houses compared to greenhouses. Table 3.8 shows that this results in a positive private and social balance for geothermal extraction for greenhouses in every scenario. For residential houses the social balance is only positive in the 2°C scenario. This can be explained mainly by the higher investment costs for the distribution grid in residential areas.
In both cases (greenhouses and residential houses) the social balance for the 2°C scenario is the best and ‘high’ the worst. This is because in ‘high’ the gas price is low, resulting in less savings when choosing geothermal energy instead of gas. In the 2°C scenario the gas price is also relatively low and the CO_2-price relatively high (just like in the ‘high’-scenario), but here the gas-emission reduction is higher. In the ‘low’ scenario the gas price is high, which results in higher avoided gas costs and thus putting the social balance in between ‘High’ and ‘2°C’ and having the best private balance.

The conclusion is that from a social point of view the extraction of geothermal energy is more favourable with greenhouses compared to residential houses. In addition, the extraction of geothermal energy gets more attractive in a scenario targeting high emission reductions. The SCBA result for greenhouses is positive in all scenarios. For new heating grids serving residential houses the SCBA is positive only for the high emission reduction scenario (2°C).

	Greenhouses			Residential Houses		
	Low	High	2°C	Low	High	2°C
Investment costs						
Investment costs	24	24	24	49	49	49
Well	*19*	*19*	*19*	*19*	*19*	*19*
Distribution grid	*5*	*5*	*5*	*29*	*29*	*29*
Reinvestment costs	6	6	6	0	0	0
Operational costs						
Operational costs	15	15	15	30	30	30
Energy costs	5	6	7	5	6	7

Revenues						
Avoided gas costs	57	34	34	95	57	57
Effects						
Forgone energy taxes	4	2	2	23	14	14
SDE grant	30	32	32	30	32	32
Climate benefits	6	22	101	6	22	101
Environment benefits	1	1	1	1	1	1
Supply security	PM	PM	PM	PM	PM	PM
Environment effects	PM	PM	PM	PM	PM	PM
Private balance	36 + PM	14 + PM	13 + PM	41 + PM	4 + PM	3 + PM
Social balance	9 + PM	3 + PM	82 + PM	-4 + PM	-18 + PM	61 + PM

Table 3.8 – results of the model operation for the extraction of geothermal energy from the underground

In the second phase the geothermal model operation is implemented in the hypothetical 'maximal renewable' scenario. In this scenario the transition to renewable energy is realised as soon as possible. This is best achieved by using the full potential of the underground for the exploitation of geothermal energy. This potential however is very hard to estimate and while assessing the research of CE Delft, the Geothermal Platform came up with quite different data and estimates. The most important part is that in the 'maximal renewable' scenario it is assumed that the development of geothermal energy for greenhouses and residential houses will proceed quite equally. According to the Geothermal Platform this is very unlikely as in 2016 15 out of 16 existing geothermal installations are (or will be) serving greenhouses. Furthermore it should be noted that the substitution of fossil energy sources of existing district heating grids by geothermal energy is – for SCBA purposes – identical to the greenhouses model and consequently belongs in this greenhouses category. In the analysis above it is shown that the social balance for greenhouses is better than for residential houses.

Also, the social balance very much depends on the scenario for the future it is projected on. As said before geothermal energy is favourable in a scenario targeting high emission reductions. Therefore the government of the Netherlands needs to decide on a very strict climate policy to realise a positive social balance, which can't be achieved with low gas prices as explained above.
The CE Delft study emphasises that the scenarios and results are subject to many uncertainties – in fact inducing the authors to call the study an 'exploration on welfare effects' rather than a SCBA. Some factors such as increased security of supply and positive environmental effects could not be quantified and were listed as PM. Also some quantifiable variables such as CO_2 prices, natural gas prices and discount rates all have huge impact on results – and are notoriously difficult to predict.

3.2.3 Conclusion and discussion

Over all it can be concluded that the current forms of geothermal energy in The Netherlands – the supply of heat to greenhouses – have a positive SCBA balance in all investigated scenarios. Existing district heating grids fall in the same category and should benefit from identical SCBA scores. The supply of deep geothermal heat via new district heating grids to residential areas is obviously costlier and the SCBA balance hinges on the scenario inputs. In this context it is interesting to note that the Dutch Ministry of Economic Affairs very recently published its energy vision for the period up to 2050 (Ministerie van Economische Zaken, 2016). An important role in this vision is reserved for the phasing out of natural gas used for heating of houses. This implies a very substantial increase of new district

heating grids – in addition to a wide variety of individual stand-alone options for replacing natural gas heating of houses.
Either case it is very clear that geothermal energy is a favourable option to achieve high emission reductions and will definitely have a positive social balance when the government of the Netherlands decides on a strict climate policy. Therefore we can conclude that the extraction of geothermal energy in the Netherlands has a positive effect on the welfare of our society.

4. Discussion

As is mentioned before in this report, there has been a previous research on the sustainability of geothermal energy in 2012/2013, which is the only Dutch research on the subject known to the author and the Dutch Geothermal Platform. Research from other countries were found irrelevant as the circumstances were always very different from the situation in the Netherlands.
The previous Dutch research however was solely on one well, namely Green Well Westland. The results were very good, but back in 2012 Green Well Westland was considered one of the best operational doublets, if not the best. The main reason for this new research was thus to obtain a complete perspective on the sustainability of geothermal wells in the Netherlands, based on more than just one doublet. As explained in chapter 3 the results of the first part of this new study turned out to be much alike the results of the first research, confirming that the extraction of geothermal energy in the Netherlands is a sustainable energy source.

In order to support this even more, this new research was planned to be extended with a social cost and benefit analysis. It was decided to cooperate with CE Delft who were also doing an SCBA on geothermal energy (see chapter 2.2) and would most likely – as a company – be able to be more extensive and thorough in their study. Unfortunately their research encountered many delays, causing this research to become delayed too. It turned out to be hard for CE Delft to make the SCBA as thorough as at first anticipated; many aspects of the SCBA were not easy to quantify and are subject to many uncertainties. Therefore CE Delft decided to call their study an 'exploration on welfare effects' rather than a SCBA. The SCBA part of this report is therefore also rather an exploration and an indication of the effects of the extraction of geothermal energy on the welfare of the Dutch society.
Also, when cooperating with CE Delft, it was noted that the data that they used as input were not commonly supported by the geothermal community. Thanks to our cooperation this has been slightly adapted to more likely data, but as the data is still subject to many uncertainties, the accuracy of the results can still be questioned.

Unfortunately, as the study took longer than expected due to the delay in the SCBA part of the research, the analysis on the data of 2014 became already somewhat outdated when the data of 2015 became available in April of 2016. To keep the results relevant when published, in chapter 3 an update is written based on a more rough analysis of the data of 2015. This update shows that the geothermal wells became more sustainable through the years, predicting even better results for the years to come. In line with this observation it can be stated that back in 2012 GWW was indeed a relatively good well compared to the others. By now there are several other wells that are more sustainable and have a higher production and COP. Expected is that this trend will continue in the coming years, making geothermal energy an even increasingly sustainable energy source.

5. Conclusions

In this research it is investigated how sustainable the extraction of geothermal energy in the Netherlands is, based on the average of the 10 operational geothermal doublets in 2014. This is done in terms of a Life Cycle Analysis (LCA) including the Energy Payback Time (EPBT) and an exploratory Social Cost-Benefit Analysis (SCBA).

The average EPBT is 1,8 months for the energy that is needed for drilling the well. In addition it takes 3,2 months of production to compensate the amount of CO_2 that is emitted during the drilling. Assuming that a geothermal well has a lifetime of 30 years it will produce a net amount of energy of 5,5 million GJ (1,5 million MWh). The amount of natural gas that will be saved in this period by using geothermal energy instead, is 174 million m^3, while saving the emission of 297.000 tonnes CO_2. That is the same as consumed by 3.625 households. The COP of the average of the wells is 21,9.
When looking back at the previous research on the sustainability of geothermal energy in the Netherlands of 2012/2013, which only included one well, it can be concluded that the sustainability of the well from GWW is in line with the other wells. When taking a brief look at 2015, 2016 and the near future, it can be expected that the results will get better as the trend for geothermal doublets is to become deeper with higher capacities and production rates, making them more efficient and sustainable.

Other environmental effects are not as easy to quantify as the CO_2-emission or energy production. The auditory and visual nuisance for the surroundings are very low. The risks on environmental damage are also low, but would have a greater impact on the surroundings. For these risks – like on seismic activity, the impact caused by NORM/LSA or the best way to handle decommissioning – guidelines and industrial standards are or will be established by DAGO. As the geothermal industry in the Netherlands is still quite young, there is still a lot of experience to be developed and various different developments are taking place on this account, for example in the different studies of the Kennisagenda Aardwarmte. These results and the industrial standards will make it easier to share experiences on the extraction of geothermal energy in the Netherlands, thus reducing risks and possible negative environmental effects.

The exploratory SCBA shows that the current forms of geothermal energy in the Netherlands – the supply of heat to greenhouses – have a positive SCBA balance. An exact, quantified SCBA was hard to realise as a lot of aspects of the SCBA were subject to uncertainties. Nevertheless it is clear that geothermal energy is a favourable option to achieve high emission reductions and will have a positive social balance when the government of the Netherlands decides on a strict climate policy for the future. Therefore we can conclude that the extraction of geothermal energy in the Netherlands has a positive effect on the welfare of our society.

Appendix I - Justification use of constants

Steel:

Originating from the website of ArcelorMittal (ArcelorMittal b, 2014):

- Energy consumption: 23,8 GJ/tonne liquid steel
- CO_2 emissions 2,09 tonne/tonne steel

Energy consumption:

In the energy consumption 'mines' and 'transportation' are not included. (ArcelorMittal a, 2014). In the sustainability research of 2012/2013, 40,1 MJ/kg (Lenzen et al., 2000) was used with the assumption that this would also include mining and transport. However, new research provided new documentation:

Many references were found in which the energy consumption was around 20 MJ/kg, excluding mining and transport. Michaelis et al. (1998) wrote that the total exergy consumption is 22 GJ/mt, including the mining of coal and iron ore and their transport. This suggests that the energy consumption of mining and transport does not have a very significant part in this number. This is confirmed by several articles, for example Michaelis et al. (2000) in which the energy consumption of mining varies from 0,08 – 0,9 MJ/kg. The article also states that the exergy consumption per tonne of steel is reduced almost twofold since 1954: from 59 GJ/t of steel to 29 GJ/t. This reduction was over the period 1954-1994.

It appears that the energy consumption has not changed much since 2000, but as more recent data is preferable over 15 year old data, the number of ArcelorMittal is used in this research: 23,8 GJ/tonne. (For Dutch insiders: this is also in line with the GER-list of RVO, which states a number of 23,3 GJ/tonne.)
ArcelorMittal was also one of the suppliers who delivered most of the steel to the geothermal operators, which makes this choice even more well-grounded.

CO_2 emissions

For the CO_2 emission of steel production the value 2,09 tonne CO_2/tonne steel is chosen, also from ArcelorMittal. In the previous research this value was 2,15 tonne/tonne. Apparently their process has improved a little since 2012.
In the research for the CO_2 emission of steel production no other (very variant) value was found. For this reason, and the reasons stated above (in the section about energy consumption), the value 2,09 tonne CO_2/tonne steel from ArcelorMittal was used.

Cement:

Research has taken place to see if there is new data on the production of cement, but no relevant new data was found since the previous research in 2012/2013. Therefore the values 820 kg CO_2 / tonne cement and 4,5 GJ / tonne cement have been used in the calculations, as justified then.

Electricity:

Emission factor:
0,526 kg CO_2 / kWh (CO2 emissiefactoren.nl, 2015)
This number is slightly higher than the value used in the previous research. This is because this time the emissions are included that are emitted by the production of fuel for the power plant.

If you don't include this fuel, the value is 0,464 kg CO_2 / kWh, still slightly higher than used in the previous research.

Efficiency power plant:
52,5%
Like in the previous research this value is extrapolated for 2014 from the efficiency values from previous years. (CBS, 2012)
This is equivalent to 6,86 MJprim/kWh.

Sidenote:
A few operators sometimes use CHP installations to generate both electricity and heat – instead of a gas fired heat boiler. As none of the operators operate their CHP constantly, it complicates the calculation to the extent that the reference installation varies over time. The installations are operational in periods of relatively high electricity prices (high spark spread). Nationwide the spark spread and CHP production levels have decreased considerably over the recent years. (CE Delft, 2014) For this reason and for the sake of simplicity the CHP usage is not taken into account in this research. All electricity use is allocated to the grid.
Also the use of green electricity, without emissions, is not taken into account here.

Natural Gas:

Emission factor:
56,4 kg/GJ (RVO, 2013)
This value has decreased 0,2 kg/GJ.

Calorific value:
31,65 MJ/m^3 (lower heating value)
This value has stayed the same in the Netherlands over the last years.

Appendix II - General sustainability

As mentioned in this report the lifetime of a geothermal well is generally assumed to be 30 years. This is based on the knowledge that after approximately this time the injected cold water reaches the production well, thus lowering the temperature of the production water. This does not mean that the geothermal well is useless after this time, only that it's efficiency will decrease. There are wells known in Italy that have exceeded this expectation by many years. For example in Lardarello (Italy); this oldest geothermal well that is still in operation was constructed in 1933.

When the efficiency of a well has decreased down to unacceptable levels and is thus taken out of operation, it will regenerate in about a hundred years. The cooling took place only around the injection well which is completely insignificant from the point of view of the earth, whose core is around 6000 degrees Celsius. The small cooling on its crust will have no effect on the earth at all. Therefore geothermal energy is internationally accepted as a green and sustainable energy source.

Furthermore there is a possibility to extend the lifespan of a geothermal well by drilling a new production well into a different direction. This way new warm water can be extracted from another point in the reservoir, making it possible to use the well for a longer period of time.

Another benefit of geothermal energy, is that it's dependable all through a year – a geothermal well is not effected in any way by varying wind and insolation.

(Platform Geothermie, 2015)

Appendix III

As discussed in the report this appendix presents the complete results from the analysis as done with the Excel tool. Every geothermal doublet is included in the tables III.1-3, presented with its own (illogical) number to warrant the operators privacy.

The average data are discussed in chapter 3.1 of this report.

Geothermal well	Capacity	Production 2014 [GJ]	Production 2014 [MWh]	COP
1	10,4	241.879	67.189	41,3
2	13,5	409.455	113.738	48,0
3	5,4	137.914	38.309	10,8
4	9,2	169.844	47.179	26,2
5[11]	7,4	180.300	50.083	11,5
6[11,12]	7,6	183.928	51.091	22,0
7[11,12]	6,4	119.737	33.260	22,0
8[12]	5,9	123.000	34.167	9,8
9	15,4	288.347	80.096	15,4
10	12,0	189.326	52.591	12,0
Total		2.043.730[13]	567.703	
Average	9,3	204.373	56.770	21,9
Weighted average				25,6

Table III.1 – Results individual geothermal doublets

	Saved in 2014			
Geothermal well	Energy [GJ]	Energy [MWh]	Natural gas [m3]	CO2 [tonne]
1	230.728	64.091	7.289.994	12.787
2	393.192	109.220	12.423.120	21.846
3	113.521	31.534	3.586.758	5.907
4	157.474	43.743	4.975.473	8.630
5[11]	150.437	41.788	4.753.148	7.878
6[11,12]	168.006	46.668	5.308.237	9.152
7[11,12]	109.369	30.380	3.455.577	5.958
8[12]	98.835	27.454	3.122.757	5.090
9	252.690	70.192	7.983.871	13.528
10	159.292	44.248	5.032.926	8.374
Total	1.833.544	509.318	57.931.861	99.150
Average	183.354	50.932	5.793.186	9.915

Table III.2 – Results individual geothermal doublets

[11] Berekend met geschat elektriciteitsverbruik tijdens boring
[12] Berekend met geschat jaarlijks elektriciteitsverbruik
[13] This is not the real total amount of energy produced, as it includes the compensation for some wells that were completed in this year, as explained in chapter 2.

	Needed for drilling		Payback time	
Geothermal well	Energy [GJ]	CO_2 [tonne]	Energy [months]	CO2 [months]
1	31.509	2.940	1,6	2,8
2	24.831	2.426	0,8	1,3
3	22.213	1.858	2,3	3,8
4	20.252	1.815	1,5	2,5
5[11]	20.913	1.861	1,7	2,8
6[11,12]	22.663	2.072	1,6	2,7
7[11,12]	18.149	1.530	2,0	3,1
8[12]	23.637	2.142	2,9	5,1
9	31.109	3.065	1,5	2,7
10	32.046	3.257	2,4	4,7
Total	247.322	22.966		
Average	24.732	2.297	1,8	3,2

Table III.3 – Results individual geothermal doublets

In chapter 3.1 the production data is discussed in terms of gross and net. Table III.1 presents the gross amount of produced energy and III.2 net. The amount of gas and CO_2 saved plus the payback times are calculated with the net amount of produced energy.

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