Geothermal energy and support schemes in The Netherlands

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Keywords: Geological risk, guarantee/insurance scheme, exploitation scheme, feed-in premium.

ABSTRACT

The Dutch government intends to stimulate the development of geothermal energy by opening support schemes. Three schemes are installed: investment, guarantee/insurance and exploitation subsidy schemes. The support schemes attracted a relatively large number of applications and can be regarded as successful instruments for the development of geothermal energy. The investment subsidy was granted to proposed innovative energy concepts in the horticultural sector. Application of geothermal energy for the heating of greenhouses was such an innovative investment. The guarantee scheme is an insurance system for the geological risk: the underperformance of a doublet with respect to the pre-drill P90 geothermal power estimate due to disappointing aquifer characteristics. The exploitation scheme (SDE+) is a subsidy on produced geothermal heat to level the difference between conventional heat cost price and the cost price of geothermal heat. All projects in the guarantee scheme and most projects in the exploitation scheme are granted on a pre-drill estimate of the geothermal power to be realised. This implies that the schemes have to deal with large pre-drill uncertainties, predominantly in the estimated geothermal power. Both schemes use a dedicated software package to estimate the indicative geothermal power, including the uncertainty range. Based on the outcome of this program, the guarantee scheme insures the P90 geothermal power. The SDE scheme makes a budget reservation for the future subsidy (feed-in premium) required for the geothermal energy produced over a 15 year production time. This future subsidy reservation is based on the calculated P50 geothermal power. The subsidy amount is calculated by subtracting the conventional heat cost price from the cost price for generating geothermal heat. The calculation of the cost price of geothermal heat is done using reference projects with an estimated cost structure and heat produced.

1. INTRODUCTION

Geothermal heat production is relatively new in the Netherlands. It took off in 2005 with two geothermal exploration licence applications. Before that, hot saline water production for use in spa's was the only geothermal heat production. First attempts for a wider use of geothermal energy were initiated in the 1980's after the first oil crises. One demonstration well was drilled in 1986. It failed to be successful because of low transmissivity. Interest for geothermal energy declined dramatically, also because fossil fuel, especially gas, was relatively cheap in the Netherlands. Renewed interest in geothermal energy started early this century. A pilot project was initiated in the western part of the Netherlands in one of the main greenhouse areas. One doublet was drilled in 2006/2007 in Lower Cretaceous marginal marine sediments within the structural geological unit the West Netherlands Basin (WNB). It proved to be very successful. Subsequently, a dramatic increase in geothermal exploration licence applications followed. Drilling activity followed, but at a much lower pace. Various explanations are possible to explain the mismatch between the number of exploration licences and the drilling activity. Possible explanations include: geological uncertainties resulting in economic and financial hurdles, rig availability and regulatory constraints (increased safety awareness due to the Gulf of Mexico, Macondo incident). Presently, 15 more wells have been drilled, adding up to 8 geothermal systems (7 doublets and 1 triplet). Beyond that, 2 production licenses and 73 exploration licences are granted. For 7 of the exploration licences a production licence is applied for.

The first doublet was realised with an energy innovation (EOS) subsidy of Agentschap NL (part of the Ministry of Economic Affairs (MEA)) and a dedicated subsidy scheme, installed by the Ministry of Agriculture (now merged into the MEA) and the agricultural/horticultural sector organization "Productschap Tuinbouw". Following the success of the first doublet, it was realised that it was difficult to build a financially and economically sound geothermal project without public support. Two key issues are paramount:

1. the inherent geological uncertainty in the estimation of aquifer properties resulting in a

"geological risk" of achieving the anticipated (pre-drill) geothermal power and

2. the costs of geothermal energy compared to the cost of fossil fuel energy for the same amount of energy.

In this article three Dutch support schemes are discussed:

1. Investment subsidy, the Environment-Energy-Innovation (MEI) subsidy,
2. The Geothermal Guarantee Scheme (insurance) for geological risk (AgentschapNL, 2012b) and
3. Exploitation subsidy, the Stimulation Sustainable Energy production (SDE+) scheme (AgentschapNL, 2012a).

2. INVESTMENT SUBSIDY SCHEME.

Untill 2012, the Market-introduction Energy Innovation (MEI) subsidy scheme was available for geothermal projects in the agricultural sector. The MEI subsidy was intended especially for the greenhouse farmers who were aiming at making their business more energy efficient through innovative changes to their energy system. Application of geothermal heat is regarded as such. The MEI-subsidy is granted on a proposed investment. The maximum allowance was 2.0 M€ (million Euro), later reduced to 1.5 M€ per project.

However, with the introduction of geothermal energy in the exploitation subsidy scheme (SDE+), the MEI investment subsidy was terminated for geothermal projects.

3. GEOTHERMAL GUARANTEE SCHEME.

All activities aiming at extracting resources from the subsurface suffer from geological uncertainty. This is one of the main factors influencing the success of the operation. Transmissivity is the product of net aquifer thickness and average aquifer permeability. It is the major factor controlling the flow of water through the aquifer and thus the geothermal heat produced. It is also one, if not the most difficult parameter to estimate in the deep subsurface. The support scheme "*Risk insurance geothermal heat*" was developed by the Dutch Ministries of Economic Affairs and Agriculture together with NL Agency (Agentschap NL in Dutch) and TNO and installed in 2010, aiming to provide an insurance for the geological risk.

Geological risk is considered the risk of realising less geothermal power than expected due to poorer aquifer quality than anticipated. The pre-drill geothermal power estimate of a project is best expressed as a range of possible outcomes with an equal likelihood of realisation. This range can be calculated by means of a stochastic simulation which uses the uncertainty ranges of the input aquifer parameters. This is best illustrated in a probability density function. Figure 1 shows such a curve. The P90 geothermal power is the value for which 90% of the simulation results is higher. In other words this means that with 90% certainty the geothermal power realised will be higher than the P90 value - under the condition that the underlying geological assumptions are sound.

The guarantee scheme insures a geothermal power ($P_{insured}$) which is lower than or equal to the P90 geothermal power estimate from the geothermal power probability density function of the project (Figure 1). Additionally, the $P_{insured}$ should be larger than 2 MW.

In 2012 the Geothermal Guarantee Scheme has been updated and early 2013 an updated version of the scheme has been published by the Minister of Economic Affairs (Agentschap NL, 2012b). Two types of geothermal projects are accepted in the scheme: 1) a regular geothermal project – production of heat from a depth up to 3500m and 2) deep geothermal projects for the production of heat from depths larger than 3500m. The applicant has the option to insure either the whole doublet or just one, the first, well.

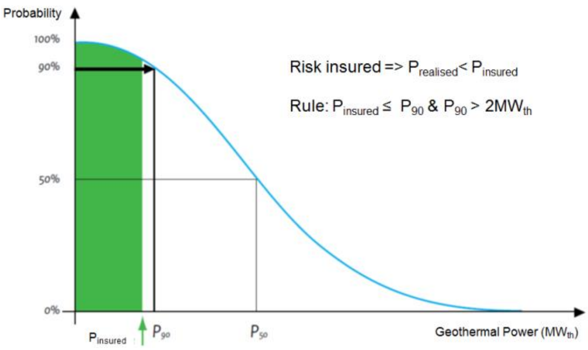

Figure 1: Probability density function of the geothermal power.

3.1 Geothermal power calculation

The pre-drill geothermal power is estimated using the "DoubletCalc" software program, which was built especially for the Guarantee Scheme (Mijnlieff et al 2012). This application generates an indicative geothermal power estimate in terms of P90, P50 and P10 values, including a probability density graph as presented in Figure 1. The input of the application includes a number of basic geological and installation parameters. Figure 2 shows the input screen of the application. The scheme is primarily geared to insure the risk related to geological uncertainties. Therefore, the geological input parameters should be given as a range. Figure 2 shows input fields for the minimum, median and maximum values for the geological parameters aquifer thickness, N/G (net-to-gross), permeability, depth and formation water salinity. The geothermal gradient, which is also an uncertain geological factor, is entered as a single figure. The uncertainty inherent to this parameter is thought to be adequately included in the default 10% uncertainty range on the depth of the aquifer.

Installation parameters include the casing or tubing scheme, the depth of the pump in the production well, the subsurface well distance at aquifer level, the well diameter at aquifer level, the deviation and the penetration angle of the wells. Also two operational parameters, namely the injection temperature and the pressure difference over the pump are part of the input.

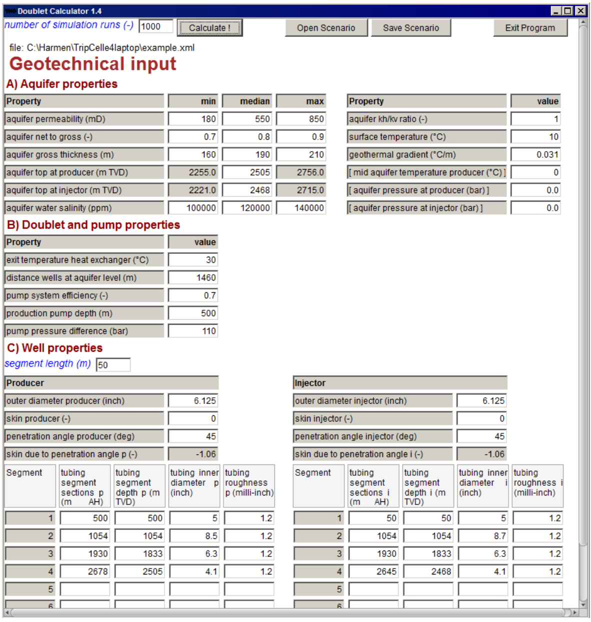

Figure 2: Input screen DoubletCalc.

The program calculates the geothermal power stochastically. Typically some 1000 simulations are executed to create a sound range of equally probable geothermal power estimates for a given pump pressure difference. From the results the geothermal probability density graph is compiled. Figure 3 shows a typical result graph including the P90, P50 and P10 geothermal power estimates.

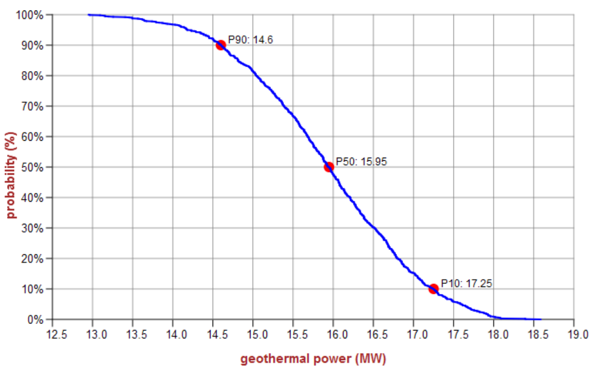

Figure 3: DoubletCalc probability density graph of the indicative geothermal power.

3.2 Guarantee scheme systematics

A prerequisite for entering the guarantee scheme is that all geological input parameters are well defined and supported by a sound geological evaluation document. With the application for the scheme a geological evaluation report of the project location should be filed. This report holds the supporting evidence for the aquifer- and other geological parameters which were used for calculating the geothermal power. Additionally, a report on the financial, economic, technical, organizational and planning aspects of the geothermal project needs to be filed with the application at NL Agency.

The application is granted when the result of the audit of the geological, economic, financial and other relevant project issues proves positive. The operator is given a guarantee that if the realised geothermal power is lower than the insured power, (at the "insured" pump pressure difference), with the installation parameters used in the application document, a refund on missed geothermal power due to unfavourable geological circumstances can be claimed.

The guarantee scheme will refund eligible costs of a regular geothermal project to a maximum of €7,225,000. A deep geothermal project has a maximum of €12,750,000. The guarantee scheme includes a list of eligible investment costs. The scheme is open for applications periodically. In the 2013 round a total refund budget of M€43.35 is made available. Within the present round maximally one deep project will be honoured.

Because the refund is maximised on 85% of the eligible costs, the maximum project costs (operator risk) under the guarantee scheme for regular projects is €8,500,000. For deep projects it is €15,000,000. If the anticipated investments costs exceed these maxima, the project can still be guaranteed, however the refund will be corrected using the "support percentage" (S) which scales it back to the maximum refund amount (see Figure 4). S is 85% at most.

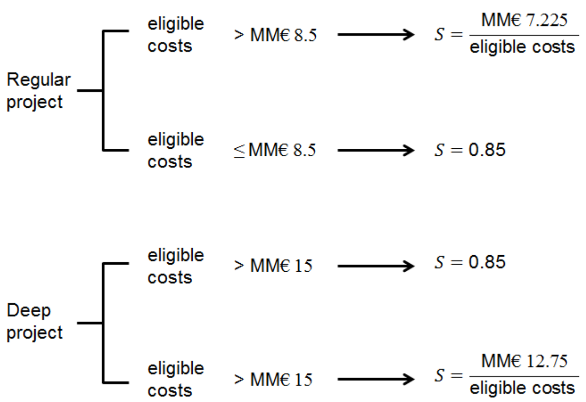

Figure 4: the support percentage (S)

The refund strategy of the guarantee scheme has some degree of flexibility. These are the two basic refund methods:

1) the stop refund→ $P_{realised}$ is zero and

2) the ratio refund→ $P_{realised}$ is larger than zero (but less than the P90).

The ratio refund depends on the ratio of the $P_{realised}$ and the $P_{insured}$. Figure 5 presents the refund percentage of the invested capital versus the ratio. This figure clearly shows that the refund will always be lower than or equal to 85% of the invested capital.

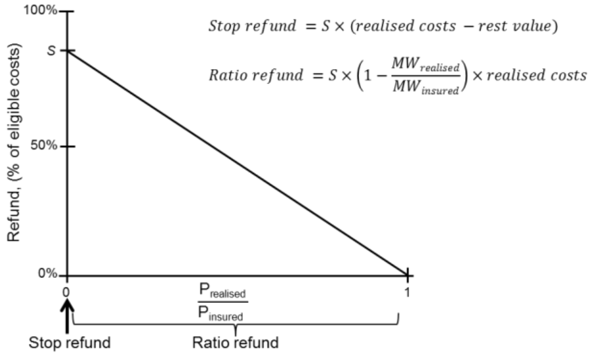

Figure 5: refund strategy including formulas for calculating the refund percentage of realised costs (S is at the most 85%).

It is obligatory to perform a well test on the wells. The well test should be designed and executed in such a way that the transmissivity of the aquifer can be interpreted with a high degree of certainty. Additionally, from other well data, e.g. electrical logs, the net thickness of the aquifer should be deductible with reasonable certainty. From the results of the first well the indicative geothermal power of the doublet can be calculated assuming the second well has the same outcome. Using the “realised” geological parameters and the installation parameters from the application document, a first pass geothermal power figure ($P_{realised}$) can be calculated using DoubletCalc.

In case the applicant has insured the entire doublet, the possible project result scenarios are given in Figure 6. If the $P_{realised}$ is larger than 75% of the $P_{insured}$ the second well needs to be drilled. No refund is given when the applicant stops the project. If the $P_{realised}$ is less than 50% of the $P_{insured}$ the “stop refund” is awarded. The $P_{realised}$ is regarded 0, thus the maximum refund will be given. If $P_{realised}$ lies between the above refund criteria the decision is to the applicant.

For an insured doublet, the results of the second well will be essential in the final determination. When $P_{realised}$ is higher than $P_{insured}$ the guarantee scheme regards the project as a success, hence no refund will be issued. If the $P_{realised}$ is smaller than $P_{insured}$ the refund will be a function of the ratio between $P_{realised}$ and $P_{insured}$: the ratio refund.

The refund scenarios of the single well insurance are simpler. If the $P_{realised}$ is 75% of the $P_{insured}$, then a second well is obligatory according to the scheme and no refund is given. If the $P_{realised}$ is smaller than 75% of the $P_{insured}$, then the operator has the option to request refund or to proceed with the second well of the doublet (see Figure 7).

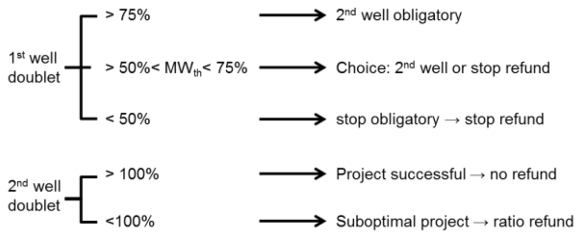

Figure 6: percentage of $P_{realised}$ to P_{90} and matching refund scenario’s for a doublet.

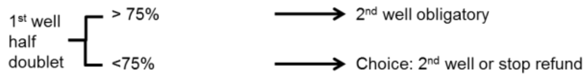

Figure 7: Refund scenario’s for a “half” doublet (the first well)

In case the $P_{realised}$ is lower than the $P_{insured}$, according to the scenarios described above, a refund can be claimed. However, to promote an optimal use of the drilled well(s), the guarantee scheme encourages the investor to invest in improvements to increase geothermal power (in case of underperformance) or in alternative use (in case the doublet is not completed), as for example high temperature storage. In these cases additional investment costs and/or operational costs are taken into account in the refund scenarios. However, the maximum possible support is determined by the result of the primary well test(s). The formulas below show how the refund is calculated.

$$Ratio\ refund\ = \left(S \times \left(1 - \frac{MW_{realised}}{MW_{insured}}\right) \times realised\ costs\right) + (S \times improvement\ costs) \quad \textbf{[1]}$$

Formula [1]: Refund as function of the ratio of $P_{realised}$ and $P_{insured}$ in case of underperforming but operational systems, where investments were made to increase flow and thus geothermal power produced.

$$refund_{alternative}\ = S \times \begin{pmatrix} realised\ costs\ - rest\ value_{alternative} \\ +additional\ costs_{alternative} \end{pmatrix} \quad \textbf{[2]}$$

Formula [2]: Refund in case the doublet will not function as planned, but the installation can be used in an alternative way. Costs for redesigning the installation can be refunded.

The Geothermal Guarantee Scheme has turned out to be a crucial instrument in propelling geothermal energy in The Netherlands. A wide range of projects has been granted admission to the Guarantee scheme in the previous two application rounds, particularly in new geothermal areas. Apart from the risk-mitigation, the Guarantee Scheme proved essential to assure financing for several projects. Next to these direct benefits the Geothermal Guarantee Scheme also serves as a transparent and objective benchmark for the market, thus stimulating private initiative.

4. EXPLOITATION SUBSIDY

Because the cost price of renewable energy is higher than the cost price of conventional energy, most renewable energy projects are uneconomic. The SDE+ scheme is an exploitation subsidy scheme for the production of sustainable energy. It aims to level the cost prices of sustainable and conventional energy. This exploitation subsidy scheme is used for all types of sustainable energy, such as electricity from wind farms, renewable combined heat and power, and green gas (biogas). It was decided by the MEA to include renewable heat in the 2012 application round of this support scheme. This would create a level playing field for all renewable energy forms, as was advised by ECN and DNV KEMA.

4.1 Exploitation scheme systematics

The SDE+ scheme is open for projects that have not yet been realised or are not in operation yet. To apply for the exploitation subsidy, the operator should file application documents at the government (also NL Agency) stating the expected geothermal power to be produced within a 15 years period, along with financial, economic and legal documents pertaining to the geothermal project.

In total 33 geothermal heat projects signed up for the 2012 SDE+ subsidy scheme. As stated before, some 75 licences already existed in which one or more doublets are planned. Because almost all geothermal projects are uneconomic without subsidy, the large initial number of applications can be explained by a 'storage reservoir' effect because this was the first time this scheme was open for geothermal energy projects.

The NL Agency will subsequently audit the applications, assisted by TNO for the geological chapters. The audit should determine whether the geothermal power applied for in the project can be realised with reasonable certainty. It has been decided that the (pre-drill) P50 geothermal power of a project is the value to audit. All applicants were requested to calculate the P50 geothermal power using DoubletCalc. Geologic parameters, especially the transmissivity are of major importance to the expected geothermal power. The audit of the geothermal power will therefore focus on the validity of the estimated transmissivity.

The SDE scheme has a number of parameters that control the amount of subsidy:

1. Base rate → the envisaged cost price of geothermal energy production in €/GJ as a flat rate for the duration of the subsidy.

2. Correction rate → the market price of non-renewable energy production in €/GJ. This is the average actual market price during the year. The correction rate varies during the duration of the subsidy and is recalculated at the end of each year.

3. Base energy price → the SDE lower threshold of the market price of the non-renewable energy production, in €/GJ as a flat rate for the duration of the subsidy

4. Subsidy amount→ base rate minus correction rate

5. Full load hours→ the maximum amount of full load equivalent production hours for which the subsidy will be calculated

The fact that the base rate and the base energy price are "flat rates" for the duration of the subsidy (15 years), and that the correction rate varies per year, means that the actual subsidy awarded also varies on a yearly basis. Two extreme results for the subsidy amount are:

1. No subsidy, if the non-renewable energy cost price (correction rate) is higher than the base rate, the cost price for geothermal energy.

2. The maximum subsidy amount, if the non-renewable energy cost price sinks below the lower threshold (base energy price).

Figure 8 illustrates a hypothetical correction rate scenario resulting in variable SDE subsidy during the 15 years of production. Depending on the market price for heat, the final correction rate over the year can vary between €4/GJ and €10.90/GJ.

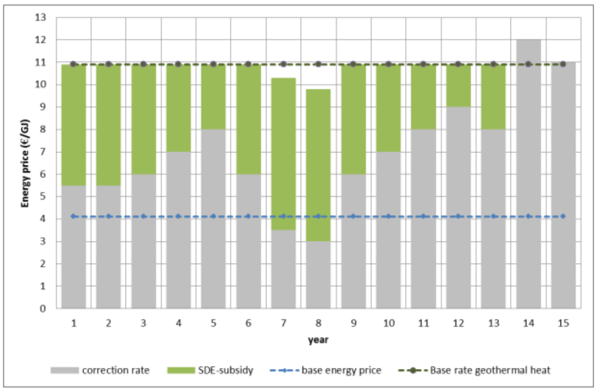

Figure 8: the SDE-subsidy as a function of the non-renewable energy price. Energy prices in the first column are the SDE 2012 rates.

Geothermal heat became eligible for subsidy in the framework of the SDE+ in 2012 with a base rate of €10.90/GJ for up to 7,000 full-load hours. For a geothermal installation of $7MW_{th}$ the maximum subsidy amount on produced geothermal energy for the start year is calculated as follows:

$$7MW_{th} * 7000hr = 49000MWh$$

which is equal to 176,400GJ. The subsidy amount for start year is €10.90 (base rate) minus €5.4 (correction rate) = €5.5/GJ. Thus, the maximum subsidy for the year 2013 is

176,400GJ * €5.50/GJ = €970,200.

4.2 Exploitation scheme developments

The admission of geothermal projects to the SDE scheme was a success with regard to the amount of applications. This success resulted in relative large budget reservations for geothermal projects, which limited the total amount of SDE+ subsidy-budget available for other sustainable energy sources. Most likely the reason is the pile up of projects that had been waiting for SDE+ subsidy during the last years. During the second application year for geothermal heat, fewer projects are expected.

4.3 Geothermal potential and drilling depth

In 2011 the Ministry of Economic Affairs published a vision on geothermal energy in the Netherlands (EZ, 2011), which indicated a geothermal energy potential of 11 to 14 PJ/year in 2020. No distinction was made between geothermal heating projects with different drilling depths. Due to lack of data, a relation between the geothermal potential and drilling depth is difficult to establish quantitatively. Nevertheless, it seems realistic that a geothermal potential of the order of magnitude of 14 PJ/year in 2020, or 700 MW_{th} for 5500 full-load hours/year, will be difficult to achieve without deep geothermal projects. Over 100 reference projects of 6.2 MW_{th} would have to be operational by 2020. Including deeper geothermal projects, which produce higher temperature brines and have a higher associated power (9 MW_{th}), would make this target more feasible. The higher temperature wells also allow for applications other than low temperature greenhouse heating. Finally, the deeper projects unlock the geothermal potential in areas in the Netherlands that only have potentially suitable aquifers at larger depths. Even without quantifying the amount of additional geothermal potential, it is safe to say that tailoring the SDE+ scheme to deeper projects would significantly increase the geothermal potential in the Netherlands. To also benefit from the deeper geothermal potential, ECN, DNV KEMA and TNO were consulted by the MEA on the potential and base cost-rate of geothermal energy at vertical depths larger than 2700m. A second category of 2700 m depth and more is added to the scheme.

4.4 Base rate and reference cases

ECN and DNV KEMA analysed the cost of geothermal heating for the SDE+ in 2013 using two reference cases. This resulted in the following calculated base rates (Lako et al, 2012):

- For geothermal heating based on a vertical depth of less than 2700 m: €11.8/GJ for up to 5,500 full-load hours, and up to 12.4 MW_{th};
- For geothermal heating based on a vertical depth of 2700 m and more: €12.8/GJ for up to of 5,500 full-load hours, and up to 18 MW_{th}.

Paramount in the SDE scheme is the calculation of the base amount in relation to the full load hours. ECN and DNV KEMA have evaluated the cost structure for two reference cases to define the base amount for these cases at 5500 full-load hours. ECN and DNV KEMA calculated the base rates for geothermal heating based on generic project characteristics. The characteristics of future geothermal projects will almost certainly differ in some ways from the characteristics of the reference projects. The uncertainty with respect to the techno-economic parameters will only decrease with increasing knowledge of the subsurface for geothermal energy projects and with increasing numbers of geothermal projects realized.

The reference cases comprise a doublet with a reference depth of 2300 m depth and a category of 3000 m depth. Geothermal power of these doublets is estimated to be 6.2 MW_{th} and 9 MW_{th}, based on the standard geothermal gradient in the Netherlands and a flow rate of approximately135 m^3/h. For estimating the investment costs of these reference cases an estimation of the main costs was made. Drilling costs are a significant part of the project budgets. Drilling costs from various sources were aggregated in a well cost versus depth plot (Figure 9).

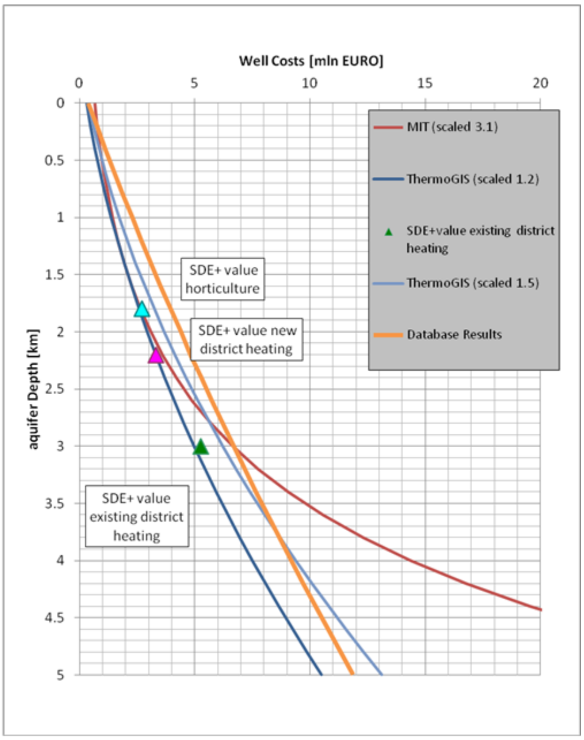

Figure 9: Drilling cost as a function of depth (Straathof, 2012). Note: Triangles refer to estimates of the cost of drilling for geothermal heating projects in greenhouse farming or for existing or 'green field' district heating in (Lako et al., 2011).

The curve 'ThermoGIS (scaled 1.2)' (van Wees 2010) presents an accurate view of estimates of drilling costs for geothermal heating up to a depth of 3000 m in (Lako et al., 2011). Drilling costs for a reference depth of 2300 m in (Lensink et al., 2012) coincide with this graph. Lensink et al. (2012) include costs for separation of hydrocarbons in their drilling costs estimates. The curve 'Database Results' refers to a database of German and Dutch geothermal projects in (Straathof, 2012).

Almost all doublets in the Netherlands co-produce hydrocarbons (in the order of 1 $Nm^3 gas/m^3 water$). Separation of the gas or oil is sometimes necessary. Additional investments are therefore needed. Table 1 shows the estimates for the drilling and hydrocarbon separation costs for the reference projects.

Drilling depth	Unit	Net drilling costs	Reserve for separation of hydrocarbons	Drilling costs including separation of hydrocarbons
2300 m	[M€]	5.7	1.0	6.7
3000 m	[M€]	11.0	1.0	12.0
4000 m	[M€]	16.5	1.0	17.5

Table 1: Drilling costs for geothermal energy (doublet) including separation of hydrocarbons

The estimation of the geothermal capacity and the drilling costs is characterized by a large uncertainty. Caution is therefore warranted in the interpretation of the results of the reference geothermal heating plant at a depth exceeding 2700 m. Extrapolating these estimated drilling costs will increase the uncertainty further and differences due to much greater drilling depths are only accounted for to a limited extent.

Taking into account the uncertainty, techno-economic parameters have been estimated for the MEA. These parameters are listed in Table 2 for the reference project at 2300 m depth and the (added) reference project at 3000 m depth. In accordance with (Lensink *et al.*, 2012), the cost price calculations compensate for a residual value of 35% of the investment after a period of 15 years of SDE+ subsidy.

4.4 Drilling depth and production costs uncertainty

The Ministry also asked ECN and DNV KEMA to take into account the range to be expected in production costs, based on the scatter seen in flow rates and capacities. ECN and DNV KEMA considered various variants for the two reference depths of 2300 m and 3000 m. One of the variants is a so-called '*Sweet spot*' variant, presuming a high flow rate of 180 m^3/hour, which may (or may not) be based on using fraccing to increase the flow rate. Another variant is a 'Triplet' variant, which is based on two production wells and one injection well or one production well and two injections wells, to increase the flow rate. In order to put the range of production costs in a better perspective the 'Reference SDE+ 2300 m' was redefined as 'Drilling depth 500 - 2700 m' and the new category for geothermal heating as 'Drilling depth 2700 m and more'. The boundary depth between these two categories was chosen at 2700 m. The techno-economic parameters used in the reference case calculations are shown in Table 2.

		Reference case 2300m - target depth 500 – 2700 m			Reference case 3000m - target depth > 2700 m		
		Variant Doublet	Variant 'Sweet spot'	Variant Triplet	Variant Doublet	Variant 'Sweet spot'	Variant 'Triplet
Flow rate	[m^3/h]	137	180	2x137	133	180	2 x 133
Geotherma l capacity	[MW_{th}]	6.2	8.1	12.4	9.0	12.15	18.0
Full-load hours	[h/a]	5,500	5,500	5,500	5,500	5,500	5,500
Investment cost	[€/kW_{th}]	1,527	1,261	1,132	1,743	1,381	1,321
Fixed O&M cost	[€/kWth]	30	25	23	35	28	26
Variable O&M cost	[€/GJ]	2.2	2.2	2.2	1.85	1.85	1.85
Base rate	[€/GJ]	11.8	10.3	9.5	12.8	10.6	10.2

Table 2: Techno-economic parameters of geothermal energy with variants for a drilling depth of 500 - 2700 m and >2700 m

Table 2 shows that the geothermal capacity is assumed to be significantly higher for the variants 'Sweet spot' and 'Triplet' than for 'Doublet' as a result of the higher flow rates achieved. 'Triplet' has the lowest heat production cost, as it is assumed for this variant that the geothermal capacity may be twice that of the 'doublet'. This presumes that the 'Triplet' variant is based on two production wells and one injection well. However, it is acknowledged that there is no experience in the Netherlands with such variants until this date. Also, injectivity instead of production rate may be a constraint for a geothermal project, which is why two production wells and one injection well ('Triplet') may not be feasible. The base rates for a depth of 500 - 2700 m and ≥ 2700 m are €11.8/GJ and €12.8/GJ, respectively. The maximum capacities correspond to the 'Triplet' variants with flow rates of 2 x 137 m^3/h and 2 x 133 m^3/h, and geothermal capacities of 12.4 MW_{th} and 18.0 MW_{th}, respectively (see Table 2).

Based on theoretical considerations, ECN and DNV KEMA anticipate that the base rate will decrease with increasing geothermal capacity at a specific depth. However, there are factors that increase costs as a function of capacity. It is uncertain whether cost decreasing or cost increasing factors will dominate for geothermal projects with different depths. To include an expected cost reduction as a function of geothermal capacity in the advice for the Ministry, this theory has to be supported by practical data. However, data of geothermal projects in the Netherlands is scarce and the same holds for data of representative geothermal projects in other countries that is usable in the Netherlands.

Based on data provided by TNO, ECN and DNV KEMA have calculated the production costs for a number of geothermal projects with increasing capacities. The calculation honours accepted assumptions with respect to the number of full-load hours and the financial return on investment (Figure 10).

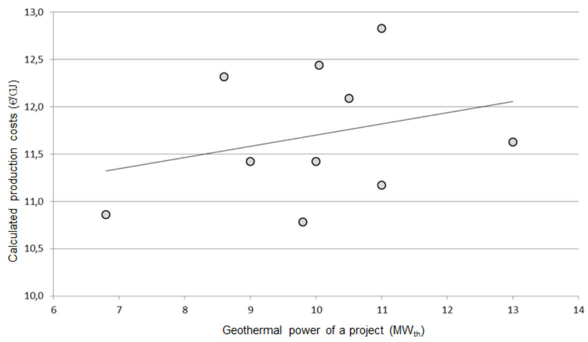

Figure 10: Indicative production costs and geothermal capacity for several geothermal projects under development in the Netherlands (depth up to 2700 m)

The standard deviation of the production costs is 0.7 €/GJ. This witnesses that the production costs tend to increase slightly with capacity, rather than decrease. The regression line is representative of the average cost level of geothermal projects to be developed in the Netherlands. The production cost at a reference capacity of 6.2 MW_{th} in accordance with (Lensink et al., 2012), is 11.2 €/GJ. The reference geothermal plant has to be representative for a range of geothermal projects with slightly different characteristics and the base rate is selected at a level where the majority of the projects can be developed. Therefore the aforementioned level of 11.2 €/GJ is increased with one standard deviation of 0.7 €/GJ, resulting in a base rate of 11.9 €/GJ. Figure 10 shows, however, that practical data of geothermal projects to be developed do not warrant the introduction of a variable base rate depending on the geothermal capacity as the scatter is too large and the correlation between production costs and geothermal capacity is weak.

5. CONCLUSIONS

The support schemes for geothermal energy in the Netherlands appear to be successful based on the number of applications. The main issues in the applications are the uncertainties in the pre-drill geothermal power estimation, and in the investment costs. The DoubletCalc software efficiently calculates an indicative geothermal power range which can be used to execute the support schemes. Continuous amendments to the schemes are carried out to meet new requirements by the operators and the government in an ever changing geothermal scene. With increasing experience with the realized doublets the schemes can evolve to satisfy all stakeholders.

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Acknowledgements

The authors are aware that with initiation, installation and execution of the support schemes numerous stakeholders and persons are involved. All these persons and stakeholders are invaluable for the success of the schemes. However, the Dutch Ministry of Economic Affairs and the former Ministry of Agriculture (now merged into the MEA) deserve special mention for having taken the initiative to put in place the support schemes described in this paper. Although this paper has been composed with utmost care, the authors do not accept any liability for possible errors. Also the views and opinions of the authors do not necessarily state or reflect those of the Dutch government.