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Geothermal energy in the Netherlands: current state, challenges and future prospects

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ABSTRACT

Geothermal energy production in the Netherlands has seen a gradual but fluctuating growth from 0 PJ in 2007 to 7.49 PJ in 2024. The 7.5 PJ was produced by 23 geothermal systems, mostly providing heat to greenhouses. The use of geothermal energy in the built environment lags behind the horticultural sector. This paper provides a comprehensive overview of the current state of geothermal energy production in the Netherlands, examining geothermal resources, heat supply and demand, and governmental policies. A production forecast is presented, illustrating the potential development of geothermal energy and identifying key bottlenecks that could impact growth.

The forecast indicates that while the Dutch government's target of 15 PJ by 2030 is achievable, the more ambitious goal of 80 PJ by 2050 appears unattainable under current conditions. Key bottlenecks include high investment costs and significant project risks. Furthermore, the deployment of geothermal systems in the built environment remains limited due to various challenges, including the adaption of geothermal systems to provide the baseload of heat demand and the complexity of developing heating grid infrastructure in urban areas.

To mitigate some of these challenges, a portfolio approach to drilling, a CAPEX subsidy and the use of unconventional drilling techniques are possible options. Furthermore, reducing geological uncertainty through continued exploration and adapting regulatory frameworks to support longer project timelines are crucial steps. Lastly, embedding geothermal systems in providing the baseload of heat demand, possibly with ATES, and clear legislation surrounding ownership of the heating grid infrastructure could support the development of geothermal energy production in the built environment.

Overall, while geothermal energy has the potential to significantly contribute to the Netherlands sustainable energy goals, addressing the identified bottlenecks and uncertainties is essential for realizing this potential.

1. INTRODUCTION

Exploration for deep geothermal resources in the Netherlands commenced in the late 1970s. The well Asten-GT-02 was drilled into Lower Cenozoic sediments to assess their potential for heat supply and storage for local greenhouses. However, poor transmissivity and low natural gas prices made the project uneconomical, a second well was never drilled (Dufour and Hederik 2019).

Decades later, geothermal energy in the Netherlands got renewed interest with the realization of the first geothermal doublet. Due to increased and volatile natural gas prices, the horticulture sector sought a stable alternative energy source for heating greenhouses (Mijnlieff 2020). The doublet, initiated by horticulturalist Van den Bosch, commenced production in 2008 and its success led to another doublet in 2009. This inspired other entrepreneurs in the horticulture sector but also the built environment to (try to) develop geothermal energy as a primary heat source. The first project in the built environment, in The Hague, initially failed despite drilling two successful wells, due to the housing market crash and subsequent loss of heat demand (Mijnlieff 2020). However, a decade later, in 2021, production finally began following reinvestment and a restored heat demand.

As of early 2025, 33 geothermal systems were realized in the Netherlands, of which 23 are in production (KGG 2025). This paper provides an overview of the current state of geothermal energy production from the Dutch deep subsurface, following a brief examination of the geothermal resources, heat demand and current governmental policies regarding geothermal energy. Additionally, it presents a production forecast illustrating the potential development of geothermal energy. Furthermore, multiple bottlenecks that (could) impact this development are discussed.

2. SUPPLY AND DEMAND

2.1 Geothermal resources

In the Netherlands, geothermal energy is currently produced from reservoirs of Upper-Jurassic/Lower-Cretaceous, Triassic and Permian age (Mijnlieff 2020; KGG 2025). Hot water is produced primarily from matrix permeable clastic sedimentary reservoirs, although fractured/faulted carbonate and sandstone reservoirs were also utilized. Consequently, all Dutch geothermal plays can be classified as a *Hot Sedimentary Aquifer* (Breede at al. (2015). Heat transport throughout the Dutch subsurface is due to conduction, classifying it as a *Conductive Play* (Moeck 2014). The average geothermal gradient in the Netherlands is 31 ℃ km^{-1} with an average surface temperature of 10 °C (Bonté et al 2012). This categorizes Dutch geothermal plays as *low temperature* or *low enthalpy* (Dickson and Fanelli 1990). Depending on the geothermal system, the produced water temperatures range between 25 °C and 110 °C.

Kramers et al. (2012) estimated, based on resource potential maps, that Dutch geothermal plays in total hold 821,000 PJ of Heat in Place, with 85,616 PJ considered Recoverable Heat. Updated potential maps are available on www.ThermoGIS.nl, a tool developed by the Dutch Geological Survey (GDN). These maps are based on an extensive 2D- and 3D-seismic and well dataset, resulting in net thickness, porosity, permeability and temperature maps. The vast dataset is the result of decades of hydrocarbon exploration and production in the Netherlands. Most of this data is publicly accessible on www.nlog.nl. Mijnlieff et al. (2020) made a first attempt to align the Dutch geothermal resource assessment with the UNFC classification system (UNECE 2016).

2.2 Heat demand

Owing to the extensive natural gas reserves, a significant portion of the heat supply in the Netherlands derives from combustion of the natural gas. In 2023, total heat consumption amounted to 806 petajoules (PJ), which is 40% of the energy use in the Netherlands. From this, 68% is sourced from natural gas combustion (EBN 2025). Due to the reliance on this relatively cheap and readily accessible resource, limited district heating networks were realized. It is estimated that in 2023 only up to 30 PJ of heat was distributed via district heating (CBS and TNO 2020). In 2019, 62% of the heat in these networks originated from fossil fuels.

At present, 50% of the heat demand is from the built environment, 40% from the industrial sector and 10% from the horticultural sector (CBS and TNO 2020). It is anticipated that this demand distribution will not change much in the future, but the source of heat will. Natural gas will be phased out and in 2050 an expected heat demand of close to 800 PJ has to be replaced by sustainable heat sources. Projections for the contribution of geothermal energy to the heat demand by 2050 vary, ranging from 14% (Wiebes 2018) to as high as 23% (EBN et al. 2018).

3. GOVERNMENTAL POLICIES AND SUPPORT

3.1 Ambition

Following the Paris Agreement, the Dutch government enacted a Climate Law in 2019 with the ambition to reduce CO_2 emissions by 49% in 2030 and 95% by 2050. The European Climate Law enacted in 2021, which the Netherlands adopted, states that in 2030 the reduction should be 55% and in 2050 the EU should have net zero greenhouse gas emissions.

In a letter to the parliament (Wiebes 2018), the Dutch government stated the ambition of an annual production of 15 PJ of geothermal heat in 2030. In the same letter the government refers to a production of 80 PJ in 2050 for the built environment and horticulture sector. The Dutch government has consistently emphasized the necessity of ramping up geothermal production to meet these targets. To facilitate this, various policies and support mechanisms were implemented.

3.2 The Mining Act

The Mining Act establishes a regulatory framework for mining activities in de Dutch deep subsurface. Geothermal projects were initially required to adhere to the same permitting procedures as oil and gas projects. A somewhat arbitrary boundary was set at 500 meters to distinguish ‘deep’ geothermal energy from shallower Aquifer Thermal Energy Storage (ATES) projects.

In 2023, the Mining Act was revised, introducing an amendment that included a new licensing system for deep geothermal energy. This system comprises:

1. *Search area allocation permit*: grants a party exclusive rights within the licensed area to study the geothermal energy potential and heat demand. Based on these studies, the party can apply for an SDE++ subsidy. Maximum duration of this license is 5 years, during which the party must apply for a start license
2. *Start license*: provides the party with exclusive rights to drill for and produce geothermal energy. Maximum duration is 3 years, and based on the geology encountered, production behaviour and thus the economy of the project, a follow-up license can be applied for.
3. *Follow-up license*: Grants rights for long-term production of geothermal energy within an authorised operational regime to ensure optimized and safe production. The standard duration of this license is 35 years, with the possibility of extension.

The revised Mining Act puts greater emphasis on risks such as induced seismicity and seal failure (Mijnlieff et al. 2025). Guidelines to support license applications for the seismic Hazard and Risk and the seal failure analysis were developed. These guidelines are accompanied by a tool to perform a quantitative analysis (Mijnlieff et al. 2023; Mijnlieff and Maaijwee 2023).

3.3 Financial support

The Dutch government initiated various forms of financial support to promote the transition to sustainable energy. Three direct financial support measures are of importance for the development of geothermal energy (Mijnlieff et al 2013).

The *Market-introduction Energy Innovation* subsidy supported the horticultural sector with an investment subsidy from the first geothermal project in 2007 until the introduction of the SDE in 2012.

The *Exploration Guarantee Fund*, established in 2010, provides an insurance covering a part of the investment for the drilling- and testing phase. In cases where reservoir quality falls below 75% of the pre-drill P90 geothermal power refund may be applied for. Applicants are required to pay a premium fee. The Exploration Guarantee Fund is currently under evaluation to see what possibilities there are to align it with the current needs of the geothermal sector.

In 2012, geothermal energy production was introduced in the *Stimulating Sustainable Energy-production* (SDE) subsidy scheme. SDE is an exploitation subsidy scheme that compensates for the cost difference between producing sustainable energy and current natural gas price, within predetermined limits, over a period of 15 years. It has been instrumental in the development of sustainable energy projects, including geothermal energy. The pre-drill estimated P50 geothermal power is used in order to determine the value of the subsidy.

Since the 2023 Mining Act revision, Energie Beheer Nederland (EBN), a state-owned entity, can now hold a 20% to 40% share in geothermal projects from the moment a “search area allocation” is granted to an operator (EBN 2025a).

3.4 Support in exploring the Dutch subsurface

In 2017, the *Green Deal Ultra Deep Geothermal Energy* (UDG) program started, with the government committing to cover 50% of exploration costs. The goal was to identify a potential geothermal source in the deep subsurface, capable of providing temperatures up to 200 °C for industrial use. Coordinated by EBN and supported by the GDN, it also involved five consortia aiming to utilize UDG as a sustainable energy source. The Dinantian limestones, buried at more than 4 km depth, were marked as having the most potential source. Studies on seismic and borehole data revealed significant uncertainties regarding the presence, depth and reservoir quality of the potential carbonate platforms. It was also recognised that UDG also posed a risk of induced seismicity, because at those depths fractured/faulted reservoirs were anticipated to be the most likely targets. Consequently, the financial and safety risk associated with such projects were deemed too high, leading to the project’s suspension (EBN 2025b).

It is estimated that 80% of the heat demand in the Netherlands is situated in regions with limited or no data of the deep subsurface (EBN et al. 2018). In 2019 EBN received the task from the Dutch government to investigate the potential for geothermal energy in these data-poor areas by improving the subsurface data coverage (Van der Molen and Tolsma. 2024). The *SCAN* program’s initial two phases involved reprocessing legacy 2D seismic data, followed by acquiring new regional 2D seismic lines. Based on the new data, phase three includes drilling multiple exploration wells, targeting various reservoirs at depths between 500 and 4000 meters in different areas of the Netherlands that have a significant heat demand. Data acquisition, such as logging, coring and testing, is conducted in each well. Phase three will conclude in 2025 and the subsequent phase will focus on the most promising areas. This will involve acquiring 3D seismic surveys and additional appraisal drilling to further reduce geological uncertainties (EBN 2025c).

A new initiative may see the Dutch government providing support to initiate and scale up geothermal projects within the low-temperature domain, at depth ranges of 500 to 1500 meters. A market consultation was organized in early 2025.

4. GEOTHERMAL ENERGY IN THE NETHERLANDS

4.1 Geothermal licenses

Table 1 provides an overview of the number of geothermal licenses (applied for) in the Netherlands as per status date 01-01-2025.

Table 1: Geothermal licenses (applied for) as per status date 01-01-2025 (KGG 2025).

Amount	License type
74	Search area allocation permit
5	Start license, applied for
18	Start license
4	Follow-up license, applied for
18	Follow-up license

Most start and follow-up licenses with geothermal systems are located in areas with high concentration of greenhouses (Fig. 1). In contrast, most ‘search area allocation’ permits are situated in urban areas with significant heat demand. This distinction is evident when comparing geothermal licenses attributed to a primary heat demand in the built environment versus the horticultural sector (Fig. 2). Although the total number of licenses per category is similar, significantly more start or follow-up licenses (and applied for) cater to the horticultural sector’s heat demand, indicating different maturation levels of geothermal projects between these sectors. The underlying reasons will be discussed in Chapter 6.

As previously mentioned, the initial geothermal systems were predominantly initiated by horticultural entrepreneurs. In contrast, the majority of geothermal operators currently developing new projects are corporations that own multiple licenses and in some cases multiple geothermal systems. Their core business is to produce and sell heat, rather than using it for their own and neighbouring greenhouses as the horticultural entrepreneurs did.

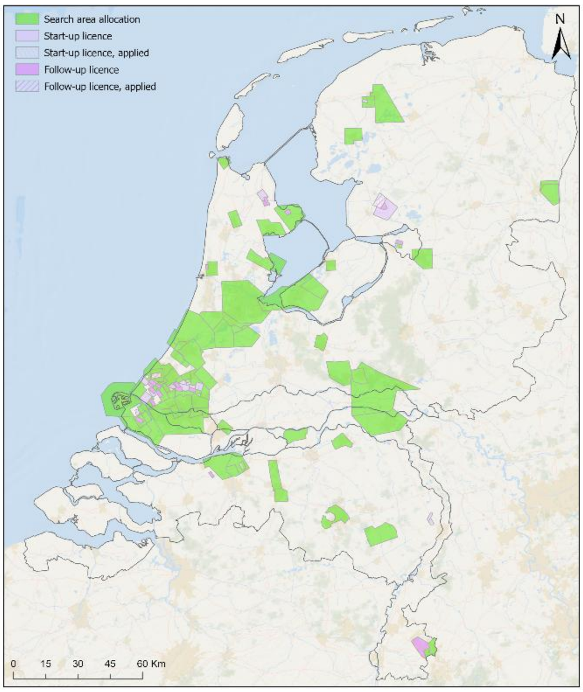

Figure 1: The Netherlands, with (applied for) geothermal licenses, status date 01-01-2025.

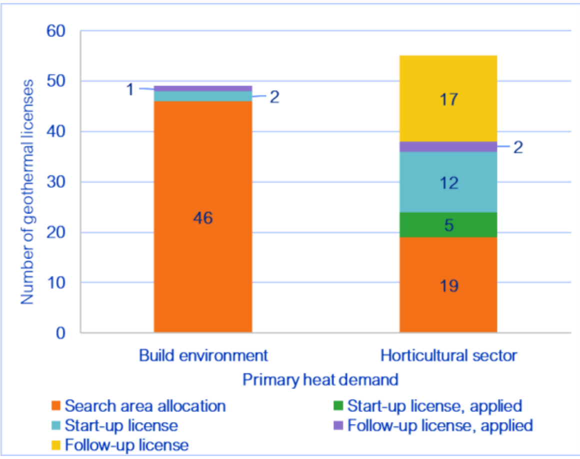

Figure 2: Geothermal licenses categorized in primary heat demand, status date 01-01-2025. Note: total numbers differ from Table 1 due to bundling of some smaller licenses that act as one.

4.2 Geothermal wells

Since 2007, a total of 90 geothermal wells were drilled in the Netherlands as part of (future) geothermal production systems (Fig. 3). In 2023, 12 wells were drilled, resulting in six new geothermal systems. In 2024, eight wells were drilled. Of those, three are classified as technical failure for which drilling is expected to resume in 2025. One new geothermal system was realized in 2024 and two older suspended systems were revived by newly drilled replacement wells.

Furthermore, three SCAN exploration wells were drilled in 2023/24 and proved the presence of suitable geothermal reservoirs. It is anticipated that four more SCAN exploration wells will be drilled in 2025.

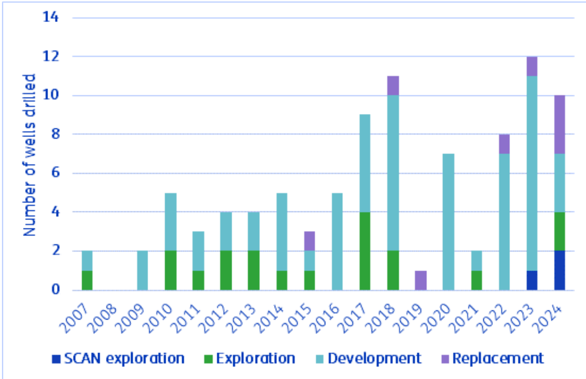

Figure 3: Geothermal wells drilled from 2007 to 2024. "Exploration", "Development" and "Replacement" wells are utilized in (future) geothermal systems. "Replacement" wells (new wells or sidetracks) are used to substitute older, malfunctioning wells.

4.3 Geothermal production systems

Currently, all geothermal systems are open-loop systems that produce hot water from a reservoir via a production well. The heat is extracted using a heat exchanger at the surface and the cooled water is re-injected into the same reservoir through an injection well (Mijnlieff 2020). Typically, geothermal systems are doublets, consisting of 2 wells, although some systems have more than 2 wells. One system in the southeastern part of the Netherlands utilizes flooded, abandoned coal mines, where the water is used as a thermal energy storage (TES) (Verhoeven at al. 2014). The mine-water project is considered a different type of 'geothermal system' and is not further discussed in this paper.

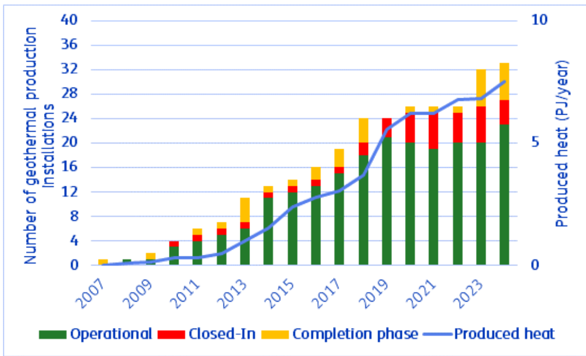

Figure 4: Produced heat (blue line) and the number of geothermal production systems, per year. The geothermal systems are categorized by their status: operational, closed-in or in the completion phase.

In 2024, 23 geothermal production systems were operational, with three starting production that year (Fig. 4). Concurrently, six systems are in the *completion phase*, which spans from the completion of drilling operations to the start of production. During this phase, the production facility and district heating infrastructure are developed. Four systems were closed-in during 2024.

4.4 Geothermal production

From 2007 to 2024, geothermal production exhibited periods of both robust and modest growth (Fig. 4). In 2019, production increased by 50% compared to 2018, while in 2023, growth was limited to 0.5%. In 2024, production increased by 10.2% to 7,49 PJ. Cumulatively, ~55 PJ of geothermal heat has been produced to date.

Several factors contributed to these variations. The number of geothermal wells drilled annually, and consequently the resulting geothermal systems, has fluctuated significantly over the past decade (Fig. 3). The average number of systems that are (temporarily) closed-in has also increased during this period (Fig. 4). Additionally, the duration of the completion phase varies considerably for each new geothermal system and tends to increases over time (Van der Molen and Tolsma 2024). The average operational hours per year fluctuate due to, amongst others, (extended) maintenance periods. The relative low production growth in 2023 was primarily due to the reduction in operational hours (Van der Molen and Tolsma 2024), whereas the stronger growth in 2024 was largely attributed to the restoration of the operational hours to pre-2023 levels (Van der Molen et al. in prep.).

Furthermore, variations in heat demand can influence the capacity factor; here expressed in terms of full load hours which showed a decline in 2023 and an increase in 2024. Finally, technical issues such as scaling, sand production or clogging of perforations (temporarily) impeded production in some systems.

5. PRODUCTION FORECAST

5.1 Methodology

To evaluate the feasibility of the Dutch government's ambitions for annual geothermal production, 15 PJ in 2030 and 80 PJ in 2050, a production forecast was made. Given the significant uncertainties associated with future, long-term production scenarios, a stochastic approach utilizing a numerical method is used. The independent parameters are described using a double triangular probability density distribution defined by low, mid and high input values for the parameters: yearly geothermal energy production or geothermal power and operational hours or full load hours. The forecast results in multiple production profiles which are subsequently presented in the form of a (corrected) P90, P50 and a P10 production profiles.

The UNFC resource classification system (UNECE 2016) has been adopted and tailored to a fit-for-purpose classification, categorizing geothermal projects into six groups:

1. Geothermal projects in operation;
2. Geothermal projects in the completion phase;
3. Defined geothermal exploration projects in Start licenses;
4. Defined geothermal exploration projects in 'Search allocation area' permit and with a SDE subsidy grant;
5. Notional geothermal exploration projects in a 'Search allocation area' permit without SDE subsidy grant;
6. Notional geothermal exploration projects in open acreage.

This classification reflects project maturity and associated uncertainty, with Group 1 having the highest maturity/certainty and Group 6 the lowest. Different sets of uncertainty ranges or corrections are applied per group, as summarized in Table 2. Calculations are run from 2025 through 2050, assuming continuous production without downtime.

Table 2: Overview of groups used in the production forecast, its differences and what uncertainties/corrections are applied.

Group	License	Status system	SDE	Production uncertainty (%)	Realization Correction factor (-)	Power Correction Factor (-)
1	Follow-up	Operational	√	7	-	-
	Start	Operational	√	10	-	-
2	Start	Not-operational	√	From license application	-	0.8
3	Start (applied)	Not-realized	√	From license application	0.8 – 0.9	0.8
4	Search allocation area	Not-realized	√	From SDE grant	0.7 – 0.8	0.8
5	Search allocation area (applied)	Not-realized	-	From license application	0.5 – 0.6	0.8
6	None	Not-realized	-	Average of Group 4 & 5	-	0.8

Annual geothermal production was estimated for each project and year. Within each group, system-level production values were summed, assuming variable independence. To account for potential correlations, the P10 and P90 production estimates from the stochastic simulations were adjusted using the group's minimum and maximum values. Specifically, the corrected P90 is the mean of the original P90 and the minimum, while the corrected P10 is the mean of the original P10 and the maximum. This approach captures correlation-driven uncertainty without explicitly modeling interdependencies. For simplicity, the results section only presents corrected P10 and P90.

An analysis comparing the pre-drill P50 geothermal power estimation from the SDE subsidy, with the actual maximum monthly geothermal power achieved reveals that the latter is frequently lower than the former (Fig. 5). The average discrepancy is -20%. This difference can be attributed to several factors, including:

- Higher or lower than expected reservoir quality (e.g. permeability or thickness);
- Deterioration of well productivity or injectivity due to scaling or clogging of perforations;
- Higher or lower heat demand than expected.

In this forecast, the average variation of -20% is accounted for in groups 2 to 6, where no production is currently taking place, by applying a power correction factor of 0.8 to the yearly production for each system (Table 2).

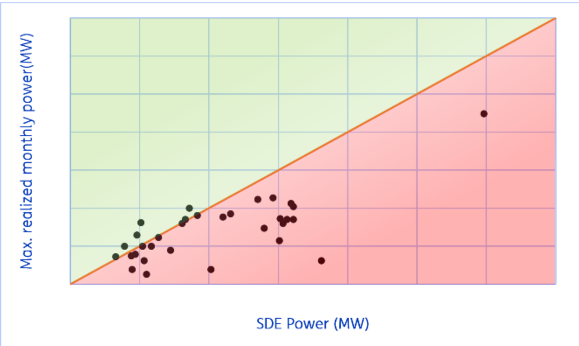

Figure 5: Comparison of P50 geothermal power used in granted SDE subsidies with the actual realized monthly maximum geothermal power. Each dot represents a realized system. Both axes are devoid of values due to confidentiality. The orange line represents a 100% match of the SDE power and the realized power, while the red area indicates an overestimation and the green an underestimation.

Group 1 Geothermal projects in operation. This group comprises 19 geothermal systems that were operational in 2024. One system will be closed-in from 2025 and onwards as it will be replaced by a new system. For each system, the yearly heat production of 2023 or 2024 was used as the mid case, whichever was higher. This production data is provided by the geothermal operator to TNO on a monthly basis. Based on data of 12 systems that have been in operation for at least five years, an average variation in yearly production of 7% was observed. This 7% is applied as an uncertainty range on the mid case, serving as the low and high cases for systems with a follow-up license. Systems with a start license which have been in operation for a maximum of three years, proved to be challenging to determine a reliable level of production that can be applied on the long-term. To address this, the standard error of the mean (for N = the average of 2 years) is added to the standard deviation for an adjusted standard deviation of 10%. This adjusted standard deviation is used as the uncertainty range for systems in a start license.

Group 2 Geothermal projects in the completion phase. This group consists of 9 systems that are in the completion phase, awaiting commencement of production. The pre-drill estimated minimum, average and maximum geothermal power in mega-watts (MW) provided in the applications for a start license are used for the low, mid and high cases. The expected operational hours are adopted as the mid case, with a 10% variation for the low and high cases. The forecast incorporates the anticipated month/year for the start of the production.

Group 3 Defined geothermal exploration projects in Start licenses. This group encompasses all projects with (applied for) start licenses, which are still in the exploration phase. Similar to Group 2, the pre-drill estimated geothermal power, operational hours and anticipated start date provided in the license application are used as input. The key difference is the uncertainty regarding whether all projects in this group will be realized or not. Based on available (confidential) data, an “expert judgement” estimates that between 10% to 20% of these projects might not be realized. This uncertainty is factored into the calculation of annual geothermal production of projects in Group 3 by using a realization correction factor, ranging from 0.8 to 0.9, applied in a uniform distribution (Table 2).

Group 4 Defined geothermal exploration projects in ‘Search allocation area’ permits and with a SDE subsidy grant. Group 4 includes projects that have been granted a ‘search allocation area’ permit and a SDE subsidy, but are still in the exploration phase. The minimum, mode and maximum geothermal power values are derived from the SDE subsidy grants. These pre-drill estimates are based on detailed local geological studies. The mode full load hours are specified per subsidy category and can either be 3500, 5000 or 6000 hours. The minimum and maximum full load hours are determined by applying a 10% variation to the average. Start dates of production are not provided, but a SDE subsidy award is valid for 6 years. For this forecast, it is assumed production will commence in the 5th year following the year of subsidy grant. Similar to Group 3, there is an uncertainty regarding realization of the projects. An “expert judgement” gives an estimation that 20% to 30% of projects in Group 4 might not be realized. This uncertainty is incorporated into the forecast with a realization correction factor of 0.7 to 0.8, applied in a uniform distribution (Table 2).

Group 5 Notional geothermal exploration projects in a 'Search allocation area' permit without SDE subsidy grant. Unlike Group 4, projects in Group 5 do not have a SDE subsidy grant yet. The pre-drill estimated minimum, average and maximum geothermal power are based on regional geological studies that have identified one or more geothermal prospects. Full load hours are not always provided. Therefore, an estimation is made based on whether the project has a primary heat demand from the horticulture sector or the built environment, whether district heating is already present, and what required temperatures are. Search allocation area licenses often cover a sufficient area to incorporate more than one geothermal system. It is assumed that only one system is realized per license, unless a well-substantiated work plan is provided that includes different geothermal powers per potential system. Occasionally, a geothermal operator provides an updated work plan, including a more certain date for the commencement of geothermal production. However, more often projects within such licenses have outdated and often very general work plans. Therefore, an estimation of the start of production is made based on the expiration date of the license, the possible duration of applying for a start license, plus three years. Based on an "expert judgement" it is estimated that 40% of the projects in Group 5 have a possibility of not being realized. Additionally, an estimation based on the number of expired licenses indicates that 50% of projects in Group 5 might not be realized. Consequently, the realization correction factor used for this group is 0.5 to 0.6, again applied in a uniform distribution (Table 2).

Group 6 Notional geothermal exploration projects in open acreage. This group encompasses notional geothermal projects, representing the assumption that new 'search allocation area' licenses will be applied for in the future or that additional geothermal systems will be realized in licenses that have sufficient space for new systems. The minimum, mode and maximum geothermal power is derived from the average geothermal powers in Groups 4 and 5: respectively 5, 15 and 27 MW. Full load hours are determined using a double triangular distribution, which depends on the likelihood of heat demand originating from either the horticulture sector or the built environment. Currently, only 5% of the 20 operational systems primarily provide heat to the built environment. However, several studies predict a significant increase in this percentage. TNO (2024) estimates 57% by 2050 in the ADAPT scenario and 75% in the TRANSFORM scenario, while the Masterplan Geothermie (EBN et al. 2018) estimates 77% by 2050. Based on current geothermal licenses, 50% of the primary heat demand is from the built environment (Fig. 2). On average, this is 65% and the increase from 5% to 65% by 2050 is considered in the selection of the full load hours. For notional projects in the horticultural sector, a value of 6000 full load hours is selected, while for the built environment, a weighted average of 5270 hours is used. Each year, the number of newly notional operational systems varies between 0 and 10. This is based on drilling activities over the past decade (Fig. 3) and near-future expectations. A trapezoid distribution is utilized, where the probability increases between 0 and 2 systems, remains uniform between 2 and 6 systems, and decreases again between 6 and 10 systems. The annual production from hypothetical projects in Group 6 is projected to start from 2033, based on the assumed start date of the most recently awarded 'search allocation area' permit.

5.2 Results

The cumulative results are presented in Figure 6. Group-specific results, along with the overall result, are detailed in Table 3, categorized in P90, P50 and P10 for the years 2030 and 2050.

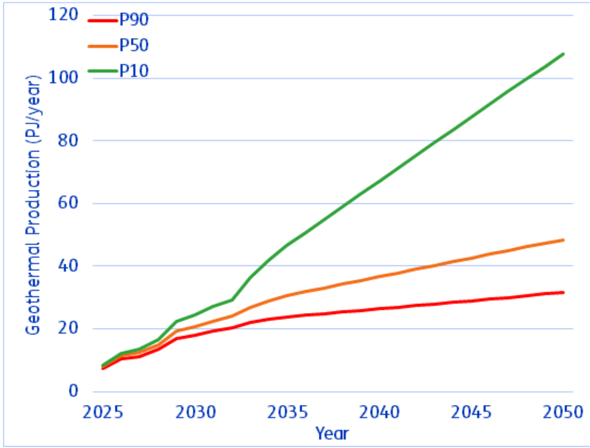

Figure 6: Production forecast results, presented in P90, P50 and P10 geothermal production per year.

The projected P50 annual geothermal production for the years 2030 and 2050 is 20.8 PJ and 48.51 PJ. Based on this forecast, the Dutch government's target of 15 PJ by 2030, will be achieved, even when considering the P90 result of 18 PJ per year. However, the target of 80 PJ by 2050 appears unattainable. Only in the optimistic P10 scenario, with an annual production of 107.9 PJ, can this ambition be realized.

Table 3: Production forecast results, both group-specific and combined for all groups for 2030 and 2050, presented in P90, P50 and P10.

Group	Geothermal Production (PJ/year)					
	Year 2030			Year 2050		
	P90	**P50**	**P10**	**P90**	**P50**	**P10**
1	7.05	7.37	7.7	7.05	7.37	7.7
2	3.08	3.62	4.17	3.08	3.62	4.17
3	3.61	4.44	5.27	3.61	4.44	5.27
4	3.35	4.3	5.61	3.69	4.73	6.14
5	0.72	1.06	1.8	4.92	6.85	10.92
6	0	0	0	8.84	21.48	74.17
All	*18*	*20.8*	*24.35*	*31.65*	*48.51*	*107.9*

6. DISCUSSION

The production forecast results presented in the previous chapter indicate a substantial short-term growth in the geothermal energy production, increasing from 7.49 PJ in 2024 to an anticipated 20.8 PJ in 2030. Even considering only contributions from Groups 1, 2 and 3, the Dutch government's ambition of 15 PJ is met, albeit marginally. However, the long-term average growth in production appears less robust and is considerably more uncertain. This uncertainty is predominantly influenced by Group 6, which comprises production from notional exploration commencing in 2033. Nevertheless, the cumulated projected annual production till 2050 constitutes only a fraction of the Recoverable Heat estimated by Kramers et al. (2012), which amounts to 85,616 PJ. Consequently, the Dutch subsurface holds ample potential for additional heat extraction, provided that the geothermal resource or supply location aligns with the local heat demand location. The development of these resources may see several bottlenecks impeding or halt development, some of which are discussed below.

6.1 Challenges and uncertainties in geothermal project development and financing

One of the greatest uncertainties arises from the number of new systems being realized. A major bottleneck for the development of geothermal projects is currently the high investment costs combined with significant project risk (EBN and GNL 2021). The capacity of a geothermal system can only be determined with certainty after drilling and testing the reservoir. It may further be constrained by limitations set on the operational parameters like injection pressure, flowrate and/or temperature, in either the start or the follow-up license. This uncertainty regarding the geothermal power output can deter investors from committing to geothermal projects.

Until approximately 2020, banks provided loans prior to the drilling phase. Currently, a bank loan for a geothermal project is only issued once the actual geothermal power is known (Van der Molen & Tolsma 2024). This introduces greater financial risk for the geothermal operators must invest more of their own capital without a guaranteed outcome.

Similar to other sustainable heat sources, geothermal projects rely on SDE subsidies. In early 2025, a letter to the parliament indicated that no budget might be available for new projects in 2026 (Hermans 2025). This could potentially delay the realization of new geothermal systems and thus production. Additionally, it creates uncertainty for operators and investors, as it is unclear whether this budget issue is limited to 2026 or extends to subsequent years.

As a (partial) alternative for the SDE subsidy, the Dutch geothermal sector advocates for a CAPEX subsidy, which would (partially) cover the realization costs such as drilling (van der Molen & Tolsma 2024).

6.2 Feasibility of drilling operations

A potential bottleneck is the feasibility of drilling the required number of wells for new systems. Assuming an average geothermal power output of 15 MW and 6000 full load hours, approximately 8 new wells need to be drilled annually from 2025 to 2049 for 4 new systems a year to achieve the P50 production forecast in 2050. However, to meet the Dutch government's target of 80 PJ, an average of 16 wells must be drilled annually for 8 new systems a year. Historical data of the number of wells drilled shows such high number of wells drilled has not been achieved yet. To increase the number of wells drilled per year, a portfolio approach can be adopted, wherein multiple wells across various projects are drilled back-to-back (TNO and EBN 2018). This approach potentially reduces drilling costs and risks. However, it necessitates substantial investments in rapid succession, thereby increasing financial risk, which may render this approach less favorable. The aforementioned CAPEX subsidy could mitigate overall investment costs and, consequently, financial risks.

In addition, to accommodate the higher number of wells drilled per year, several drilling rigs must be available year-round. Furthermore, given the current nitrogen deposition thresholds in the Netherlands, fully electric drilling rigs are preferred (Van der Molen and Tolsma 2024). These rigs are not only more rare and expensive, but also face challenges due to grid congestion that currently plagues new projects in the Netherlands. The latter hampers the access to necessary power for e.g. drilling activities.

Currently, investigations are performed focusing on unlocking the low temperature domain at depths of 500 to 1500 meters for geothermal production. As previously mentioned, the Dutch government considers to financially support (exploration of) low-temperature geothermal projects. A key question is whether in all cases a heavy drilling rig, including a BOP, is necessary for these shallow targets. If not, a selection of these targets/projects could be executed independently of the drilling sequence for deeper targets. Although the projects would yield lower geothermal power output, they would contribute to annual production, aiding in the achievement of the 80 PJ target. Therefore, these low-temperature projects are be included in future production forecasts.

6.3 Uncertainty on geothermal power

The general input minimum, mode and maximum geothermal power in Group 6 exhibit substantial uncertainty: 5 PJ, 15, PJ and 27 PJ, respectively. These values are derived from the estimated P50 geothermal powers of projects in Groups 4 and 5, which include projects with high expected power in the province of Zuid-Holland and lower expected power in the Amsterdam region.

Reducing geological uncertainty is crucial for mitigating financial risks but also for the national resource estimation. To achieve this, it is essential to continue thorough exploration of the Dutch subsurface through new seismic data acquisition and/or exploration wells. The current SCAN program represents a first attempt, but mostly on a regional scale. Consequently, geothermal operators must undertake exploration projects themselves. However, data acquisition entails significant additional costs and also comes with operational risk. Most geothermal operators have expressed reluctance to carry these additional financial risks (Van der Molen & Tolsma 2024). A potential solution under investigation involves adapting the Exploration Guarantee Fund regulation to include data acquisition and its anticipated risk.

The data acquisition will ultimately lead to better a estimate the potential of exploration projects by operators. It is also to improve the geological maps on basis of which potential power estimate of notional exploration projects can be derived. The notional geothermal prospect portfolio then can serve as the input for exploration simulation scenario’s.

Another identified bottleneck which hampers potential exploration projects is the duration of ‘search allocation area’ permits and start licenses (Van der Molen & Tolsma 2024). Both can only be extended by one year, while the execution of an exploration project including data acquisition and processing of e.g. new 2D seismic data and subsequently drilling an exploration well, requires much more time. To stimulate exploration, the Dutch government is advised to reconsider the maximum extension duration of the aforementioned permit and licenses.

As previously mentioned, the P90 geothermal power of Groups 4 and 5 combined is 5 MW. In areas with high heat demands, this power may be insufficient. By employing alternative well designs like horizontal drilling, multi-laterals, radials or well-stimulation techniques, the geothermal power per system can be increased. Although these methods incur additional costs, they could ultimately be cost-effective for the additional power it brings (EBN and GNL 2021).

6.2 Complexity of the built environment

Despite significant heat demand from the built environment and numerous defined geothermal projects to meet this demand, only two geothermal systems have been realized in this domain: one operational and the other in the completion phase. The deployment of geothermal production in the built environment lags behind the horticulture sector. This is due to the greater variation in daily and yearly heat demand in the built environment compared to the horticultural sector, resulting in relatively low prognosed full load hours. However, geothermal systems operate optimally with low variation in flowrate and return temperatures, making them suitable for providing the baseload of the heat demand in the urban environment (Van der Molen & Tolsma 2024). Many new geothermal projects in development aim to provide this baseload, as indicated by the expected full load hours provided in their applications.

High Temperature Aquifer Thermal Energy Storage (HT-ATES) may play a crucial role in optimising geothermal production in the built environment. The geothermal system operates at flat rate year round and the surplus of produced in summer is buffered in the HT-ATES system for use in winter. Presently there is one HT-ATES system in operation in the Netherlands connected to a geothermal system providing heat to greenhouses. It is estimated the combined system has an increased capacity of 10 MW over an extended (Van der Molen and Tolsma 2024).

Another major bottleneck in the development of geothermal energy in the built environment is the establishment of heating grid infrastructure. The complexity of developing such infrastructure in urban areas, characterized by a high number of connections to e.g. households, potential societal resistance, complex and lengthy permitting procedures, and high costs, poses significant risk on the demand side of a geothermal district heating project (Van der Molen & Tolsma 2024). A future new law, Wet Collectieve Warmte, mandates that at least 51% of heating networks be publicly owned. Currently, most heating grids are privately owned, and the uncertainty surrounding the new law has put the development of many new heating grids on hold (Van der Molen and Tolsma 2024), thereby delaying the development of new geothermal projects.

7. CONCLUSIONS

Geothermal energy in the Netherlands has shown significant growth and the production forecast suggests that this growth will continue in the near-future, likely achieving the Dutch government’s target of 15 PJ of annual heat production by 2030. However, despite governmental support through policies and financial incentives, the ambition of 80 PJ by 2050 is unlikely to be met under current conditions and model assumptions.

The development of geothermal energy in the built environment lags behind the horticultural sector, due to the complexity of integrating geothermal systems as a baseload and the challenges associated with developing heating grid infrastructure. Overall obstacles to rapid development include high investment costs, geological uncertainty in the calculation of expected geothermal power and subsequent associated project risks.

Geothermal energy has the potential to be a key sustainable heat source in the Netherlands, but overcoming the aforementioned bottlenecks and uncertainties is crucial.

REFERENCES

Bonté, D., Van Wees, J.-D. and Verweij, J.M.: Subsurface temperature of the onshore Netherlands: new temperature dataset and modelling, *Netherlands Journal of Geosciences*, 91 e4, (2012), 491-515.

Breede, K., Dzebisashvili, K. and Falcone, G.: Overcoming challenges in the classification of deep geothermal potential, *Geothermal Energy Science*, 3, (2015), 19-39.

CBS and TNO: Warmtemonitor 2019 (TNO 2020 P11264), (2020).

Dickson, M.H. and Fanelli, M.: Geothermal energy and its utilization, in: Small geothermal resources, Dickson, M.H. and Fanelli, M. (Ed.), 1-29, *UNITAR/UNDP Centre for Small Energy Resources*, Rome, (1990).

Dufour, F.C. and Heederik, J.P.: Early Geothermal Exploration in the Netherlands 1980-2000, *Proceedings European Geothermal Congress 2019*, The Hague, Netherlands, (2019).

EBN: Infographic 2025. Website EBN. https://www.ebn.nl/feiten-en-cijfers/infographic, last accessed on 23 April 2025

EBN: Website Rol EBN bij aardwarmteprojecten. https://www.ebn.nl/aardwarmte/rol-ebn-in-aardwarmteprojecten/, last accessed on 23 April 2025, (2025a)

EBN: Website geleerde lessen UDG rapporten. https://www.ebn.nl/aardwarmte-onderzoek-naar-aardwarmte-onderzoek-naar-udg-geleerde-lessen-udg-rapporten-geleerde-lessen-udg-rapporten/, last accessed on 23 April 2025, (2025b)

EBN: Workshop on the Results of the first SCAN Well Amstelland-01, (2025c).

EBN and GNL: Integraal Kostprijsreductie Programma Aardwarmte. Whitepaper status december 2021, (2021).

EBN, Platform Geothermie, DAGO, Stichting WarmteNetwerk: Masterplan Aardwarmte in Nederland. Een brede basis voor een duurzame warmtevoorziening, (2018).

Hermans, S.Th.M.: Kamerbrief openstelling SDE++ 2025, (2025).

Kramers, L., Van Wees, J.-D., Pluymaekers, M.P.D., Krominus, A. and Boxem, T.: Direct heat resource assessment and subsurface information systems for geothermal aquifers; the Dutch perspective, *Netherlands Journal of Geosciences*, 91 e4, (2012), 637-649.

Mijnlieff, H.F.: Introduction to the geothermal play and reservoir geology of the Netherlands, *Netherlands Journal of Geosciences*, 99 e2, (2020).

Mijnlieff, H.F. and Maaijwee, C.: Evaluatiemethodiek voor geothermieprojecten. Bepaling integriteit afdichtende gesteentepakketten voor geothermieprojecten in Nederland (TNO 2023 R11773), (2023).

Mijnlieff, H.F., Buijze, L., Rosendaal, E., Schoof, F., Vorage, R. and Van Wees, J.-D.: Geothermal energy – from potential plays to successful growth, in: Geology of the Netherlands. Second edition. Ten Veen, J., Vis, G.-J., De Jager, J. and Wong, T. (Ed.), 701-728, *Amsterdam University Press*, Amsterdam, (2025).

Mijnlieff, H.F., De Vries, S, Jaarsma, B. and Vogelaar, B.: Seismic Hazard and Risk Assessment for geothermal projects in The Netherlands, (2023).

Mijnlieff, H., Ramsak, P., Lako, P., Smeets, J., In ’t Groen, B. & Veldkamp, H.: Geothermal energy and support schemes in The Netherlands, *Proceedings European Geothermal Congress 2013*, (2013).

Mijnlieff, H.F., Van Kempen, B., Tolsma, S.P., De Vries, C., Martins, J.E., Veldkamp, H., Struijk, M., Vrijland, M. and Van Wees, J.-D.: The Dutch Geothermal Resource Base: Classified Using UNFC Resource Classification System and its Potential to meet the Dutch Geothermal Ambition, *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland, (2020).

Ministry of Climate and Green Growth (KGG): Hoofdstuk 5. Aardwarmte, in: pre-publication Jaarverslag 2024. Delfstoffen en Aardwarmte in Nederland, *KGG*, The Hague, (2025)

Moeck, I.S.: Catalog of geothermal play types based on geological controls, *Renewable and Sustainable Energy Reviews*, 37, (2014), 867-882.

TNO: Towards a sustainable energy system for the Netherlands in 2050. Scenario update and scenario variants for industry (TNO P10607), (2024).

TNO and EBN: Play-based portfoliobenadering, eerste inzicht in zes voordelen voor veilig en verantwoord, kosteneffectief versnellen van geothermie, (2018).

UNECE, Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources, (2016).

Van der Molen, J. and Tolsma, S.P.: Aardwarmte in Nederland. 2023: een recordjaar, maar toch teleurstellend, (2024).

Van der Molen, J., Tolsma, S.P., Davids, B. and Mijnlieff, H.F.: Aardwarmte in Nederland. 2024: hernieuwde groei na teleurstellend jaar, (in prep.).

Verhoeven, R., Willems, E., Harcouët-Menou, V., De Boever, E., Hiddes, L., Veld, P. OP’t and Demollin, E.: Minewater 2.0 project in Heerlen the Netherlands: transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling, *Energy Procedia*, 46, (2013), 58-67.

Wiebes, E.D., Beleidsbrief geothermie, (2018).