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GEO4ALL: Driving the next frontier of geothermal innovation in the Netherlands

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1 INTRODUCTION

Geothermal activities began in the Netherlands in 2007 with a focus on direct use to provide sustainable heat for the horticultural industry. Since then there has been a steady growth in heat production for both horticulture and the urban environment resulting in 33 geothermal site locations across the Netherlands providing 7.9 Peja Joules of heat in 2024 (Figure 1). This heat generation is equivalent to approximately the annual consumption of 263,000 Dutch households, a consumption in comparison to the entire city of the Hague. This renewable heat saves 426,000 tones of CO_2 and 225 million cubic metrics of natural gas (Geothermie Nederland 2025).

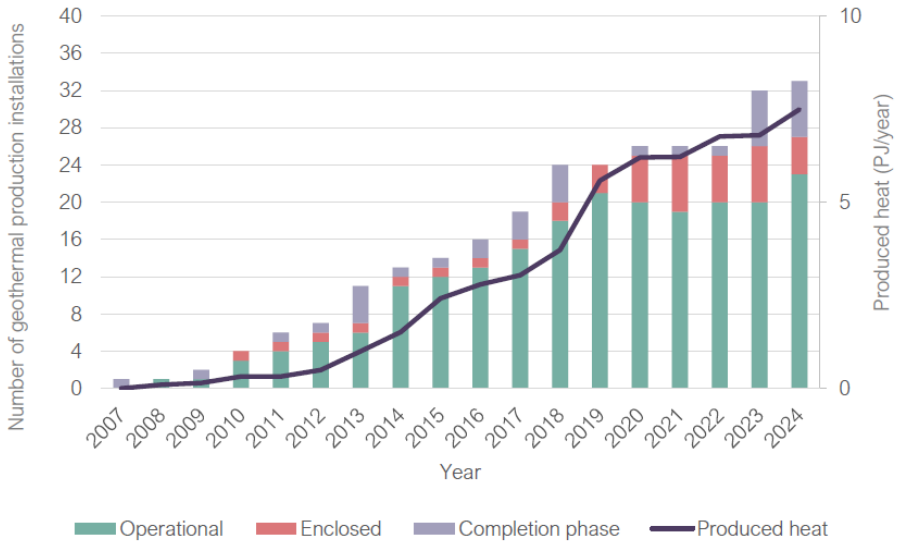


Figure 1. Graph from the annual report on geothermal energy in the Netherlands by the Ministry of Climate and Green Growth (2025) shows the number of geothermal production installations by status- operational, enclosed and completion, plotted against annual geothermal energy production (PJ/year).

Over these last decades the geothermal sector has started to mature and with it raised a series of topics which needs further research. In 2018 a report was commissioned by a coalition of industry organizations (Geothermie Nederland, 2018), which summarized that the Netherlands faces a major challenge to reduce CO_2 emissions by 40% by 2030 and 95% in 2025. There is an ambition by the industry to scale up geothermal production up to 50PJ by 2030 and over 200 PJ by 2025. However to achieve these goals the report identified that innovation could play a large role. In 2023, the innovation inventory by EBN and Geothermie Nederland (Geothermie Nederland and EBN, 2021) identified key research areas essential for advancing geothermal energy in the Netherlands, related to quantifying seismic risk, increasing the value of geothermal heat through integration with the built environment and heat networks, reducing the levelized cost of geothermal heat and extending the lifespan of geothermal installations.

The GEO4ALL programme was therefore established as a national innovation 4-year research programme in 2024 focusing on advanced geothermal research and development in the Netherlands. The programme consists of a consortium of 23 partners who represent the entire geothermal value chain (research institutes, operators, horticulture, drilling companies and service providers) with the aim to improve the efficiency, safety and sustainability of geothermal energy production whilst fostering collaboration across geothermal stakeholder.

The programme supports the generation of high-quality data as well as policy development and promotes innovation through knowledge sharing whilst ensuring solutions are based in scientific evidence and real-world experience The programme is still ongoing and this extended abstract gives an overview of the main results thus far.

All partners within the programme agree that it is important to take steps on these topics for further growth of the Dutch sector. Given the amount of public investment in the programme, all data and reports will be made public after the usual quality checks have been completed. In doing this, the research community can build further on the most recent data and findings. News on the programme can be found on the programme' s website (GEO4ALL, 2025). As a result, research spinoffs have already been established in this way supporting the acceleration of geothermal development within the Netherlands.

The programme is organized into six work packages, each addressing key research challenges in advancing geothermal energy across locations in the Netherlands (Figure 2). WP1 Medium Deep Geothermal focuses on unlocking the potential of low temperature medium-deep geothermal systems (500–1,500 m) by compiling lessons learned and developing a technical roadmap. WP2 Marginal Reservoirs examines marginal reservoirs through case studies to optimize well concepts for open systems in diverse geological settings and development stages, tackling challenges in reservoir characteristics, well geometries, and technologies to enhance productivity and injectivity. WP3 Closed-loop Systems investigates specifically deep borehole heat exchangers (300–1,500 m), assessing the benefits of increased soil conductivity and thermal gradients via advanced monitoring, while promoting robust business cases and environmental sustainability. WP4 Cold-front and Induced Seismicity addresses cold-front evolution and induced seismicity in sedimentary reservoirs by applying monitoring, measurement, and modeling techniques to reduce uncertainties in productivity lifetime and define operational bounds for injection parameters, seismic hazards, and caprock integrity. WP5 Geothermal Production Data leverages operational data to improve efficiency and extend the lifespan of geothermal installations through better monitoring, standards, and practices aimed at minimizing footprint, energy consumption, inhibitors, and waste. Finally, WP6 Communication and Knowledge Sharing ensures effective communication, knowledge sharing, dissemination of results and to further grow and support the development of the geothermal community within the Netherlands.



Figure 2. Map shows the geographical distribution of the geothermal projects involved in GEO4ALL.

2 METHOD & RESULTS

2.1 Low Temperature Geothermal Energy

The study of Peters et al (2025) summarizes the existing knowledge level of geothermal and hydrocarbon projects in the low-temperature geothermal (LTG) medium-depth domain (500-1,500 m) of potential geothermal reservoirs in the Netherlands using an approach that combines literature review and data analysis by synthesizing geological, petrophysical and operational data from Dutch projects. The research finds that several sedimentary formations have sufficient porosity and permeability for economically viable LTG exploitation, through reservoir quality varies. Directional drilling and optimized well design enhance production, while sustainable heat extraction is achievable for 20-30 years if managed carefully. The study identifies operational challenges such as scaling, corrosion, losses, differential sticking, presence of mobile/active clays and hard stringers. The knowledge gaps have been identified related to the operational questions: safe constraints for rate

and pressure, but also on cost reduction e.g. use of slimmer rigs. LTG is shown to be cost-competitive with other renewables, especially when integrating into district heating, but financial success depends on drilling outcomes, reservoir characteristics and heat demand. The research also highlights the importance of clear permitting, data sharing and financial incentive to accelerate LTG deployment.

2.2 Marginal Reservoirs

Here the GEO4ALL programme applies advanced, open-source optimization frameworks, primarily the EVEREST platform (Hanea, et al, 2025; Fonseca, et al, 2017) to support geothermal field development, particularly in marginal reservoirs where flow rate is limited and project viability is sensitive to well design and field strategy. The approach integrates high-fidelity 3D simulation, dedicated techno-economic analysis and robust optimization algorithms to account for geological, operational and economic uncertainties. The workflow is flexible and customizable, enabling uses to optimize well number, location, trajectory and type (production/injector), while honoring drilling, geomechnical and production constraints. The methodology has been demonstrated so far through case studies such as Zwolle and Koekoekspolder geothermal projects, where multiple well concepts (e.g. deviated, sub-horizontal, and multi-lateral wells) were evaluated using stochastic ensemble modeling and multi-objective optimization. The application of this optimization framework has led to possible significant improvements in the techno-economic performance of geothermal doublet systems e.g. optimization of well locations and trajectories resulted in better-balanced flow rates, delayed cold water breakthrough, and reduced costs. Overall, the results demonstrate that numerical optimization as a tool can give input on the possibilities for enhancing the business case for geothermal projects by enabling site-specific, cost-effective, and technically feasible field development strategies, even in the presence of significant subsurface uncertainty.

2.3 Closed-Loop Systems

Research is ongoing on promoting the use of deeper closed-loop systems (300-1,500 m) by demonstrating how these systems can be optimized for different subsurface conditions and locations. The methodology here centers on monitoring pilots at two sites, with the first plot at a Museum in Vosbergen involving the drilling of two 490 m depth closed-loop boreholes, installation of high-temperature heat pumps and data acquisition. GEO4ALL deployed fiber optic cables for distributed temperature sensing (DTS) and groundwater flow studies. Initial logging has confirmed lithological intervals correspond well with national Dutch subsurface model. Ongoing and future work includes temperature monitoring campaigns, further sample analysis, and development of optimization software to refine system design and management. The second site will be realized in 2026 in a different geographical location to obtain more data.

2.4 Cold Front Evolution

Buijze et al (2025) investigated the geomechnical and thermal effects of long-term geothermal production in a Dutch sandstone reservoir in situ. This was done by acquiring and analyzing an extensive suite of well logs in a new injection well GT-11 at Middenmeer which was located near a former injector that had operated for 10 years and thus cooled the reservoir. The methodology included petrophysical, sonic and temperature logging, as well as resistivity image analysis to characterize lithology, porosity, permeability, elastic properties and fracture networks. Stress test and temperature logging results revealed that cooling of the reservoir was heterogeneous and primarily confined to the lower third of the reservoir. This correlated with more porous facies, while the most porous zones did not always correspond to most cooled zones, likely due to presence of deformation bands and variations in clay content. The study found that such heterogeneity in cooling and geomechanical properties significantly impacts fault reactivation modelling and caprock integrity assessments, highlighting the importance of accounting for reservoir variability in geothermal risk analysis and operational planning.

2.5 Geothermal Production Data

Research is ongoing on how to optimize geothermal plant operations by making better use of production data. The methodology involved defining key performance and reliability indicators (KPIs) for geothermal assets, developing a standardized template for data collection, and gathering operational data from over 15 geothermal sites in the Netherlands. A shared database is being established to store performance and failure data, with the aim of supporting knowledge sharing and benchmarking across the sector in the Netherlands. Preliminary findings show significant variation in uptime and flow rates among wells, highlighting the value of standardized monitoring and data-driven decision-making.

3 DISCUSSION AND CONCLUSIONS

Regarding LTG, this research demonstrates that combining field data, modelling and case studies provides a robust assessment of the technical and economic feasibility of LTG in the Netherlands. The results confirm that sustainable and cost-effective exploitation of LTG is achievable, providing that careful attention is given to site selection, well design and operational management. Furthermore, the research offers practical guidelines and policy recommendations that can support the scaling up of LTG as an integral part of the Dutch energy transition.

The application of advanced, open-source optimization framework such as EVEREST has proven effective in giving options to improve the cost-effectiveness and technical feasibility of geothermal field development, particularly in challenging marginal reservoirs. The case studies like Zwolle and Koekoekspolder demonstrate that numerical optimization of well locations, trajectories and types can significantly enhance techno-economic performance, resulting in increased net present value and more robust well designs. The flexibility of the workflow allows for integration of site-specific geological uncertainties and operational constraints, enabling a bespoke solution for each project and there is no universal solution. However, the optimization approach can give input to substantially strengthen the business case for these marginal reservoirs and support its broader adoption in the industry.

Initial research into borehole heat exchangers show they can be effectively implemented and optimized for various subsurface conditions in the Netherlands, as demonstrated by the Vosbergen pilot site. Results are incoming and more will be known later in the programme when exploring a second pilot site. It is expected that there will be a creation of a knowledge base on these systems and best practices to support a wider adoption of deep closed-loop systems, helping to de-risk investment, inform policy and accelerate the transition to sustainable heating solution across the Netherlands. The data might also be valuable for the design of borehole heat exchangers at a shallower levels.

The results from understanding the cold front of geothermal activities highlight that cooling in geothermal sandstone reservoirs is highly heterogenous, closely related to facies e.g. clay content and geomechnical properties which can significant influence both fluid flow and extent of cooling, meaning porous zones do not always correspond to most cooled areas. These findings have important implications for geomechnical modelling, as they show that uniform assumptions about reservoir properties may mispresent the risk of fault reactivation and caprock integrity. This was emphasizes the need for high-resolution, site-specific monitoring and modeling to improve seismic hazard assessment and operational safety in geothermal projects. Ultimately these insights contribute to more reliable, efficient and scalable geothermal developments.

Work on geothermal production data has established a standardized approach to collecting and analyzing geothermal production data. Key findings reveal significant difference in well performance, uptime and flow rates, emphasizing the need for consistent monitoring and benchmarking. The creation of a shared database and automated data extraction tools enable operators to better understand equipment reliability and optimize operations. This collaborative, data-driven methodology not only supports more proactive maintenance and cost reductions but also fosters knowledge sharing across the sector.

The programme will run until 2028, so more results are to be expected in a later phase. As the necessity to tackle these topics for future growth of the geothermal sector, the acquired data and reports published within this programme are made public after the quality control on the website (GEO4ALL,2025).

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