

Original Article

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Ensuring safe growth of the geothermal energy sector in the Netherlands by proactively addressing risks and hazards

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Abstract

The main objective of this paper is to give an overview of the risks seen in the exploration and production of geothermal energy from the viewpoint of the regulator. The risks are categorised as conventional risks, ultra-deep risks and enhancing factors. These risks are similar to those seen in the oil and gas industry, but the maturity of the geothermal sector in terms of managing such risks is much lower.

Another objective of this paper is to discuss how these risks are managed and mitigated by the sector and the supervisor, State Supervision of Mines (SodM). Portfolio operators developing multiple projects, using skilled employees and embracing continuous improvement are seen as the way forward for the sector to grow safely and sustainably.

This paper concludes that positive developments have started, but a lot of work still needs to be done to ensure safe growth of the geothermal energy sector.

Introduction

The use of geothermal energy is predicted to increase significantly in response to the proposed Dutch Climate Act. This Act lists the measures needed to achieve a reduction of CO₂ emissions by at least 49% in 2030 relative to 1990. For the geothermal sector a tenfold increase in activity is expected within the next 12 years. Recently the ambition document 'Masterplan Aardwarmte Nederland' was published by DAGO (Dutch Association of Geothermal Operators), Stichting Platform Geothermie, Stichting Warmtenetwerk and Energie Beheer Nederland B.V. (EBN) and supported by the Ministry of Economic Affairs and Climate Policy and the Ministry of Internal Affairs (DAGO et al., 2018). EBN is an independent company owned by the Dutch state as its sole shareholder. It implements the energy policy of the Ministry of Economic Affairs and Climate Policy for the oil and gas sector and now also for the geothermal sector. In this document, the number of geothermal doublets in operation is predicted to be 175 in 2030 and 700 in 2050. Employment in this sector is expected to increase from 240 full-time equivalent (fte) in 2018 to 3400 fte in 2050. Additionally, the Green Deal Ultra-Deep Geothermal Energy (UDG) (www.greendeals.nl/green-deals/ultradiepe-geothermie) has been signed between the industry, knowledge institutions and the government. The purpose of this Green Deal UDG is to stimulate the exploration and development of ultra-deep geothermal projects. All the above activities focus on increasing the total output of geothermal energy in the Netherlands.

State Supervision of Mines (SodM) is the regulator overseeing the operator's safety performance and care for the environment. SodM is neutral about predicted growth as long as it is managed in a safe, professional and responsible manner. In this article, the steps needed to mitigate risks and hazards related to the predicted growth are identified and addressed from the perspective of the regulator to ensure that safety of people and safety of the environment are not compromised.

The geothermal sector, accompanying laws, regulation and supervision

Geothermal project types

To produce geothermal energy, wells are drilled into the subsurface to depths ranging from 500 m to over 7000 m. In the Netherlands, geothermal projects for which wells are drilled to a depth of 500 to 4000 m are classed as *conventional* geothermal wells. Projects with wells deeper than 4000 m are classed as *ultra-deep* geothermal wells (UDG wells). Both groups of wells and the surface geothermal installations are supervised by SodM. Shallower wells drilled to depths less than 500 m, which are used for low-temperature heating purposes, are supervised by the provinces. To date, small-scale developments of around 23 geothermal doublets and triplets have

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been realised consisting of wells drilled up to 2800 m depth. The majority of these projects have been executed by horticulturists to heat their greenhouses.

Geothermal permits and consents

In the Netherlands, geothermal operators must comply with the same set of laws as other mining companies: the Dutch Mining Act. SodM is appointed as the regulator responsible for supervising geothermal activities which are classed as mining activities under the Dutch Mining Act (including the Mining Decree and the Mining Regulation). When a geothermal operator wants to develop a geothermal project, various permits and consents are required. A summary of the most important ones is given in the following paragraphs.

The first one is the exploration permit (*opsporingsvergunning*) issued by the Ministry of Economic Affairs and Climate Policy. The permit provides the operator with exclusive rights to explore for geothermal reservoirs in the licensed area. It covers the time frame from exploration (finding) of the reservoirs to drilling of the exploration wells. Typically, these exploration wells are subsequently also used as production wells. The permit sets out the framework and conditions for the geothermal project, the organization, perceived risks and mitigations.

To continue the process by drilling geothermal wells and building a geothermal installation, a location permit (*omgevingsvergunning*) is required. Then, if geothermal wells have been drilled successfully and a surface installation has been built, a production permit (*winningsvergunning*) is needed to produce heat. In addition, approval from the ministry is required for the production plan (*winningsplan*).

The various permits provide the framework within which geothermal heat can safely be produced with minimal damage to the environment.

During the various stages of the project, the Dutch Mining Act requires operators to meet a number of monitoring and reporting conditions concerning the geothermal site and wells. In addition to these, additional conditions with respect to monitoring, reporting, research and/or risk mitigation measures can be imposed per permit.

SodM roles and responsibilities

As the regulator, SodM supervises the activities of the geothermal operators under the permits as described above and relevant Acts and regulations such as the Working Conditions Act and the Environmental Act. If the operations do not follow the law and/or permit conditions, SodM has the authority to intervene and enforce compliance by imposing punitive measures, from fines to the suspension of operations. In addition, SodM provides advice to several governmental bodies, such as the Ministry of Economic Affairs and Climate Policy, on the safety and environmental aspects and to municipalities and provinces in relation to mining operators and their activities.

To perform these roles, multidisciplinary teams are used consisting of engineers and advisers skilled in surface and subsurface processes, the environment and legislation. Various tools are used to identify and classify risks. Through stakeholder contacts with operators of projects, local and federal governments, sector organisations, banks, citizens and the media, SodM gains insight into areas of development and improvement for the industry.

Recently, the 'toezichtarrangement geothermie' has been developed by SodM which details the supervisory topics of SodM

according to the mentioned Acts (SodM, 2019). This document sets out the legal framework and expectations regarding health, safety and environment. With this document SodM wants to ensure that all stakeholders have a common understanding of the (legal) requirements for safe operations from design to production and abandonment. This allows geothermal operators to proactively manage the risks. The supervision framework (*toezichtarrangement*) provides SodM with a basis to supervise and inspect projects to ensure that safety and care for the environment are not compromised.

SodM also initiates research through independent bodies to identify risks and mitigations. The results of this research are incorporated into the regulatory tools and framework that SodM uses or are communicated to the ministry to be incorporated into new policy.

Analyses and results

Which risks are identified and anticipated?

In the following subsections, the technical and organisational risks for conventional and UDG wells are given. We only address risks which are of concern to SodM, e.g. risks to employees, civilians and the environment. Project-specific risks to the operator such as underperformance of the system and commercial risks are outside the scope of our inventory. This inventory results from the history of SodM's supervision activities in the field of geothermal energy and anticipates some of the future risks that will be encountered. Factors which potentially increase these risks are also identified. This section concludes with good practices and positive developments in the sector around risk reduction.

Risks related to conventional geothermal projects

To produce conventional geothermal energy through wells up to 4000 m deep, various geological formations are encountered. Some of these formations can contain oil or gas, as geothermal target formations are often the same as for hydrocarbon production. It is therefore not surprising that the technical risks for geothermal exploration are comparable to the risks seen in the oil and gas industry.

The major risks have been identified by SodM and published in the 'Staat van de Sector geothermie' (SodM, 2017). In this document the following key risks (in terms of unwanted events) for the conventional geothermal sector are listed:

- Uncontrolled flow during drilling (e.g. potentially leading to loss of containment and, worse yet, blowout)
- Environmental damage
- Personal injuries
- Groundwater contamination
- Induced earthquakes

Ensuring that operators manage these risks at each stage of the work is the principal focus of SodM's supervision of conventional geothermal projects.

Risks related to ultra-deep geothermal projects

The objective of the Green Deal UDG, as mentioned in the Introduction, is to develop UDG projects where temperatures and depths of the target reservoirs are higher than 120°C and deeper than 4000 m. These projects require complex technology, sophisticated engineering and labour skills due to the reservoir conditions and the aggressive nature of geothermal brines at these

depths. In addition to the risks mentioned in the previous sections, the following hazards will have to be dealt with specifically for UDG:

- High temperatures
- High pressures
- Higher chances of induced seismicity
- More naturally occurring radioactivity
- More scaling

In UDG projects abroad, induced seismicity (e.g. Basel, Switzerland), radioactive produced water (e.g. Balmatt, Belgium) and radioactive scaling have been observed. Operators wishing to develop these reservoirs in the Netherlands will have to be able to mitigate these and any other risks. They will have to demonstrate that risks have been reduced to a level as low as reasonably practicable (ALARP). While invariably associated with complexity and cost, these risk mitigations are the basis for safe operations and protection of lives, the environment, assets as well as reputation.

Escalating factors for identified risks

Here we list several factors which increase (escalate) some of the risks mentioned in the previous subsection:

- Lack of appropriate geological data. The availability of geological data (e.g. pressure data, log data and seismic surveys) is important to mitigate the risks of uncontrolled flow and environmental damage. Adequate data is also important in the production phase as fault reactivation and induced seismicity can be prevented if wells are located away from critically stressed faults.
- While the technical risks for oil and gas versus geothermal projects are comparable, the organisational risks are very different. The oil and gas industry in the Netherlands is very mature due to its long history of development since the 1960s. More than 5300 wells have been drilled by multinational oil and gas companies. As a result, a high level of knowledge, skills and organisational structures exists within the sector and its operators. In contrast, the first geothermal project in the Netherlands was only realised in 2007. To date, 23 projects have been developed. Often, operators are horticulturists and not skilled mining professionals. Furthermore, these operators have often executed a single doublet, which means that only limited learning and limited continuous improvement have been achieved due to the lack of a single operator having developed a portfolio of multiple projects.
- Lack of knowledge of and compliance with laws and regulations. Through the various permits, risks identified in a geothermal project are listed, along with mitigation measures to reduce these risks to an acceptable level. Quite often operators proceed from the well-testing phase to the production phase of a geothermal doublet without the required permits and a fully implemented health, safety and environment (HSE) management system (*Veiligheids- en Gezondheidszorgsysteem*). This is generally due to either lack of knowledge of the law or lack of understanding of the importance of these requirements. These documents and permits provide the basis for risk identification and mitigation, approved by the Ministry of Economic Affairs and Climate Policy, and thus provide the framework to produce geothermal heat safely. It is therefore important that

knowledge of and compliance with laws is embedded in the organisation and project plans of each operator.

- Availability of workforce, equipment and materials. In view of the growth of the sector as anticipated in the 'Masterplan Aardwarmte Nederland', with the number of doublets growing to 175 by 2030 and 700 by 2050, a large number of new wells will have to be planned and drilled. This will require a more skilled and experienced workforce who are familiar with the Dutch mining regulations and mining activities. Large numbers of certified drilling rigs and a lot of other equipment will be needed to drill wells and build geothermal plants in order to achieve the projected growth. When many projects are executed concurrently, there may be a shortage of suitable equipment, experienced personnel and contracting staff. The result may be suboptimal choices such as unsuitable rigs, unqualified staff and general shortcuts, leading to a higher exposure to safety and environmental risks.
- Spatial planning and well-site sizing. Because heat is difficult and expensive to transport over large distances, geothermal projects for domestic heating are planned to be developed in or near urban areas close to residential housing. Drilling rigs must drill, work-over and abandon wells in the lifetime of the project and this requires sufficient access to and space on geothermal well-sites. Furthermore, sufficient space needs to be available for auxiliary equipment and materials, to ensure safe working conditions for personnel while avoiding nuisance to the surrounding residents. In one case it has proven difficult to maintain safe access to the site during remedial well activities. SodM is concerned that unsuitable locations too close to residential housing will be used to build geothermal installations, leading to escalation of risks.

Positive developments in risk reduction

The geothermal sector has seen a number of positive developments lately. Most, if not all, operators are members of the branch organisation DAGO. DAGO develops industry standards and shares knowledge and best practice among its members. In addition, the organisation Stichting Platform Geothermie engages with a wider group of consultants, service companies, utility companies and local governments with the purpose of sharing knowledge and promoting safe and sustainable geothermal energy. DAGO and Stichting Platform Geothermie play an important role in the development of a professional geothermal industry.

There are positive and encouraging experiences with operators, several of whom proactively share information, knowledge and experiences. A few operators are jointly applying for exploration licences for geothermal projects. In addition, work is ongoing to implement and improve HSE management systems to manage the geothermal operations safely and efficiently. DAGO is facilitating the development of a Code of Conduct for operators on the subject of stakeholder management, which will be launched at the end of 2019. SodM continues to encourage operators to work safely, acquire additional data before, during and after drilling, use better materials and equipment and execute additional studies.

Above all, SodM welcomes the trend of companies entering the geothermal sector with a portfolio approach, and operators with experience in the oil and gas sector. SodM is confident that the sector will demonstrate its growing maturity by showing even stronger emphasis on health, safety and environment.

Discussion and conclusions

How to manage and mitigate these risks?

The mitigations for the risks mentioned in previous paragraphs are described here.

Mitigation measures related to conventional geothermal projects

Considering the risks mentioned, the most important lever for risk management is sound technical knowledge and experience in developing geothermal projects (wells and surface installations). These skills provide the optimal basis to develop projects safely from the concept stage where well designs are made, right through the execution and production phases. Sound technical knowledge of the drilling process and subsurface risks is key to preventing uncontrolled flow during drilling. Where the operator has a horticultural background, (drilling) contractor selection becomes very important. Learning from other projects will have to be carried over through these contractors to ensure risks are properly managed. Good knowledge and experience is also important to minimise personal injuries during the execution phases. In addition, an important role for EBN and DAGO in this area is to provide compliance assistance to (single) project operators to ensure sound technical knowledge and skills are used in project decision making.

An area where improvements can be made to prevent groundwater contamination and potential hydrocarbon ingress into the wells is in the design stage. Corrosion and well integrity problems have been seen in several doublets. Due to the corrosive nature of geothermal brines, careful consideration must be given to well metallurgy, barrier philosophy and monitoring during the design and production phase. To date, several wells designed to last >30 years have encountered serious problems related to well integrity. Remedial work has taken place on these wells, ranging from installing scab liners and inhibitor injection to re-drilling the entire well.

Because of these issues, SodM will increase the level of supervision in this area to ensure that each operator has an up-to-date well integrity management system. SodM will also develop additional guidelines or regulations for well design for future wells, to ensure that safety and integrity is maintained for the full life cycle of the well. Recently the province of Noord-Brabant, local municipalities, Geothermie Brabant BV, DAGO and Brabant Water have jointly signed a guidance document to ensure groundwater protection is incorporated in geothermal well design. Dual casing strings, proper cementing and monitoring are the most important measures in this document (Provincie Noord Brabant, 2019). Improvement in these areas is an important lever to prevent groundwater contamination and potential hydrocarbon ingress into the wells.

To reduce subsurface uncertainties and risks of induced seismicity, SodM will continue to stress the importance of the value of (geological) data in its interactions with operators and the ministry. SodM advises the minister to exclude seismically active areas from geothermal development or to suggest conditions for safe geothermal exploration and production. It is encouraging to note that EBN is embarking on a large seismic campaign to provide more geological data that is publicly available. With this data, risks can be reduced with the goal of safely drilling and developing geothermal projects. In the meantime, SodM will take a highly precautionary approach in areas with insufficient geological data.

Finally, SodM demands full compliance with all laws and regulations from operators and will continue to enforce these to

improve all stages of the project life cycle in the context of current and newly planned geothermal wells and installations. Operators who continue to produce geothermal heat without the required permits and consents will face enforcement actions from SodM.

Mitigation measures related to ultra-deep geothermal projects

A few companies are planning to develop projects for UDG heat. Little is known about the subsurface at these depths (>4000 m). Reservoir properties like permeability, pressure, connectivity and structure (faults) are uncertain. Gathering adequate geological data in these projects becomes even more important to proactively manage the subsurface risks and uncertainties.

Appropriate risk mitigation and experienced personnel will have to be in place to ensure these projects are executed safely with minimal damage to the environment. SodM will require that knowledge of high pressure and temperature (HPHT) is used for project planning and execution. Also, geomechanical and radiation experts may be required for UDG projects.

In addition, SodM has initiated a study to investigate the risks and mitigation measures linked to the development of UDG projects. This study is supervised and executed under the KEM panel (Kennisprogramma Effecten Mijnbouw). The KEM panel executes independent research to address risks related to mining issues (KEM, 2017). SodM will use the results of this UDG study to optimise its supervision of these projects and expects that each operator is fully aware of the risks and mitigation measures when developing UDG projects.

Mitigation measures related to escalating factors

The combination of lack of expertise, experience and subsurface data and limited learning opportunities makes it difficult for single doublet operators to improve their performance and safety. While such operators are pioneers and have been instrumental in the development of the first geothermal doublets, a change will be required to make the geothermal industry a sustainable and safe business for the coming decades. This change may lead to consolidation of the industry along segments of the value chain. From a regulatory HSE point of view, a concentration of know-how and 'how-to' is an attractive way to enable a maturing industry. One may argue that the subsurface component of a larger number of geothermal projects will be developed by large entities or geothermal operators who specialise in exploration and production of geothermal energy.

In any event, it is important that companies work with specialists capable of learning and innovating from one project to the next. In addition, a multi-year programmatic approach can be taken by companies in terms of resources (long-term contracts for rigs, equipment and materials) and personnel (focusing on technical skills development and knowledge of laws and policies). If this approach is taken, it is expected that geothermal wells and installation design can be further optimised, produced and maintained for the life of the project, leading to fewer operational risks, maintenance and downtime.

Meanwhile the heat produced can be marketed as a commodity by these companies. Recently, larger companies intending to develop multiple doublets have applied for geothermal exploration licences. It is too early to see any portfolio benefits yet, but SodM anticipates that this way forward is beneficial towards the ultimate goal of SodM: to have geothermal projects executed in a safe and responsible manner.

A factor mentioned in the previous section relates to skilled workforce and equipment availability. With the projected increase

in geothermal activities, more resources will be required. Careful planning and a multi-project approach will be required to ensure that no concessions are made in terms of competences and quality in these areas.

Therefore SodM has drawn up minimal competence criteria for key project roles in geothermal projects as part of the supervisory framework. By ensuring that these minimum standards are met, the risk of employing unskilled workers should be mitigated upfront. SodM will also increase the level of inspections in projects deemed to have a higher exposure to risk. Finally, EBN is expected to play an important role in ensuring that high project quality and safety standards are being met.

On the subject of spatial planning, the anticipated growth of the geothermal industry will lead to large numbers of projects and, in particular, wells that will need to be drilled and operated in urban and residential areas. Operating a geothermal project is an industrial process. Consequently, care will have to be taken when it comes to planning new geothermal sites. Designated industrial estates/zoning should be preferred to land zoned for residential use. In addition, local governments, members of the public and neighbours of a geothermal site will have to be informed about the project and all the risks as soon as possible, to ensure complete transparency. Extra measures will have to be taken in the design of a project to ensure nuisance is kept to a minimum and acceptable level.

As already mentioned in this article, DAGO and Stichting Platform Geothermie play an important role in the anticipated growth of the geothermal sector in the Netherlands. These organisations are instrumental for safe growth and further developments in the sector. SodM encourages learning and sharing of knowledge and standards across the organisations and amongst its members.

Conclusions

Geothermal energy has demonstrated to be a proven energy source developed with appropriate technology to deliver heat from the subsurface. Positive developments are visible, although current installations in operation leave room for improvement. It is envisioned that portfolio operators developing multiple projects, using skilled employees and embracing continuous improvement are the

way forward to ensure that the sector can grow safely and sustainably. By incorporating learning into future projects together with full life-cycle design and planning, well and plant design can be improved, ultimately leading to fewer incidents and regulatory issues. In addition, good spatial planning will ensure that operations fit within the built and natural environment whilst minimising nuisance. SodM is also developing guidelines for well design to ensure that safety and integrity is maintained for the full life cycle of the well.

When it comes to developing UDG projects, current risks seen in conventional geothermal projects are likely to be more pronounced. The first few projects will have a highly exploratory character, and operators will have to be able to cope with these uncertainties and risks both technically and financially to achieve a safe and successful project. SodM will intensify the supervision for these projects to ensure risks are properly managed and mitigated.

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