Impact of the Dutch geothermal innovation roadmap

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ABSTRACT

The potential and upscaling of the use of geothermal energy in the Dutch energy transition is highly dependent on technical innovation strategies. As the geothermal energy sector is a developing one, identifying and connecting both the short-term and the long-term innovation needs remains a challenge. This study, commissioned by the Dutch Ministry of Economic Affairs and Climate Policy (EZK) and Energie Beheer Nederland (EBN) in 2018, identifies 22 technical innovation needs, their impact, and when and how these should be addressed.

The result is an innovation roadmap that provides an overview and plan of action of the necessary technical innovations in the (near) future to enhance the success of the geothermal energy sector in the Netherlands. The roadmap categorises innovation needs in three categories: exploration & realisation, production, and demand & system integration. Our findings indicate that some innovation trends are being picked up by the sector, such as improving drilling techniques and drilling materials. Other trends are not being pursued by the sector. These include geothermal district heating demonstration projects or sector wide innovations, such as subsurface spatial planning and reservoir management.

As an independent, international, engineering & project-management consultancy firm, we were able to provide a broad and relevant insight into the development of geothermal energy in the Netherlands. Our innovation roadmap has been valuable to several market players. Energie Beheer Nederland (EBN) and the Dutch Ministry of Economic Affairs and Climate Policy (EZK) have used this study as input for the "Masterplan Geothermal Energy in the Netherlands", hereby presenting the Dutch national geothermal energy strategy.

This year (2019), one year after the completion of the study, we looked at the impact of the roadmap on the decision-making process of the stakeholders. Through interviews with key players in the geothermal sector we have evaluated the progress of innovation in the geothermal sector since last year. Not only did we evaluate the status of ongoing innovations and research, but we also reviewed whether the innovation needs are fulfilled and whether previously identified gaps in innovation in the Netherlands have been addressed.

1. INTRODUCTION

1.1 Context

With the Paris Agreement widely accepted, the 195 UNFCCC members (United Nation Framework Convention on Climate Change) agreed to undertake ambitious efforts to combat climate change and to strengthen the global response to the threat of climate change by keeping the global temperature rise during this century well below 2°C (UNFCCC, 2017). As a result, the Netherlands has set its aim to reduce its anthropogenic CO_2 emissions significantly; by half in 2030 and close to zero in 2050. This ambition is stated in the Energy Agenda of March 2017 (EZK, 2017) and communicated to all major industries and governmental bodies in the Netherlands. To reach these ambitious goals, it will be necessary to transition away from traditional fossil fuels towards renewable and low- or zero-carbon energy sources. These include solar, water and wind energy, hydrogen fuel, and last but not least geothermal energy.

Geothermal energy is a relatively attractive option in the Netherlands, with the potential to be implemented on a large scale in the built environment. The concept of geothermal energy entails the production and injection of large volumes of water into subsurface reservoir rock to use the produced heat for heating purposes on the surface.

1.2 Future vision

Currently, the share of geothermal energy to the Dutch energy supply is fairly limited as it is a relatively small and young sector. The majority of the active geothermal energy plants has been operational in the horticultural sector. However, these days a shift from the horticultural sector towards the built environment housing and the industry as end-users is being observed (no projects however). For geothermal energy to be adopted as a major contributor to the Dutch energy supply and to play an important role in the energy transition, hence to enable upscaling, the sector has to develop and mature. As such, the potential for upscaling the Dutch geothermal energy sector is highly dependent on technical innovation strategies. As the sector is a developing one, identifying and connecting both the short-term as well as the long-term innovation needs remains a challenge.

In a study, commissioned by the Dutch Ministry of Economic Affairs and Climate Policy (EZK) and Energie Beheer Nederland (EBN - Dutch Energy Administration) in 2018, we identified technical innovation needs, their impact, and when and how these should be addressed. The result is an innovation roadmap that provides an overview and plan of action of the necessary technical innovations expected in the (near) future to enhance the success of the Dutch geothermal energy sector.

Our findings furthermore indicated that some innovation trends are being picked up by the sector, such as improving drilling techniques and drilling materials. Other trends might need government support by funding, such as geothermal district heating demonstration, or might benefit from government ownership, such as subsurface spatial planning and reservoir management. Mid 2018, SPG (Stichting Platform Geothermie), DAGO (Dutch Association Geothermal Operators), WNW (Stichting Warmtenetwerk) and EBN presented a geothermal energy strategy, "Masterplan Geothermal Energy in the Netherlands", describing what is needed according to the sector to achieve 200 PJ geothermal heating in 2050. The innovation chapter in this report was mainly based on the innovation roadmap.

1.3 Aim

In this paper, we present the impact of the innovation roadmap on the decision-making process of the stakeholders, one year after completion of the study. Through interviews with EBN, TNO (Toegepast Natuurwetenschappelijk Onderzoek-instituut – Dutch research institute) and Huisman (drilling company and operator), we evaluate the progress of innovation in the geothermal sector since last year. In addition, we review whether the innovation needs are being fulfilled and whether previously identified gaps in innovation in the Netherlands are being addressed.

2. APPROACH

Prior to this paper we identified 22 innovation needs, their impact, and when and how these should be addressed through interviews with fifteen key players in the geothermal energy sector. We asked them to share their view on the geothermal energy sector, future vision and the essential needs and conditions for the sector to grow and mature. The result provided a broad and relevant insight into the development of geothermal energy in the Netherlands. As the results of this prior study are the starting point of this paper, we will start by listing the innovation needs and their impacts (Table 1).

We will then continue with presenting the results of follow-up interviews held with EBN, TNO and Huisman to evaluate the progress of innovation in the geothermal sector since last year. Based on these interviews we will present the status of ongoing innovations and research and review whether the innovation needs are being fulfilled. Previously identified gaps in innovation in the Netherlands are once again reviewed to see if they are being addressed. We will focus on four innovation trends that should have started prior to or from 2018 onwards.

3. ROADMAP RESULTS

The identified innovation needs are aimed at creating sustainable geothermal energy systems that will produce safe and economically sustainable energy. In order for the geothermal sector to scale up it has to meet three conditions:

1. Safe and responsible – the production of geothermal energy may never impact the safety of the environment;
2. Increasing application possibilities – diversification of types of geothermal energy and its consumers must be investigated;
3. Reduction of costs – scaling up must be accompanied by cost-efficient technologies and more sustainable materials.

To meet the three conditions the sector needs innovation. Mapping these innovation needs has been done through interviews with fifteen key players in the Dutch geothermal sectors. The innovation needs were then categorised into three categories:

- Exploration & realisation: these innovations relate to the activities starting at geologic research to well testing;
- Production: operational innovations needed to improve production;
- Demand & system integration: innovation relating to the route of heat from well to customer.

3.1 Exploration and realisation innovations

After the first operational geothermal energy projects in the Netherlands, the sector learnt that the subsurface reservoir conditions specific to the Netherlands, namely low temperature and high salinities, differ significantly from other countries. Many of the innovations in the category "exploration and realisation" are therefore aimed at improving the technology and materials used to drill and realize geothermal wells (E1-E5, Table 1). These innovations lead to increased heat production and more cost-efficient geothermal systems:

Table 1: Overview technical and social innovation needs.

Exploration and implementation	Production	Demand and system integration
E1: Improve ESP and apply alternative production methods	P1: Improve water-injection	D1: Combine natural gas and geothermal energy systems
E2: Improve drilling techniques	P2: Extent the lifecycle of a well	D2: Demonstrate low-temperature delivery
E3: Improve reservoir stimulation	P3: Cost-effective abandoning	D3: Optimize usage of produced energy
E4: Develop more sustainable equipment	P4: Prevent induced seismicity	D4: Apply smart heat networks
E5: Design fit-for-purpose wells	P5: Improve reservoir management	D5: Apply storage concepts
E6: Develop deep seismic data acquisition for application in the built environment		D6: Apply hybrid networks
E7: Re-use of existing infrastructure		D7: Demonstrate high temperature delivery
E8: Effective use of the subsurface		D8: Develop system integration between different types of energy
		D9: Developing CO_2-storage and geothermal energy systems

- *E1: Improve ESP and apply alternative production methods*
  Improving the lifespan and reliability of Electrical Submersible Pump (ESP) and applying alternative production methods, such as gas lift and surface pumps. The Dutch geothermal energy sector does not yet have the scale for companies to be interested in the development of these technologies.
- *E2: Improve drillings techniques*
  Using other drilling techniques and drilling processes to lower the construction costs of a well.
- *E3: Improve reservoir stimulation*
  Implementing existing stimulation techniques from the oil and gas sector and testing new techniques to enhance the effect of reservoir stimulation.
- *E4: Develop more sustainable equipment*
  Developing new materials and using the most suitable equipment for the well and aboveground installations to lower operational costs.
- *E5: Design fit-for-purpose wells*
  Further development and application of alternative well designs for different geological formations. Adjusting the well design to safety risk and enhancing the lifetime of a well by choosing more durable materials.

Whereas E1-E5 focus on improving the functioning of geothermal wells, E6-E8 relate to regional or sector wide innovation:

- *E6: Develop deep seismic data acquisition for application in the built environment*
  Developing data acquisition techniques that are suitable to gather deep seismic data in the built environment.
- *E7: Re-use of existing infrastructure*
  Cost reduction by re-using existing infrastructure, including from the oil and gas sector, for the production or transport of geothermal energy.
- *E8: Effective use of the subsurface*
  Further development of spatial planning in the subsurface to be able to produce geothermal energy as efficiently as possible.

3.2 Production

After realization, the operational geothermal projects in the Netherlands have encountered many challenges mostly related to production, water injection, and failing well components. As a result, maintenance and repair was more frequent than expected leading to decreased heat production. Related to these problems. we identified the following innovation needs:

- *P1: Improve water injection*
  Preventing the injection capacity from declining during the operational phase. Preventing and monitoring the migration of

injection water to other (water bearing) layers.

- *P2: Extend the lifecycle of a well*
  Preventing processes such as corrosion and scaling that can lead to a lower heat production of the well.

Moreover, we found that innovation is needed for topics that are not (yet) relevant for single projects but are important for the increase of the production of geothermal energy in the Dutch geothermal sector in general. These topics concern decommissioning, induced seismicity, and reservoir management:

- *P3: Cost-effective abandoning*
  Reducing costs by including measures for well abandonment in the well design, taking into account the specific geological conditions. The *Nextstep* program from the oil and gas industry can serve as an example for large-scale and cost-effective abandonment.
- *P4: Induced seismicity*
  Increase insight into the development and mitigation of induced seismicity, in particular the effects of water injection on seismicity. Studying the interaction between geothermal energy and existing mining activities, such as gas extraction.
- *P5: Improve reservoir management*
  Development and application of an integrated management approach for geological formations in the Netherlands. Applying the knowledge and experience from the oil and gas sector to the geothermal energy sector.

3.3 Heat demand and system integration

Other innovation needs are aimed at developing the use of and extending a heat network from the horticultural sector to the built environment (district heating) and industry. Additionally, once the application of geothermal heat is widespread, it will require dedicated forward planning to optimize subsurface usage and prevent unwanted production interference.

Applying geothermal energy in district heating networks will be one of the biggest innovation challenges with respect to matching the heat demand with subsurface potential. The first step is the integration of geothermal wells with existing high temperature heat networks in cities. Next, is the implementation of demonstration projects (new networks) of hybrid systems fueled with a fossil fuel energy source (gas, residual heat of power plants and/or waste treatment plant), and eventually sustainable energy sources (bio-mass, green gas and geothermal energy). Demonstration of success is then followed by optimization by means of heat storage to meet demand and supply and smart networks. This is to optimize heat usage and to increase the usage potential.

We see that innovations are necessary for connecting geothermal heat to the built environment and the industry. These innovations relate to the suitability of district heating networks in incorporating geothermal heat by using multiple heat sources, smart usage of heat, and heat storage:

- *D3: Optimize usage of produced energy*
  Development of an example project that makes maximal use of the produced heat by linking different users to each other (cascading).
- *D4: Apply smart heat networks*
  Development and testing of heating networks where supply and demand are closely aligned. Better prediction of the heat demand so that additional techniques, e.g. heat pumps, can cover the peak heat demand.
- *D5: Apply storage concepts*
  Further development and demonstration of underground heat storage, such as high temperature storage (HTS), or aboveground and shallow heat storage.
- *D6: Apply hybrid networks*
  Demonstrating geothermal energy and other heat sources (e.g. biomass, residual heat) linked to one heating network. Establishing a combination of heat production and heat storage in the subsurface.

Furthermore, using other forms of geothermal energy, for example shallow geothermal and ultra-deep geothermal, can increase the application of geothermal heat:

- *D2: Demonstrate low-temperature delivery*
  Enhancing the application of geothermal energy by developing and demonstrating low-temperature geothermal energy projects shallower than 1,500m.
- *D7: Demonstrate high temperature delivery*
  Enhancing the application of geothermal energy by supplying high temperature heat produced by ultra-deep geothermal wells to the industry.

Finally, matching the subsurface potential to heat demand could be improved by synergy with other types of energy such as hydrogen, carbon capture and storage (CCS), or natural gas production:

- *D1: Combine natural gas and geothermal energy systems*
  Developing double business cases for natural gas extraction and geothermal energy to achieve combined and cost-effective exploration and exploitation of wells and locations.

- *D8: Develop system integration between different types of energy*
  Developing systems that use the produced (residual) geothermal energy for the generation of other forms of energy such as hydrogen. Integrating systems that use excess electricity to re-heat buffers and geothermal storages (power-to-heat).
- *D9: Developing CO2-storage and geothermal energy systems*
  Store CO_2 in a geological formation that is also used for the production of geothermal energy by adding CO_2 to the injection water.

3.4 Impact and technical feasibility of innovation needs

All 22 innovation needs will help to accelerate the growth of the geothermal sector in the Netherlands. However, it is difficult and inefficient to develop all these needs at the same time. Therefore, to prioritize innovations needs, we created a matrix that visualizes the level of technical feasibility versus the impact of a specific innovation need (Figure 1).

The impact of an innovation need is determined by its contribution to the three conditions for upscaling during two workshops with experts:

- Safe and responsible;
- Increasing application possibilities;
- Reduction of costs.

The technical feasibility of an innovation need is determined by its Technology Readiness Level (TRL) and its complexity for the sector to develop the innovation. In the matrix, the innovation needs are divided in four quadrants, A to D:

- Quadrant A:
  The needs for innovation in this quadrant have a high technical feasibility and will have a high impact once completed. They could contribute greatly to the improvement of the Dutch geothermal energy sector. The innovations are often at a fairly high TRL level, implicating that the road to implication in the sector is relatively short.
- Quadrant B:
  Innovations listed in this quadrant have a high technical feasibility, but a somewhat lower potential in resulting in a major impact on the Dutch geothermal energy sector.
- Quadrant C:
  This quadrant shows the innovations with a high impact, but a low technical feasibility. These innovations could have a considerable impact on the improvement of the Dutch geothermal energy sector but are more difficult to develop because they often require an integral approach with multiple players and risks.
- Quadrant D:
  Innovations with a somewhat lower technical feasibility and lower impact are listed in this quadrant. These innovations will contribute to the improvement of the geothermal sector but should not be given priority over the innovations in the other quadrants.

As shown in the matrix, innovations in the A quadrant will have the highest technical feasibility and impact on the Dutch geothermal sector. Developing these innovations will improve the geothermal sector significantly. Therefore, we decided to focus mainly on this quadrant and evaluate the progress of these innovations in this study.

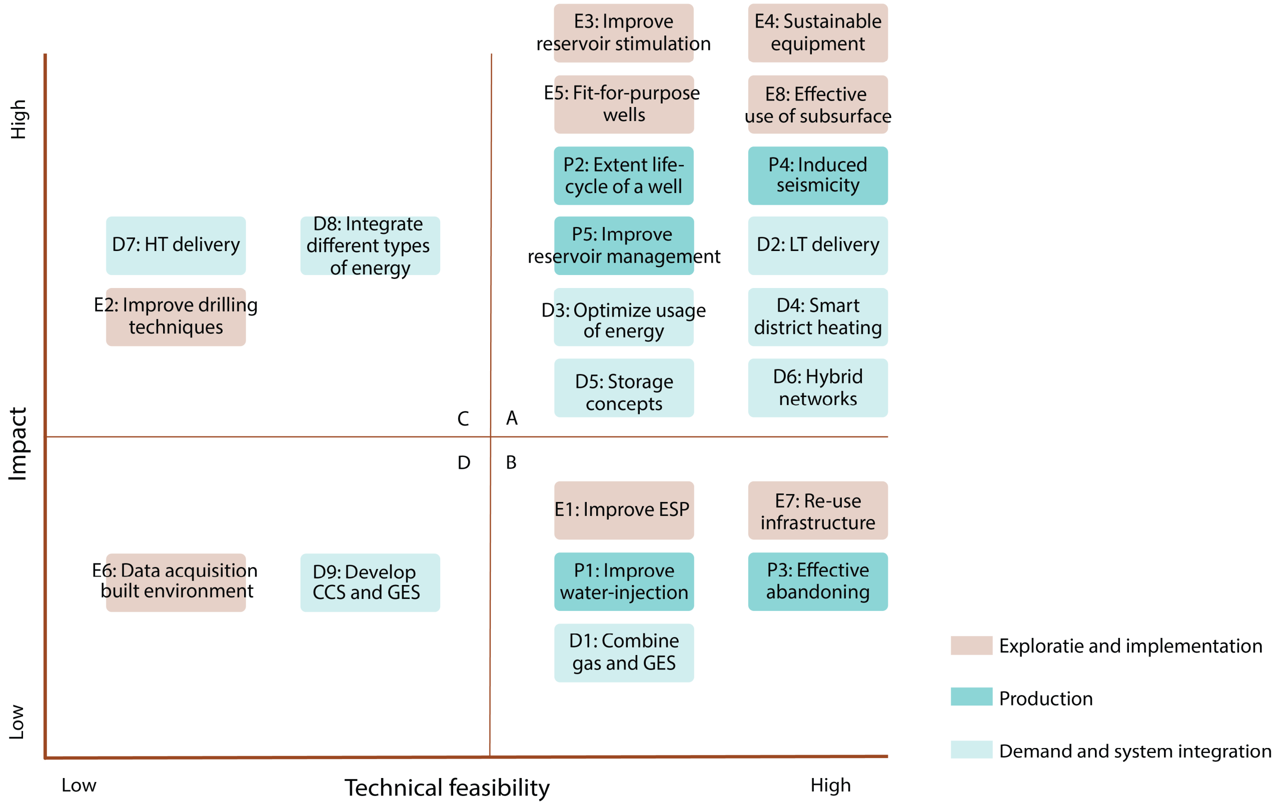

Figure 1: Impact and technical feasibility innovation needs (EBN, 2018a)

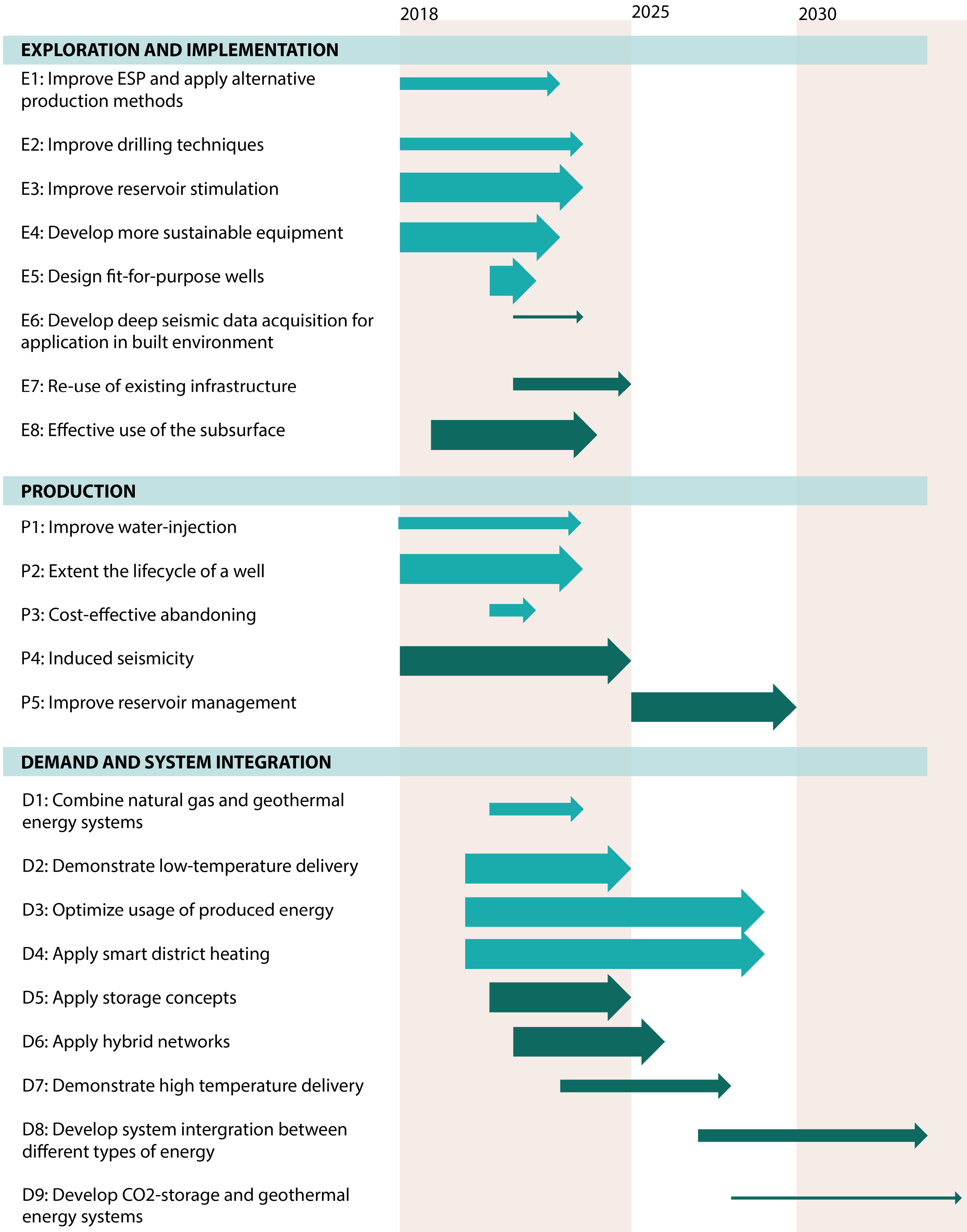

Figure 2: Innovation roadmap (EBN, 2018a)

3.5 The innovation road to scaling up

To determine whether the sector has made progress in the first year since publication of the innovation roadmap, it is important to gain insight in when an innovation could and should start its development. Figure 2 shows the innovations and visualizes when they should be developed.

The thickness of the arrows indicates the impact and technical feasibility of the innovations and relates to the quadrants in which they are placed.

Based on this figure we can summarize the road to scaling up for the geothermal sector in the Netherlands by describing four trends that should develop from 2018 onwards:

1. Innovation in drilling techniques and the materials used to prolong the lifespan of geothermal wells (E2, E4, P2). These innovations are essential in professionalizing the geothermal sector. Most of this type of innovation research is currently ongoing. The research questions typically originate from the sector itself and are funded by both government and sector. We expect this trend to continue in the near future.
2. Sector wide developments promoting efficient and safe production of geothermal energy (E3, P4, D5). Innovations in reservoir stimulation, induced seismicity, and storage concepts need research based demonstration projects to prove their potential. These projects are typically government funded and conducted by knowledge institutes in collaboration with the sector. We expect multiple demonstration projects to start on the short-term.
3. Matching and optimizing the subsurface potential to the consumers. Innovations in reservoir management and effective use of the subsurface are necessary (E8, P5). These innovations are more organisational than technical-oriented. To realize an effective subsurface spatial planning the government will need to take the lead soon, since we already see different operators exploiting the same reservoir leading to an inefficient use of *plays*.
4. Last but not least, we see that innovations are essential in getting geothermal heat to the built environment (D2, D3, D4). In order to realize large-scale geothermal district heating, demonstration projects are essential in gaining insight into the business cases of these types of projects. However, in the history of geothermal energy in the Netherlands it has mainly been the sector in collaboration with municipalities trying to realize geothermal projects in cities that have not been successful yet. To kick-start this trend, the government may need to take part in the first few demonstration projects.

The next chapter will go into last year's developments and discuss the progress made in geothermal innovations relating to these four trends.

4. RESULTS: LAST YEAR'S DEVELOPMENTS

Various technology improvement programs are taken on by Dutch service companies, operators and research institutes. These aim to extend the lifetime and reduce the costs of geothermal systems. The developments due to these programs are partly in line with the trends however, the development in some of the trends are lacking.

4.1 Innovation in drilling techniques and materials

An example of this for the first trend is the in-house innovation program for development of geothermal drilling equipment by Huisman Geo (former Huisman Well Technology). The developed enhanced casing installation (ECI) technology of Huisman Geo was recently tested at a few locations abroad and is planned for use in the LEAN geothermal project in Utrecht. The ECI technology allows for faster drilling and increased well integrity. Another development is the use of composite casings (of former Akiet), which is lower in weight, corrosion free, and allows for smaller rigs. This will be demonstrated in the CAGE project in 2020/2021, combined with other innovations such as a lower cost and high reliability ECI rotary steerable system and mudlogging automation. The development of a specialized small drilling rig for the geothermal sector is a mid-term goal of Huisman Geo (Huisman, 2019).

4.2 Efficient and safe production

In line with the second trend, several transnational GEOTHERMICA innovation projects co-funded by the EU and member states were awarded last year, such as HEATSTORE, CAGE, GeCONNECT and PERFORM. These projects relate to the geological and low enthalpy conditions in the Netherlands. TNO, in collaboration with various partners, plays a key role in these projects (TNO, 2019). An important project is HEATSTORE; the development of thermal energy storage technologies to meet variations in both the availability and demand of energy. The project aims to reduce costs, reduce risks, and optimize the performance of high temperature (between 25°C and 90°C) underground thermal energy storage technologies by demonstrating different configurations of heat sources, heat storage, and heat utilization at six locations (GEOTHERMICA, 2019). In the Netherlands, a heat storage facility of 1.5 to 2 million m^3 (5-10 MW) will be developed in an aquifer at ECW, which already operates various doublets for the horticultural sector in the province of North Holland. The start of construction is planned in June 2019.

The current permitting procedure for mining activities, which also includes the geothermal sector, is under review by EZK. The geothermal sector awaits a permitting process that is better suitable for geothermal energy processes (EBN, 2019).

Subsidies for geothermal energy innovation projects are primarily coordinated by RVO, part of EZK. The LEAN project, focussing on low cost exploration and derisking of geothermal plays in Utrecht, recently started. The reprocessed seismic data for the Utrecht City geothermal project provides information for other cities in the province of Utrecht as well. The geothermal energy potential of the Rotliegend play will be assessed at approximately 2500m. Several doublets are planned to provide heat to the existing ENECO district heating network in the city of Utrecht, allowing the network to switch from fossil heat sources to a renewable heat source. With the installation of the first doublet, the risks for further development of this play will be reduced (Huisman, 2018).

4.3 Matching and optimizing the subsurface

Key research that will help develop the third trend is the study “Opschaling aardwarmte in warmtenetten”, conducted by Berenschot, CE Delft and IF technology and commissioned by EBN and Gasunie. In this study, the application of a play-based portfolio approach in the development of geothermal energy linked to the above-ground heat demand is examined (EBN, 2018c). Additionally, the “Dutch Masterplan Geothermal Energy - a broad base for a sustainable heat source” was published in 2018 (EBN, 2018b). A framework for accelerating the geothermal energy potential in the Netherlands is presented in this plan. Besides the required technological innovations, as provided in the innovation roadmap, other factors such as the required legal framework, safe development and operations, public acceptance, and connection to the heat networks are presented.

4.4 Geothermal energy in the built environment

Demonstration projects with low and medium heat temperature are essential in the short-term in gaining experience with supplying heat to medium and larger district heating networks. The RES (Regional Energy Strategy) programme will be completed in 2021 and many city districts may have selected geothermal energy for heating (Rijksoverheid, VGN, IP, UVW, 2018). The first projects, in which geothermal energy is linked to existing 70 to 90 degrees networks, should be realized in the coming few years. One of the first systems is expected to start in The Hague in 2019, where a partly completed doublet is connected to a small district-heating network. In Utrecht, the first doublet of the LEAN project is expected to be installed in 2020 (TNO, 2019).

Expanding to either lower or higher temperature target zones will be another direction for development. For newly built houses, low temperature water of 30 to 40 degrees from the shallower sandy deposits may be commercially attractive. These formations are potentially present in large parts of the Netherlands and can be developed at lower costs. The ultra-deep geothermal (UDG) program will take more time to develop. The SCAN program for the collection of additional geological information in areas with limited subsurface data availability has recently started with a seismic test line acquired in March 2019. A 2D seismic campaign is planned for mid 2019 in a central part of the Netherlands (Energeia, 2019).

4.5 Centralizing innovation

Last year’s innovation developments described in this chapter indicate the sector is rapidly innovating. Centralizing these innovations, so the sector can use them to scale-up, is mostly done by TNO. TNO plays a key role in the demonstration projects and integrating techniques and materials.

Next to TNO, EBN plays an important role. EBN positions itself to play a key role in initiating, coordinating, and eventually financially participating in Dutch geothermal projects. Confirmation of expanding EBN’s mandate into the geothermal sector is expected in 2019. EZK has asked EBN to set up a single point to collect and determine the market-driven innovation needs as well as to periodically monitor the developments across the various subsidy mechanisms, organisations and Technology Readiness Levels (TRL) (EBN, 2019).

Another development in centralizing innovation is Shell making their former oil and gas subsurface and laboratory test facilities in Rijswijk available for geothermal research. This center will be transformed into the “Open Innovation Center Rijswijk” and will be operated by TNO for an initial period of two years. A test well of approximately 500 meters deep will be available for borehole experiments; material and equipment testing could be centralized to this laboratory (Gemeente Rijswijk, 2018).

5. CONCLUSIONS AND FUTURE STEPS

We observed many technical innovations in exploration, realisation and production that aim to make the geothermal energy production projects safer, cheaper, and more scalable. Moreover, these innovations are already demonstrated by several projects. These developments are promising and indicate that trends as described in the innovation roadmap continue.

However, the development of the heat demand side will be critical as we do not observe similar developments. The organisational, legal and financing aspects of integrated heat production and district heating systems are very complex. Demonstration projects, starting with a few across The Netherlands, are needed to develop a pragmatic project structure with developers, operators, regulators and users, where each party can play its typical role (EBN, 2018b). Social innovation to define new ways of working together and to mobilize the citizens to switch to geothermal energy is essential.

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Table 2: Interviews conducted for innovation roadmap (2018)

Company	Interviewee
HVC	Hans van Gorp
München Erdwerke GMBH	Achim Schubert
DAGO	Martin van der Hout Dio Verbiest
TKI Geo-Energie	René Peters
TNO	Maurice Hanegraaf Thirza van Daalen
TNO-AGE	Harmen Mijnlieff John Zegwaard
TU Delft	Jan Dirk Jansen Phil Vardon David Bruhn
Universiteit Groningen	Rien Herber
RVO	Paul Ramsak
Vewin	Rob Eijsink
NAM	Eilard Hoogerduin-Strating
Huisman	Remco van Ee
Stichting Warmtenetwerk	Jannes van Zanten
WEP	Henny Cornelissen