LEAN: LOW COST EXPLORATION AND DERISKING OF GEOTHERMAL PLAYS IN WHITE SPOT AREAS: THE ROTLIEGEND DEMONSTRATOR

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ABSTRACT

Sedimentary basin areas such as the Netherlands are marked by a wealth of oil and gas exploration data, allowing the development of geothermal energy with high probability for drilling a successful well (>90%) in areas with high data density. However alongside areas with high data density, so-called ‘white-spot areas’ exist, a term given to areas for which limited subsurface information is available. In the white spot areas the risk for unsuccessful wells is significant (>>10%), due to a low density and quality of information from existing wells, combined with the fact that seismic data quality from past oil and gas exploration and production can be relatively poor. LEAN aims to demonstrate three innovations to develop geothermal in such regions in a more cost effective way, at lower financial risk:

1. Significant cost savings of at least 1 M€ on drilling and completion based on innovative Slimhole drilling with open hole completion at 6’ inch diameter.
2. Demonstration of an innovative seismic reprocessing method for existing seismic data and a complementary seismic campaign including a passive seismic acquisition. LEAN’s aim is to demonstrate this step could effectively reduce pre-drill exploration costs by 0.2 M€.
3. Quantitative portfolio approach in which the prognosed NPV of the first project is taking into account the Value of Information (VoI) for the follow-up projects. To this end, the first well is marked by an extensive logging and coring program and DTS/DAS logging to retrieve information for subsequent projects. LEAN aims to demonstrate that the VoI of the 5 follow-up projects contributes significantly to the business case of the first doublet, enhancing its NPV with an order of 1 M€.

LEAN is demonstrated bydeveloping the Rotliegend reservoir in the Utrecht white spot region in the Netherlands, aiming at an increase of the probability of success for geothermal energy projects from a medium success rate (30%-70%) to a high success rate (>90%). The investments are shared among public and private partners to leverage the risk.

1. INTRODUCTION

In February 2018 the Dutch Minister of Economic Affairs and Climate, Eric Wiebes, sent a policy letter (Wiebes, 2018) about geothermal energy to the House of Representatives in the Netherlands. In this letter, it was mentioned that the potential for geothermal energy can grow from the present day 3 PJ, to 110 PJ in 2050, accounting for 14% (10% worst case, 19% best case) of the Dutch total heat demand, depending on the success of geothermal development.

According to the World Energy Council (WEC, 2018) around 225 PJ of geothermal energy was used for direct heat use in 2014, with China (+50%) and Europe (30%) being the largest users. Estimates of the worldwide potential of direct heat use vary from 10 (2.250 PJ) to a 100 times (22.250 PJ) the current production. The World Energy Council mentions as well that *“While estimating geothermal energy potential is difficult, the* *industry consensus is that growth will not be resource constrained over the next half century."*

Geothermal energy exploitation in the Netherlands is a relatively young sector, however it is developing rapidly. In 2017, there were 15 installations producing an average of 0,2 PJ of heat per installation annually. Given the physical limitations of heat transportation, geothermal energy tends to be restricted to local markets. Current installations mostly provide heat to horticultural greenhouses, and the provision of heat to the built environment is currently limited to 2 projects.

The Utrecht Province, located at the center of the Netherlands (Figure 1) and Municipality of Utrecht have strong ambitions for the energy transition, including a potentially important role for geothermal energy. However, the development of geothermal energy has thus far been limited. This is related to the fact that the Utrecht Province is considered a 'white-spot area'(Figure 1), a term given to areas for which limited subsurface information is available. The reason for this lack of information is due to the low density and quality of wells, combined with the fact that seismic data from past oil and gas exploration and production in the Utrecht area is relatively poor compared to other regions in the Netherlands. Consequently, geothermal energy exploration is hampered by high financial risk due to the possibility of drilling an underperforming well, as anticipated flow rates can vary one order of magnitude. This renders the potential contribution of geothermal uncertain, even when including incentives from the SDE+.

ENGIE has taken the initiative for a public-private consortium, consisting of the LEAN partners, to invest in a demonstration geothermal doublet to prove the suitability of the subsurface in the Utrecht region for geothermal energy production. If the project succeeds, a significant potential for follow up geothermal projects could be established. The geothermal doublets will feed their produced heat into a large district heating network owned by LEAN partner Eneco, with ca 38,500 heated buildings. The heat is currently delivered by gas-fired boilers, however these need to be replaced by renewables. In 2018, Eneco published a roadmap for renewable development of the heat network energy sources anticipating that 30MWth renewable power will be produced by geothermal doublets stemming from the success of the LEAN project.

The LEAN project aims at development of the Rotliegend reservoir. Based on existing seismic surveys and geological studies, this appears the most promising reservoir for geothermal development.

2. OBJECTIVES, AND APPROACH

LEAN aims to demonstrate three innovations to develop geothermal in a more cost effective way, at lower financial risk and focused towards accelerating the growth of geothermal energy in white-spot areas such as the Rotliegend in the Utrecht region:

- Significant cost savings of at least 1 M€ on drilling and completion through a combination of techniques:
- Demonstration of an innovative seismic reprocessing method for existing seismic data and a complementary seismic campaign including a passive seismic acquisition using TNO's instruments and processing software, potentially saving costs compared to a conventional seismic campaign for mapping the subsurface. LEAN's aim is to demonstrate this step can effectively reduce pre-drill exploration costs by 0.2 M€, in particular for follow up projects in a regional white-spot area exploration strategy.
- Quantitative portfolio approach in which the prognosed NPV of the first project is taking into account the Value of Information (VoI) for the follow-up projects. To this end, the first slimhole is marked by an extensive logging and coring program and DTS/DAS logging to retrieve information for subsequent projects. Eneco has committed to 5 follow up projects. LEAN aims to demonstrate that the VoI of the 5 follow-up projects contributes significantly to the business case of the first doublet, enhancing its NPV with an order of 1 M€.

The slimhole drilling, combined with open-hole completion and advanced drilling methods developed by HUISMAN, reduces the costs by 25% compared to conventional borehole construction while reducing the capacity with by only a few percentage points, as expected flowrates are relatively low. The slimhole is designed larger than usual slimholes to retrieve as much information as possible from the slimhole for the portfolio of remaining doublets to be developed. The significantly lower drilling and completion costs, enhanced by cost reduction from reprocessing of vintage seismic significantly reduces the financial risk of the geothermal project, resulting in a prospective business case for the Rotliegend reservoir in the Utrecht area.

Through a quantitative portfolio exploration LEAN aims to demonstrate the capability to increase the probability of success for geothermal energy projects in the Utrecht region from a medium success rate (30%-70%) to a high success rate (>90%).

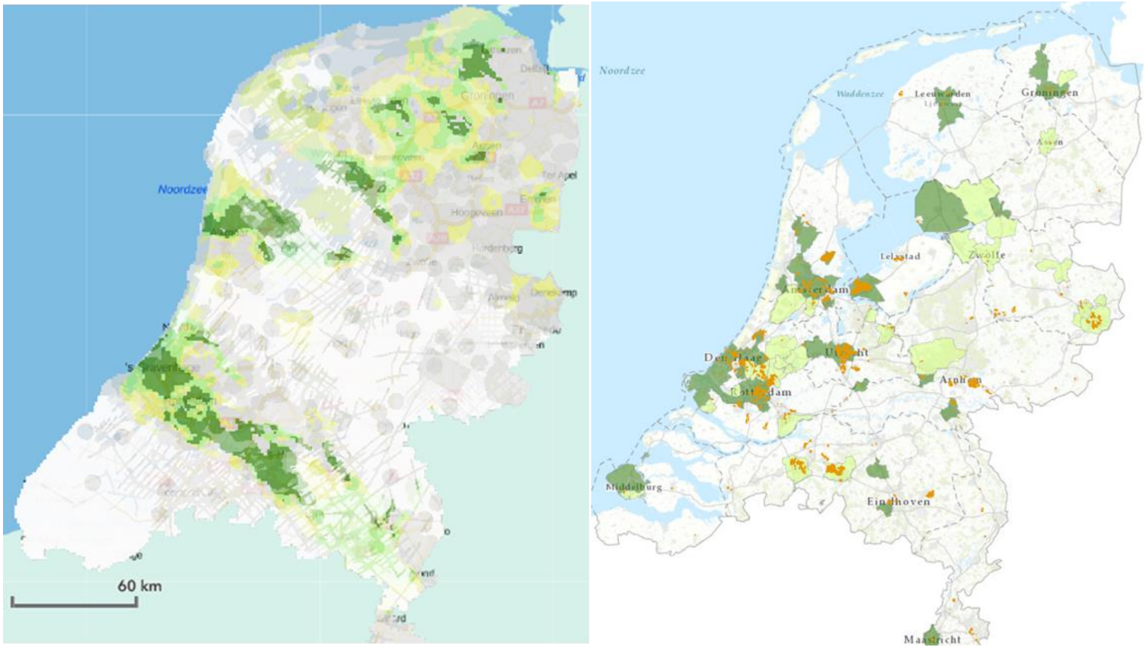

Figure 1: **(left) resource prospectivity (green shades) overlain with transparency for low data density showing white-spot for geothermal development (source thermogis.nl) and (right) existing heat networks (orange) and municipalities with strong ambitions to reduce gasfired heating (source RVO aardgasvrije wijken)**

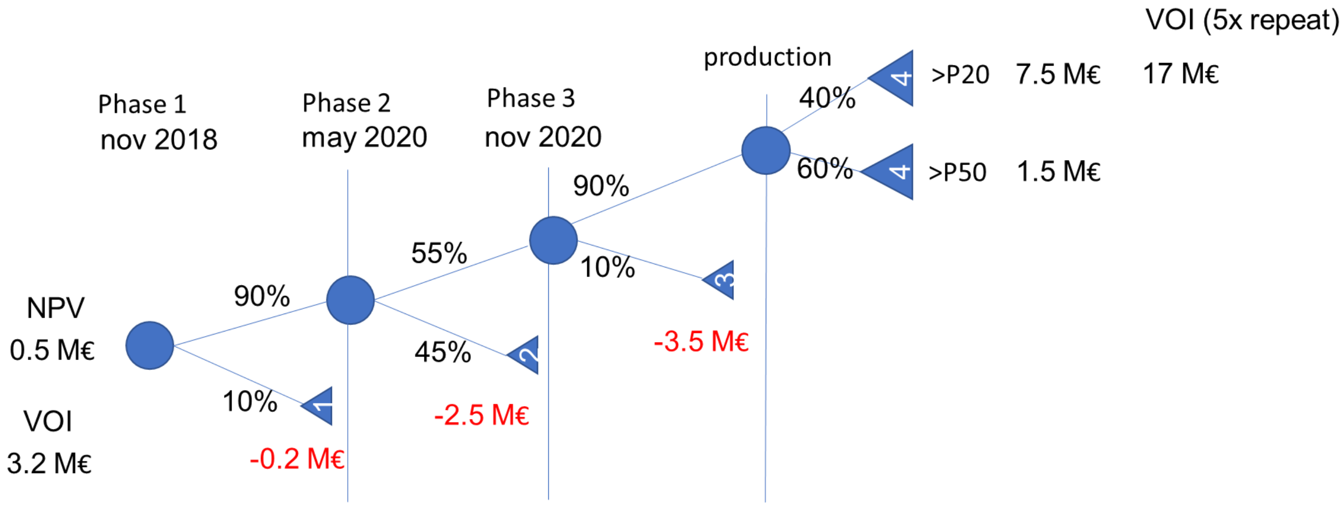

Figure 2: **Generic event tree to evaluate the business case of LEAN (numbers have been modified from the real business case for confidentiality reasons). The performances has been represented by a conservative approach with the P50 and P20 characteristics for revenues. The vertical lines represent three go/no go moments: at the end of the first second phase and third phase of the LEAN project, and corresponding to exit scenarios (1-3). The last go/no go decision corresponds to the evaluation of the performance of the second well if positive (>P50) will result in development of 5 follow up projects with significant NPV (scenario 4), added as Value of Information (VOI) to the business case.**

2.1 Work Breakdown Structure (WBS)

The LEAN project approach conforms to the staged de-risking approach depicted in the event tree in **Fout! Verwijzingsbron niet gevonden.**. It is executed in three steps separated by go/no go decision moments:

- Phase 1: PRE-DRILL EXPLORATION AND VOI
- Phase 2: SLIMHOLE EXPLORATION
- Phase 3: DOUBLET DEMONSTRATION

The go/no go will be influenced by *inter alia*: contracts & permits in place; drilling/seismicity risks mitigated to an acceptable level; acceptable economic risk; acceptable exploration/geological risks; acceptable political risks; the public opinion about the project; and acceptable project timing.

The underlying methods and technologies which will deployed in the project are detailed below

3. PRE-DRILL EXPLORATION AND VOI

In recent years, the Netherlands has experienced a rapid development of geothermal energy, taking advantage of a wealth of knowledge from oil and gas data (Van Wees et al., 2017). Approximately 20 doublets have been developed for direct heat applications in the past decade with low pre-drill risk. In all cases, business development appears to have been project based, in a stand-alone approach in terms of leveraging risk and revenues in an individual asset approach, i.e. the geothermal doublet system. Due to this approach, the development of geothermal energy is clustered in areas where the geothermal reservoir quality has been well proven.

In other areas the same reservoirs may be available, but the risk for a failing well is considered too high (>>10%) to take the investment decision to drill an exploration well. The proposed portfolio approach allows the development of high-risk areas (white-spot areas), by developing multiple prospects in a collective approach targeted at a play evolution from a low (30-70%) to high probability of success (90%). In this approach, the business case is built from the trade-off between the excess financial risk of the first doublet and its Value of Information (VoI) for the successor doublets (Figure 2).

LEAN aims to advance portfolio approaches being developed and applied by large industrial players in the oil and gas sector, and apply this approach in the geothermal energy sector for direct heat development. For the portfolio approach a number of project development and technological innovations are being developed and applied, which are critical to its success:

In the hydrocarbon industry the play-based portfolio approach is used to develop the subsurface and associated surface infrastructure in an optimal way. The portfolio approach implies that multiple prospects are developed in conjunction, in contrast to a stand-alone or one-off approach in which a specific operator limits its development to one or two doublets (Veldkamp et al., 2018). The term play refers to the fact that in a specific region, the subsurface is marked by a certain degree of spatial homogeneity (or correlation) of key reservoir properties such as permeability.

Consequently an exploration well drilled at a particular location has a large learning effect for subsequently drilled wells in the region surrounding the first well, which shares the homogeneity in reservoir properties. Evidently, the risk for failing explorative wells for follow up doublets can be lowered compared to a stand-alone approach if the information of previous projects is used in subsequent projects. This systematically increases the probability of success for follow up projects if information is used in the right way (Figure 3).

This approach results in a safer, faster, more efficient and cheaper development of geothermal potential in the subsurface.

Geothermal play: geothermal potential in a certain region, based on the presence of specific aquifers, with spatially related geological and reservoir properties.

The play-based portfolio-approach discriminates six advantages. The most fundamental concerns the geological aspect of spatial correlation (the play approach). Additional benefits of the play based collective development approach of a portfolio of prospects includes:

1. Improvement of safe and responsible integrated project development
2. Cost reduction through synergy, increased in efficiency and scope for standardized approaches
3. Optimization between subsurface development and surface infrastructure
4. Options for structural programs for R&D and innovation
5. Financing (risk sharing and reduction of costs for financing projects)

The play-based portfolio approach for geothermal energy development is potentially a promising approach which can result in substantial reduction of risks and costs and can lead to higher revenues, and is key to enhancing the upscaling of geothermal energy as a competitive and renewable energy source for the Dutch demand in heating. It can be beneficial for geothermal development in the Netherlands and in the Utrecht region in particular.

In LEAN the benefit of improved financing capabilities for developing white spot areas in the portfolio approach is clearly demonstrated as investments are shared among public and private partners to leverage the risk.

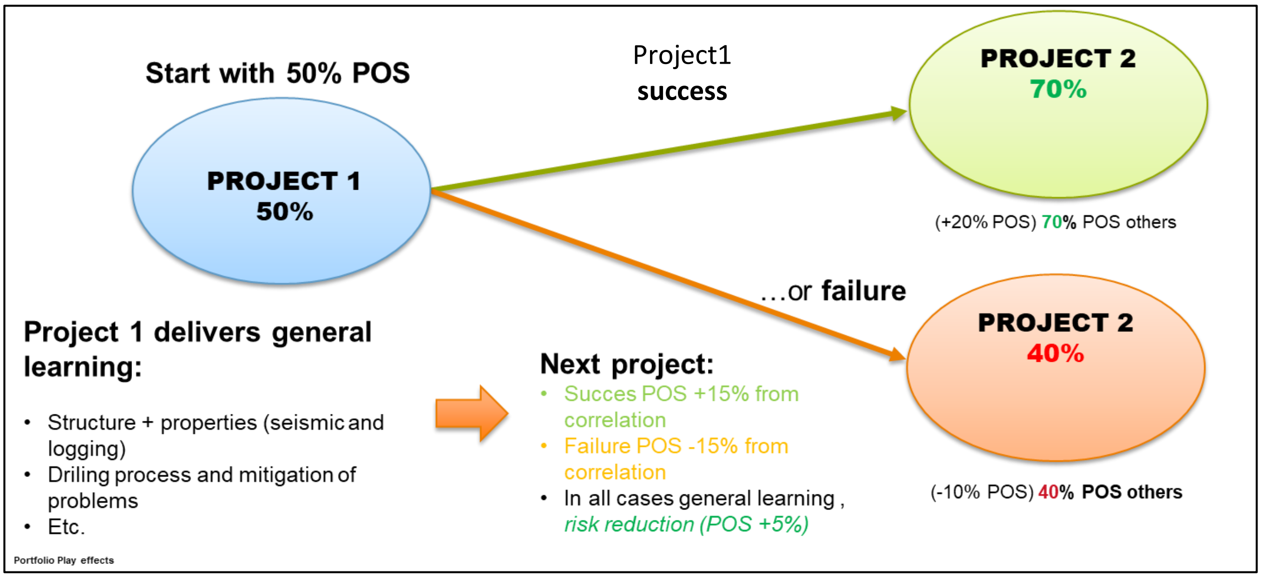

Figure 3: Portfolio learning or derisking of project 1 with initial probability of success of 50% for follow up project 2 in the same region with limited correlation strength of properties in terms of affecting Probability of success by 15%. In addition general learning contributes to a higher probability of success. The actual increase in probability of success for follow-up projects is strongly dependent on geological conditions and the distance to preceding projects. For the Utrecht region LEAN assumes the probability of success can increase to 90% for successor projects in case the first project is marked by success.

3.1 Advanced Exploration techniques

In the white spot area existing geological data will be analysed. In order to improve the estimation of the Rotliegend reservoir depth and thickness, a cost-effective seismic campaign combined with passive seismic using TNO's instruments and processing software, in conjunction with reprocessing and re-interpretation of existing seismic data will be performed, and the properties analysed.

In LEAN, seismic reflection lines will be shot in conjunction with the deployment of novel passive seismic acquisition and processing using TNO's instrument pool and reprocessing methods of vintage seismic data (Carpentier et al., 2016). TNO has developed multiple new innovative reprocessing methods for imaging the subsurface. The main incentive for generating these methods is the need for cost-effective processing and imaging tools that can accelerate and de-risk the realisation of geothermal projects. A development guideline for achieving sufficiently increased exploration cost-effectiveness versus reduced subsurface risk is the 80-20 rule. 80% of the maximum possible state-of-the-art reprocessing quality should be achieved at 20% of the industry standard costs. Should a 99% solution be necessary, it is always available if needed but at 100% of the maximum costs. A workflow was established that includes fast-track conventional reprocessing tools enhanced by fast-computing algorithms that together reprocess both post- and pre-stack seismic data. Included in the workflow are among others pre-stack migration, selective stacking, data (gaps) interpolation, broadband-processing, edge-preserving de-noising, de-multiple processing.

Within the EU FP7 project IMAGE project this workflow with the aforementioned methods has been developed and successfully tested on real data cases. Results have shown significant improvements compared to existing reprocessing workflows that are available in the market today.

Faster reprocessing at sufficient quality is only one part of the optimization of cost-effectiveness versus de-risking. If vintage seismic data can be re-used with this technique, the effort of acquiring new seismic data is also greatly reduced. Vintage data is often available free of charge and is of sufficiently high standard to be considered in subsurface de-risking of geothermal projects. Therefore using the combination of fast-track reprocessing and vintage seismic data is a double advantage over acquiring and processing new seismic data.

The technology and strategy of fast-track reprocessing vintage seismic data, developed by TNO, is based on a different approach from conventional seismic imaging approaches that are available. The vintage data and reprocessing workflow can be selected and designed tailor-made such that it resolves as much information as possible on the targeted geothermal site and for the region and province of Utrecht. Ultimately the reprocessed vintage seismic lines should be tied to processed new seismic lines and passive seismic reflection and tomographic lines. The workflow saves considerable time and cost up to 0.2 M€ per doublet, in particular when compared to shooting and interpreting new seismic.

3.2 Preliminary results on reprocessing

Figure 4 shows the seismic lines which are used in the interpretation of the Utrecht subsurface. All the analogue (dotted) lines have been removed, as they were of lower quality and because there is no pre-stack data available of these surveys they could not be reprocessed. Although the DEEP-NAM-84 line is also close to Utrecht and of high quality, the pre-stack data was not available, so it could not be reprocessed. The MZ85-15 in east Utrecht was reprocessed by Abidin (2018). MZ85-13 to the north east of Utrecht and MZ85-14 in west Utrecht were chosen to be reprocessed. These ExxonMobil lines are the most proximal to the area of interest and are of high enough quality to allow interpretation of the deeper sequences. Furthermore, the seismic lines run perpendicular to the direction of faulting in the region, which allows the faults to be interpreted. ExxonMobil lines from the 1987 and 1988 surveys were also used when interpreting the subsurface of Utrecht.

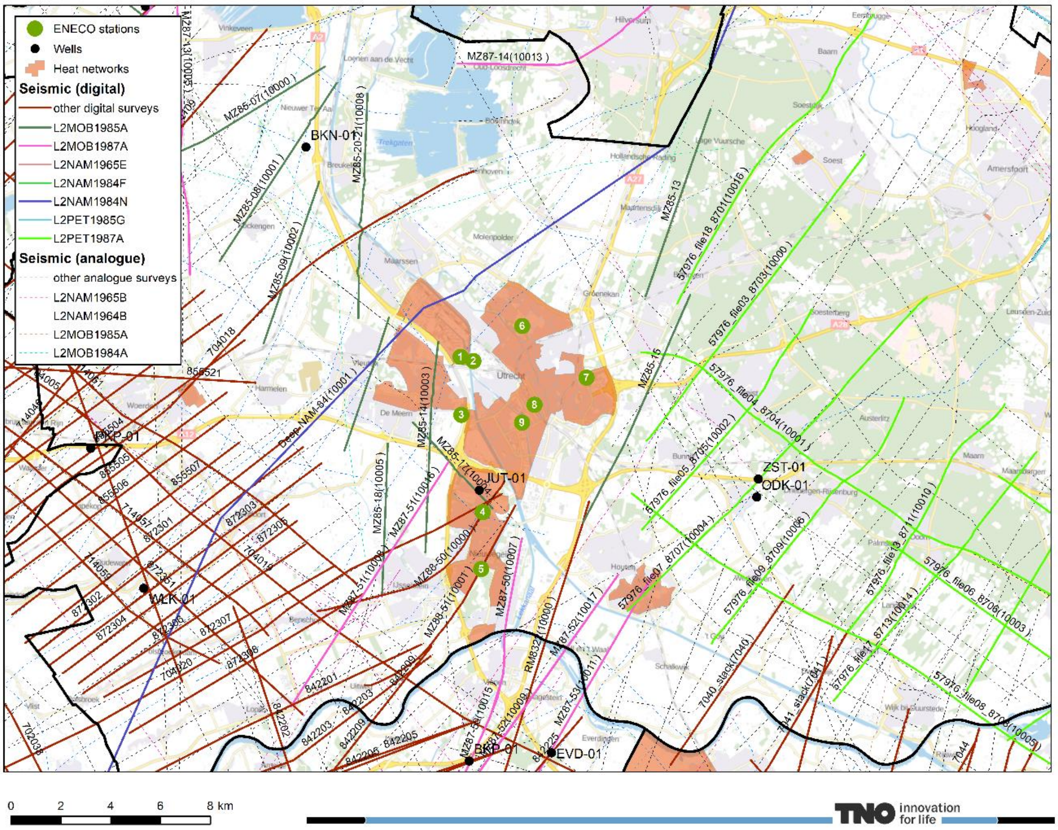

Figure 4: All the available (analogue and digital) seismic lines in the area surrounding Utrecht. Green dots are existing substations of the Eneco district heating network and thus preferred locations to feed in the produced geothermal heat (source Vijverberg, 2019)

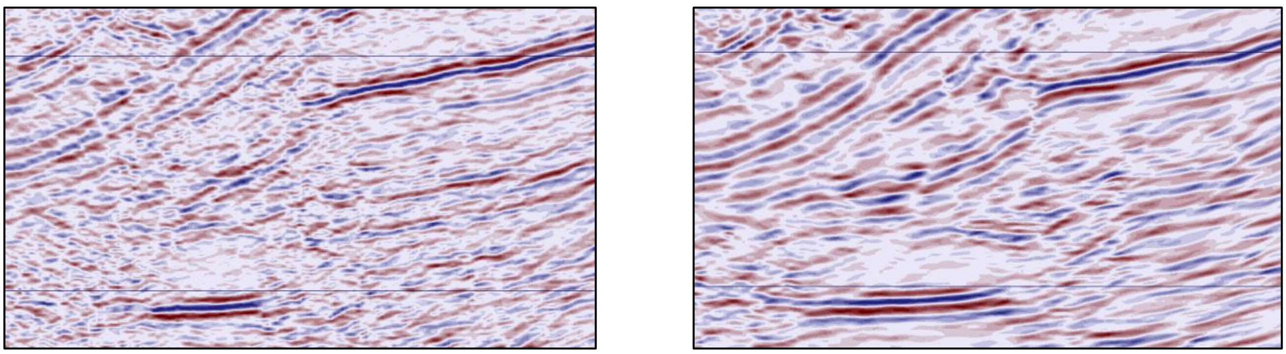

Figure 5: Enlarged (left) and reprocessed (right) section of the MZ85-14 line. Focused on the relevant depth of the Rotliegend reservoir (source Vijverberg, 2019)

4. SLIM HOLE EXPLORATION DRILLING

LEAN integrates a number of innovations for slimhole drilling and completion of a doublet marked by relative low flow rates. These technologies supplied and developed by HUISMAN Well Technology (HWT) can result in an expected cost saving of at least 2 M€ compared to a conventional doublet (1 M€/well). Key to 0.5 M€ per well cost savings is an innovative well design allowing to drill at smaller diameter with open-hole completion at 6' at reservoir level, which is considerably smaller than the conventional wells drilled at 7' reservoir completion. The larger diameter in conventional wells is required for sufficient room for wire wrapped screens and/or casing, which is not required in the LEAN well as the reservoir is considered sufficiently stable.

Slim hole drilling itself is not innovative, however the combination of technological innovations to manage and steer the drilling and completion process developed is, resulting in more safe and technically reliable drilling and completion, which results in an additional cost saving of 0.5 M€/well. The combination of key innovations related to the drilling and completion within the LEAN project comprise of:

a. Safe and reliable Slim hole drilling and completion, capable of running a full suite of logging and coring programmes.
b. Managed Pressure Drilling (MPD).
c. Enhanced Casing Installation (ECI).
d. Rotary Steerable System Drilling (ECI-RSS).

Slim hole drilling
The *slimhole*/lean well design is made one size smaller than normally done which is possible thanks to the *open-hole completion*. An open-hole completion is possible because it is expected that the Rotliegend formation is stable enough to handle. Slimming down the well design results in a cost saving of about 500k€ because a smaller hole is drilled resulting in less cutting to dispose and higher drilling rates and less steel for casing and cement is needed. However, a smaller well will increase the pressure induced drilling risks which account for almost 50% of all non-productive time causing events what will be mitigated by the MPD system in the deeper sections.

Managed Pressure Drilling (MPD)
Managed Pressure Drilling (MPD) is a high-tech system that is used to drill difficult wells that require special mud pressure control e.g. slim well designs. HWT is working on an integrated and (semi)-automated system including the required redundancies to allow the drilling crew with a minimum of extra staff to operate it. The two different predictive flow models that are used in combination with coordinated pump control provide an exceptional fast responding, safe and accurate MPD system. That result in higher drilling rates (>30%), more accurate influx detection but maybe most important: minimal reservoir damage.

MPD is used in oil and gas wells with tight pressure regimes e.g. deepwater wells It will be the future standard drilling technology as well for land drilling. MPD systems are offered by specialized service companies and typical service requires currently a number of experienced operators to install the system on the rig for each well and to manage it while drilling by verifying the various measurements vs. expected values. Typically, adjustments in drilling parameters require manual validated adjustments hence changes such as making a drilling connection are time consuming while delays are minimal with an integrated system. So, by seeing the MPD system as part of the rig instead of as a separate, both hardware as software connections can be built making the whole workflow a lot simpler.

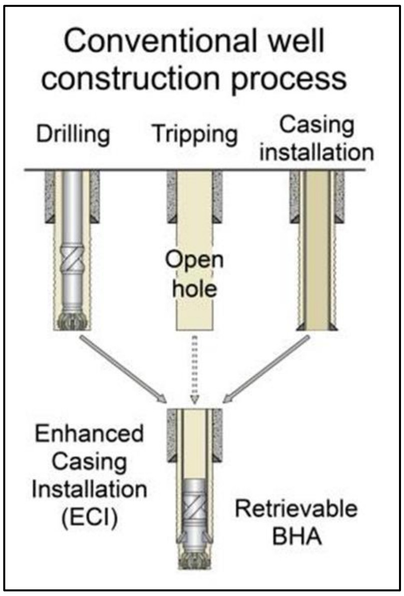

Figure 6: Enhanced Casing Installation

Enhanced Casing Installation (ECI)
The *Enhanced Casing Installation (ECI)* installs casing while drilling and minimises the open hole time and the associated risks. At the required depth, the drilling assembly is being pulled out by the heavy-duty winch that is part of the Huisman rig. The for ECI required casing drive, multi-size pipe handler and winch are all part of the LOC400 and controlled by the driller. This allows a level 3 casing drilling to operate at cost level similar to conventional drilling but with a significant reduced risk and well construction time. The ECI system has already been demonstrated on a geothermal well in the Netherlands but this time the complete integrated system will be employed and combined with MPD.

Rotary Steerable System (ECI-RSS)
An important and unique addition to the ECI system is a rig integrated *Rotary Steerable System* (RSS) i.e. the rig will automatically and continuously steer the full-mechanical RSS by altering top-drive speed. Although developed for deviated wells, the technology is well

suited to drill vertical as well. The tool is specifically designed for ECI and is cheaper to build, to operate and to maintain when compared to conventional Rotary Steerable equipment and mud motors. Similar to all RSS tools, drilling performance is maximized.

The combination of ECI and MPD simplifies the required cementation because the casing is already installed hence the pressure can be controlled all the way to the deepest point of the well at all times. This is not the case for conventional drilling where casing installation and cementation is more complicated.

LEAN well design

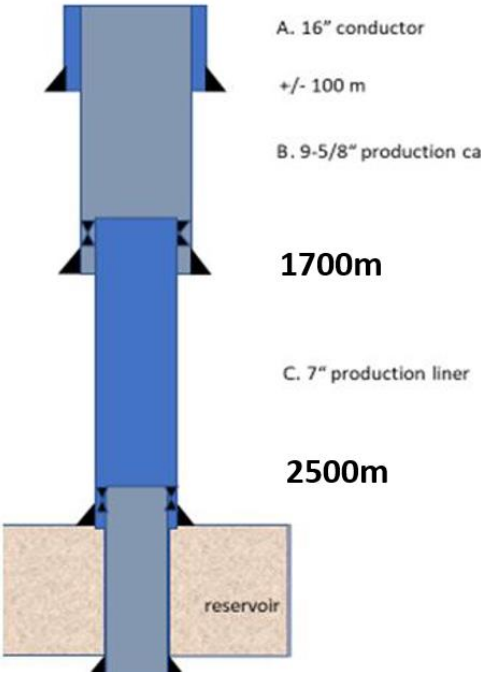

Figure 7: LEAN well design

The new technologies will be applied at different parts of the well (Figure :

- The top-hole will be drilled with the Enhanced Casing Installation (ECI) system to ensure that the casing is set at the deepest depth possible in the relative small hole size while keeping the mud program as simple as possible.
- HWT's rig integrated MPD system is used to maintain constant pressure on the reservoir and to minimize over-pressure for high drilling rates, while keeping formations stable.
- Once the desired depth is reached a heavy pill is spotted inside the casing string while the bottom hole pressure is kept constant by the MPD system. The drilling Bottom Hole Assembly (BHA) will be retrieved at the final section depth using a heavy duty winch through the heavy pill and followed by the cementation. The cable retrieving results in significant time savings and eliminates the requirement of 5" drill pipe completely. An ECI prepared rig comes with the crew and equipment needed to operate the system at a minimum of additional cost.
- Depending on project geological target requirements, HWT's Rotary Steerable System is used to maintain verticality.
- The complete well will be drilled using the integrated and semi-automated Managed Pressure Drilling (MPD), which is used to drill with lighter muds while increasing the influx detection capabilities. The lighter and cheaper muds will results in higher drilling rates and lower drilling pressure (variations) in the relative small holes while the better influx detection will make the drilling safer and allowing to extend casing setting depths. MPD allows the reservoir to be drilled with a minimum of overbalance or underbalance to produce it while drilling to prevent (skin) damage by starting to produce and test it while drilling. Producing the reservoir while drilling will result in better producing reservoirs and time-savings. The proposed rig integrated and automated system offers the service with a minimum of extra equipment or personnel. The amount of testing that can be performed depends on the reservoir properties and gas levels.

5 DOUBLET DEMONSTRATION AND REPEAT POTENTIAL

An extensive coring, logging and testing program will be executed on the first well. The performance of the reservoir and the implications for the portfolio will be analysed by an extensive study of the well data. Based on the evaluation of the performance of the first slimhole and a VoI analysis of the remaining portfolio, a go/no-go decision will be taken on the drilling the second well of the doublet

If the well test is successful, the doublet will be made production-ready and connected to a heat network operated by Eneco in Utrecht. The reservoir, well and drilling data, obtained in the second slimhole, will be used to again update the VoI analysis for the entire opportunity portfolio, evaluate the actual drilling cost reduction and evaluate the expected performance of future doublets.

6. OUTREACH

The LEAN consortium has developed a communication strategy in order to inform and get the interest and support of the general public in the Utrecht area. To this end communication between different geothermal initiatives has been aligned through the warmtebron.nu website. Special attention will be paid to establishing a dialogue with residents in the direct vicinity of potential drilling locations.

The LEAN project approach is highly relevant for other municipalities and regions with a heat demand in the Netherlands and abroad. The Ministry of Economic Affairs and Climate has identified a number of white-spot area's (areas with limited geological data but with a demand for heat).

TNO and EBN will organize a knowledge sharing event for stakeholders in these white-spot area's including municipalities, operators of heat networks and potential geothermal operators.

The goal of the project is to de-risk the area. Therefore, it is the intention of the consortium to make all relevant project information public after the project.

7. CONCLUSIONS

The LEAN project demonstrated an innovative approach to explore for geothermal energy in a white-spot region in the Netherlands. It integrates both technical and non-technical aspects. Key is the development of the region in a portfolio-approach and multi-stakeholder oriented fashion. This effectively allows to mitigate high upfront exploration risks, through the trade-off of the high financial risk of the first project with future benefits of follow-up projects and the sharing of the risk over both industrial and societal stakeholders. Furthermore the development of the white spot areas can gain significantly from improved exploration techniques reducing costs of explorative studies and drilling. Cost reduction and improved robustness of geological models is in part related to more effective use of existing information, such as through reprocessing vintage seismic data.

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