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Play-based portfolio approach for geothermal development

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ABSTRACT

The geothermal sector in the Netherlands has grown from 1 doublet in 2006 to 25 in 2018. The industry is expected to further expand significantly in the coming decades. The geothermal sector in the Netherlands has put forward an ambition to grow from 3 PJ in 2018 to 50 PJ in 2030 and 200 PJ in 2050, according to the ‘Masterplan Geothermal Energy in the Netherlands’ (SPG et al., 2018). This should be achieved in a safe and responsible way, in a cost efficient manner, and rapidly in order to meet the Paris Climate Agreement objectives. The way exploration and development are currently carried out can be improved by a collective approach. Most operators only develop a single doublet. Therefore the learning effect is suboptimal, and the exploration risk remains higher than it could be under ideal circumstances. A play-based portfolio approach, which is common in the oil and gas industry, can help in accelerating the development of the geothermal industry. The basis of the methodology is a subsurface play-based approach, which enables strong geological risk reduction by deploying the value of information for the portfolio of the play, trading off with the risk of the first wells.

The added value of the portfolio approach can be demonstrated easily by comparison to a play which is developed by individual operators ‘stand-alone’, where value of information is not used. Each new project will be equally risky, and therefore relatively unprofitable. In the case of a portfolio approach, all experience about the play is used optimally for derisking. In case of success, subsequent projects will have a higher chance of being successful, due to the experience gained in previous projects. Even in case a project fails, this may help in increasing the probability of success for subsequent projects. For plays that are initially considered too risky for the market to start developing, the value of information of a play-based portfolio approach will help by derisking the play to such an extent that it becomes attractive for the market to develop, even at high initial risk. It can be demonstrated for a number of geothermal plays in the Netherlands that by adopting the portfolio approach, the probability of a play being developed becomes higher, the number of successfully developed projects increases, and the average profitability of the project will also be higher.

Five further advantages are continuous improvement by integrated project development, cost reduction through synergy, efficiency and standardization, optimization of the surface heat demand and infrastructure, the possibility of structural research and development and innovation, and financing advantages. The advantages reinforce each other.

A preliminary estimate of the geothermal potential of the Netherlands adopting the portfolio approach is between 100 and 300 Petajoules (PJ). For about 200 doublets being developed, producing about 40 PJ, the value of the advantage of the play-based portfolio approach has been estimated at up to 2 billion euros (2 bn€) for the three main plays Rotliegend, Triassic and Jurassic/Cretaceous. The learning effects of synergy, efficiency and standardization have been estimated at another 1 bn€.

1 INTRODUCTION

Geothermal energy is relatively new to the Netherlands. The first successful deep geothermal doublet was drilled in 2006. After this well, 22 more doublets were drilled (Ministry of Economic Affairs, 2018), most of which are currently in operation, or are being prepared for production. In 2017, 3.4 PJ of geothermal heat was produced (Ministry of Economic Affairs, 2018). The current rate of development is more or less steady at 1-3 doublets per year. The ‘Masterplan Geothermal Energy (SPG et al. 2018) aims at a production of 50 PJ in 2030. This requires that the development accelerates. This should be done in a safe and reliable way. The State of the Sector report (State Supervision of the Mines, 2017) is concerned about the professionalism of the sector, which is still young and relatively unexperienced, but is learning fast. Major risks are geological, technical operational and financial. Therefore often the probability of success is less than required for a positive business case (P90). This hampers acceleration of safe, reliable and profitable exploration required to reach the 2030 target.

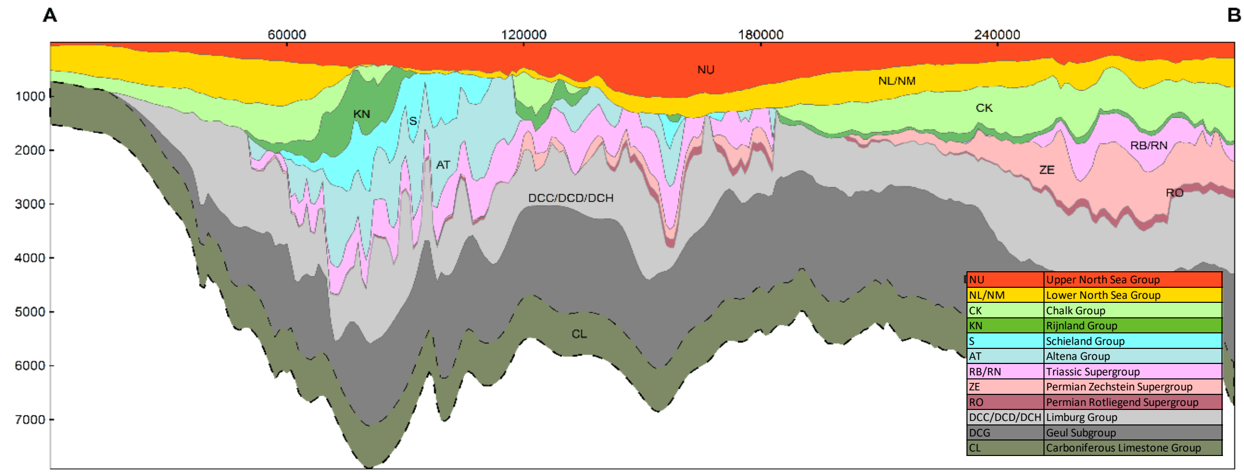

Figure 1: Cross section through the Netherlands showing the main geological units.

2 GEOLOGY AND PLAYS

The Dutch subsurface is heterogeneous and displays a complex variability in composition that was formed over a hundreds of millions of years. Figure 1 shows the variation in presence, depth and thickness. The different rocks and their position and history determine those characteristics that define the geothermal potential like temperature (strongly correlated to depth), thickness and permeability. In our approach, a geothermal play is therefore defined as geothermal potential based on the presence of water in a formation with comparable geological characteristics and circumstances.

Following www.thermogis.nl, the homogeneous units that are currently considered suitable for geothermal heat production and can therefore be considered as geothermal plays are the following (from young to old) (Vrijlandt et al. 2019):

- Tertiary (North Sea Supergroup)
- Cretaceous (Rijnland Group / Vlieland Formation) and Jurassic (Schieland Group / Nieuwerkerk Formation)
- Triassic (Main Buntsandstein Subgroup / Detfurth, Hardegsen, Volpriehausen Formations)
- Permian (Upper Rotliegend Group / Slochteren Formation)
- Carboniferous (Carboniferous Limestone Group / Zeeland Formation)

With the exception of the Zeeland Formation, all units comprise sandstones with primary porosity and permeability. Detailed descriptions can be found online in the Dutch Stratigraphic Nomenclator at www.dinoloket.nl.

The composition of the rocks within a Group or Formation (and therefore within a play) is relatively homogeneous with respects to the surrounding layers. This does not mean that the rock composition within a play cannot differ considerably from one location to another. Heterogeneity is very much scale dependent. For instance, the Permian Rotliegend Group consists largely of permeable sandstone. On a national level the Rotliegend can thus be considered as a single play. Locally, however, shales may occur, or the burial history may be such that the permeability has deteriorated.

Error! Reference source not found. shows that most units occur under large parts of the Netherlands, but their depth (and temperature) and thickness varies. A good example is the Dinantian, which occurs at shallow depth in the South, making it a good target for direct heat. In the remainder of the country the rocks are buried very deeply, possibly making it a target for industrial processes A layer which was homogeneous during deposition may develop characteristics that are laterally very different by geological processes like burial, diagenesis and faulting. It is therefore possible to differentiate subplays within a play. A subplay is internally more homogeneous than a play as a whole. In the current study a regional division into subplays on the basis of a more detailed geological differentiation was not made yet.

In contrast to oil and gas production, in the geothermal industry it is important that production and demand are close (‘matched play’ or ‘matched recoverable heat’ – Kramers et al. 2012). Because of the relatively high transportation cost, compared to electricity or gas, the heat demand should not be further away than a few tens of kilometres at maximum. Heat demand, however, is not included in the definition of a play. Heat demand is, in part, feasible: if a suitable source of geothermal energy is found, demand may be created close by, for instance by building greenhouses on top.

By combining the knowledge of the Dutch subsurface, available as geothermal potential maps in the ThermoGIS system, with heat demand maps, the geothermal potential of each play can be calculated.

3 PLAY APPROACH AND GEOLOGICAL RISK REDUCTION

Because the geological characteristics within a play are closely related, the information that is gained when an exploration well is drilled has a significant value for the development of subsequent projects. When a first exploration well is drilled in an underexplored play, the uncertainty regarding the geothermal potential is large. It is uncertain what will be encountered: the reservoir rock, fluids and gases in the rock, under- and overlying rock, etc. When a second well is drilled nearby, the uncertainty is less, due to the knowledge gained from the first well. The third, fourth and subsequent wells in the same layer will decrease the uncertainty even further.

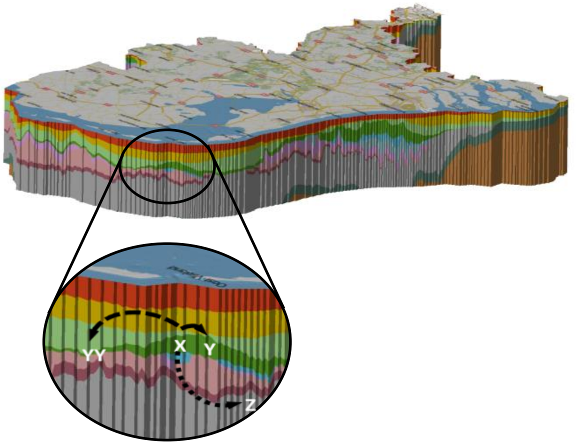

Figure 2: A project at location X contributes more to risk reduction at location Y (with very similar circumstances) than at YY (less similar). A project at location X does not contribute significantly to a project at Z in a different play.

This is illustrated by Figure 2. When the subsurface characteristics at location X have been determined by a first well, the likelihood is fair that at nearby location Y the characteristics are similar. The experience gained during this drilling operation regarding the subsurface decreases the risk that a well drilled to location Y fails. Generally speaking: the further away a second well in the same layer is, for example at YY, the smaller the risk reduction. The maximum distance at which a well at location X is relevant for the subsurface at location YY depends on the layer – some layers can be correlated over large distances, while others can't. A well at location X is relevant for the subsequent wells at Y and YY, but much less about a project at location Z in a different layer or play. In each plays an important generic correlation exists.

An optimal play approach uses that fact that exploration wells and projects in a single play are comparable, and that data, knowledge and experience have a large value for reducing the geological and technical risks for subsequent wells. The use of subsurface data and knowledge of a location X for the reduction of the risks at location Y is called derisking. The value is called Value of Information (VoI). Effective use of derisking and VoI constitute the basis of a play approach for risk and cost reduction. This means that potential projects in plays are best developed in conjunction for optimal risk and cost reduction. The required knowledge is acquired by:

- Studying geological knowledge (analogues, literature)
- Detailed geological investigations
- Data acquisition
- Constructing a preliminary and final design of applicable technology
- Data acquisition and management during drilling
- Reservoir management during the exploitation phase.

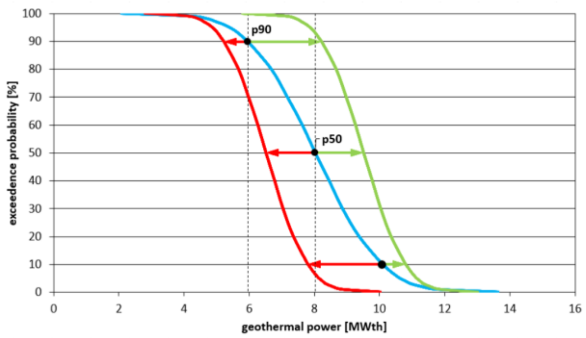

Figure 3: Changing power expectation curve as a result of increased subsurface data and knowledge. Blue curve: before exploration. Red curve: after exploration, negative result. Green curve: after exploration, positive result.

The pre-drill expectation of the power of a doublet is expressed as a power-expectation curve (Figure 3). Such a curve is based on a probabilistic calculation of the flow rate, which depends on an interpretation of the reservoir parameters and the underlying uncertainty, such as depth, thickness, permeability, etc. The steepness of the curve depends on the amount of uncertainty about the subsurface. An expectation curve is project-specific. The difference between P90 and P10 (i.e., the 90 and 10 percentile levels, respectively) is large in areas where large uncertainty exists about the subsurface characteristics. Therefore, the P90 is relatively low, and often too low for a positive business case. If, by exploration of the subsurface, the characteristics of the reservoir at X, for instance permeability, are better than expected, the chances are that at Y, which is near X, the permeability is also more favourable. Due to the information that was collected at X, the uncertainty at Y decreases, but also the expected value of the permeability increases. Because there is a positive correlation between permeability and flow rate, this means that, in terms of the expectation, the curve steepens and moves to the right. The difference between P90 and P50, and between P50 and P10 decreases. This is illustrated by Figure 3. The pre-drill expectation of the doublet is the blue curve. The expected power is 8 MW_{th} (P50). The expected value for a negative exploration result is 6 MW_{th} (P90). By exploration, for instance a seismic campaign or additional exploration well, the uncertainty, the distance between P90-P50 and P50-P10, decreases. Once the reservoir has been drilled, the curve becomes steeper for subsequent doublets within correlation distance. If the outcome of a prior project is better than expected, the curve shifts to the right, in this example the P90 from 6 to 8 MW_{th}, and the P50 from 8 to 9.5 MW_{th}. It is also possible that the P50 remains the same after drilling a successful well, and only the P90 is shifted. When the result of the project is less than expected, the curve shifts to the left, in the example for the P90 to 5.5, and the P50 to 6.5 MW_{th}. After a successful project the chance of achieving a sufficient flow rate for a positive business case becomes larger for all subsequent projects. After an unsuccessful project, it becomes smaller. During the exploration phase of the subsurface, the power expectation curve changes after each new well.

Information coming from geological analogues, studies, outcrops, research, seismic data, core measurements etc. of a project are relevant, not only for later projects in the same layer, but also in younger strata. If a project targets a deep layer (for instance in the Permian), information can also be collected from shallower layers (for instance the Triassic). If the exploration and monitoring program takes this into consideration, the shallow targets can be derisked at little extra cost. This is called the multi-layer effect.

The fact that knowledge gained from one project is valuable for subsequent projects in the same play means that significant risk and cost reductions are possible if projects within a play are developed in conjunction rather than in splendid isolation. This constitutes the core of the play approach. Because one project derisks subsequent projects, the total value of all developed projects in conjunction is larger than the sum of all projects developed as stand-alone, where value includes both produced power and monetary value.

3.1 Value estimation optimal play-development versus stand-alone

The value of optimal play development with respect to the development of stand-alone projects can be quantified in terms of costs and benefits. This is done by calculating the net present value (NPV) of the development of a potential geothermal project in a play, while taking into account the risk reduction achieved by the learning effect of exploration. The risk reduction of subsequent projects is accounted for by a reduced risk of failure after a successful project, and an increased risk of failure after an unsuccessful project. A successful project yields revenues, and a failed project has sunk costs. For a stand-alone development the risk reduction is zero, because gained geological and technical knowledge and information is not shared.

The starting situation is a play in which little exploration has been done. The uncertainty regarding the subsurface is large. Suppose that a project has a P50 expectation value for an economically viable project of 10 MW_{th}. There is a 50% chance that the project will be successful, and 50% chance of failure. If the project fails, we suppose that the costs of the first well, arbitrarily set at 5.5 M€, are lost. If the doublet has a power exceeding 10 MW_{th}, the project is successful. The NPV is set conservatively at 1 M€, which is slightly higher than the NPV of 0 which equals the P50 case. The expected value of the NPV for a stand-alone development is then:

$$NPV = 0{,}5 \times 1 + 0{,}5 \times -5{,}5 = -2{,}25 \text{ M€}$$

It is clear that due to the negative NPV this project is unlikely to be drilled. Suppose on the other hand that the repeat potential in this play is 10 (i.e., 10 additional prospects), then the 'stand-alone' risked NPV of the projects in this play (without the learning effect and risk reduction of the play approach):

$$NPV = 10 \times (0.5 \times 1 + 0.5 \times -5.5) = -22.5 \text{ M€}$$

If the power of each doublet is 10 MW_{th} on average, then the total realizable power of the portfolio is 100 MW_{th}. This complete portfolio will also not be developed due to the strongly negative NPV, unless the society is willing to subsidize each project with 2.25 M€.

The NPV of this portfolio will look different for 10 projects in a play approach, taking into account the extra gained geological and technical data, knowledge and learning effects. The NPV of the portfolio, developed using a play approach, is visualized in Figure 4, where project 2 learns from the experiences in project 1. Because this information is transferred to the next project, the initial chance of success increases.

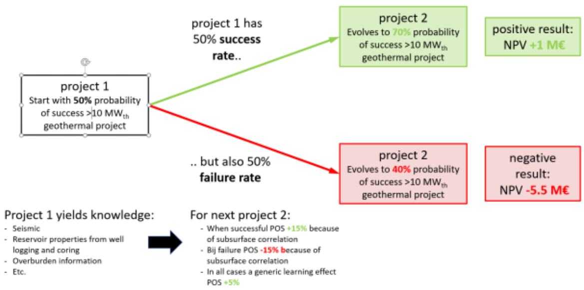

Figure 4: Learning or derisking effect of a project for a subsequent project.

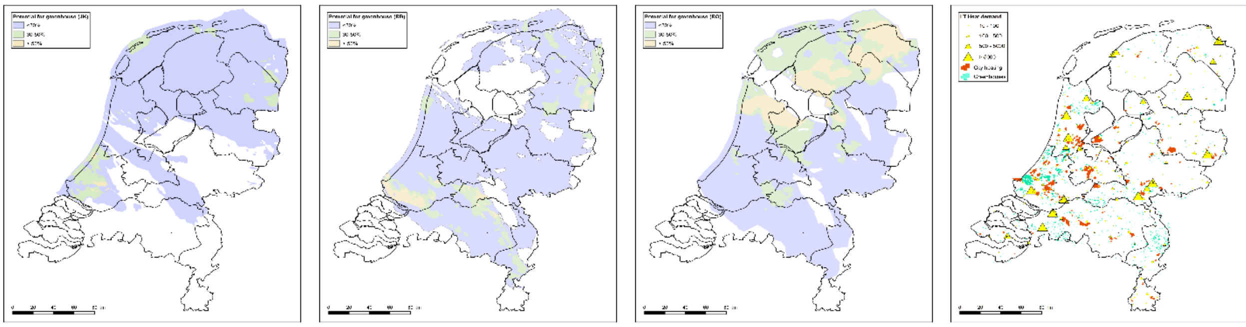

Figure 5: ThermoGIS geothermal potential for the Jurassic/Cretaceous, Triassic and Rotliegend plays expressed as the probability of successfully establishing a 10 MW_{th} doublet, and heat demand.

We presume the following:

- When a project is successful, the success rate is increased by 20%, and when a project fails it is lowered by 10% - figures that are comparable with similar play-probability trees in the oil and gas industry.
- The correlation of the learning effect is limited to a number of projects. If the success rate (in this case for a 10 MW_{th} project) is developed to 90% (of a successful business case), it is presumed that it will not further increase significantly.

If two subsequent projects fail, causing the success rate to become unacceptably low, further exploration is stopped.

Figure 6 shows the entire tree of 10 projects. The costs and revenues in the various branches have been worked out in the right-hand side. For the green branches a situation arises where the repeat potential can be further developed. The expected NPV for the entire tree is still slightly negative at -1.0 M€. This is however significantly better than the stand-alone development which has an NPV of -22.5 M€. It appears logical that society should contribute to the play approach a limited subsidy of 1.0 M€ to enable the development of 10 projects, rather than contributing more money for stand-alone developments.

Figure 6 shows that, in this example, the initial chance of successful development is 52% (the sum of all green branches). The chance of failure is therefore 48%, taking into account all background information, knowledge and expertise leads to an improvement of the NPV from -22.5 M€ to -1.0 M€ - the play approach creates an additional value of 21.5 M€. If the repeat potential is larger, the value of the total portfolio is also increased. At a repeat potential of 15 projects, the NPV becomes 1.6 M€. This means that the development of plays with a large repeat potential is more beneficial than one with a small repeat potential. This does not come as a surprise, because the first exploration projects in a new play have the largest risks and costs. The less risky follow-up projects developed after the exploration phase are required to earn back the money spent in the exploration phase.

The optimal play development tree can also be calculated using different assumptions, such as a new play with higher uncertainty. For a play having an initial chance of success of 30% (P30) and a similar set of the remaining assumptions, the NPV of a stand-alone development is $0.3\times10\times1+(1-0.3)\times10\times-5.5= -35.5$ M€. For play development the NPV becomes -7.3 M€. The added value of the play approach is therefore higher than in the P50 case, namely 28.2 M€.

The advantage of a higher NPV results in a lower cost price of geothermal energy. This allows the required subsidy to be lowered.

3.2 Application to main plays

The method described above was applied to the main plays Jurassic / Cretaceous, Triassic and Rotliegend in order to estimate the order of magnitude of the additional monetary value of the play approach. ThermoGIS maps with current success probabilities for a 10 MW_{th} doublet of the three main plays were used (Figure 5). The local heat demand was determined from:

- existing heat networks (RVO WarmteAtlas), assuming that a 10 MW_{th} doublet produces heat for 6000 houses (35 GJ/year/house comparable to the 36 GJ given by ENECO et al. 2017);
- Low temperature industrial heat demand (RVO WarmteAtlas), in TJ/year;
- Greenhouses (Kadaster Top10Vector). One 10 MW doublet is assumed to produce heat for 20 hectares (0.5 MW_{th} per hectare).

Repeat potentials were then calculated within the plays by summing the identified heat demand in regions. A detailed description of these regions is beyond the scope of this paper. Ideally, these regions should be defined geologically as subplays. Further assumptions were:

- NPV_{succes} 1.0 M€, $NPV_{failure}$ -5.5 M€;

- Probability tree as Figure 4and Figure 6;
- ThermoGIS probabilities for 10 MW_{th} between 30 and 50% conservatively set to P30, >50% to P50
- A 10 MW_{th} doublet produces about 0.2 PJ per year based on 5500 full load hours;
- The maximum number of failures before exploration stops is 2. The exploration phase lasts a maximum of 6 projects to reach P90.

The order of magnitude of the differences in NPV for the two approaches is substantial, and largest for the Jurassic/Cretaceous play. For a repeat potential of 288 projects split in 7 regions the NPV for play approach is about 1 bn€ larger than for a full stand-alone approach, For the Triassic play and 198 projects the NPV difference is about 440 M€, and for the Rotliegend with 276 projects, about 660 M€. The total NPV difference for all these plays is therefore about 2 bn€.

Given the specified assumptions and input, the realised geothermal potential in the three main plays is about 200 doublets and 40 PJ. The calculated amounts of potential doublets or repeat potential (total 763) were corrected for the calculated chances of successful development given an initial chance of success of 30% or 50%. In a probability tree that has +20% and -10% per step, and a halt after two subsequent failures these are respectively 18% and 52%.

3.3 Meaning of the value and sensitivity

It is important to realise that the value difference of 2 bn€ will never be achieved. First, the two extreme situations sketched (full cooperation versus splendid isolation) are not realistic. The play approach will stop after two subsequent failures because the chance of success is then considered too low for continuing exploration. In the stand-along scenario exploration will continue longer, assuming the same probability of success, but not indefinitely. Therefore the full repeat potential will not be developed when the number of failures becomes too large. It is therefore important to put the large difference in NPV in the right perspective, and focus more on the potential number of doublets that can be realised using portfolio theory – a portfolio approach offers a substantial added value over stand-along.

To obtain an impression of the sensitivity of the assumptions, some were changed to evaluate the influence on the outcome of the calculations, relative to the base case of Table 1.

- Allowing three failures before exploration stops leads to a 20-50% higher success rate, resulting in an additional 15 PJ over the original 40 PJ. The exploration phase would then cost an additional 100 M€.
- Rather than adopting an initial 30% chance of success for the area 30-50%, 40% can be used, and 70% for the area >50%. This results in an additional 30 PJ and an additional cost saving of 0.3 bn€ over the original 2.0 bn€.
- When the generic learning effect is lowered from 10 to 5%, the resulting success rate of the portfolio is 25-50% lower. This decreases the realised potential by about 25 PJ. This also decreases the cost saving by 0.1 bn€. More knowledge sharing results in a higher efficiency in terms of realised power.

The used assumptions are considered conservative for various reasons:

- ThermoGIS was designed for projects on a stand-along basis. Therefore large areas were ruled out that are possibly relevant for geothermal development when a portfolio approach is followed.
- Further, P30 was assumed as lower cut-off – the areas shaded in blue in Figure 5 were also ruled out – if a large repeat potential exists, exploration of these areas could be considered. Some current exploration activities are already focusing on these areas.
- The multilayer effect, meaning that multiple plays can be derisked in a single project. This lowers the cost of derisking, which means that for instance more failures can be accepted, which increases the probability of successful development.
- Synergy with other subsurface activities was not taken into account, for instance with oil and gas exploration. This can be knowledge sharing but also double play concepts (Van Wees et al., 2014) and re-use of old wells.
- Shallow reservoirs like the Paleogene North Sea Group were disregarded because of the low temperature. However, exploration of this play is currently also picking up, in combination with the use of heat pumps. Similarly, the deep Dinantian Limestone reservoir (Heijnen et al. 2019) offers potential that was disregarded until now.
- The heat demand was considered to be static, but in reality it changes, for instance when new city heating networks are developed. The current heat demand is 424 PJ, of which only 158 PJ within the current plays >P30.

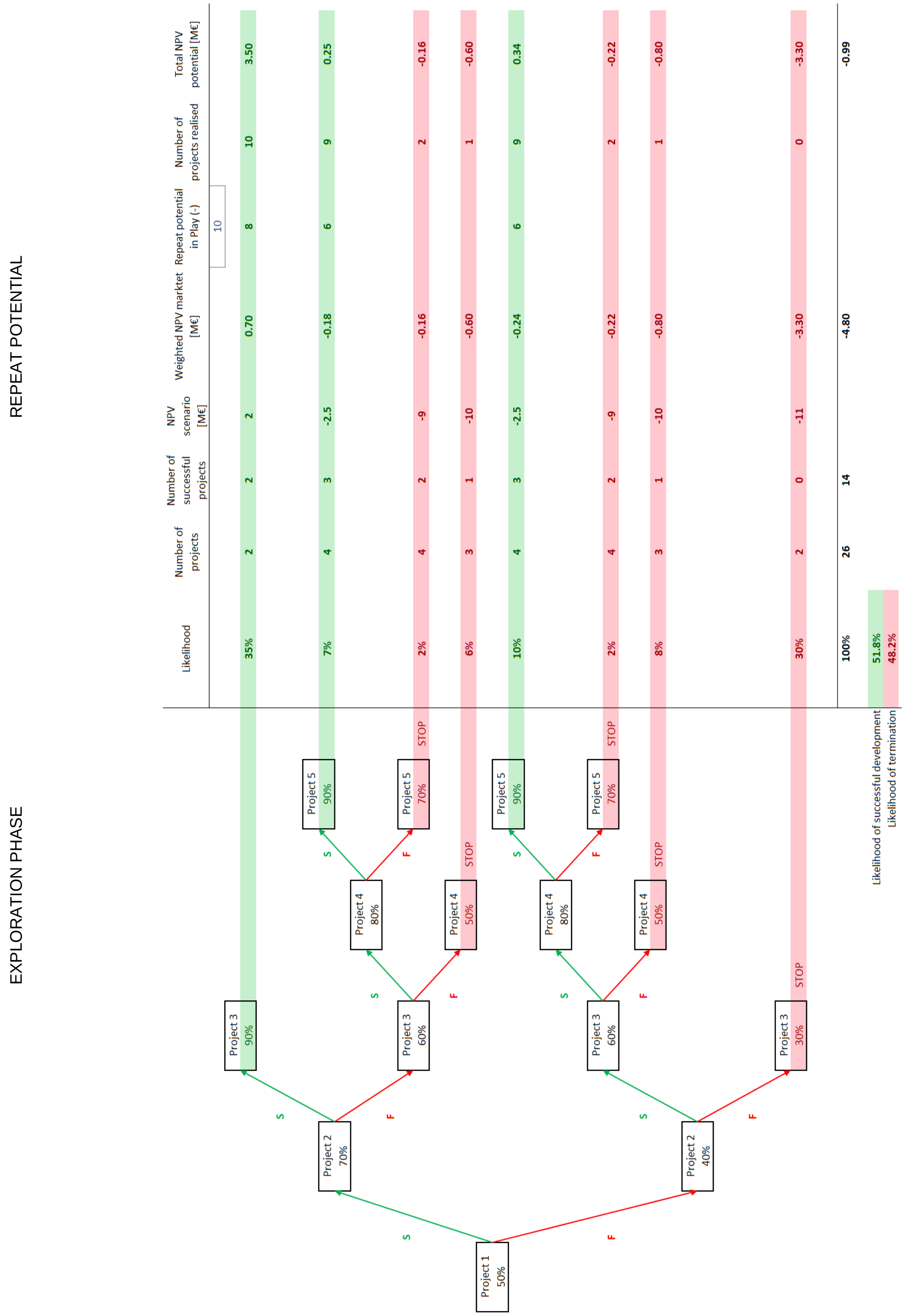

Figure 6: Probability tree for an optimal play approach (S: success, F: failure).

Table 1: Portfolio and realisable potential in the three main plays

greenhouse+industry+city heating (combined)		Jurassic/Cretaceous	Triassic	Rotliegend	total
portfolio	doublets	288	198	277	763
	energy	57 PJ	39 PJ	55 PJ	151 PJ
realisation	doublets	59	61	80	200
	energy	12 PJ	12 PJ	16 PJ	40 PJ
	NPV	-20 M€	-30 M€	-4 M€	-59 M€
	ΔNPV	940 M€	411 M€	665 M€	2,011 M€

4 OTHER ADVANTAGES OF A PLAY APPROACH

Because geological plays have different characteristics resulting in differences in exploration per play, also the optimal well configuration and design, engineering, drilling activities, risk estimation and reservoir management are play-specific. This means that also other advantages than only geological risk reduction can be optimized when a play approach is followed. The five advantages are described as follows:

4.1 Integral project development

Integral project development means that the dependencies between all activities during the lifetime of a projects are well considered. They can be optimised, and, on the basis of experience from comparable projects, continuously improved. With respect to the ‘stand-along’ practice, two developments could contribute to better integral project development:

- Strong geothermal operators that develop more than a single project, as ‘going concern’ activity
- Play-based development of projects, on the basis of comparability of multiple projects. The more comparable projects are, the better relations between the activities can be optimised.

4.2 Cost reduction by synergy, efficiency and standardisation

Executing a project multiple times may create added value due to synergy between project developments. It allows better efficiency and standardisation. The more similar and well known the subsurface is, the more unambiguous the well design and configuration, design, rig, risk management etc. can be. Synergy is a smart way of combining activities that are required for more projects, like geological studies, seismic acquisition, rig contracting, the development of HSE-systems, etc. Efficiency refers to smart investment at the right time in the life cycle to prevent risks and costs, or increase revenues. Examples are omission of a gas separator if gas is known not to be present, or adding extra measuring or monitoring equipment to detect problems in an early stage. Standardisation is the identification and optimisation of repetitive activities during the life cycle, like contracting, database setup, design and engineering activities, logistic and construction activities, etc.

4.3 Optimisation demand and infrastructure

Currently, the geothermal source and the end user are geographically very close – the heat is used at the location where it is produced. The geothermal industry is expected to expand, apart from the greenhouse sector, to industry, utility building and residential areas. This increases the complexity of the feed-in, because the dependence of multiple providers and clients, transportation lines and heat networks also increases. Therefore the importance of the optimisation of supply, demand and the development of optimal heat networks is also increased. The following questions need to be addressed:

- Where is the actual demand located, and where will it possibly newly develop? What is the required temperature and volume, and user profile in time?
- Where are the geothermal plays suitable for providing the anticipated demand?
- How many doublets would be needed to supply sufficient heat?
- How can the doublets be positioned in such a way that they are optimally connected to the heat infrastructure, in terms of safety, spatial planning and cost?
- How do the costs of the development of the geothermal portfolio relate to the costs of alternative heat sources, on the short and long term?

4.4 Structural R&D and innovation

The interest in R&D and innovation in the geothermal sector is growing. More focus is still on solving everyday problems than on future risk and cost reduction. Structural R&D is however required for the sector in order to continue risk and cost reduction, and increasing benefits. Geothermal operators have a crucial role as investor, executor and responsible organisation, and those who have the most interest in an efficient industry. The largest risk- and cost categories should be identified in order to be able to realise reductions. R&D and innovation should be linked to the development of projects in the sector. Examples of R&D include subsurface exploration technology, rig and drilling innovation, well completion aiming at well integrity, improved well configuration and stimulation, measuring and monitoring techniques, project risk minimisation and stakeholder communication, and system integration.

4.5 Financing

The previously mentioned advantages all result in risk and cost reduction, and increased revenues. This will make the sector more attractive to financing organisations. On the other hand, various points of attention with respect to financing were identified:

- Geological risk
- Quality and knowledge of contractors
- Exploitation risk
- Laws and regulations
- Risk of failing demand
- Operator credit worthiness risk
- Shortage of risk-bearing capital
- Reputation risk

These items have a negative influence on the ability of the projects to be financed. Advantages of a portfolio approach related to financing are:

- Risk spreading if more financial institutions are investing in the sector.
- Increased trust in larger and more experienced sector and operators.
- Increased possibilities for financing when more parties become involved in a growing sector.

5 CONCLUSIONS AND FUTURE OUTLOOK.

In this paper we demonstrated the added value of the portfolio approach for well-known play structures in the Netherlands.

In the portfolio approach, the value of information of a first project for follow-up projects is taken into account and used in decision making for continuation or exiting a concerted exploration campaign for a set of prospects to be developed. This approach contributes significantly to reduction of financial risk compared to a stand-alone approach for the development of geothermal plays. Furthermore it allows to develop prospects which -from a stand-alone perspective- would be considered too risky -in financial terms- to be developed

A first application of the portfolio theory to the Netherlands using subsurface reservoir data from the 2017 version of ThermoGIS shows that about 200 doublets can be developed in the three main plays: Rotliegend, Triassic and Jurassic/Cretaceous. These are capable of producing about 40 PJ. The monetary value of the advantage of the play-based portfolio approach has been estimated at up to 2 bn€.

Five further advantages are continuous improvement by integrated project development, cost reduction through synergy, efficiency and standardization, optimization of the surface heat demand and infrastructure, the possibility of structural research and development and innovation, and financing advantages. The advantages reinforce each other. The learning effects of synergy, efficiency and standardization have been estimated at another 1 bn€.

The outcomes are relatively conservative due to the bias towards low P-values adopted for the plays, and therefore marked by a considerable potential upside of at least 50 PJ. Further the estimates will in future be updated based on a newer version of ThermoGIS (cf. Vrijlandt et al., 2019), which is expected to result in an increased resource base and potential. In addition a number of plays, including Tertiary clastic formations and Early Carboniferous and Devonian reservoirs have not been included. These are expected to increase the resource base by over 50 PJ. In addition seasonal storage can significantly add to the load factor and associated cumulative yearly heat production Consequently, the preliminary estimate of the total geothermal potential of the Netherlands adopting the portfolio approach is estimated between 100 and 300 PJ.

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