Expediting Geothermal Exploration in Indonesia: Should We Consider Slimhole Drilling?

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ABSTRACT

The Indonesian government has just revised the national target for the utilization of geothermal energy from 7,200 MW in 2025 to 7,000 MW in 2030. Unfortunately, this revision does not necessarily eliminate the main challenge of geothermal development, which is the slow-going exploration activities. Several factors have been identified as possible causes that hinder the geothermal exploration activity in Indonesia, one of them is the high resource risk. This high risk is due to the investors must invest a large amount of capital for drilling activities while the subsurface uncertainty is still very high. The high upfront drilling cost is influenced by many factors, one of which is the type of well chosen (e.g. big, standard, or slim hole well). Even though slimhole well is cheaper than standard/big hole, the current trend of geothermal industry in Indonesia is to use standard or even big hole for exploration drilling. Moreover, slimhole is considered to possess many disadvantages such as longer drilling operation days and difficulties to be used as production well.

One emerging question is that whether slimhole should be considered by geothermal developers in Indonesia as one option of exploration planning strategy. To answer the question, this research conducts literature study regarding the past operation of slimhole drilling in exploration projects in Indonesia. This paper also aims to summarize the results of literature study and brainstorming session conducted by authors for the past several months on the pros and cons of slimhole drilling for geothermal exploration with regards to current state of Indonesia energy industry as the context. Finally, this paper is expected to trigger more discussion among geothermal practitioners about when and how to incorporate slimhole drilling into their exploration strategy with the hope of optimizing the acceleration of exploration projects in Indonesia.

1. INTRODUCTION

1.1 Geothermal Development in Indonesia

Indonesia is known as one of those countries with the largest geothermal potential in the world, with approximately 25 gigawatt (GW). However, the amount that have been utilized up until today is only around 8% or equivalent to 2,130 megawatt (MW) installed capacity (EBTKE, 2020). This considers the geothermal development in Indonesia to run at a very slow pace, remembering the fact that the very first geothermal well was drilled in 1926 (Hochstein and Sudarman, 2008) and first geothermal power plant in Indonesia was operated in 1983. This history shows that within the period range of 1983-2020, Indonesia is only capable to increase its installed capacity with an average rate of 57 MW per year. This rate is indeed still far from sufficient to achieve the 2030 national geothermal development target of 7,000 MW that requires a rate of 487 MW additional installed capacity per year.

Various challenges, such as those pivoting around regulation, social, environment, and technical aspects, which are considered in contributing to the slow geothermal development in Indonesia have been identified (Umam et al., 2018; Darma, 2016; Poernomo et al., 2015). One challenge that is currently being a hot topic among geothermal practitioners in Indonesia is the high resource risk in the early stages of a geothermal project. This high resource risk is a combination of high sub-surface uncertainty of a geothermal prospect in the exploration stage and high exploration drilling cost (Gehringer and Loksha, 2012; Purba, 2018). This condition surely requires decision makers in geothermal development companies in Indonesia to find the most cost-effective method in formulating exploration strategies in each of their geothermal prospects. The high geothermal exploration cost that investors must spend when the geothermal resource uncertainty is still also high, will result in more difficult and slow decision making. If this continuously happened, it would further result in even slower geothermal energy development in Indonesia as a whole.
1.2 Geothermal Exploration Challenges in Indonesia

Geothermal systems in Indonesia are generally associated with tectonic and volcanic activity. This causes challenges for the geothermal developers to face because the targeted geothermal resources are located at high-relief terrain, which further will be discussed in the following section (Utami, 2010; Purba et al., 2020a; Umam et al., 2018).

1.2.1 Difficulty in Locating Flat Land Area

One challenge due to high-relief terrain is the difficulty in locating sufficient flat land area for a wellpad and other infrastructure purposes, such as the supporting facilities for drilling activities. This becomes more challenging with the fact that the flat land areas are often occupied by the local communities for agriculture purposes as their main source of income. If not managed properly and carefully, this conflict of interest between geothermal developers who want to acquire land area for their exploration project and local communities who do not want their daily activities to be interrupted, can actually result in delays or even termination of the exploration project.

1.2.2 Poor Road Access

As an archipelago, poor transportation and road access in many areas in Indonesia is also a challenge in geothermal development. In this current time frame, the Indonesian government is still working to build supporting infrastructure to connect many islands in Indonesia, ranging from Sabang Island (most western part) to Merauke (most eastern part). This condition, as shown in Figure 1, surely causes geothermal developers to spend even greater logistics costs, especially for the transportation of the drilling rig, heavy equipment, and other supporting equipment. The larger the capacity of a drilling rig used in the exploration stage, the higher the cost required in the project to build road access and supporting infrastructure.

![Figure 1: Photos of access road condition in one of the geothermal prospect areas in Eastern Indonesia](image)

1.2.3 Lack of Geothermal Project Awareness

Majority of Indonesians who live around the geothermal area are still not educated enough about both benefits and risks of a geothermal project. The fact that geothermal prospect areas are usually located close to residences, is often not considered seriously by geothermal developers in Indonesia and the education process of the people that usually takes a lot of time, is often not well-scheduled by developers. In some cases, several development companies do not send experienced teams or competent personnel to handle this issue and build community engagement. This can result in unpleasant relationships between companies and local communities.

1.2.4 No More “Low Hanging Fruit” Prospects

Indonesia’s geothermal prospects considered to be “low hanging fruit” are getting much more difficult to discover. This is caused by many factors such as (1) only a few geothermal manifestations found on the surface; (2) only a small amount of geothermal resource detected by 3-G (geology, geochemical, geophysical) surveys in a specific area, and (3) the prospective zone is located inside a national park (conservation zone). Increasing levels of difficulties in defining subsurface conditions of a geothermal prospect forces geothermal developers make decisions carefully prior to commencing the drilling stage, in view of the relatively higher cost of drilling compared to the costs of the 3-G surveys. (GeothermEx, 2010; Purba, 2018; Purba et al., 2020).

1.2.5 Lack of Competencies

Purwanto et al. (2018) has summarized the historical journey of geothermal drilling in Indonesia from 1970s to 2018, that 711 geothermal wells have been drilled in Indonesia with the most active period range of 1996 – 2000 (192 wells). If this is translated into chart form, geothermal drilling activities in Indonesia did not occur at a stable rate. Authors view this pattern as a cause that leads geothermal drilling personnel to involve in drilling activities depending on the availability of projects. When there are only a few geothermal drilling projects in progress, most likely those personnel will tend to resort to the oil and gas industry, which in Indonesia, is likely to be more active and stable compared to geothermal.

In summary, this phenomenon, when combined with no integrated drilling database, contributes to the slow learning curve in geothermal drilling industry in Indonesia. Fewer competent personnel available today often causes geothermal drilling projects in Indonesia to hire
drilling personnel from oil and gas industry, who are very often not properly assessed on their comprehensive knowledge and competencies in geothermal environment.

1.3 Exploration Drilling
Geothermal exploration activities are generally commenced with 3-G surveys with the objectives of determining the top of reservoir depth, the area of the reservoir, and to predict the temperature gradient, and stratigraphic faults, which usually takes time around 5 (five) years in normal cases and cost up to approximately US$30 million (Purba et al., 2019). After 3-G surveys are completed, geoscientists will sit together to build a conceptual model with the objective of describing and illustrating essential features of the geothermal system. This model will be used in field development planning and well siting as well as being the basis for numerical modeling and reservoir assessment (Mortensen, 2013). Some developers even choose to commence reservoir numerical modeling from the very beginning of the exploration stage despite not having completed drilling any deep wells. The result of this process is a decision to proceed to the next stage, the exploration drilling, where well targeting is one of the most critical components in the decision.

Exploration drilling refers to activity of drilling a well with objectives to prove the existence of geothermal resource in the investigation area and to test the geothermal system conceptual model created, based on the data obtained in the 3-G surveys (Saptadji, 2018). Several size alternatives of wells known in geothermal industry are big hole, standard hole, slimhole, which comparison can be seen in Figure 2. Currently, developers in Indonesia tend to conduct geothermal exploration drilling with using standard well type or big hole with considerations to later transform the well into production or injection well in the development stage. This becomes clearly reasonable if the probability of success of the drilling is high. However, with the fact that it is difficult now to find “low hanging fruit” prospective areas, the decision to drill big hole type in the exploration stage has become a question, due to the cost that can be as high as approximately 3-4 times the cost to drill a slimhole.

The high resource uncertainty combined with high drilling cost for big hole made some stakeholders considers the use of slimhole drilling for geothermal exploration. Slimhole drilling for geothermal exploration itself in Indonesia had seen some use in the 1990s, but has not been used afterward until Ijen drilling campaign in 2016 (Mackenzie et al., 2017; Adityatama et al., 2020), even though it is commonly used in many geothermal exploration projects around the world.

![Figure 2: Configurations of common well types used in geothermal exploration drilling in Indonesia (Purba et al, 2019).](image)

1.4 Study Objectives and Method
This study has objectives to expose several challenges in geothermal exploration in Indonesia, key considerations in the exploration phase, and a framework in a form of decision tree analysis to help geothermal developers decide the most economical well type to use in the exploration drilling according to the probability of success set by the geoscientist team.

This research has been conducted through a literature study of past operations of exploration drilling projects in Indonesia and around the world, including the challenges and important key points to consider in proceeding with geothermal exploration. The decision tree analysis is carried out using a calculation of expected values of several scenarios with each having different combinations for number of wells, well type, and probability of success. This calculation is then varied with different well costs, which will be later compared in the sensitivity analysis to find out variables with the highest influences on an exploration drilling.

2. KEY CONSIDERATIONS IN EXPLORATION PHASE
The authors used this section to explore factors that can be considered by the decision makers prior to entering the exploration drilling stage. These various factors have been discussed in detail by Purba et al. (2019).

2.1 Exploration Objectives
The main objective of geothermal exploration is to answer the question of the presence, size and viability of a geothermal system in the potential area by conducting 3G (Geology, Geophysics, and Geochemistry) surveys and exploration drilling. The data collected from the 3G surveys are utilized to generate an initial conceptual model. However, this initial conceptual model is still crude and incomplete. Exploration drilling is the next stage of this exploration process to obtain direct subsurface data such as lithology, hydrothermal alteration mineralogy, caprock/alteration zones, key reservoir parameters, etc. and validate the geoscientific information derived from the 3G
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surveys. The data from exploration drilling are then used to update the conceptual model and generate a numerical model for reservoir simulation. As mentioned by Ciriaco et al. (2020), numerical modeling is beneficial and should be adopted from the early stage of development.

Furthermore, O'Sullivan & O'Sullivan (2016) stated that numerical modeling is a key tool for planning and managing the project. It should be applied throughout the life of the geothermal project (including the exploration phase); the exploration and monitoring guidance can be constructed by applying sensitivity studies and data-worthy analysis to the computer model. Hence, the authors agreed that the development of a numerical model should start from the early exploration stage and be used as a guide to the exploration process. To support that aim, it is imperative to obtain reliable subsurface data during exploration drilling.

There are several options for exploration drilling such as deep slimhole, standard hole, and a big hole. Each of those alternatives has advantages and disadvantages, which will be elaborated on later in this paper. However, as Mackenzie et al. (2017) has stated, the "low hanging fruit" geothermal fields in Indonesia have been exploited; thus, the most economic drilling option should be considered for the future geothermal exploration in Indonesia. Deep slimhole is one of the best options for exploration drilling since it cost only ~40% of the full size well (Riza & Berry, 1998). Currently, there is a debate among geothermal experts in Indonesia regarding the use of deep slimhole wells. It is considered that the data generated from deep slimhole wells cannot be used to make numerical models. Thus, the authors will identify what data is needed for making a full-scale numerical model and which data can be obtained from a deep slimhole.

The authors has collected information on the required data to generate a full-scale numerical model in the exploration phase from various sources (Nugraha, 2020; Nugraha et al., 2018; O'Sullivan & O'Sullivan 2016; O'Sullivan et al., 2015; Ratouis et al., 2015) and the results are summarized in Table 1.

### Table 1: Required data to generate a full-scale numerical model in the exploration phase (Nugraha, 2020; Nugraha et al., 2018; O'Sullivan & O'Sullivan 2016; O'Sullivan et al., 2015; Ratouis et al., 2015)

<table>
<thead>
<tr>
<th>Data category</th>
<th>Data required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology</td>
<td>Topography, rock stratigraphy, lithology, regional fault structures, thermal feature location, nature of hydrothermal alteration, heat source type, location permeable zones, water table levels</td>
</tr>
<tr>
<td>Geophysics</td>
<td>Surface heat flow, subsurface structures, area extent and thickness of caprock/alteration zones, temperature gradient</td>
</tr>
<tr>
<td>Geochemistry</td>
<td>Thermal feature data: area, type, pH, temperature, chemical content, fluid type, flowrate, gas flux</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Rock type and properties (porosity, density, resistivity, and heat capacity), temperature, fluid chemistry (type, pH, and chemical content), permeability, pressure, top of reservoir, reservoir thickness, reservoir structures, saturated and undersaturated zones</td>
</tr>
<tr>
<td>Well</td>
<td>Productivity/injectivity index, feed zones, downhole temperature and pressure profile, permeability, well location and trajectory</td>
</tr>
</tbody>
</table>

With proper well testing design, slimhole drilling can provide similar subsurface data as conventional drilling (Mackenzie et al., 2017; Riza & Berry, 1998). The lithological information in the reservoir section can also be obtained in the form of the full core sample, in contrast with conventional rotary drilling where it is difficult to get a full cutting return during drilling in the reservoir section.

The subsurface data that can be provided by slimhole drilling is summarized in Table 2. The data provided by deep slimhole are more than adequate for the generation of a full-scale numerical model in the exploration phase. Thus, a deep slimhole drilling method can undoubtedly become an alternative option for exploration drilling with the lowest cost than the others.

### Table 2: Subsurface/downhole data that able to be provided by deep slimhole drilling (Mackenzie et al., 2017 and Riza & Berry, 1998)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous coring program</td>
<td>Accurate depth and lithology, rock stratigraphy, hydrothermal alteration mineral, caprock thickness, key reservoir parameters (top reservoir, porosity, permeable/structure features, density, resistivity, heat capacity, rock type, and thickness)</td>
</tr>
<tr>
<td>Well logging</td>
<td>Downhole temperature and pressure profile, saturated and undersaturated zones</td>
</tr>
<tr>
<td>Well testing</td>
<td>Productivity/injectivity index, feed zones, permeability</td>
</tr>
<tr>
<td>Well sampling</td>
<td>Reservoir fluid type and chemistry, temperature, pH, chemical content</td>
</tr>
</tbody>
</table>

### 2.2 Exploration Schedule

The Indonesian government had regulated geothermal exploration activity within the Government Regulation no. 7 year 2017 about Geothermal Energy for Indirect Use, which states that a geothermal field developer has five years in the exploration phase to conduct a
feasibility study, starting from the date that the permission is issued by the Ministry of Energy and Mineral Resources (Kementerian ESDM). Should the developer have an issue in the first 5 (five) years, the exploration phase may be extended twice, for an addition one year period. This limited time granted by the government to conduct this exploration phase requires the developers to utilize the time as best as they can. One thing that might prolong the exploration is the long time needed to locate the large area required for the construction of the wellpad, basecamp, warehouse, access roading, water supply, etc. The larger the rig capacity that will be used, the longer the time needed to acquire the land and to construct the supporting facilities (Adityatama et al., 2020; Mackenzie et al., 2017).

2.3 Exploration Budget
The overall cost of a geothermal project may arise significantly because of the initial high-risk nature of exploration projects. Gehringer dan Loksha (2012) had explained the correlation between project risk, cumulative cost, and bankability of a geothermal project, including in the exploration phase. In practice, the cost of a project may rise much higher than expected, due to the occurrence of non-productive time (NPT) in drilling, which in Indonesia, is likely to be caused by (1) Social rejection (2) Undesired drilling hazards encountered.

In many cases in Indonesia, social rejections from locals are often encountered by geothermal developers, leading to the project time extension to accommodate the problems. The Baturaden geothermal project is one example among many others that have experienced rejections, with the main concern of the opposing group is the environmental issues, due to limited exposure and awareness on geothermal (Meijaard et al., 2019). This project time elongation will essentially result in higher overall cost due to the additional daily rate of a drilling rig.

In the early stage of geothermal development, operators often still do not have a fully developed mitigation plan to overcome undesired drilling hazards that possibly occur during the operation, such as lost circulation and stuck pipe incident. Lost circulation and stuck pipe incidents are proven to be two main NPT events that possibly elongate the duration of a drilling project, which also leads to the overspending of drilling rig daily rate (Nester, 2016). Both incidents are encountered at the Blawan-Ijen drilling campaign in East Java, 2016 and the impact is the longer drilling duration than previously expected, it went out of schedule by ~100 days (Sunarso, 2020).

Even though stuck pipe is a common problem in geothermal drilling, but as currently there are a lot of developers in Indonesia that are new to the geothermal industry (let alone drilling), authors’ experience showed that the stuck pipe risk is currently underappreciated by the management/developer, particularly new investors. The developers often see the drilling as a straightforward operation and is not subjected to any uncertainty that can cause problems, which is not the case in the exploration drilling.

2.4 Probability of Success (POS)
Probability of Success (POS) or usually referred as success ratio is a number that represents the likelihood of an event to be successful over all outcomes. Ways to estimate POS could be different for each decision makers, depending on the variables to consider. Common approach that is usually practised in measuring success is to hit the geothermal system that includes geological and geochemical information such as presence of clay cap and reservoir system, adequate formation pressure, permeability and temperature, and presence of benign fluid. While Sanyal et al. (2011) mentioned that in some cases well that are less than 3 MW in capacity is considered non-commercial although it cannot necessary being defined as unsuccessful wells.

Figure 3: Average drilling success rate versus number of wells using data from Indonesia (Sanyal et al., 2011)
Additionally, statistics of 215 wells conducted by Sanyal et al. (2011) have clearly concluded that the success rate in Indonesia fluctuates between 20-40% for first 30 wells and reach its stable rate at 62% while reaching approximately 90 wells. Despite these statistics are taken from mostly Pertamina’s wells, other geothermal developers in Indonesia will be likely to experience the same POS profile.

2.5 Comparison between Well Types

Well types that are going to be compared in this study are slimhole and big hole. Slimhole is commonly defined as any well with wellbore diameter less than 6" with typical vertical depth of 500-2,000 m (Mackenzie et al., 2017). Aside of its objectives to confirm adequate temperature for commercial production and to conduct productivity test, the use of slimhole in geothermal exploration delivers several advantages such as relatively lower cost due to less infrastructure required for wellpad requirement, thus may shorten the total exploration time, yet it is still capable of providing appropriate geologic and measurement or testing information in a way that big holes would do (Adityatama et al., 2020).

On the other hand, big hole is considered attractive in the exploration drilling as the developers are able to transform the well into production or injection wells later in the development stage due to its adequate wellbore size to deliver large amount of fluids up to the surface. Larger size of its diameter also allows the well to be drilled directionally and to be compatible with various logging tool sizes (Adityatama et al, 2020).

3. DECISION TREE ANALYSIS

In this study, authors simulate various scenarios that might be encountered by the decision makers once they about to enter the exploration drilling stage. This simulation involves decision tree analysis which is often considered to be the most common used decision-making tool due to its ability to help decision makers in evaluating and comparing various options and their results.

Several scenarios that will be simulated in this study are comparisons between combinations of well type selection (big hole, slimhole or combination) and probability of success (20-50%) that has been discussed in section 2.4. After these scenarios are created, authors proceed to the sensitivity analysis with variations of big hole drilling cost because this factor is one critical component in well type selection. Several assumptions used in the simulation will be discussed briefly in following subchapters.

3.1 Minimum Number of Exploration Wells

In this simulation, it is assumed that decision makers need minimum 3 (three) wells that successfully penetrate into the reservoir that has passed the project economical study from the temperature, permeability and fluid properties, so that the geo-science team is able to obtain justification to upgrade the resource classification from indicated resource to probable/proven reserve, which can be seen Figure 4 (Brotheridge, 2017). This assumption means that the number of wells to drill will be adjusted with the probability of success (POS) estimated by the geoscientist in the decision-making process. For instance, if the POS is assumed to be 30%, the minimum number of wells to drill in order to obtain 3 (three) successful wells is 10 (ten) wells. However, this does not necessarily translate into statement that developer should drill 10 wells to obtain 3 successful wells. It is possible for developer to have obtained 3 successful wells even before drilling 10 wells. Authors bring up this statistic to show that in the exploration stage, there is a possibility for developer to prepare cost and time equivalent with those required to drill 10 wells in order to obtain 3 successful wells.

![Figure 4](image_url)

Figure 4: Necessity of 3 (three) successful wells for upgrading the status from "Indicated Resource" to "Probable/Proven Reserve" (modified from Brotheridge, 2017)

3.2 Well Type

Well types to be compared are big hole and slimhole. Authors assume that the drilling cost of big hole and standard hole is approximately the same, regardless of their different capacity. Slimhole is chosen due to lowest drilling cost but still able to be used to obtain various subsurface data that have been discussed in section 2.5. The well depth is assumed to be 2,000 meter-MD.
3.3 Well Cost

Well cost is assumed to be US$ 2 million/well in average for slimhole with well total depth of 2,000 m-MD, which is based on the most recent slimhole drilling experience in East Java, Indonesia (Adityatama et al., 2020; Sunarso, 2020). With well number more than 3, authors believe this number is reasonable because the more wells to drill, the less cost required for rig service and other supporting equipment. This number already includes tangible cost (casing and wellhead), drilling and wellpad construction with the size of 40 m x 40 m.

According to Purwanto et al. (2018), approximate geothermal well cost in Indonesia is US$1,000 – 4,000/meter with the chosen cost baseline is US$3,960/meter. With well depth assumption of 2,000 m-MD, big hole drilling cost will be varied starting from US$5-10 million/well in average. This number already includes tangible cost (casing and wellhead), drilling and wellpad construction with the size of 100 m x 80 m. Authors believe that big hole drilling cost in Indonesia to be most likely US$6 – 8 million per wells in average. However, it should be taken into account that the application of standard or big hole is prone to the possibility of overbudget up to US$16 million per well as shown in Figure 5, meanwhile the application of slimhole has low possibility of overbudget and exceed US$5 million per well. This is substantially caused by the rental rate of conventional rig with an average of ~US$22,000/day for a 1,000HP rig compared with a slimhole rig that only costs ~US$8,000/day in average.

![Figure 5: Distribution of geothermal well cost in Indonesia (Purwanto et al., 2018; Purba et al., 2020)](image)

3.4 Well Value if Success

Decision makers often use different assumptions of well value if the well is proven to be successful after being drilled. Melosh (2017) suggests that US$5 million is representative for the information value provided by a slimhole well. For a big hole well, the proposed value is US$10 million with a calculation that the well is able to provide information value and potential steam flow. In this study, authors assume well value of slimhole is US$5 million and US$ 15 million for big hole if succeed.

The well value is simplified with an objective to facilitate the exercise in this study. Every geothermal developers are able to establish their own assumptions regarding the well values of each slimhole and big hole, and are allowed to adopt the method presented in this study to generate decisions related to the exploration strategy in the geothermal prospect working area.

3.5 Expected Value

Expected Monetary Value (EMV) or Expected Value (EV) represents the total amount of money (US$) expected to return for each scenario which outcomes are predicted in advance.

As an example, shown as Figure 6, authors estimate for scenario “A1-Big10M”:

\[
\text{Total EV} = \text{Success EV} + \text{Fail EV} \\
\text{Total EV} = (\text{POS} \times (\text{Total Well Value} - \text{Total Well Cost})) + (\text{POF} \times (-\text{Total Well Cost}))
\]
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It can be clearly seen that, in this study specifically, EV will be impacted significantly by the probability of drilling success that has been discussed in section 2.4. Calculating EV will be more complicated when the decision makers encounter more complex situations such as blind geothermal system, with very few or no surface manifestations.

<table>
<thead>
<tr>
<th>Total Well Cost</th>
<th>Scenario</th>
<th>Minimum # of wells to get 3 (three) successful wells</th>
<th>Remarks</th>
<th>Probability of Success (POS)</th>
<th>Probability of Failure (POF)</th>
<th># of slimhole wells</th>
<th># of big hole wells</th>
<th>Success EV</th>
<th>Fail EV</th>
<th>Total EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>24,000,000</td>
<td>A1</td>
<td>12</td>
<td>12 slim</td>
<td>20%</td>
<td>80%</td>
<td>0</td>
<td>12</td>
<td>7,200,000</td>
<td>-19,200,000</td>
<td>-12,000,000</td>
</tr>
<tr>
<td>72,000,000</td>
<td>B1</td>
<td>12</td>
<td>6 slim + 6 big</td>
<td>20%</td>
<td>80%</td>
<td>6</td>
<td>6</td>
<td>9,600,000</td>
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<tr>
<td>120,000,000</td>
<td>C1</td>
<td>12</td>
<td>12 big</td>
<td>20%</td>
<td>80%</td>
<td>0</td>
<td>12</td>
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<td>-96,000,000</td>
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</tr>
<tr>
<td>22,000,000</td>
<td>A2</td>
<td>11</td>
<td>11 slim</td>
<td>25%</td>
<td>75%</td>
<td>11</td>
<td>0</td>
<td>8,250,000</td>
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<tr>
<td>62,000,000</td>
<td>B2</td>
<td>11</td>
<td>6 slim + 5 big</td>
<td>25%</td>
<td>75%</td>
<td>6</td>
<td>5</td>
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<td>11 big</td>
<td>25%</td>
<td>75%</td>
<td>0</td>
<td>11</td>
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<tr>
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<td>A3</td>
<td>10</td>
<td>10 slim</td>
<td>30%</td>
<td>70%</td>
<td>10</td>
<td>0</td>
<td>9,000,000</td>
<td>-14,000,000</td>
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<tr>
<td>60,000,000</td>
<td>B3</td>
<td>10</td>
<td>5 slim + 5 big</td>
<td>30%</td>
<td>70%</td>
<td>5</td>
<td>5</td>
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<td>-42,000,000</td>
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<td>C3</td>
<td>10</td>
<td>10 big</td>
<td>30%</td>
<td>70%</td>
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<td>15,000,000</td>
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<tr>
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<td>A4</td>
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Figure 6: Expected Value (EV) Calculation for Each Scenario at Big Hole Cost of US$10M

3.6 Simulation Results

Authors have simulated 21 scenarios that each combines POS and well type selection (all slimhole, combination and all big hole). Figure 6 shows a simulation example with big hole drilling cost assumption of US$10 million. The simulation is then repeated with an objective to analyze the sensitivity by testing various big hole drilling cost between US$5-10 million with an increment of US$1 as shown in Figure 7.

Figure 7 shows that in the simulation with big hole drilling cost of US$8-10 million, decision of using all big hole and combination well types will never be economical compared to all slimhole for POS range of 20-50%. When big hole drilling cost is assumed to be US$7 million, it comes to a point where all well type selections (all slimhole, combination and big hole) become economically equal at POS of 50%, and this simulation suggests the decision makers to all slimhole.

When the big hole drilling cost is under US$7 million, “all big hole” scenario shows more interesting EV compared to combination and slimhole at POS more than 40% (big hole cost US$6M) and POS more than 30% (big hole cost US$5M).

In this study, authors only conduct sensitivity test with various big hole cost US$ 5-10 million because it is assumed to be highly possible for a deviation to occur in such pattern shown in actual geothermal well cost in Indonesia that has been summarized by Purwanto et al. (2018). Slimhole well cost is set at US$2 million per well, as the authors believe slimhole is more likely to have lower deviations remembering drilling rig equipment used in the drilling activity is much simpler and has lower daily rate.

The EV is not simulated for POS above 50% because the authors believe it is difficult to be certain to have POS above 50%. This argument is supported by the statistics of 215 wells in Indonesia by Sanyal et al. (2011).
Figure 7: Sensitivity of EV vs POS towards various well type applications (All Slimhole, Combination and Big Hole) with big hole cost variation between US$5 million to US$10 million

4. DISCUSSION

This study has simulated 21 scenarios by combining POS and 3 well type applications (all slimhole, combination slimhole and big hole, all big hole). The sensitivity of the total expected values as the simulation result are then assessed with big hole drilling cost, that leads the author to conclude several things as follows:

1. Slimhole becomes more attractive for developers in terms of EV when big hole well cost is approximated to be around US$8-10M and POS less than 50%. Authors believe this case along with the numbers are very likely to happen in many geothermal explorations in Indonesia.

2. At big hole well cost of US$7M and POS 50%, simulation shows same value of EV at all well type selections. At this condition, authors suggest decision makers to consider the total cost, as the “all big hole” application will require US$42M total cost to drill 6 big hole wells.

3. Big hole becomes attractive when it only costs the developer US$6M with POS less than 40% or US$5M with POS less than 30% despite authors believe these two cases are very difficult to have in the exploration stage due to the assumed cost in this study that already includes wellpad construction cost and are average values from all wells drilled. In addition, at the exploration stage, the team has just been formed and adjustments are very likely to happen and leads to what’s called as “learning curve”.

4. From the side of downhole or subsurface data acquisition, a numerous amount of publications has stated that a properly designed slimhole is able to obtain downhole data required in the exploration stage, including flow testing.

5. Decision makers must thoroughly recognize various kinds of data required in the running exploration stage to decide what well type selections to use. As an example, drilling rigs used in slimhole drilling are generally designed in advance to have coring abilities, meanwhile big hole drilling rig has to be equipped with additional tools to be able to proceed coring operation, which possibly leads to additional cost and operation duration significantly. Other challenge is to ensure the outside diameter (OD) of tools used in big hole drilling rig to be able to enter the well at the targeted depth.

This study is admittedly still in the preliminary phase, with several room for improvement as follow:

1. Assessing the method for obtaining more representative well values of slimhole and big hole. This is important especially for slimhole, because unlike big hole that can use potential productivity of the well, the value of information obtained by slimhole well cannot be directly converted into MW or USD.

2. Improving and give more detail to the definition of successful wells (success criteria) and probability of success (POS).

3. Gathering more actual drilling data to provide more representative cost baselines for slimhole and big hole well in Indonesia.

4. Developing a more comprehensive drilling risk comparisons between slimhole and big hole with supporting evidences, which might include risks of non-completion to TD, stuck pipe risk, risk of unable to obtain reliable reservoir data.

Nevertheless, through simulations in this study, authors argue that the use of slimhole in the exploration drilling is capable in accelerating explorations in Indonesia, especially in those geothermal fields that are considered challenging to be inferred through surface manifestations or geophysical surveys. Lower cost required to drill slimhole and much easier drill site preparation process compared to big hole will lead to an easier decision-making process as well.
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Exploration phase comes with an objective to prove the presence of a geothermal system underneath the earth surface, and this resource proving process can only be confirmed by drilling some wells. If this resource was not proven to exist, efforts in minimizing the financial loss caused by the dry holes should be made in advance.

Subsequently, each geothermal developer is free to develop their own exploration strategy according to their own “risk appetite”. The methods and arguments presented in this paper are intended to be an example and serve as considerations for any decision-makers in selecting the appropriate and most optimum well type to satisfy the exploration objectives. There are numerous methods and decision-making tools available, and it is up to the decision-maker to use the methods with their own data and assumptions. But the most important thing is that the final decision of selecting the well type or exploration strategy should be based on a proper decision-making process and not just an arbitrary process if Indonesia wants to accelerate its geothermal development.

REFERENCES


Purba, D.P., Adityatama, D.W., Umam, M.F., and Muhammad, F.: Key Considerations in Developing Strategy for Geothermal Exploration Drilling Project in Indonesia, Proceedings, 44th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, United States (2019).


