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Drilling Rig Selection for Geothermal Exploration: Evaluating Factors and Decision-making Criteria

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ABSTRACT

The selection of an appropriate drilling rig is crucial for the success of geothermal exploration projects, as it directly influences both operational efficiency and cost. This paper delves into the critical factors and decision-making criteria for selecting drilling rigs in the context of geothermal exploration, emphasizing the importance of making informed and strategic choices. It underscores the necessity of aligning rig capabilities with the specific needs of each project, focusing on optimizing operational efficiency and cost-effectiveness.

This study introduces a framework for evaluating and comparing drilling rigs, which considers key technical specifications, environmental impacts, and economic factors. Moreover, the paper highlights the significance of conducting thorough market surveys as an integral part of the rig selection process. These surveys provide vital insights into the latest technological advancements, market trends, and availability of rigs, thereby enabling stakeholders to make well-informed decisions based on comprehensive market intelligence.

Furthermore, the paper emphasizes the collaborative efforts required among geoscientists, drilling engineers, and project managers, advocating for a multidisciplinary approach to ensure that the chosen rig aligns with all aspects of geothermal exploration. By offering a systematic set of criteria and emphasizing the value of market surveys, the framework aids stakeholders in selecting drilling rigs that not only fulfill the technical and budgetary requirements but also enhance the prospects for successful project outcomes. This methodical approach aims to streamline the rig selection process, thereby contributing to more efficient and effective geothermal exploration endeavors.

1. INTRODUCTION

1.1 The Importance of Geothermal Exploration for Indonesia

Indonesia is one of the countries that is estimated to have the most considerable geothermal energy potential in the world, with an estimated potential of approximately 18,000-megawatt electricity (MWe). However, from that vast potential, currently, Indonesia only utilizes approximately 13% of the total potential, which is 2,356 MW installed capacity (ThinkGeoEnergy, 2023). This utilization rate is low compared to New Zealand, which used 38% of its total potential, while the United States used 21% of its total potential (Asokawaty et al., 2020). To increase geothermal energy utilization in electricity, the Government of Indonesia (GoI) is currently targeting 5,486 MWe of geothermal power plant installations by 2030 (Direktorat Panas Bumi, 2022).

Many published studies and papers have discussed the challenges the Indonesian government and the geothermal developers will face in developing geothermal projects in Indonesia (Ibrahim et al., 2005; IGA, 2014; Poernomo, 2015; Darma, 2016; Purba, 2018; Umam et al., 2018; Purba et al., 2019; Purba et al., 2020). Despite those challenges, the exploration phase is currently the most critical phase that Indonesia needs to take into action to seriously achieve the national geothermal target. Figure 1 shows that Indonesia has only been developing a few geothermal areas for geothermal power generation despite Indonesia's vast potential.

Figure 1 (Pusdatin ESDM, 2020) also shows Indonesia's distribution of geothermal areas according to each area's progress. Areas colored green, light green, and yellow indicate areas that have been through a preliminary survey, commonly the 3G survey. In some areas, the government, academic institutions, and geothermal developers have conducted surveys such as the temperature gradient hole or deep slim hole. Pink indicates the areas ready for development, whereas red indicates areas that have already been developed.

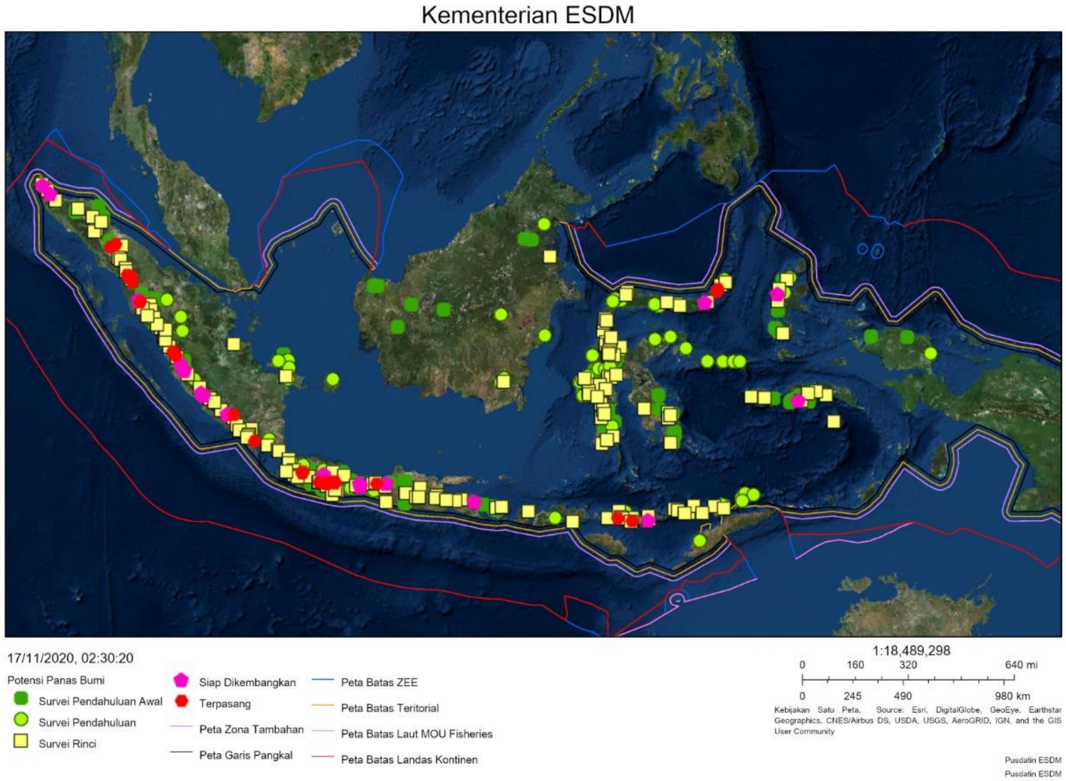

Figure 1: Maps of geothermal potential area in Indonesia with its status (Pusdatin ESDM, 2020).

While Table 1 shows the list of the 22 geothermal prospect areas or concession areas still in the exploration stage and is expected to contribute to achieve the aforementioned national geothermal target.

Table 1: List of Indonesia's Geothermal Prospect Areas/ Concession Areas in the Exploration Stage (modified from Direktorat Panas Bumi, 2022; Siahaan et al., 2023).

No.	Name of the Prospect Area / Concession Area	Location	Estimated Potential Capacity (MWe)	Developer
1.	Tulehu	Maluku	31	PT PLN (Persero)
2.	Gn. Ungaran	Central Java	150	PT PLN (Persero)
3.	Atadei	East Nusa Tenggara	40	PT PLN (Persero)
4.	Songa Wayaua	North Maluku	42	PT PLN (Persero)
5.	Danau Ranau	South Sumatera	210	PT PLN (Persero)
6.	Oka Ile Ange	East Nusa Tenggara	50	PT PLN (Persero)
7.	Kepahiang	Bengkulu	254	PT PLN (Persero)
8.	Gn. Sirung	East Nusa Tenggara	152	PT PLN (Persero)
9.	Tangkuban Perahu	West Java	375	PT PLN (Persero)
10.	North Patuha (WKP Patuha)	West Java	55	PT Geo Dipa Energi
11.	Candradimuka (WKP Dieng)	Central Java	50	PT Geo Dipa Energi
12.	Candi Umbul Telomoyo	Central Java	92	PT Geo Dipa Energi
13.	Gn. Arjuno Welirang	East Java	302	PT Geo Dipa Energi
14.	Gn. Rajabasa	Lampung	283	PT Supreme Energy Rajabasa
15.	Rawa Dano	Banten	385	PT Sintesa Banten Geothermal
16.	Baturaden	Central Java	258	PT Sejahtera Alam Energy
17.	Telaga Ngebel	East Java	120	PT Bakrie Darmakarya Energi
18.	Seulawah Agam	Aceh	223	PT Geothermal Energi Seulawah
19.	Gn. Lawu	Central Java & East Java	332	PT Pertamina Geothermal Energy

No.	Name of the Prospect Area / Concession Area	Location	Estimated Potential Capacity (MWe)	Developer
20.	Kotamobagu	North Sulawesi	410	PT Pertamina Geothermal Energy
21.	Jaboi	Aceh	107	PT Sabang Geothermal Energy
22.	Gn. Talang – Bukit Kili	West Sumatera	90	PT Hitay Daya Energy
TOTAL			**4,011**	

Indonesia's geothermal energy target certainly requires collaborative efforts from all stakeholders, including the government, geothermal development companies, investors, off-taker, academics, researchers, affected local communities, and various institutions and companies involved in geothermal development projects. Looking at the geothermal prospects and fields map in Indonesia (Figure 1 and Table 1), the collaboration of these stakeholders should be focused primarily on efforts to complete the exploration phase in various prospect areas in Indonesia. Indonesia cannot achieve the national geothermal target without going through the exportation stage, which is the most crucial stage and has many challenges.

The level of difficulty and risk of Indonesia's geothermal exploration phase is mainly due to a combination of 2 (two) primary factors:

1. The high level of uncertainty regarding the existence of economically viable geothermal resources underneath the ground (resource risk) and,
2. The high cost of drilling activity proves the existence of these geothermal resources.

Some additional factors that intensify the geothermal exploration challenges (Utami, 2010; Chandra et al., 2021a; Umam et al., 2018; Adityatama et al., 2020; Poernomo, 2015; Purba, 2018; Purba et al., 2019) are as follows:

1. Geothermal prospect/exploration areas are usually in a volcanic setting with many geohazards, minimal road access, and hilly terrain.
2. There still needs to be a greater understanding of the local community living around the geothermal prospect area regarding geothermal projects. The low awareness often results in a higher level of community rejection of geothermal exploration projects.
3. Number of geothermal exploration experts in Indonesia from all disciplines (e.g., geoscience, drilling, environmental, social) is less than the number of exploration projects to be completed. When combining this situation with the absence of a certification program for geothermal exploration experts, many personnel with inadequate competence have the chance to run geothermal exploration projects in Indonesia.
4. In the exploration phase, there is usually not yet the certainty of the electricity prices, which creates difficulties for investors in deciding to spend the exploration budget.

Therefore, stakeholders in Indonesia need to be able to collaborate to solve the main challenges of geothermal exploration projects that have been discussed in various publications and forums to achieve the national geothermal target finally. Discussion of the challenges of geothermal exploration will be discussed in more detail in the next section.

1.2 Paper Objectives

This paper explores various factors to consider when choosing the appropriate rig for a geothermal exploration project. The selection process extends beyond mere “drill a hole” to incorporate the construction of a well that serves exploration purposes effectively. To provide context, the paper initiates a discussion on the objectives and challenges of geothermal exploration, particularly in Indonesia. Additionally, it discusses drilling cost components in a geothermal project to underscore the importance of carefulness in rig selection.

Finally, it seeks to catalyze additional discussions by leveraging the practical insights of drilling engineers or managers within the Indonesian geothermal community to identify other critical factors in planning geothermal exploration drilling in Indonesia, with a particular emphasis on drilling rig considerations. It is believed that if rig selection aligns from the beginning, the likelihood of the exploration project achieving its goals in a safe manner and within budget will be significantly higher.

2. EXPLORATION DRILLING PROJECT

Before digging into a more detailed discussion on rig selection, this paper will first explore the concept of geothermal exploration in general and its challenges in Indonesia. This discussion aims to provide context on why rig selection is crucial and should be approached with care.

2.1 Exploration Drilling Objective: The Only Method to Prove the Geothermal Resources in the Subsurface

Geothermal exploration activities are generally carried out in stages starting from activities that require the least cost and effort, then increasing to higher-cost activities as the confidence level in the project's feasibility increases.

The exploration activities can be divided into three main activity groups as follow:

1. *Surface surveys/studies* – This activity mainly includes collecting subsurface data from the surface. The assigned team performs the surveys on the surface; therefore, the cost is much cheaper than the cost of drilling a well. However, the team needs to interpret the obtained data since it does not come directly from the subsurface. The typical surface studies may include geological mapping, geochemical sampling, magnetotelluric, gravity, other geophysical data collection, LiDAR, topographic surveys, and hydrogeological surveys. It is common to conduct social mapping and environmental baseline preliminary studies to support project decisions.

2. *Data interpretation and integration, conceptual modeling, and resource assessment* – These are the activities of integrating and interpreting the data obtained through the surface survey described above. These activities include laboratory analysis, data cleansing, interpretation, and integration. Integrating all relevant data will produce a final product called a conceptual model. It is a common practice in the industry to use the conceptual model to estimate the amount of commercial geothermal reserves in the prospective area. Based on the assessment, if the geothermal developer considers the geothermal resource attractive for further research, the project will proceed to more complex and expensive activities, drilling deep wells. Drilling deep wells into predicted reservoir depth can prove the existence of geothermal resources but require high capital expenses and involve higher risks.

3. *Deep well exploration drilling* – Drilling is commonly becoming the final activity in a geothermal exploration project because, with a deep well, the geothermal developer expects to prove the existence or the absence of a commercial geothermal system below the surface. Geothermal developers will only decide to perform deep well drilling if they already have various supporting information considering the high cost and difficulty of drilling.

As the only way to prove the existence of a commercial geothermal system underneath the ground, the geothermal developer must plan and execute an exploration drilling project carefully. Exploration well(s) will only be valuable if they can reach the planned depth target and acquire the targeted subsurface data. The subsurface data includes formation characteristics, rock properties, fluid characteristics, rock permeability, and reservoir temperature (Chandra et al., 2021a). It can be acquired directly through various methods such as coring, cutting sampling, measurement while drilling (MWD), and wireline downhole logging.

2.2 Exploration Drilling Challenges and Learning Curve

Geothermal drilling in Indonesia has been carried out significantly on several prospects since the 1970s where exploration drilling was carried out in the Kamojang, Dieng, and Darajat field (Hochstein and Sudarman, 2008). Drilling activities continued intensively since the 1980s to the late 1990s, this was related to exploration activities and to fulfill steam supply in supporting the generation capacity in Kamojang, Salak, Darajat, and Sibayak fields which commercially operated within that period with total installed capacity of 778 MW by the end of 2000 (Purwanto, 2021). Drilling activity was slowed in the early 2000s as a result of the government's decision to postpone state-owned enterprise, private, and government-related projects due to the country's monetary and fiscal condition, as enacted by Presidential Decree Number 39 of 1997. From 2002 to the present, drilling activities have continued.

Theoretically, all personnel involved in a geothermal project should know that the exploration wells are crucial for the decision-making process toward the next stage. As explained earlier, the primary objective of exploration drilling in geothermal energy development is to locate, assess, and determine the size, temperature, and quality of geothermal resources in a specific area. However, not all personnel involved in a geothermal exploration drilling project may have the same understanding of the objectives of drilling exploration wells.

Therefore, the geothermal company might need to ensure their personnel has received sufficient information and training to deal with technical and non-technical challenges, such as regulation/legal, social, and environmental. Some of the challenges in geothermal exploration drilling in Indonesia can be summarized as follows (summarized from Purba et al, 2019; Chandra et al., 2021a; Utami, 2010; Chandra et al., 2021b; IGA, 2014; GeothermEx, 2010; Purwanto et al., 2018; Purba et al., 2020; Adityatama, 2020; Purba et al., 2021):

1. *Low accuracy of subsurface data* - at the exploration stage, the available subsurface data are generally still generated based upon surface studies' interpretations, so drilling planning will be carried out based on data with very low accuracy and low reliability. The drilling team may expect various surprises from formations at unexpected depths, such as massive lost zones, reactive formations, unconsolidated formations, shallow steam pockets, deeper top of reservoirs, and troublesome paleosol formations. Realizing that the geoscientific prognosis provided by the geoscience team may not match actual conditions, the drilling team must make a mitigation plan for these various scenarios or potential subsurface hazards. Failure to make a proper mitigation plan will significantly increase drilling costs and might stop the drilling team from completing the well as planned.

2. *Newly formed exploration team* – currently, in Indonesia, companies conducting geothermal exploration activities are generally newly formed with a combination of several sponsoring companies. A new company implies that the team combines several key personnel who might be their first time working together and are unfamiliar with each other's working methods and communication styles. Furthermore, due to the shortage of geothermal personnel, geothermal companies often recruit personnel from similar industries such as oil and gas or mining. Although similar, drilling challenges in the geothermal environment are significantly different compared to the oil and gas and mining environments. The failure of geothermal companies to build a competent, experienced, professional, and coherent exploration team will cause the exploration projects to run slower and ultimately increase project costs.

3. *Higher project costs compared to development stage drilling* – despite the explanation of the two points above regarding the lack of subsurface data and the exploration team being generally newly formed, the cost of exploration drilling itself is generally higher than the cost of drilling at the development stage. The higher cost is because of the project scale. In terms of scale, the number of wells drilled in the exploration stage is usually less than those drilled in the development stage. The number of these wells affects the unit prices proposed by rigs and support services providers. The more wells drilled, the lower the unit price for all drilling services, equipment, and materials.

4. *Low acceptance of local communities* – not only from the technical side but exploration challenges also come from the non-technical aspect, especially those related to local communities. In the exploration stage, people living in Indonesia's geothermal prospect areas are generally not adequately educated about the benefits of geothermal projects for their livelihood. Often, geothermal companies focus too much on planning from the technical aspect and forget about engagement with local communities, resulting in community rejection.

5. *Indonesia does not yet have a geothermal drilling database* – Indonesia does not currently have a database that collects and integrates data and lessons learned from geothermal drilling activities from all geothermal development companies in Indonesia. If Indonesia has established this kind of database, geothermal developers in Indonesia can easily take advantage by learning from other geothermal projects and avoiding the same mistakes. Without this database, each geothermal developers can only learn from its respective projects, isolated from each other.

6. *Geohazards related to volcanic area* - Indonesia, located on the Pacific Ring of Fire, faces various geohazards that pose challenges to developing geothermal projects. These include earthquakes, volcanic eruptions, landslides, flood, phreatic eruption, and tsunamis, which can disrupt or damage power plants and infrastructure, leading to production losses and environmental impacts. Moreover, active, and potentially active volcanic systems add to the uncertainty of siting and drilling for geothermal resources. Therefore, proper assessment and management of geohazards are critical for the successful implementation and operation of geothermal projects in Indonesia and demand robust risk mitigation and response strategies to minimize their impacts.

7. *Being an archipelago country and poor infrastructures* - Indonesia faces several challenges in developing its geothermal resources as an archipelago country. The country's geography, with its numerous islands spread across vast distances, presents logistical difficulties in transporting equipment and personnel to remote locations. Additionally, the lack of infrastructure and limited access to resources such as water and power can impede the development of geothermal projects. Furthermore, diverse cultures and languages across the islands can also create challenges in gaining local community support for geothermal projects. To overcome these challenges, effective collaboration and communication with local communities and investment in infrastructure and resources are essential for the successful development of geothermal energy in Indonesia.

"Learning curve" might be suitable to describe all the challenges above. It means the team is still learning and gathering information in the exploration stage, which is the beginning of a geothermal development project. Along with the increase in information, data, experience, skills, and communication quality within the exploration team, the drilling success rate will generally increase, as Sanyal (2011) shows in Figure 2.

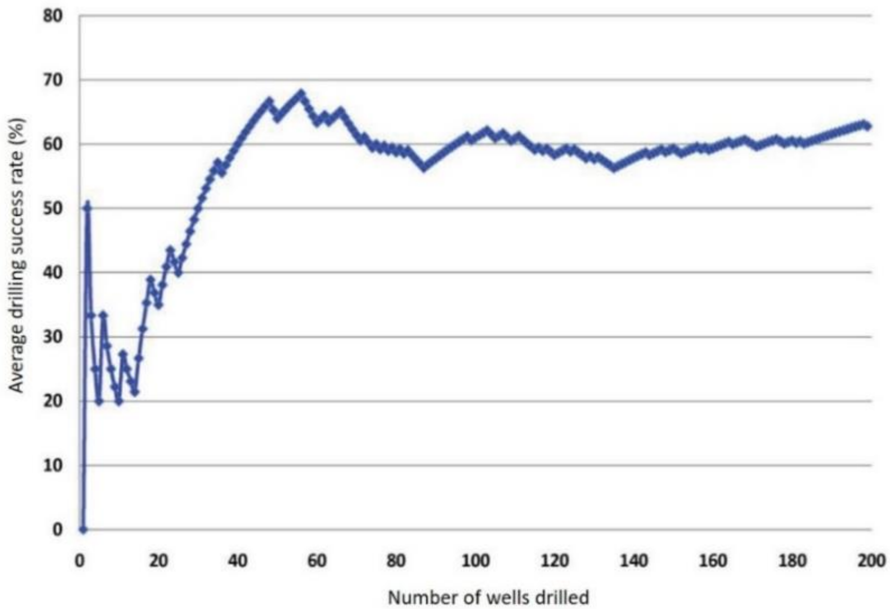

Figure 2: Average drilling success rate versus number of wells using data from Indonesia (Sanyal et al., 2011).

Geothermal developers or exploration teams need to address and mitigate the various exploration challenges outlined above to avoid an increase in the cost of exploration projects that leads to an increase in the overall cost of geothermal development projects. A significant increase in overall project costs can eventually cause the project to become uneconomical and may stop the project. The cost of geothermal exploration projects in Indonesia currently ranges from USD 15-50 million, with drilling costs as the most significant cost component (Direktorat Panas Bumi, 2022; GeothermEx, 2010; Purwanto et al., 2018; Purba et al., 2020; Siahaan et al., 2023). Based on the authors' observations, many geothermal companies in Indonesia have spent more than 50 million USD for geothermal exploration in a prospective area with inconclusive results.

In addition to project cost overruns, another factor that can cause an exploration project to stop is work incidents. If not managed properly, some work incidents may impact the environment and residents around the project. Recent incidents in geothermal drilling projects in Indonesia (DPR RI, 2022a; DPR RI, 2022b; MCG, 2022; MCG, 2020; SOL, 2019) indicate the difficulty of geothermal drilling activities in Indonesia. Like other energy development projects, human and environmental safety must be the top priority for any geothermal drilling exploration project in Indonesia.

2.3 Drilling Cost Component in a Geothermal Project

Geothermal drilling project is complex since it involves multiple stakeholders, organizations, and equipment (Bodley, 2018; Gul and Aslanoglu, 2018). Inadequate project management could spin a project out of control (Discenza and Forman, 2007). Southon and Gorbachev (2003), Kipsang (2015), Bodley (2018), and Otieno (2016) clearly mentioned the paramount of planning phase and understanding of all drilling activities to control the drilling cost. Additionally, Hole (2008) mentioned that there are two categories of influences that are driving up the cost of drilling, the one that we have little or no control over and the one that we can control. Thus, the authors use this section to discuss several aspects that play crucial roles in a geothermal drilling project to understand the wide variation of drilling cost observed in Indonesia.

In any geothermal project, drilling activities are performed in the exploration and development phase. The purpose of drilling activities in each of these phases is different, which can be described as follows:

1. In the exploration phase: the aim is to answer the question of the presences, size and viability of a conventional geothermal system in the area with drilling cost as low as possible.
2. In the development phase: the aim is to meet the number and size of the production and injection wells required to exploit the geothermal resources as economically and sustainably as possible.

One of the challenges that is often discussed in the geothermal community in Indonesia is the high cost of drilling activities. Worldwide, including Indonesia, shows that every geothermal project cost mainly dominated by two major components, which are power plant construction and drilling. In addition to that, Purwanto et al. (2018) mentioned that for a 55 MW geothermal project in Indonesia, drilling cost accounts for 58% of total project cost. Figure 3 provides an example of cost distribution for 3 geothermal development projects in

Indonesia occurring during the period of 2010 - 2024 on the islands of Java and Sumatra. These three projects demonstrate a significant portion of drilling cost components compared to the overall expenses, ranging from approximately 30% to 50%.

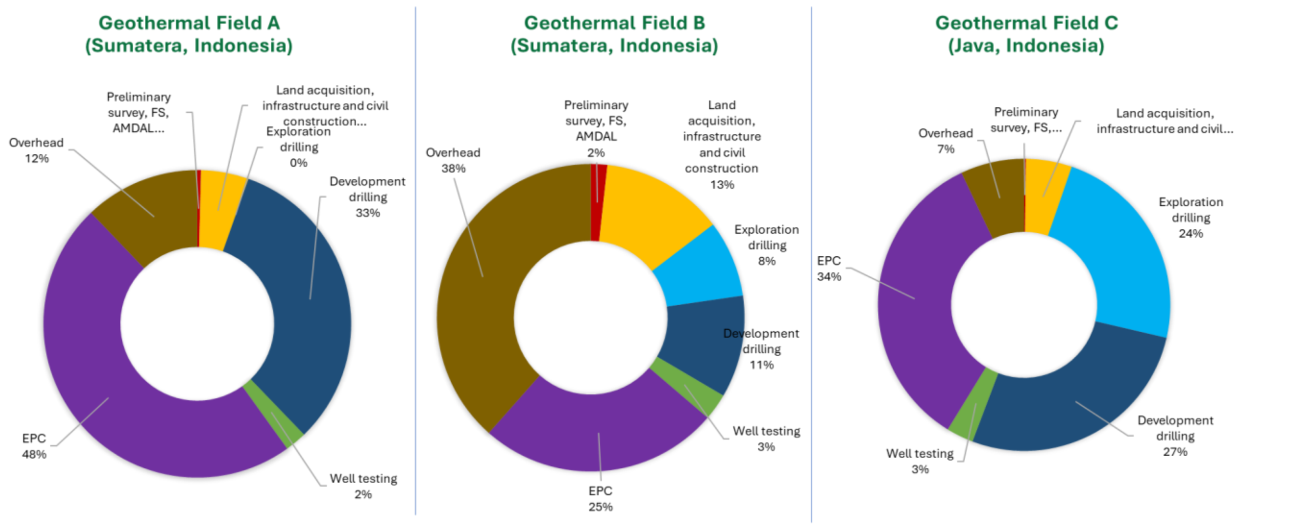

Figure 3: Example cost distribution of three geothermal projects in Indonesia during the period 2010 - 2024 on the islands of Java and Sumatra.

With a significant portion of expenses and coupled with high risks associated with subsurface uncertainties, it is critical for the Indonesian geothermal community to explore methods to optimize drilling costs, thereby enhancing the economic viability of geothermal projects.

The drilling project complexity, as an implication of multiple parties involved, must be managed by the geothermal company by legally translate the verbal agreements, with all related parties, into a written contract document formulating the collaboration mechanism. Typically, in a geothermal drilling project in Indonesia, there are about 18-25 contracts required if each service and materials are treated individually (Purba et al., 2020), including tangible such as casing, wellhead, and master valves. Figure 4 shows the example of actual cost distribution based on drilling services. The chart summarizes actual drilling cost from two geothermal fields in Indonesia that authors have on hand at the time of this study.

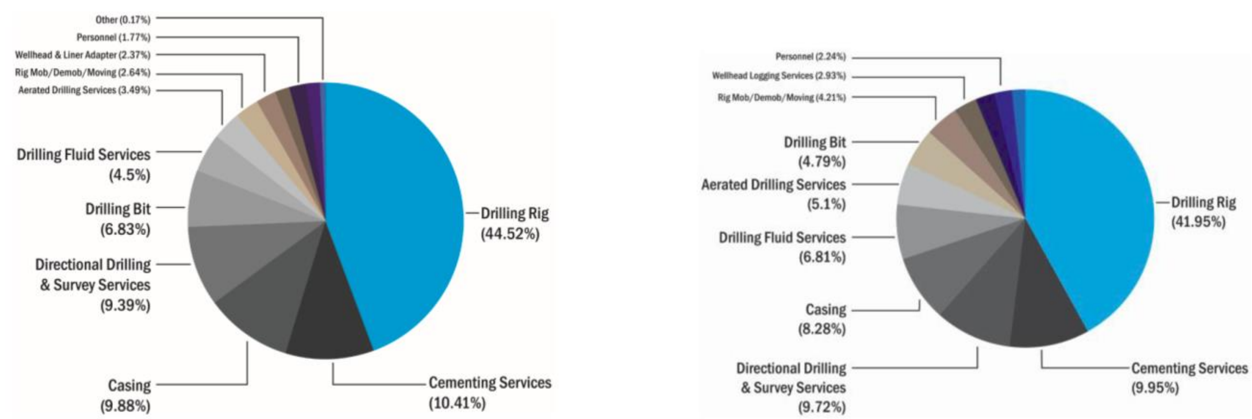

Figure 4: Summary of actual drilling cost from two geothermal fields in Indonesia. One field is in Central Java (left) and the other is in West Java (right).

The chart shows that both fields have relatively similar drilling cost allocation. The top contributors are drilling rig, cementing, directional drilling, casing, drill bit, and drilling fluid/mud, which in total contribute to roughly 80% of total drilling cost. This is consistent with Pareto law stating that "80% of the effects come from 20% of the causes". If the pattern of this cost distribution is always consistent throughout all geothermal drilling operation in Indonesia, then the drilling team should focus more on managing these six drilling service contracts that influence more than 80% of drilling costs instead of investing equal portion of time and effort to all 25 contracts.

Cost wise, the same rules apply for the drilling project, as in any project, the total cost incurred is the result of multiplication of unit price with quantity. The higher the unit price that we agreed in the contract with our drilling partners, the higher the total cost that will occur. Similarly, with quantity, the more drilling days, tools, equipment, drilling materials, consumables, and personnel we consume or utilize, the higher the total drilling cost appears in our project. In this study the authors chose to discuss the top four drilling cost contributors, which is drilling rig.

To provide additional examples, this study successfully collected actual geothermal drilling data from the 51 geothermal wells in Indonesia (1997 – 2023), presented in a different manner (Figure 5). It is evident that the portion of drilling rig costs is significantly higher compared to other cost components. Focusing on optimizing drilling rig costs will directly impact the overall geothermal project costs. The second ranking after “Rig” is "Others," which consists of a combination of costs including wireline logging, mud logging, waste management, H2S, and several other minor cost components.

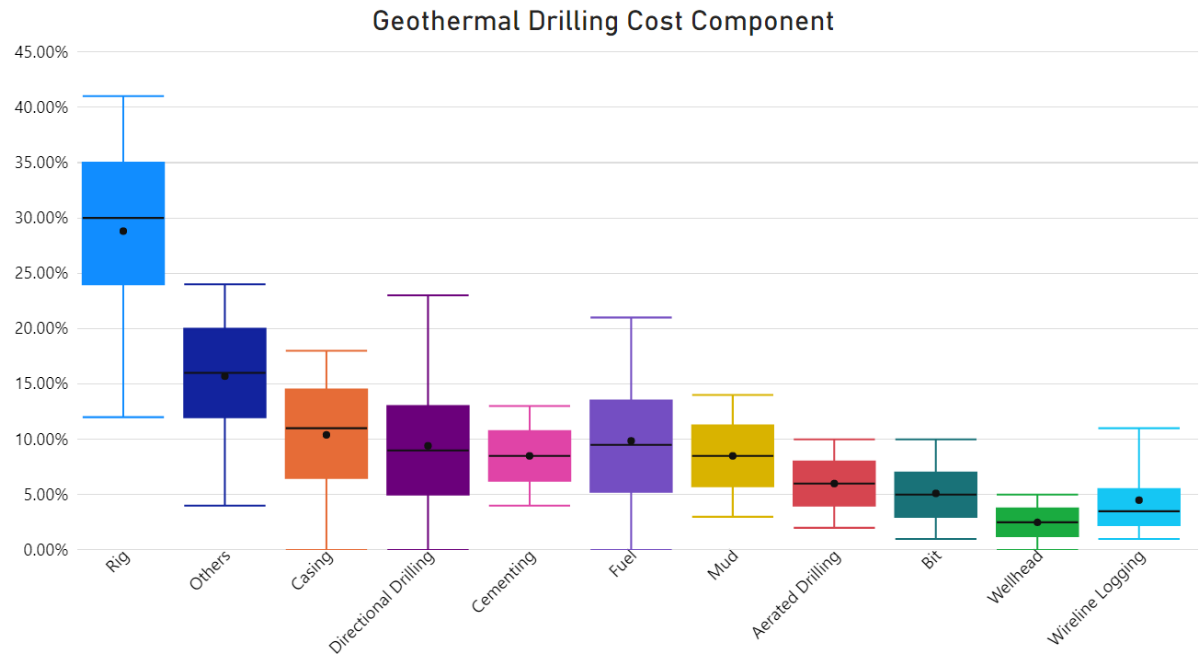

Figure 5: Distribution of Drilling Cost Component from Actual Drilling Project (51 wells) in Indonesia Combined (1997 – 2023)

2.4 Why Selecting Fit-for-Purpose Rig is Important?

As discussed in the previous section, the rig accounts for the largest portion, 40-45% of the total drilling cost (Figure 4 and Figure 5), making it the primary focus of this discussion. A drilling rig is the main equipment in any drilling operation. It is important that the drilling engineer in charge properly calculates the maximum anticipated load and pressure to avoid procuring over-specification rig and eventually lead to higher overall drilling cost.

Generally, in terms of load and pressure rating, the 1,500 HP and 2,000 HP rigs are considered to have more than enough capacity to drill standard wells/big holes to the depth of 2,000 - 2,500 meters in Indonesia. But those capabilities require higher fuel consumption, larger footprint and higher ODR compared to a 1,000 HP rig. Table 2 shows a comparison of several types of drilling rigs used in Indonesia, based on their capacity, which are commonly expressed in horsepower (HP).

Table 2: General comparison of conventional rotary drilling rig capacity (land operation) that typically available in Indonesia (Purba et al., 2020).

Comparison Items	750 HP	1,000 HP	1,500 HP	2,000 HP
Hookload	410,000 lbs	550,000 lbs	750,000 lbs	1,000,000 lbs
Hoisting capacity	10 Lines - 300,000 lbs	10 Lines - 400,000 lbs	12 lines - 750,000 lbs 10 Lines - 640,000 lbs 8 Lines - 530,000 lbs	12 lines - 840,000 lbs 10 Lines - 700,000 lbs 8 Lines - 560,000 lbs
Setback capacity	200,000 lbs	250,000 lbs	500,000 lbs	600,000 lbs
Mast standing	1 stand - 2 joints	1 stand - 2 jts or 3 jts	1 stand - 3 joints	1 stand - 3 joints
Rotary table opening	27.5"	27.5"	37.5"	37.5"
Clearance height under rotary table	16 feet	20 - 24 feet	27 - 29 feet	27 - 29 feet
Mud pump size	2 x 800 HP	2 x 1,000 HP	3 x 1,300 HP	3 x 1,600 HP
Top Drive System (TDS)	TDS250 Ton	TDS350 & 500 Ton	TDS350 & 500 Ton	TDS350 & 500 Ton
Number of loads	60 - 80 loads	80 - 100 loads	80 - 120 loads	80 - 140 loads
Minimum footprint size	80 x 70 meter	100 x 80 meter	130 x 90 meter	130 x 90 meter
Daily fuel consumption (average)	4,000 - 6,000 liter	6,000 - 8,000 liter	7,500 - 9,000 liter	8,000 - 10,000 liter
Typical drill pipe stock	5,000 feet (1,524 m)	7,500 feet (2,286 m)	10,000 feet (3,048 m)	12,000 feet (3,658 m)
Mud system capacity	1,000 bbl	1,000 - 1,500 bbl	1,500 - 2,000 bbl	2,000 bbl
Typical standpipe pressure rating	4" at 5,000 psi	4" at 5,000 Psi	4" at 5,000 - 10,000 psi	4" at 5,000 10,000 psi

It is uncommon for geothermal companies in Indonesia to own and operate the rig. They usually rent the rig and crew from a rig company, which serves both geothermal and oil and gas industries. This is the reason why many geothermal projects are also affected by the continuously changing rig rental price following oil price fluctuations as mentioned by Gul and Aslanoglu (2018). When oil prices are high, the oil and gas industry will most likely be executing drilling activities aggressively, which creates difficulty for geothermal companies to get drilling rigs. Thus, in such circumstances, the geothermal drilling engineer often will be forced to contract a rig with the capacity higher-than-required due to rig availability issue.

Typically rig size or capacity is one of the main factors that influence the rig rental rate, which influenced by (Purba et al., 2020):

1. Casing design: Well type (i.e., big hole, standard hole, or slimhole). The bigger the hole size the higher rig capacity required.
2. Casing setting depth: Depends on casing setting depth for each hole section / casing size. Mainly defined by the Top of Reservoir (TOR) and deepest feed zone targeted. Hole problems (i.e., reactive formation, unconsolidated formation, and shallow permeable zone) contribute to the casing setting depth decision-making.
3. Deepest feed zone depth: Mainly defined by the Top of Reservoir (TOR) and deepest feed zone targeted. Hole problems such as reactive formation, unconsolidated formation lost circulation, and shallow permeable zone are some considerations used in defining the casing setting depth.

In brief, to effectively optimize rig costs, a drilling engineer should be capable of determining the minimum specifications of a rig that can efficiently drill and construct geothermal wells according to the design. The following section will specifically discuss several examples of criteria that must be fulfilled to calculate the minimum requirements of a rig in a hypothetical geothermal exploration project.

3. RIG SIZING: EVALUATING FACTORS AND DECISION-MAKING CRITERIA

3.1 Rig Sizing Process: Why and How

Referencing Table 2 in the earlier section, it is evident that rig capacity selection cannot be arbitrary, as it significantly impacts costs, especially daily rental expenses and fuel consumption. Furthermore, larger rigs may require more expansive wellpad areas and longer mobilization times. Hence, selecting a rig according to the project's needs is crucial.

The objective of this paper is to provide preliminary rig sizing based on proposed well design. The purpose of rig sizing is to determine the appropriate size and capability of the drilling rig required to drill the well safely, efficiently, and economically. The rig size is determined based on various factors such as the depth of the well, the diameter of the wellbore, the drilling method to be used, and the anticipated drilling flow rate.

The rig's size, power, and capacity must match the drilling program's requirements to ensure efficient drilling operations. For instance, if the well depth is deep, the rig must have sufficient power and drilling capacity to penetrate the formation and reach the target depth. Similarly, the rig's size must match the drilling program's requirements to ensure that it can fit on the drilling site and operate efficiently.

The importance of rig sizing lies in the fact that the rig size and capability have a significant impact on the overall cost and timeline of the drilling project. A rig that does not meet the minimum criteria for the drilling program may not be able to perform the necessary tasks, resulting in project delays, increased costs, and even safety hazards. On the other hand, a rig that is too large (overcapacity) for the job may be unnecessary and result in unnecessary extra expenses.

Figure 6 provides a simple flowchart outlining the typical actions performed by a drilling engineer during rig sizing, which are generally similar between the petroleum and geothermal industries. The difference lies in the input parameters used in the analysis. During this process, experienced drilling engineers also rely on their expertise to quickly verify the reasonableness of the analysis results.

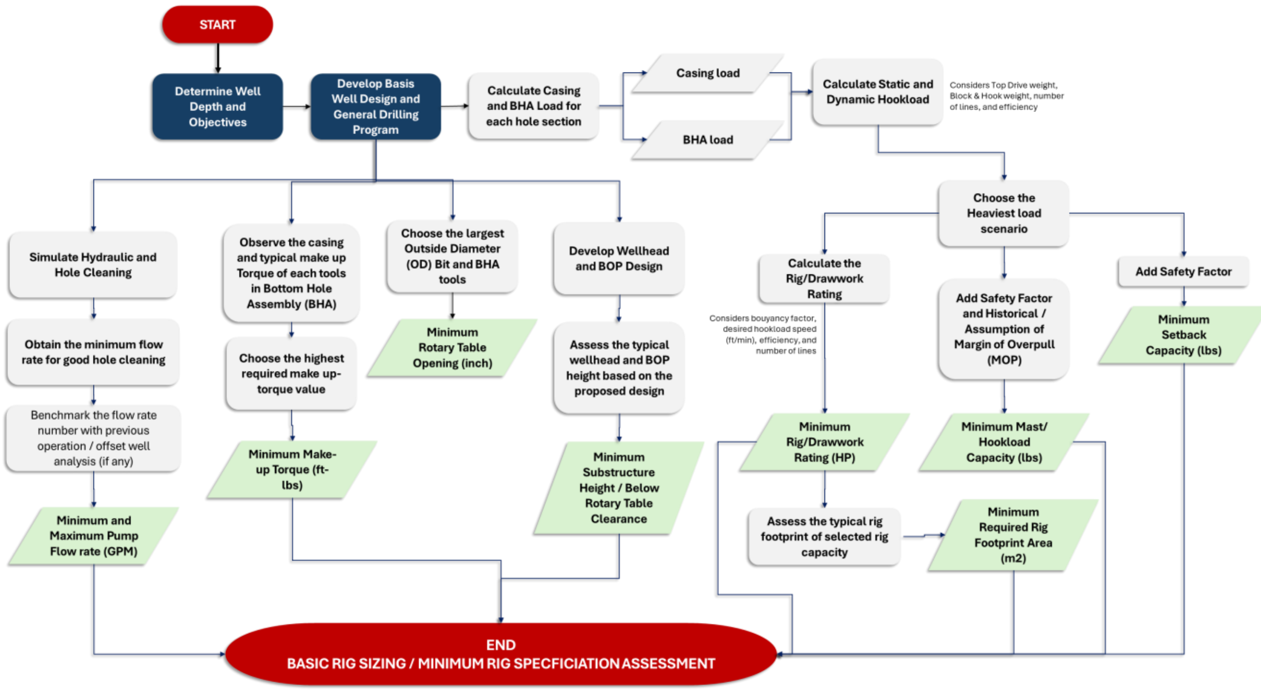

Figure 6: Simplified Flowchart of Rig Sizing Process

Proper rig size also affects the safety and efficiency of the drilling operation. A rig that is too small may not have the necessary equipment or capacity to handle unexpected situations or emergencies that may arise during the drilling process. The determination of minimum rig criteria also helps in evaluating and selecting the appropriate rig for the drilling program. By knowing the minimum rig criteria, drilling engineers can evaluate the different rigs available in the market and select the most cost-effective option that meets the drilling program's requirements.

Furthermore, Figure 6 illustrates that the beginning of rig sizing involves obtaining clarity from the geoscience team regarding the objectives of drilling and obtaining subsurface prognosis to serve as the basis of well design. While it may seem straightforward, miscommunication between the drilling and geoscience teams can result in an ill-suited well design and ultimately selecting an inappropriate rig. Several real-world examples highlight instances where rig capacity was insufficient to reach the desired depth target due to communication failures regarding subsurface hazards during the planning phase.

To provide an example of how the flowchart presented in Figure 6 is applied, this paper draws data from an actual geothermal project in a field in Indonesia, which is presented in several following sections. It's worth noting that the example application is condensed compared to the steps outlined in Figure 6 for simplification, allowing direct focus on the critical load calculation often considered when selecting rig capacity.

3.2 Subsurface Prognosis and Well Design

Subsurface prognosis plays a crucial role in the foundation of well design and the minimum rig specifications required for a geothermal drilling project. This process entails evaluating the subsurface environment to inform critical decisions regarding the design and operational aspects of drilling wells, including those for geothermal energy extraction.

Subsurface prognosis helps identify potential hazards like abnormal pressure zones, unstable rock formations, or high-temperature zones. Understanding these risks beforehand allows for designing wells that can withstand such conditions, thereby reducing the likelihood of operational failures or accidents. Understanding the subsurface conditions is essential for determining the type of rig and equipment necessary for the project. Factors such as depth, pressure, temperature, and the mechanical properties of the subsurface materials dictate the required rig capabilities, ensuring that the selected rig is neither under- nor over-specified.

The subsurface data essential for geothermal well design and rig sizing need to be gathered and analyzed to ensure the operational success and safety of drilling activities. As shown in Figure 7, there are several data that are required for developing basis of well design. This minimum data set begins with basic well data, which encompasses well targeting information detailing both surface and subsurface coordinates. Such data are pivotal for delineating the well's precise location and plotting its trajectory, thereby optimizing the path to effectively intersect the permeability target. The trajectory data informs the drilling direction and angle, crucial for reaching the permeability target and optimize energy extraction.

The top of reservoir (ToR) depth information is also important for well design, which serves as a benchmark for setting the production casing depth that ensures the reservoir is effectively isolated and the well's structural integrity is maintained. Equally important is establishing the well's total depth, which influences various aspects of the drilling operation, including limitation of equipment selection and operational planning. Temperature and pressure prognoses are vital for selecting materials and designing components that can endure the harsh subsurface environment, while fluid chemistry analysis informs the choice of corrosion-resistant materials and fluid management systems.

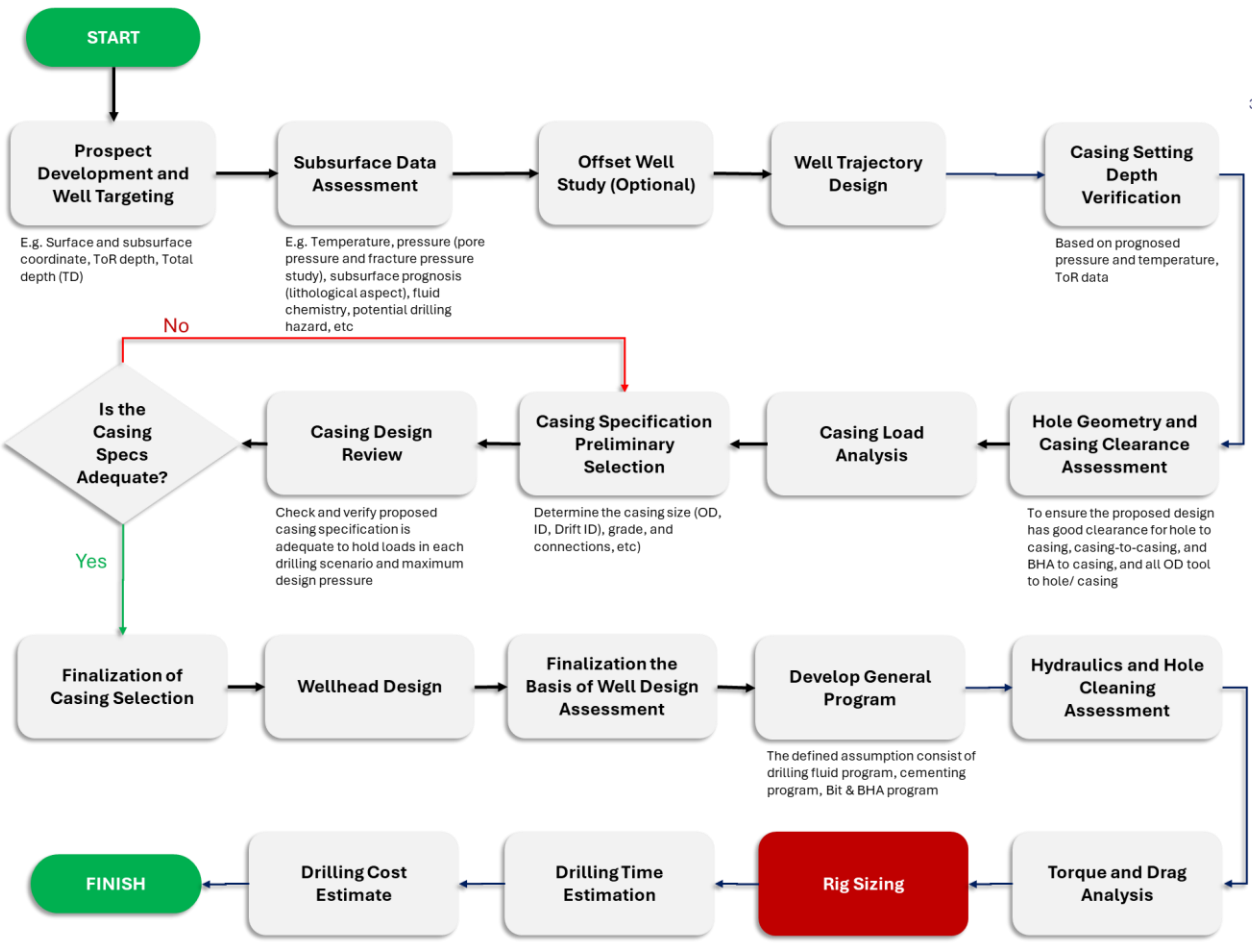

Figure 7: Basis of Engineering Well Design Typical Workflow

In the context of rig sizing, the crucial data includes casing design and bit & BHA design, which are necessary for calculating Mast/Hookload Capacity, Drawwork/Rig Rating, Setback Capacity, Torque, and Pump Flowrate. The minimum substructure height calculation requires BOP and wellhead design, both tightly influenced by pressure and temperature data.

As briefly mentioned earlier, determining the appropriate rig size involves gaining a clear understanding from the geoscience team about drilling objectives and acquiring subsurface prognosis to inform well design. Despite its apparent simplicity, miscommunication between drilling and geoscience teams can lead to poorly matched well designs and the selection of an unsuitable rig. Real-world cases emphasize situations where rig capacity fell short of reaching the drilling target depth due to communication breakdowns regarding subsurface hazards during the planning stage.

To provide context from other angle, Figure 8 illustrates a simple illustration of how rig cost, which is the largest cost component in a drilling project, is influenced by various factors. Rental prices and the number of drilling days will be primarily influenced by well design factors, which are greatly affected by well objectives, subsurface conditions, subsurface data acquisition plans, and drilling hazards. Various information will be needed by the Drilling Engineer and will only be obtained from the Geoscience team.

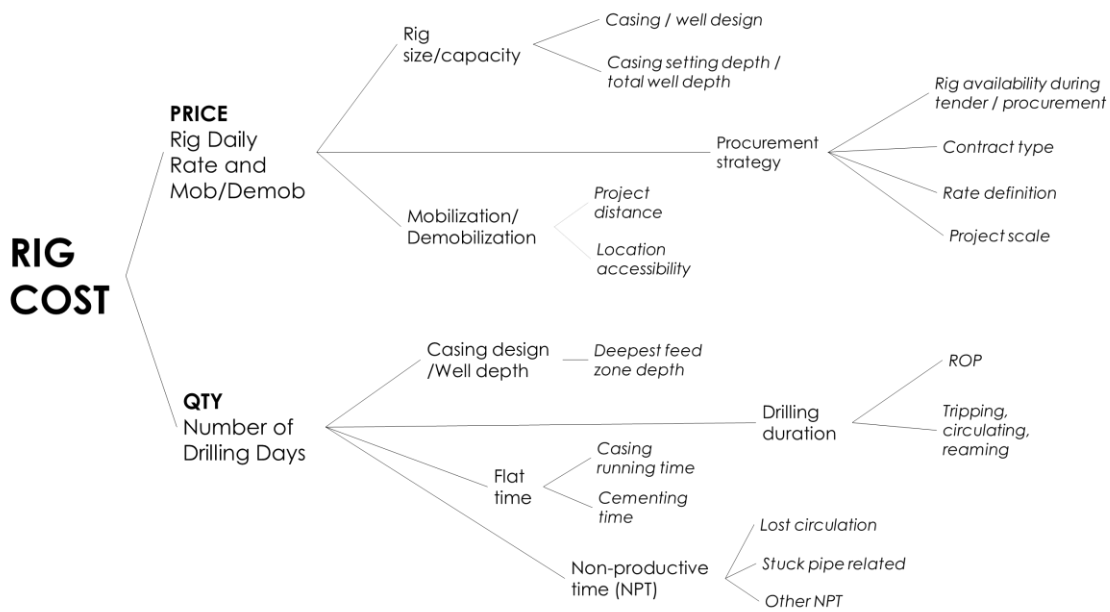

Figure 8: Simplified Illustration of Factors Impaction Rig Cost as Considerations in Rig Selection Process (modified from Purba et al., 2020)

The factors related to subsurface prognosis and well design can be summarized as follows (Table 3):

Table 3: Description of several factors related to subsurface prognosis and well design that should be considered when conducting rig sizing and rig selection (modified from Purba et al., 2020).

Factors	Remarks	Impact
Casing design	The casing design for geothermal wells is generally quite typical, where well types are categorized as big hole, standard hole, or slimhole. The larger the hole size, the higher the rig capacity required.	Directly influences the rig capacity.
Casing setting depth	Depends on casing setting depth for each hole section / casing size. Mainly defined by the Top of Reservoir (TOR) and deepest feed zone targeted. Hole problems (i.e. reactive formation, unconsolidated formation and shallow permeable zone) contributes to the casing setting depth decision-making.	Directly influences the rig capacity.
Deepest feed zone depth	Mainly defined by the Top of Reservoir (TOR) and deepest feed zone targeted. Hole problems such as reactive formation, unconsolidated formation lost circulation, and shallow permeable zone are some considerations used in defining the casing setting depth.	Be Directly influences the casing setting depth and the casing design
Potential zone causing lost circulation and stuck pipe	In the case of geothermal drilling, lost circulation zones are commonly encountered, and if not managed properly, they can lead to stuck pipe incidents. The rig's ability to accommodate drilling strategies when encountering lost circulation zones and other problematic zones (unconsolidated, swelling, etc.) must be considered from the outset by understanding the types of formations to be encountered.	Directly influences the rig capacity and casing setting depth

3.3 Rig Sizing Calculation: Hoisting Capacity

Simply, the derrick/mast capacity can be defined as the capacity of the derrick/mast to withstand the load of the BHA/drillstring when it is running into the well which usually stated in pounds (lbs). The hoisting capacity of the derrick or mast is an important factor in the rig sizing assessment for geothermal exploration drilling projects because it determines the maximum weight of the drill string and associated equipment that can be lifted during drilling operations.

The objective of assessing the derrick or mast hoisting capacity is to ensure that the drilling rig selected for the project has sufficient capacity to handle the weight and size of the drilling equipment and materials required for the geothermal exploration drilling program. This is critical for the safe and efficient execution of the drilling operations and helps to minimize the risk of accidents, equipment damage, and operational downtime.

If the derrick or mast hoisting capacity is insufficient for the required drilling equipment and materials, it can lead to delays, cost overruns, and safety hazards. Therefore, it is essential to preliminary determine the hoisting capacity of the derrick or mast and select a drilling rig that has sufficient capacity to meet the needs of the project.

For example, in a drilling project, if it is found that the heaviest BHA load expected is the BHA when drilling 12-1/4" hole section with total 338,943.32 lbs, and it is found that the heaviest casing load is when running casing 13-3/8" with total load 292,543.95 Lbs then the hook load capacity is usually used for the heaviest identified load with consideration of margin of overpull which in this assessment is assumed with 100,000 lbs and apply safety factor which ranging from 110% - 125%.

Considering the heaviest load which is BHA 12-1/4" load with total load 338,943,32lbs, the minimum rig hoisting capacity required to execute proposed well design and drilling program is 548,679.15 lbs. It also must be noted that the heaviest BHA load above is the weight on air, which is very unlikely to happen as the wellbore is supposed to be filled with drilling fluid/water during the drilling operation. The summary of minimum rig hoisting capacity is summarized in Figure 9.

Load Summary			
BHA Load		**Casing Load**	
BHA 26"	115371.56 lbs	Casing 20"	284020.82 lbs
BHA 17-1/2"	251600.86 lbs	Casing 13-3/8"	292543.95 lbs
BHA 12-1/4"	338943.32 lbs	Tie-Back 13-3/4"	197410.76 lbs
BHA 9-7/8"	325512.92 lbs	Casing 9-5/8"	219896.79 lbs
BHA 7-7/8"	333117.43 lbs	Liner 10-3/4"	197410.76 lbs
BHA 6-1/8"	176760.09 lbs	Liner 8-5/8"	140330.85 lbs
		Liner 7"	136871.46 lbs
		Liner 5-1/2"	116115.13 lbs
MOP (Assumption)	100000 lbs		
SF	1.25		
Minimum Rig Hoisting Capacity	548,679.15 lbs		

Figure 9: Example of BHA Load and Casing Load Summary

3.4 Rig Sizing Assessment: Drawwork Rating

Simply, the rig rating / drawwork rating can be defined as the power possessed by the rig when carrying out certain activities and certain depths which generally stated in horsepower (HP). The drawworks is a hoisting mechanism that is responsible for raising and lowering the drill string during drilling operations. The drawworks rating is an important factor in the rig sizing assessment for geothermal drilling projects because it determines the maximum depth and size of the hole that can be drilled.

This sub-section contains results of the calculation of drawwork capacity (HP) required to carry out drilling operations based on the BHA that have been explained in the previous section. The objective of assessing the drawworks rating is to ensure that the drilling rig selected for the project has sufficient power to lift and lower the drill string and associated equipment during drilling operations.

The drawworks rating is critical for the safe and efficient execution of the drilling operations and helps to minimize the risk of accidents, equipment damage, and operational downtime. If the drawworks rating is insufficient for the required drilling depth and hole size, it can lead to delays, cost overruns, and safety hazards. Therefore, it is essential to preliminary determine the drawworks rating and select a drilling rig that has sufficient power to meet the needs of the project.

In general, the hoisting equipment on the rig consists of drawwork, overhead tools (top drives, traveling blocks, hooks, elevators), and drilling lines (Herianto, 2008). The values for parameters such as drill pipe weight, block and hook weight, top drive weight, lifting speed, and margin of overpull (MOP) which will affect the amount of power/rating that will be required by the rig in carrying out an operation. The heavier the equipment used and the faster the lifting speed, the greater the amount of force needed in the drawworks.

To drawworks rating, it is necessary to calculate the static hook and dynamic hook at the first place. Static hook is a heavy accumulation of BHA, block and hook, and also top drive. While the dynamic hook is the sum of the static hook, fast line and deadline taking into account the overpull and safety factor (SF). Then, this value can be converted into the power needed by the drawwork by involving the value of lift speed, efficiency, and the number of lines owned by the rig (Herianto, 2008).

For example, continuing the previous example (Figure 9) of the drawwork rating calculation, to execute the proposed well design require at least 1,264 HP rig. For safety factor, it is recommended to upsize the calculated minimum requirement to 1500 HP drawwork rating. Moreover, the availability of 1300 HP rig is also not much in Indonesia's market. The summary of minimum drawwork rating calculation is summarized in Figure 10.

DRAWWORKS			
Heaviest Drill String (lbs)	338,943	lbs	12-1/4" drill string+ top drive+block
Heaviest Drill String (lbs) with bouyancy 0.87	295,838	lbs	assume hole full of water
Desired Minimum Hookload Speed (fpm)	110	feet/min	
Hook HP = Total Hoist Load x Hoist Speed / 33000	986	HP	
Drawworks HP = Hook HP / Eff^no. lines	**1,258**	HP	assume 8 lines

Minimum Rig HP 1500 HP

Figure 10: Drawwork Rating Calculation Summary

3.5 Rig Sizing Assessment: Rotary Table Opening

Simply, the rotary table opening can be defined as the size of the hole in the rotary table that will be passed by the bit or tubular that usually stated in inches (in). It is an important factor in rig sizing assessment for geothermal drilling projects because it determines the maximum size of the drill string, casing, and associated equipment that can pass through the rotary table during drilling operations.

The importance of rotary table opening for rig sizing assessment in geothermal drilling projects lies in the fact that it limits the size of the drill string and associated equipment that can be used during drilling operations. If the rotary table opening is too small, it can restrict the size of the drill string, which may not be sufficient for the required drilling depth and hole size. Thus, it is essential to accurately determine the rotary table opening and select a drilling rig that has sufficient clearance to meet the needs of the project.

For example, it is found that in this project, the largest OD size of the bit and BHA that will be used based on the current drilling program is 26" of drilling bit. This size is the minimum size of the rotary table opening that must be accommodated by the rig.

3.6 Rig Sizing Assessment: Make-Up Torque

Make up torque can be defined as the amount of force required to securely tighten the threaded connections between section of BHA, casing, and other downhole tools. In short this is the ability of the rotary function on the rig in connecting tools (make-up) that generally stated in foot pounds (lbs- ft).

The importance of makeup torque in rig sizing assessment is that it helps to determine the minimum torque capacity of the drilling rig's top drive or iron roughneck, which are the primary tools used to make up or break out drill string connections.

Generally, deciding the minimum make up torque is by identifying the make-up torque from various BHA and casing. For example, in this project, based on the assessment, the highest make up torque is on drill collar (DC) with size 8" that generally used in 26" hole section until 12-1/4" hole section which the estimated make up torque is 57,400 ft-lbs. The summary of minimum make up torque assessment is summarized in Figure 11.

Casing	Pounders (lbs/ft)	Grade	M/U Torque (ft-lbs)					
			Long round thread (LC)			Short round thread (SC)		
			Minimum	Optimum	Maximum	Minimum	Optimum	Maximum
Surface 20"	133	K-55	10,890 ft-lbs	14,520 ft-lbs	18,150 ft-lbs	9,399 ft-lbs	12,532 ft-lbs	15,665 ft-lbs
Prod Casing 13-3/8"	68	L-80	N/A	N/A	N/A	7,413 ft-lbs	9,524 ft-lbs	11,905 ft-lbs
Tie Back 13-3/8"	68	L-80	N/A	N/A	N/A	7,413 ft-lbs	9,524 ft-lbs	11,905 ft-lbs
Prod Casing (Contingency) 9-5/8"	47	L-80	6,690 ft-lbs	8,920 ft-lbs	11,150 ft-lbs	5,827 ft-lbs	7,769 ft-lbs	9,711 ft-lbs
Liner 10-3/4"	40.5	K-55	N/A	N/A	N/A	3,377 ft-lbs	4,502 ft-lbs	5,628 ft-lbs
Liner 7"	23	K-55	2,558 ft-lbs	3,410 ft-lbs	4,263 ft-lbs	2,320 ft-lbs	3,094 ft-lbs	3,867 ft-lbs

OD BHA (in)	ID BHA (in)	Thread Type	Typical M/ U Torque
DC 8"	2 1/2	6 5/8" REG	57,400 ft-lbs
DC 8"	2 13/16	6 5/8" REG	53,300 ft-lbs
DC 8"	3	6 5/8" REG	50,700 ft-lbs
DC 6-1/2"	2 1/4	4 1/2" IF NC 50	29,700 - 32,700 ft-lbs
DC 6-1/2"	3	4 1/2" IF NC 50	29,700 - 32,700 ft-lbs
DC 4-3/4"	1 3/4 - 2 1/2	3 1/2" NC-38	10,000 - 11,000 ft-lbs

OD BHA (in)	ID BHA (in)	Thread Type	Typical M/ U Torque
DP 5"	4 2/7	G-105, 4 1/2" IF, NC 50	25,600 - 30,700 ft-lbs
DP 4-1/2"	3 17/50	G-105, 4 1/2" IF, NC 46	20,500 ft-lbs
DP 3-1/2"	2 3/5	G-105, 3 1/2" IF, NC 38	9,600 - 11,500 ft-lbs
DP 3-1/2"	2 3/5	S-135, 3 1/2" IF, NC 38	10,000 - 12,100 ft-lbs

Figure 11: Make up Torque Assessment for Proposed Casing and Drill Collar

A sufficient makeup torque capability is critical for efficient drilling operations and minimizing non- productive time. Without adequate makeup torque capacity, the drilling crew may struggle to make up connections properly, which can result in safety hazards, stuck pipe, or damage to the downhole equipment. Therefore, it is important to consider the makeup torque requirements when selecting a drilling rig for geothermal exploration projects.

3.7 Rig Sizing Assessment: Pump Flowrate

Simply, the pump flowrate and pressure rating can be defined as ability of pump on the rig to perform drilling activities such as circulation during drilling operation for hole cleaning and killing if well control activity occurred which generally stated in gallons per minute (GPM) and pounds square inch (psi).

In this section, the minimum flowrate assessment is used to determine the minimum rig pump capacity to supply drilling fluid during drilling operation. The assessment for this section is determined based on hydraulic and hole cleaning simulation and excel calculation that incorporates various assumption and best practice that used for geothermal drilling operation. For example, the summary of minimum flowrate for each hole section are summarized in Figure 12 and Figure 13.

Hole Section & Mud Weight	Min. flow rate for good hole cleaning	Flow rate limitation due to mud motor / MWD / another tool	Max. surface pressure
26” hole using 9 ppg MW	1177 gpm	600 – 1200 gpm (9-5/8" mud motor)	3482 psi using 1200 gpm
17-1/2” hole using 9 ppg MW	1179 gpm	600 – 1200 gpm (9-5/8" mud motor)	3667 psi using 1200 gpm
12-¼" hole using 8.33 ppg	796 gpm	600 – 1200 gpm (9-5/8" mud motor)	3060 psi using 800 gpm
9-7/8" hole using 8.33 ppg	701 gpm	300 – 900 gpm (8" mud motor)	2795 psi using 800 gpm
8-1/2" hole using 8.33 ppg	601 gpm	300 – 600 gpm (6-¾" mud motor)	2974 psi using 700 gpm
7-7/8" hole using 8.33 ppg	654 gpm	300 – 600 gpm (6-¾" mud motor)	3020 psi using 750 gpm
6-1/8" hole using 8.33 ppg	689 gpm	No mud motor on BHA	3424 psi using 500 gpm

Figure 12: Minimum Flowrate Assessment based on hydraulic and hole cleaning simulation for Each Hole Section.

Pumps Requirement							
Hole Section	26	17 1/2	12 1/4	9 7/8	8 1/2	7 7/8	6 1/8
Drill pipe OD (in)	5	5	5	5	5	5	3.5
Mud weight (ppg)	9	9	8.4	8.4	8.4	8.4	8.4
PV	8	8	8	8	8	8	8
Diameter of Cutting Dp (in)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Slip Velocity (fpm)	45.05	45.05	47.93	47.93	47.93	47.93	47.93
Minimum Pump Rate (gpm)	1197.00	1034.27	489.35	283.74	184.88	144.84	98.86
Best practice pump rate to anticipate mud degradation (due to temperature)	1197.00	1034.27	978.69	851.22	554.64	434.51	296.58

Figure 13: Minimum Flowrate Assessment based on various best practices.

3.8 Summary: Minimum Rig Specification Requirements

After carrying several assessments that already explained in the previous subsection, the summary of rig sizing assessment result is presented in Figure 14, showing the primary outcome: minimum rig specification requirements.

Aspects	Minimum Rig Specification Requirement	Basis of Minimum Requirement
Mast / Hook Load Capacity	548,679.15 lbs	Heaviest BHA load which is 12-1/4" BHA configuration + MOP assumption (100,000 lbs) with safety factor 25%
Setback Capacity	416,396.79 lbs	Minimum capacity of racked Drill string during open hole section in reservoir zone (12-1/4") + safety factor 25%.
Rotary Table Opening	27-1/2"	Biggest OD of bit and BHA that will be run in hole during operation (26"). Considering clearance 1-1/2", the minimum rotary table opening should be 27-1/2".
Below Rotary Table Clearance	Typical 4.5 – 8 m, depends on Wellhead and BOP height	Typical wellhead in geothermal has height range from 1.7 – 2.5 m, and BOP 3.5 – 4.5 m when drilling 12-1/4" hole section.
Make Up Torque	57,400 lbs-ft	Make up torque of 8" Drill Collar with ID 2-1/2"
Minimum Flowrate	250 gpm	Estimated flowrate in 6-1/8" hole section (perforated liner contingency 5-1/2")
Maximum Flowrate	1200 gpm	Based on hydraulics and hole cleaning simulation in 26" hole section and based on flowrate calculation during blind drilling scenario

Figure 14: Basis of Rig Requirement for the Example Project Well

3.9 Selecting the Rig

After determining the minimum rig specifications required, the next step typically undertaken by a drilling engineer is to compare these minimum requirements against the actual specifications of rigs available in the market. An example summary comparison of minimum requirements with typical rig specifications in Indonesia is provided in Figure 15 and Figure 16.

In this case, it was found that the project necessitates a rig with a capacity of 1,500 HP, whereas a rig with a capacity of 1,000 HP can only partially fulfill the minimum rig specification requirements. It is important to note that in this scenario, the selection is limited to three rigs: 750 HP, 1,000 HP, and 1,500 HP, assuming that only one type of rig is available at each capacity level. In reality, two rigs with the same capacity, such as 1,000 HP, may have different specifications and, in some aspects, may resemble a 1,500 HP rig. Therefore, when selecting a rig, it is crucial for a drilling engineer to conduct a market survey beforehand to gather as many available options as possible in the market at that time to increase the likelihood of choosing a rig that is fit-for-purpose.

Aspects	Minimum Rig Specification Requirement	750 HP Spec. / Rating	1,000 HP Spec. / Rating	1,500 HP Spec. / Rating	Remarks on Prefered Rig Adequacy
Drawwork Rating	1,264 HP	750 HP	1000 HP	1500 HP	1,500 HP Rig
Mast / Hookload Capacity + MOP 100,000 lbs	550,768.88 lbs	250,000 lbs	400,000 lbs	680,400 lbs	1,500 HP Rig
Setback Capacity + MOP 100,000 lbs	425,768.68 lbs	250,000 lbs	412,000 lbs	500,000 lbs	1,500 HP Rig

Figure 15: Comparison of Minimum Requirement with Typical Rig Specification in Indonesia for Load Rating

Aspects	Minimum Rig Specification Requirement	750 HP Spec. / Rating	1,000 HP Spec. / Rating	1,500 HP Spec. / Rating	Remarks on Prefered Rig Adequacy
Rotary Table Opening	27.5"	17.5"	27.5"	27.5"	1,000 HP & 1,500 HP Rig
Below Rotary Table Clearance	Typical 4.5 – 8 m, depends on Wellhead and BOP height	5.49m / 18 ft	5.49 m / 18 ft	9.45 m / 31 ft	1500 HP Rig
Make Up Torque	57,400 lbs-ft	32,000 ft-lbs (475 HP Top Drive)	45,000 ft-lbs (600 HP Top Drive)	60,000 ft-lbs (800 HP Top Drive)	1,500 HP Rig
Minimum Flowrate	300 gpm	162 gpm	189 gpm	180 gpm	All Rig Spec
Maximum Flowrate	1200 gpm	1739 gpm (750 HP x 3 pumps, 7" liner)	1754 gpm (1000 HP x 3 pumps, 7" liner)	2118 gpm (1600 HP x 3 pumps, 7" liner)	All Rig Spec

Figure 16: Comparison of Minimum Requirement with Typical Rig Specification in Indonesia for RT Opening, M/U Torque and Pumping Flowrate

4. MARKET SURVEY: THE REALITY CHECK

4.1. Market Survey for a Drilling Project

As briefly discussed earlier, after completing rig sizing, a Drilling Engineer typically conducts a market survey to explore available rig options for the project at hand. Generally, rig sizing results for geothermal projects in Indonesia with the depth of 2,000 to 2,500 mMD recommend the use of rigs ranging from 1,000 to 1,500 HP, with a 1,200 HP rig being an optimal choice. However, there is a possibility that the project timelines do not align with rig availability in the market, making it challenging to find rigs with specifications of 1,000 HP or 1,200 HP. Consequently, projects are forced to utilize rigs with 1,500 HP specifications, significantly exceeding the minimum requirements and incurring higher costs.

Considering the importance of market survey as part of rig selection, this paper briefly discusses the market survey process and its challenges. Adityatama et al., (2023) have outlined the market survey process (Figure 17), which ultimately contributes to cost estimation. This flowchart is also utilized to assess rig availability in the market. Typically, the rig availability check process is conducted in parallel with the survey of other drilling services.

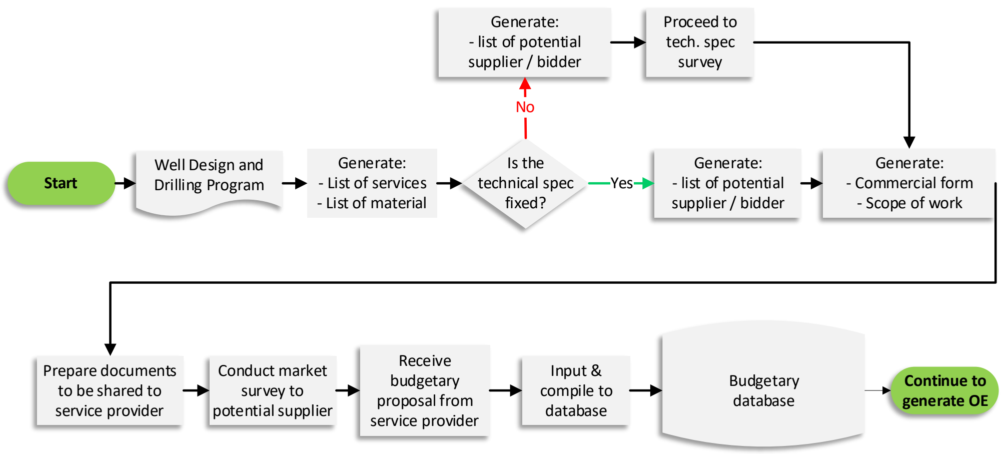

Figure 17: The Simplified Workflow of Market Survey and Cost Estimates

The market survey aims to obtain market price estimates for the previously prepared commercial form and scope of work. This step is done by carrying out formal correspondence to send the commercial form and scope of work documents for each material-service to the providers. The service-material providers will respond to the provided commercial form and scope of work documents with a list of prices that can be accommodated by each provider. However, there is also a possibility that the provider will not respond, so the developer is expected to follow up regularly.

Other aspects that may be encountered during a market survey (Geoenergis, 2024):

1. **Competition with Petroleum Industry:** Conventional rotary rig is commonly used in oil and gas industry, so that there is an impact on the geothermal industry regarding rig availability, especially in Indonesia. In Indonesia, it is uncommon for geothermal companies to own and operate the rig and both industries usually rent the rig and crew from a rig company. If there is any significant increase in oil price and become higher level than before, oil company frequently do massive drilling campaign aggressively to produce the oil and gas from their field. The implication of this kind of condition is that there is a high possibility that many oil and gas companies will fully occupy rigs for their operation. As a result, this condition will create difficulty for geothermal companies to get drilling rigs. Then in such cases, the geothermal drilling engineer is frequently forced to contract a rig with a capacity greater than required due to a rig availability issue.

2. **Limited Contractors/Supplier that has experience in Geothermal Project:** The scarcity of experienced contractors often leads to higher costs, as few suppliers have the monopoly on the required expertise and technology. This lack of competition can also limit the bargaining power of project developers, resulting in less favorable contract terms. Several drilling rig contractors even have poor historical safety/environmental records.

3. **Local Content (Tingkat Kandungan Dalam Negeri – TKDN) Requirements:** In many regions, such as Indonesia, governments impose local content requirements to support local industries. This becomes a challenge when the procurement guidelines from international financiers of the project mandate International Competitive Bidding (ICB) for certain thresholds, potentially conflicting with local content policies.

4.2. Example of the Significance of Market Survey in Rig Assessment and Cost Estimate

The involvement of the authors in the planning for geothermal drilling campaigns in West Java and Central Java from 2018 to 2023 highlighted the value of incorporating market surveys into drilling planning processes. These projects commenced with an initial phase of detailed planning and market analysis during 2018 and 2019 to determine the availability of drilling rigs and estimate the associated costs, including rental rates and mobilization-demobilization fees.

The progression of these projects coincided with the COVID-19 pandemic in 2020, which influenced global economic and industry-specific trends, including a drop in oil prices that impacted drilling service costs. Despite these challenges, the drilling activities extended until mid-2023. Following the pandemic, as the demand for oil and gas rebounded, a noticeable uptick in drilling activity occurred, affecting both the global and Indonesian markets. This increase impacted the availability and cost of drilling rigs and related services.

By late 2023 and into early 2024, when planning commenced for additional drilling at the same sites, the authors recognized changes in the market conditions. The data and contract values from the previous phase were no longer applicable for accurate cost estimation due to significant changes in the drilling rig market. The scarcity of available rigs in Indonesia necessitated considering rigs with higher capacities than initially planned, impacting project costs.

These experiences underscore that rig assessment and rig sizing only is insufficient for accurate drilling planning and cost estimation. Actual market conditions can differ substantially from theoretical assessments. Therefore, regular market surveys are essential to understand real-time availability and costs of drilling rigs. Such surveys enable drilling teams to make informed decisions and adapt their plans to align with the current market, ensuring more accurate cost estimations and efficient project implementation.

5. DISCUSSION

The complicated nature of geothermal drilling projects, characterized by diverse stakeholders, complex organizational dynamics, and multifaceted equipment requirements, underscores the pivotal role of careful rig sizing. This paper digs into the critical components and decision-making criteria supporting the selection of drilling rigs in geothermal exploration activities.

The paper commences by clarifying the significance of rig selection in ensuring efficient and cost-effective drilling operations, considering the challenges of geothermal exploration projects in Indonesia. It highlights the need for alignment between rig specifications and project demands, emphasizing that the size, power, and capacity of the rig must harmonize with the drilling program's requisites. Geothermal projects are inherently distinct, with factors such as well depth, formation characteristics, and temperature conditions influencing the selection of the most suitable drilling rig.

The discussions extend to the evaluation of rig sizing criteria, encompassing hoisting capacity, drawwork rating, rotary table opening, makeup torque, and pump flowrate. Rig sizing emerges as a critical determinant in the success of drilling operations, impacting cost, safety, efficiency, and adherence to project timelines. Proper rig sizing facilitates the seamless execution of drilling activities, preventing accidents, equipment damage, and operational downtime. Rig size and capability play a crucial role in defining drilling project outcomes, as evidenced by the interplay of unit price, quantity, and the ensuing total cost.

The findings underscore the priority of a strategic approach to rig selection, considering project objectives, geological and subsurface challenges, technical, economic, safety, and environmental factors. Collaborative engagement among geoscientists, drilling engineers, and project managers emerges as essential to the rig selection process. The study advocates for a rig sizing framework rooted in well-defined criteria, ensuring that the selected rig aligns with project specifications, optimizes operational efficiency, and mitigates risks.

After understanding rig sizing, the drilling team must also comprehend the process and challenges of conducting a market survey, as rig selection cannot solely occur by knowing the minimum rig specifications. The drilling team must also understand the market availability during project execution to select the most suitable rig while still considering safety and economic factors.

In conclusion, the thorough assessment of factors and decision-making criteria discussed in this paper empowers stakeholders to make informed choices in rig selection, leading in successful exploration outcomes while encourage safety, efficiency, and cost-effectiveness.

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