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Direct Large-Scale Vs. Staged Geothermal Field Development: Evaluating Pros and Cons and the Economic Impacts for Geothermal Projects in Indonesia

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ABSTRACT

Indonesia plans to increase the geothermal power plant installed capacity to 5,700 MW in 2030, more than double the current capacity. This accelerated development plan will put geothermal stakeholders in a dilemma, whether to directly develop the field on a large scale or staged manner.

Directly developing geothermal fields on a large scale generally yields a lower overall cost per MW but will require a longer time to construct and missed opportunity to generate revenue earlier. Direct large-scale development also exposes the developers to resource risks, such as rapid production decline due to a lack of understanding of the field characteristics required for resource management. A staged development, on the other hand, can generate revenue earlier due to a shorter development duration and provides the developer time to properly assess the resource characteristics of the geothermal field to devise a proper field management strategy such as reinjection and production strategies. However, smaller staged development tends to have a higher cost per MW developed compared to direct large-scale development. Those two scenarios may have different impacts on the whole project's economics.

This paper delves into the multifaceted nature of geothermal project development, highlighting the significant upfront capital required due to the inherent risks and exploration uncertainties. It examines the various phases of geothermal project development, from preliminary surveys to operation and maintenance, and explores the particular challenges faced in Indonesia's regulatory and geographical context. Through financial model simulations, it assesses the performance of different development strategies, comparing the internal rate of return across various project sizes and stages. The paper concludes with strategic recommendations for geothermal development, emphasizing the need for a comprehensive decision-making process that integrates geological and financial data to navigate the complexities of resource uncertainty and maximize financial returns.

1. GEOTHERMAL DEVELOPMENT PROJECT

Geothermal projects, unlike other power generation projects such as coal-fired plants and even other renewable energy sources like solar and wind, have a distinct characteristic where developers need to invest a substantial amount of capital upfront, even before they can carry out feasibility studies and reach financial closure. This significant investment is required for exploration activities and exploratory drilling to prove the existence of economic geothermal resources (Figure 1). This situation exposes geothermal developers to significant exploration risk, as there is the potential for sunk costs should the resources prove to be non-viable.

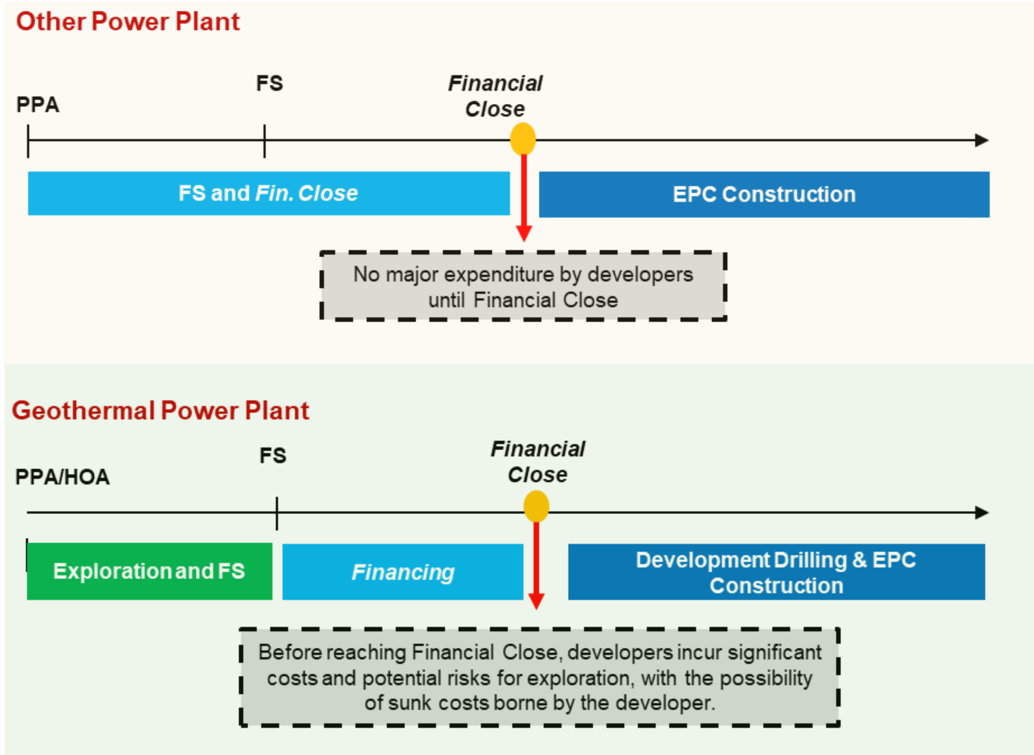


Figure 1. Distinct characteristic of geothermal power plant compared to others (Siahaan et al., 2022).

1.1. Geothermal Project Phase

In general, the development of geothermal projects can be divided into several phases, which are the preliminary survey, exploration and delineation drilling, development drilling and EPC (Engineering, Procurement, and Construction) for the power plant, and then followed by steam production and maintenance. Figure 2 illustrates the typical stages of a geothermal project along with its associated risk profile.

a. **Preliminary Survey**: This initial phase involves identifying geothermal resources with a relatively low financial commitment but still carries resource identification risks.

b. **Exploration Drilling**: In this phase, the risk and costs increase significantly as developers invest in drilling to discover geothermal resources. The capital is at risk, and it is primarily equity since the resource is not yet proven.

c. **Delineation Drilling**: After successful exploration, the project moves into delineation where the resource is further assessed. The risk begins to decrease but remains moderate, and the cost increases as more information about the resource is gathered. This phase involves both resource risk and financing risk since it requires more capital.

   Typically, once the resource has been delineated, developers may need to perform Confirmation Drilling, as shown in Figure 5, to meet specific proven capacity requirements. For instance, financiers may require proof that 50% of the planned power development capacity is secured by the wells already drilled (the common term used is "50% steam under wellhead"). If a project plans to develop a 50 MW facility, the developer must demonstrate possession of at least 25 MW from the existing wells. If this threshold is not reached, further drilling may be necessary to fulfil these financial prerequisites.

   Subsequent to confirmation drilling and meeting the megawatt threshold, developers are tasked with producing a bankable Feasibility Study. This document is crucial for securing funding and reaching Financial Close, which is the point at which all necessary finances for the project have been secured and construction can begin.

d. **Production Drilling & Power Plant Construction**: Once the resource has been delineated, the project transitions to production drilling and construction of the power plant. The risk significantly drops post-financial close as financing is secured and the project becomes less speculative. Costs continue to rise as construction begins.

e. **Operation & Maintenance**: The final phase is the operational phase where the plant generates electricity and revenue. The risk is at its lowest as the project is now operational, but cumulative costs have reached their peak over the lifecycle of the project.

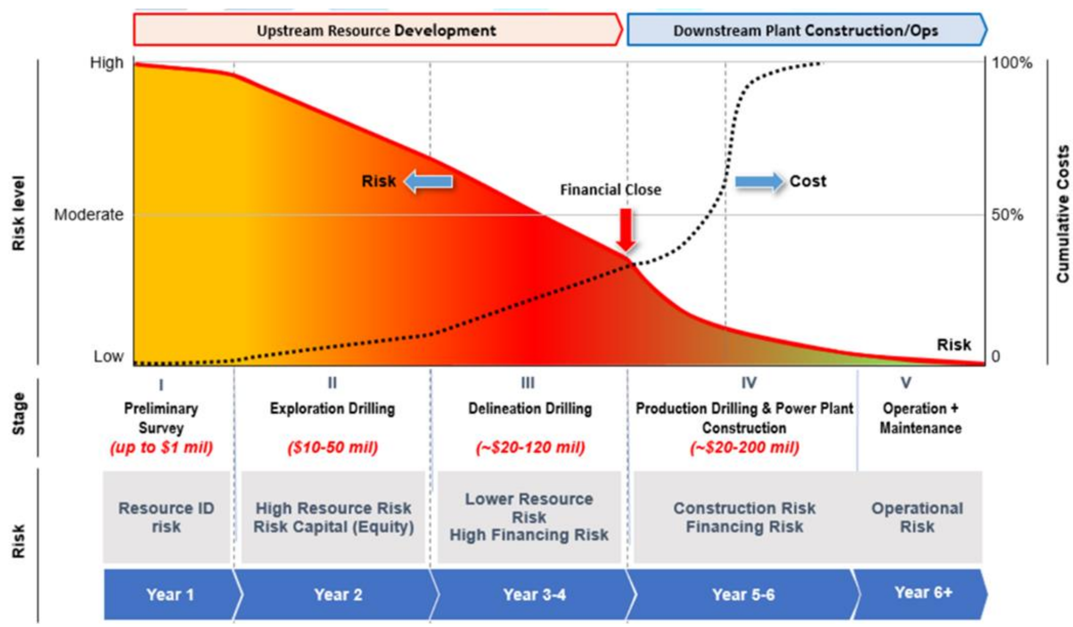


Figure 2. Geothermal development project phases and typical risk profile (modified from World Bank, 2019).

1.2. Geothermal Development Phase in Indonesia

The development stages of geothermal projects in Indonesia are governed by the Indonesian government, as illustrated in Figure 3. Developers have two pathways for project development:

- If a developer proceeds via the Preliminary Survey and Exploration Assignment (*Penugasan Survei Pendahuluan dan Eksplorasi* / PSPE) route, they are required to conduct preliminary surveys and at least one exploration drill. Following this, they must enter a limited geothermal area auction to secure a Geothermal License (*Izin Panas Bumi* / IPB). The PSPE license is initially valid for three years and can be extended twice for one year each time.
- Alternatively, if a developer chooses to develop a field through the Working Area Bid (WKP) route, they are granted the IPB directly and must undertake exploration activities until they gather sufficient data for a Feasibility Study. This study is then submitted to the government, which will decide whether the field will be developed. The exploration permit under this route lasts for five years with the possibility of two one-year extensions.

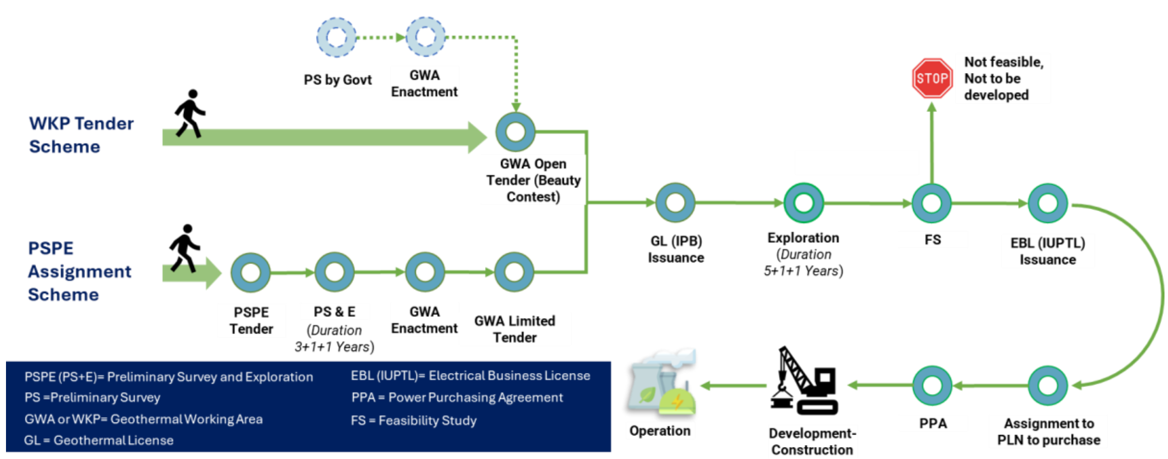


Figure 3. Geothermal development phase in Indonesia (modified from EBTKE, 2023).

Considering that the exploration phase can last between 5-7 years, and the development drilling and EPC for the power plant can take an additional 2 years, developers typically require 7 to 9 years from the start of exploration to reach the Commercial Operation Date (COD) and begin generating revenue.

However, the actual timeline for development, beginning with the drilling of the first exploration well, often surpasses this estimate, as shown in Figure 4. In some cases, the development timeline has even extended beyond a decade. It should be noted that there have been instances of faster development in recent years, such as in Sorik Marapi and Sokoria (although the actual exploration activities including the land acquisition were started years before first well drilling in those fields.

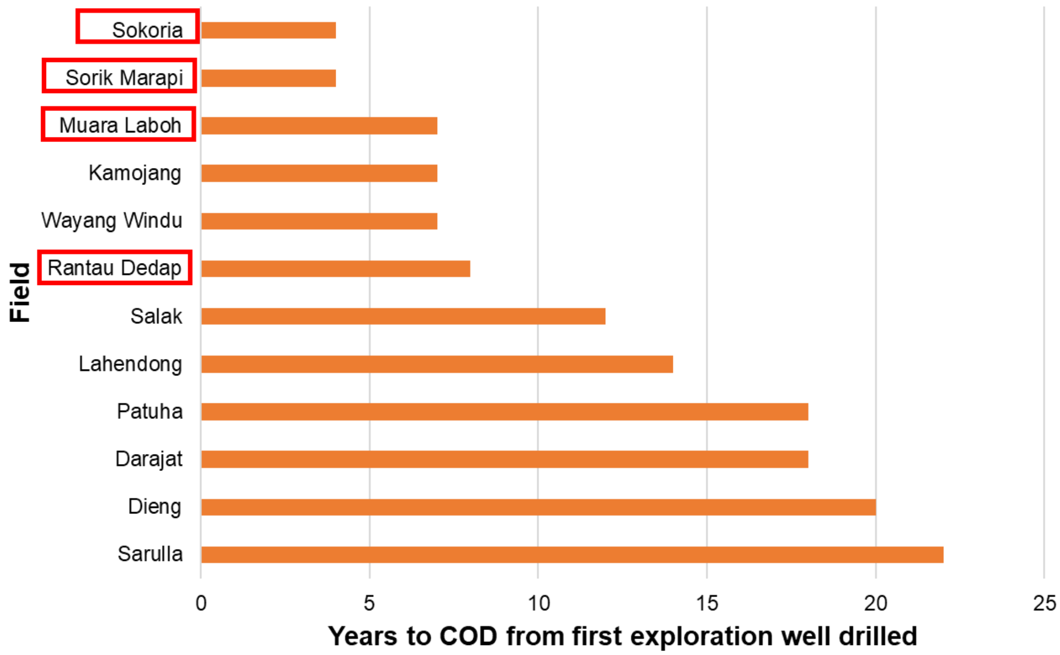


Figure 4. Time to power plant COD from the first exploration well drilling (Modified from Jacobs, 2022). The

It should be noted that the graph in Figure 4 does not show the whole picture of geothermal landscape in indonesia. From 2010 to 2021, there were exploration drillings in 13 Geothermal Working Areas (WKP), yet only 4 fields have been able to reach the production stage, highlighted by the red boxes in Figure 4. This fact underscores the significant challenges and complexities inherent in geothermal project development.

The extended duration to reach COD means that developers may face a delay before they can begin generating revenue, significantly affecting the project's financial viability. When formulating a development strategy, there is a trade-off: choose a staged development and developers might face relatively smaller revenue streams against higher initial capital expenditures (CAPEX) per MW, or tries to accelerate the development to reach bigger development size and lower cost per MW at the risk of high cost of failure and may be slower to reach COD. The delicate balance between revenue, CAPEX, and resource uncertainty poses a critical challenge in geothermal project development.

The extended timeframe of geothermal development demands that developers continually invest capital, often derived from their equity, over a prolonged period before any revenue can be realized. This specific challenge is shown in Figure 5. Considering this, developers are tasked with not only maximizing the power plant's capacity through direct, large-scale development but also with identifying strategies to accelerate the exploration phase. However, such acceleration involves the risk of incurring significant capital expenditures—for example, drilling multiple full-sized wells—while still facing considerable resource uncertainty.

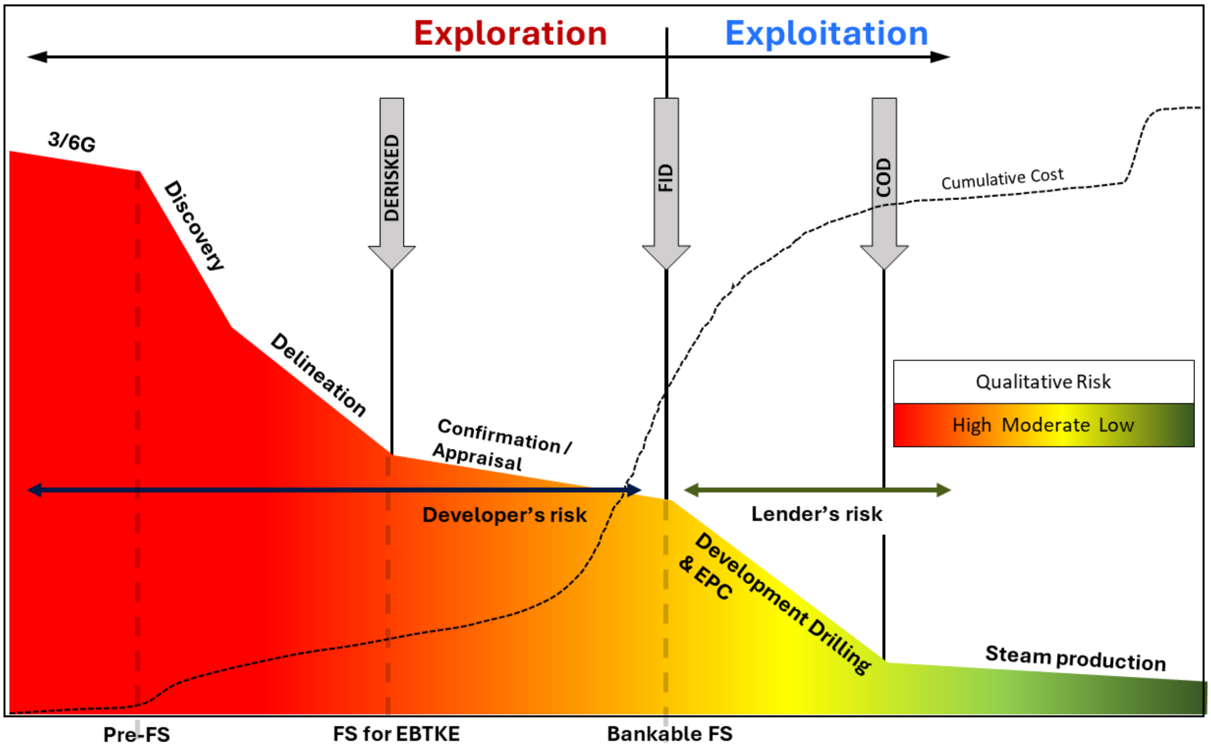
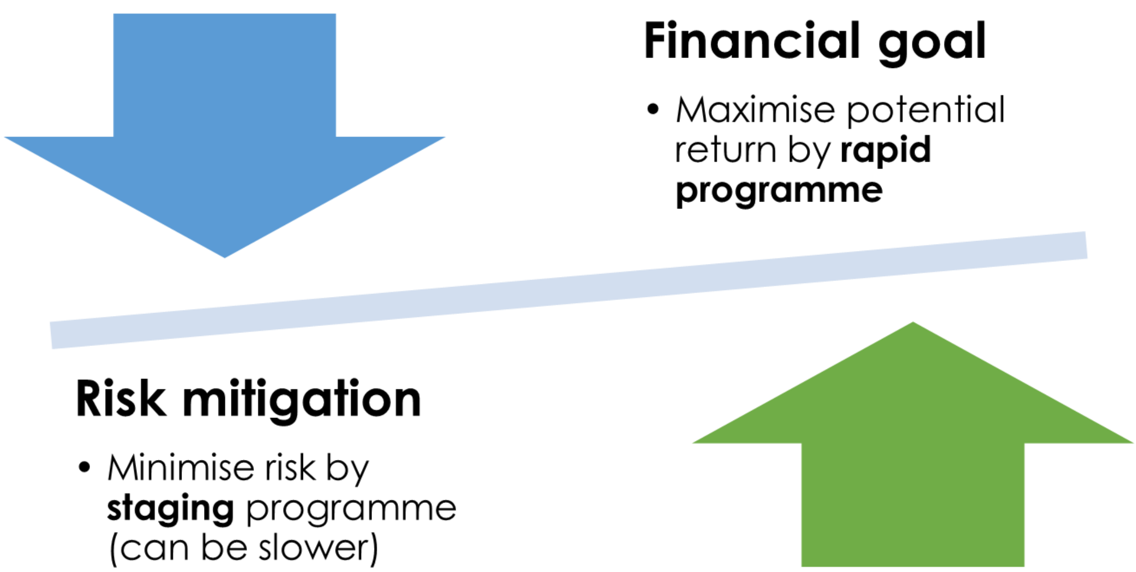


Figure 5. Geothermal project phase and risk profile (modified from Jacobs, 2021). Note that before FID and bankable FS, the developer needs to use own equity to finance the project before generating revenue.

1.3. Geothermal Development Dilemma

Given the high level of resource uncertainty during the exploration phase and the lengthy time required to reach the Commercial Operation Date (COD), geothermal developers face a dilemma: to minimize risk and the cost of failure through staged development or to try to maximize financial returns by pursuing a rapid and large-scale development program.



When it comes to development strategy, developers have a couple of options:

- They can either expedite the exploration by initiating a large-scale drilling campaign to prove the resource and get steam under wellhead all at once, or opt to conduct the drilling process incrementally, in stages.
- Developers may pursue a large-scale power plant development or rapid plant expansion, or alternatively, they can progress in phases. This allows for the observation of the reservoir's response to production and make a decision to expand once the characteristics of the reservoir are thoroughly understood.

2. GEOTHERMAL EXPLORATION DRILLING APPROACH

2.1. Type of Geothermal Drilling with Regards to Project Phase

Drilling is one of the significant expenses in a geothermal project and is an activity that occurs at almost every stage of the geothermal project lifecycle, including exploration, exploitation/development, and production. However, the purpose of drilling varies at each stage. As illustrated in Figure 6, drilling activities serve different objectives depending on the phase of the project:

- **Exploration Phase Drilling**, which typically aims for two main objectives:
    - **Discovery**: The goal is to confirm the presence of economically viable geothermal resources and to gather comprehensive information about the reservoir, such as temperature, permeability, geology, and chemistry. The success of this drilling is measured by positive results in the desired properties, like high temperature and permeability, as well as favorable chemistry.
    - **Delineation**: This drilling aims to determine the boundaries of a geothermal field to define or estimate the size of the resource or reservoir, which can then be used to project the megawatt (MW) capacity of the field. The success of delineation drilling is achieved if it can establish the boundary or extent of the resource. Consequently, even a well that encounters lower temperatures—sometimes referred to as a "cold" well—can be deemed successful if it helps to delineate the edge of the resource. The result of the exploration drilling is used for decision making process prior deciding to the next phase.
- **Appraisal or Confirmation Drilling**: This is carried out to achieve the MW target necessary for making the Final Investment Decision (FID) or achieving Financial Close, as required by the financial institution funding the development. This phase of drilling is optional and is not required if the required amount of MW is already confirmed during the exploration phase.
- **Development Drilling**: In this phase, the aim is to reach the MW target set for the Commercial Operation Date (COD). The success of development drilling is determined by obtaining the necessary MW or injection capacity outlined in the development plan.
- **Make-up Well Drilling**: This type of drilling is conducted to compensate for any decline in production or injection capacity, involving the drilling of additional wells in the area as needed.

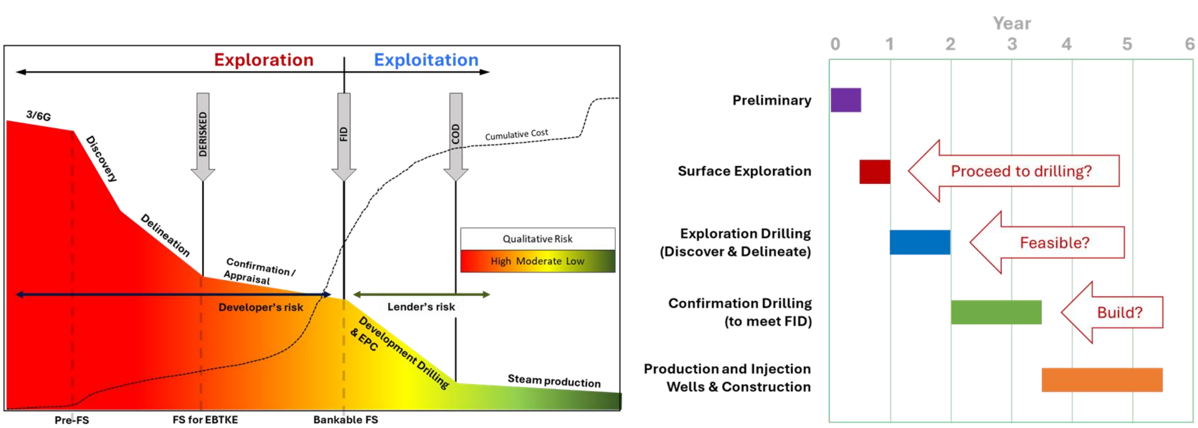


Figure 6. The various types of drilling required for each phase of geothermal project (modified from Jacobs, 2021). Note that the drilling is crucial for decision making process, as shown in the timeline illustration on the left.

The matrix comparing the differences between each of the drilling in terms of the objectives, well success criteria, and the well type typically used are shown in Table 1.

In the Exploration Drilling stage, the primary goal is to confirm the presence of a geothermal resource. Success is measured by obtaining positive data about the reservoir's characteristics, such as temperature and permeability. This stage typically involves deep slimholes or standard-sized wells.

Following this, Delineation Drilling aims to map the boundaries of a geothermal field to define the resource's extent and potential power generation capacity. A well is deemed successful in this phase even if it does not find hot temperatures, as long as it can mark the edge of the resource. Both deep slimholes or core holes and standard-sized wells can be used.

Appraisal Drilling is conducted to ascertain whether the project has enough megawatt capacity or injection capacity for a final investment decision. Success here means meeting the capacity requirements that enable financial commitments. This phase involves full-size wells with standard or large diameters.

Development Drilling seeks to reach the megawatt target for the project's commercial operation. The criterion for success is achieving the planned megawatt or injection capacity. Like appraisal drilling, this stage uses full-size wells with standard or large diameters.

Lastly, Make-up Drilling is carried out to add or replace wells to sustain or increase the existing production or injection well capacity, ensuring the continuous operation of the power plant. The success of this stage is similarly measured by the capacity to maintain power plant operations, and it also utilizes full-size wells with standard or large diameters.

Table 1. Comparison matrix showing the differences of the objectives, well success criteria, and typical well type used for various geothermal drilling objectives in each phase.

	Exploration Drilling	Delineation Drilling	Appraisal Drilling	Development Drilling	Make-up Drilling
Objective	**Prove the existence** of a geothermal resource. **Obtain** as much information on the reservoir (e.g., temperature, permeability, geology, chemistry, etc.).	Find the boundaries of a geothermal field to define the resource / reservoir size / MW capacity.	Get MW target for deciding to proceed with the project (FID / Final Investment Decision) (if required, and if not already achieved in the Exploration/Delineation)	Seek to reach MW target of the project (COD)	Drill wells to add/replace declining existing production / injection well.
Well Success	Obtain positive results on desired properties (temperature, permeability, benign chemistry, etc.)	Able to define the boundary or extent of the resource. Therefore, even a 'cold' well can be considered a 'success' if it identifies the edge of a resource.	Get sufficient MW capacity or injection capacity as required by FID.	Get sufficient MW capacity or injection capacity as required by development plan.	Get sufficient production / injection capacity to sustain the power plant operation.
Well Type	Deep slimhole Standard-sized well	Deep slimhole / core hole Standard-sized well	Full size wells – standard / big holes	Full size wells – standard / big holes	Full size wells – standard / big holes

2.2. Accelerated or Staged Exploration Drilling Strategy

As shown in Figure 6 and Table 1 previously, the geothermal exploration drilling typically has three objectives:

- Discover the resource.
- Delineate the resource.
- Confirm the resource.

Going through those objectives in stages (Figure 7) can minimize risk and reduce the potential cost of abandonment if the desired resource size and characteristics are not met. However, that may mean longer exploration time, which means longer time to reach COD and generate revenue. Consequently, some developers may opt for an accelerated process, despite the associated higher risk of increased abandonment costs, as illustrated in Figure 8.

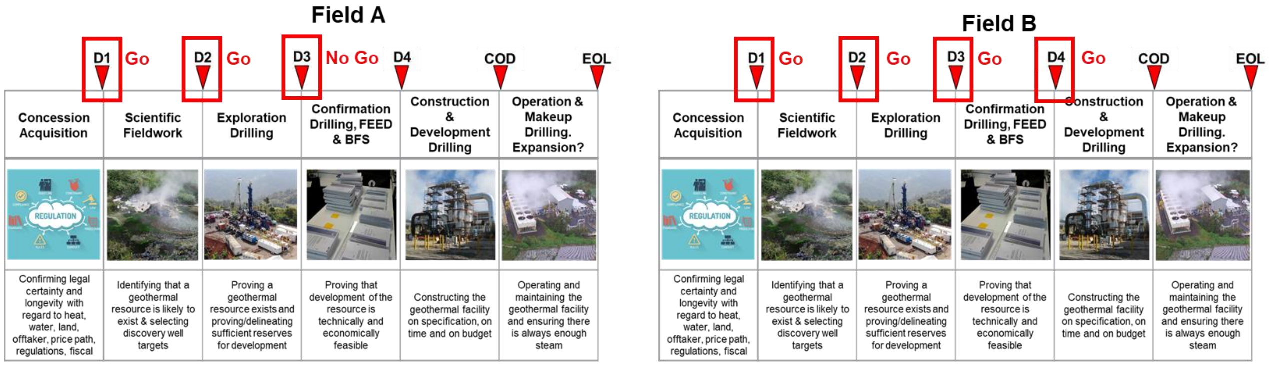


Figure 7. Illustration of geothermal project stages and decision gate prior deciding to proceed to next phase.

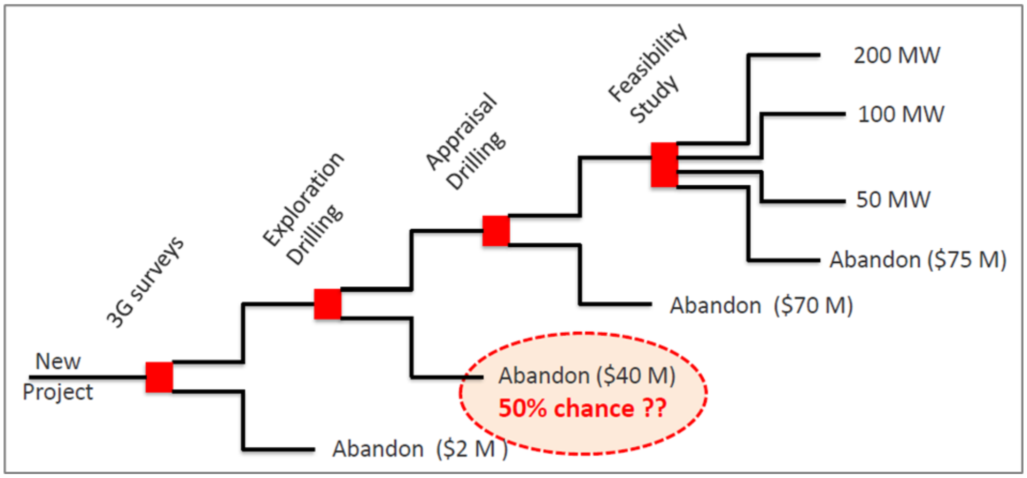


Figure 8. Illustration of cost of abandonment in geothermal project (modified from Jacobs, 2022).

The expedited exploration involves a drilling campaign that typically focuses on discovering, outlining, and at times confirming the availability of steam (a critical factor for bankable feasibility, often requiring around 50% verification of the anticipated power plant capacity) within a single campaign, as illustrated in Figure 9. The exploration is typically done with standard-sized or big-hole well. This exploration strategy was used in several fields in Indonesia, such as in Baturaden, Tulehu, Sorik Marapi, and other fields.

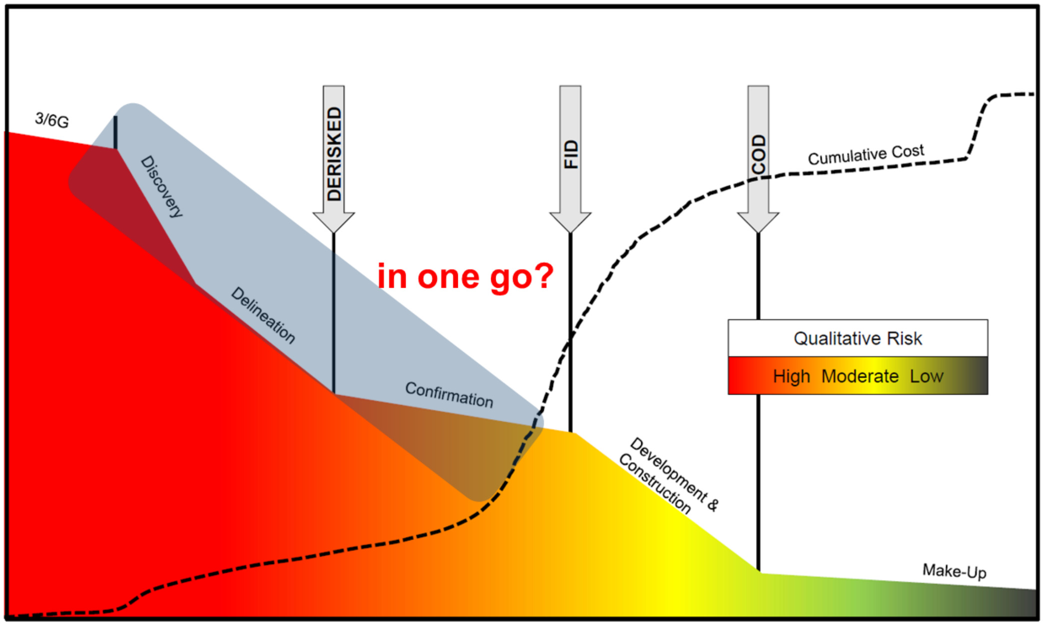


Figure 9. Illustration of accelerated exploration, aims to discover, delineate, and confirm the steam availability in one go.

This approach stands in contrast to the staged exploration strategy, where each step is conducted sequentially, and the outcome of each phase is assessed before making a decision to move forward. The primary objectives of this strategy usually revolve around minimizing the expenses associated with project abandonment, particularly in cases where resource uncertainty remains high or confidence levels are relatively low. This approach is illustrated in Figure 10. The staged geothermal exploration typically use slimhole well first to prove the existence of desired geothermal resource, before proceeding to use standard-sized or big well for the next phase such as confirmation and development drilling. This exploration drilling strategy was used in many of the geothermal fields developed in the 90s and early 2000, and recently was used in Ijen, East Java.

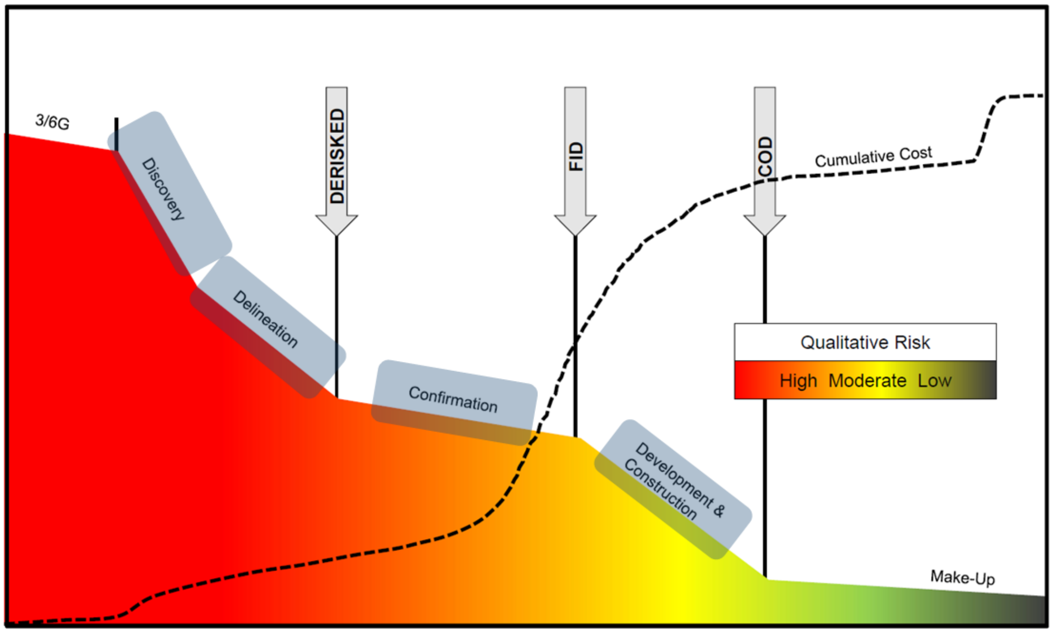


Figure 10. Illustration of staged exploration, typically aims to minimize the cost of abandonment.

3. GEOTHERMAL DEVELOPMENT SIZE SELECTION

When exploring the development of geothermal power plants, two primary strategies are considered: the construction of a large power plant in one comprehensive project or the implementation of smaller, staged developments. Each approach has distinct implications for cost, speed to market, and risk management.

Large-scale developments often benefit from economies of scale, which can significantly reduce the cost per megawatt (MW) of electricity generated. However, such projects typically experience a more extended period before reaching the Commercial Operation Date (COD), which is the point at which the plant can begin commercial electricity production. Consequently, the return on investment is delayed as revenue generation starts later.

In contrast, smaller, staged developments may incur higher costs per MW due to the lack of economies of scale. Nonetheless, they offer the advantage of reaching COD more swiftly, allowing for quicker revenue generation. This strategy can be particularly advantageous when managing geothermal resources, as it permits incremental expansion and resource assessment at each stage. This phased approach helps in minimizing risks associated with overdevelopment or overproduction, issues that have historically challenged larger projects.

Despite the potential for more sustainable resource management with smaller projects, there is a caveat. The higher unit costs and potential incremental inefficiencies can diminish financial returns when compared to large-scale developments. This presents a trade-off: smaller, staged projects may be more sustainable and adaptable, but they typically lack the economic efficiency and the swift financial payback of larger projects. The simplified comparison summary between those two strategies is shown in Table 2

Table 2. Simplified comparison of geothermal development size strategy.

Bigger Development Size	Smaller Development Size
Lower unit price (USD/MW)	Higher unit price (USD/MW)
Slower COD, slower to generate revenue	Faster COD, faster to generate revenue

The capex/MW (capital expenditure per megawatt) for geothermal development can be higher for projects with smaller development sizes due to a couple of key reasons:

- **Fixed Costs Distribution**: In smaller developments, fixed costs such as those for building access roads, other necessary infrastructure, and general overhead expenses are distributed over a smaller number of megawatts. This leads to a higher cost per megawatt as these fixed costs represent a larger fraction of the total expenditure for each megawatt of capacity developed.
- **Higher Costs for Small-scale Developments**: The costs associated with constructing the power plant and steamfield (the area where steam is collected and transported to the power plant) are typically higher for smaller developments, as shown in Figure 11. This can be due to less efficient economies of scale, as smaller plants may not benefit from the cost reductions associated with bulk purchasing of materials or the spreading of design and development costs over a larger capacity.

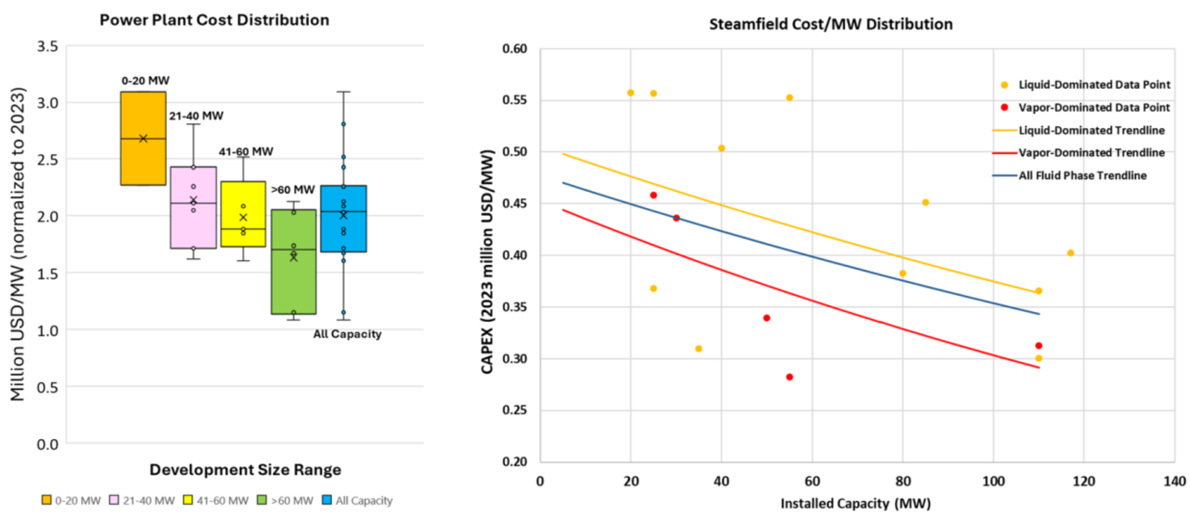


Figure 11. Power plant and steamfield cost/MW distribution. The data are from geothermal fields in Indonesia and worldwide. The cost values are normalized to the year 2023.

The critical insight from these considerations is the need for a balanced approach in geothermal power plant development. Decision-makers must weigh the benefits of rapid revenue generation and risk management against the potential for greater long-term economic efficiencies that larger developments might offer.

4. INTERNATIONAL CASE OF GEOTHERMAL DEVELOPMENT

4.1. The Geysers, USA

4.1.1. Geysers Background

The Geysers, located in the Mayacamas Mountains of Northern California, holds the distinction of being one of the world's oldest and most significant geothermal power plants. Its history traces back to the 1960s when initial exploration and development activities began. The site's rich geothermal resources were harnessed for electricity generation, making it a pioneering venture in the field of renewable energy.

4.1.2. Development of the Geysers

The Geysers' development journey was marked by innovative engineering and technical advancements. In the early stages, exploratory drilling revealed a vast reservoir of steam and hot water beneath the earth's surface. Pioneering techniques were employed to tap into this resource, including the concept of "flash steam" power plants that converted high-pressure geothermal steam into electricity.

Over time, the field's potential became increasingly evident, leading to substantial expansion efforts. The development of various power plants and the establishment of a complex network of wells, pipelines, and infrastructure turned The Geysers into a significant energy-producing hub. The collaborative efforts of geothermal companies and scientific researchers contributed to enhancing the field's productivity and shaping its future direction.

4.1.3. Production Challenges and Overproduction

While The Geysers achieved remarkable success in electricity generation, it also encountered challenges that provided valuable insights for the geothermal industry. One of the most notable challenges was the issue of overproduction. As the field's productivity increased, there were instances where the extraction of steam exceeded the natural replenishment rate of the reservoir. This led to a decline in reservoir pressure and a subsequent reduction in steam production.

The issue of overproduction underscored the delicate balance between energy generation and reservoir sustainability. Overcoming this challenge required the implementation of sophisticated reservoir management strategies. These strategies included practices such as reinjecting produced fluids to maintain reservoir pressure, optimizing production rates, and adopting measures to enhance overall resource longevity.

4.2. Ohaaki, New Zealand

The Ohaaki geothermal power plant is a facility that uses steam from the Ohaaki geothermal field to generate electricity. It is owned and operated by Contact Energy, and it has a distinctive 105 m high natural draft cooling tower, the only one of its kind in New Zealand.

The Ohaaki geothermal power plant was commissioned in 1988 with an initial capacity of 104 MW. However, the production has declined over time due to the ingress of shallow groundwater from the overlying Ohaaki Rhyolite Formation, which lowers the enthalpy and pressure of the steam. This has also caused an increase in calcite scaling, which requires antiscalant dosing systems.

The production decline has been observed since the late 1960s and early 1970s, when field testing showed a rate of 14% per annum. The decline rate was expected to be higher when the power plant was at full production.

In 1995, a deep exploration programme was undertaken to drill three deep wells to cross the regional structural trend and locate permeable fractures and zones within the greywacke below the volcanic formations. The wells encountered temperatures up to 300°C in the volcanic formations above the greywacke. As of 2011, the maximum net capacity of the Ohaaki geothermal power plant was about 65 MW with an annual output of around 400 GWh pa1 The Waikato Regional Council granted resource consents for a term of 35 years and for a take of 40,000 tonnes per day of geothermal fluid.

The Ohaaki geothermal power plant is an example of how geothermal energy can be used to generate electricity, but also how it faces challenges such as resource depletion, environmental impacts, and technical difficulties.

4.3. Summary

Both The Geysers and Ohaaki illustrate that while geothermal energy presents a valuable renewable resource, the strategies for its development must be carefully considered. Rapid expansion and large-scale developments carry inherent risks, including resource depletion and environmental impacts, which can compromise the long-term viability and financial return of these projects. These examples serve as cautionary tales for future geothermal development, emphasizing the importance of sustainable and adaptive management practices.

5. FINANCIAL MODEL SIMULATION

To simulate the effects of selecting a geothermal development strategy, financial modeling was performed with several assumption scenarios as follows:

A. The geothermal project is located in Indonesia.
B. The assumed tariff uses the current regulations in Indonesia (Presidential Decree No. 112 / 2022), as illustrated in Figure 12.
C. The field is a medium-temperature field in Eastern Indonesia, with a location factor according to the Presidential Decree of 1.20.
D. The total target for the development plan is 60 MW.
E. Development scenarios:
   a. 1 x 60 MW (direct large)
   b. 4 x 15 MW (staged development)
   c. 2 x 30 MW
   d. 1 x 15 MW first, followed by an expansion of 1 x 45 MW.

Geothermal Power Plant – electricity price

Capacity (MW)	Ceiling Price (HPT)							
	s.d 10 MW		>10 MW s.d. 50 MW		>50 MW s.d 100MW		>100 MW	
	Stg thn 1-10	Stg thn 11-30	Stg thn 1-10	Stg thn 11-30	Stg thn 1-10	Stg thn 11-30	Stg thn 1-10	Stg thn 11-30
Staging Price (cent $/kWh)	9,76 x F	8,30	9,41 x F	8,00	8,64 x F	7,35	7,65 x F	6,50
Levelized Price (cent $/kWh)	9,25		8,92		8,19		7,25	

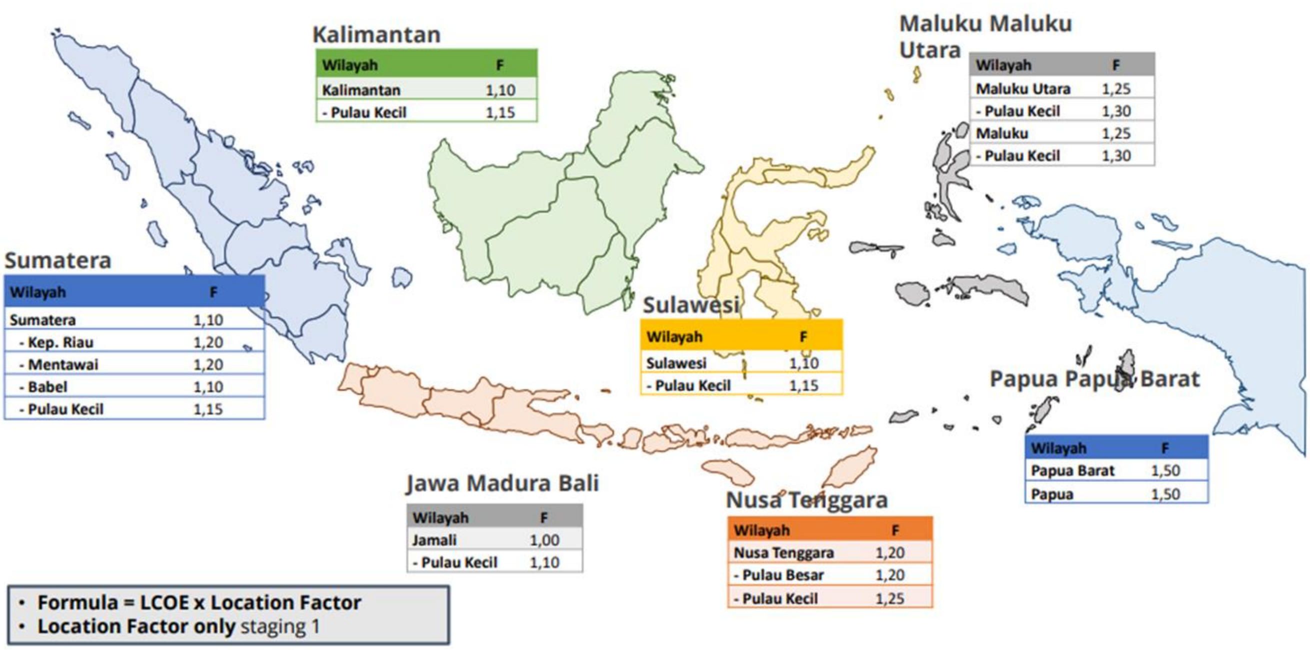


Figure 12. Electricity price as regulated by Presidential Decree 112 / 2022 (modified from EBTKE, 2022).

CAPEX assumptions are calculated using market survey data and previous contracts from geothermal projects in Indonesia. As shown in Figure 13, the CAPEX assumptions used are still within the range of estimated costs for geothermal development published by EBTKE.

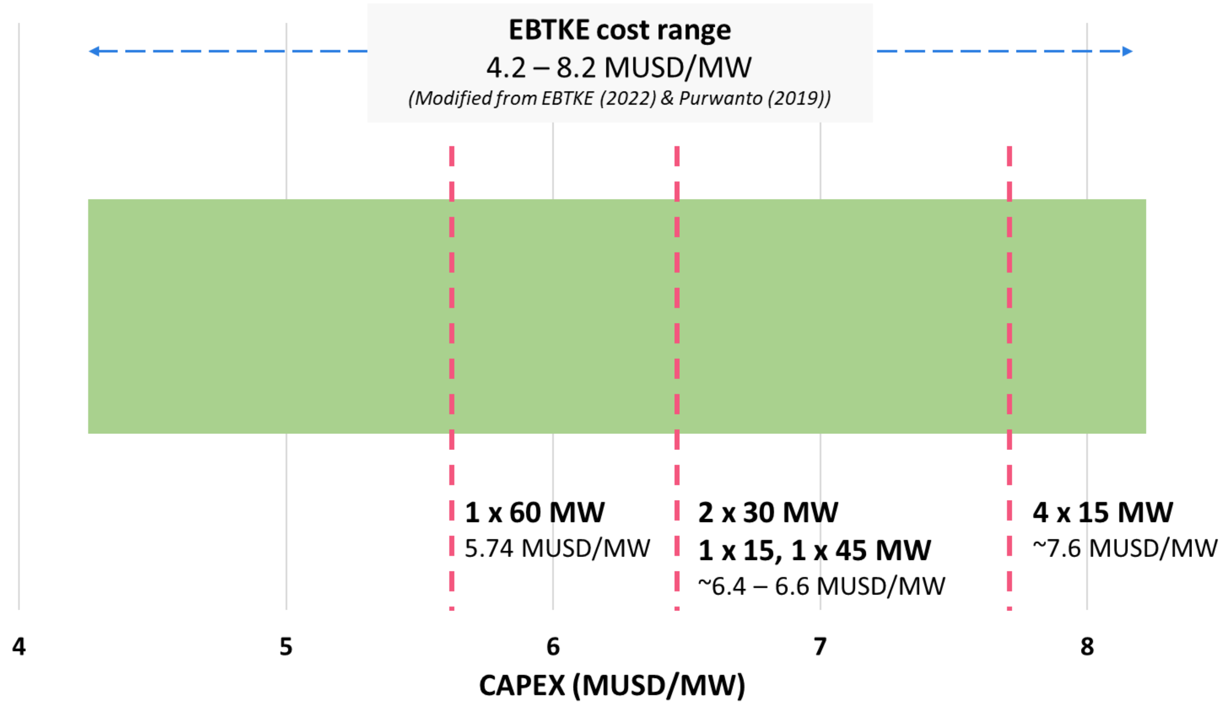


Figure 13. The CAPEX assumption range for geothermal development in Indonesia, modified from EBTKE (2022) and Purwanto (2019). The CAPEX assumptions for the 4 scenarios assessed are still within range of EBTKE's cost estimates.

5.1. Financial Model Result

To evaluate the performance of each scenario, a comparison of the Internal Rate of Return (IRR) was conducted as shown in Figure 14. From the financial simulation results, it was found that the scenario with two 30 MW plants and one subsequent 15 MW plant expansion (2x30 and 1x15, followed by 1x45 MW) performed the best among the options. As anticipated, the scenario with four 15 MW plants (4x15 MW) showed the lowest performance.

Furthermore, the configuration of a single 60 MW plant (1x60 MW) is noted for its inferior performance when compared to the two 30 MW plant setup (2x30 MW). This observation is particularly significant considering that the single 60 MW configuration has a lower Capital Expenditure (CAPEX).

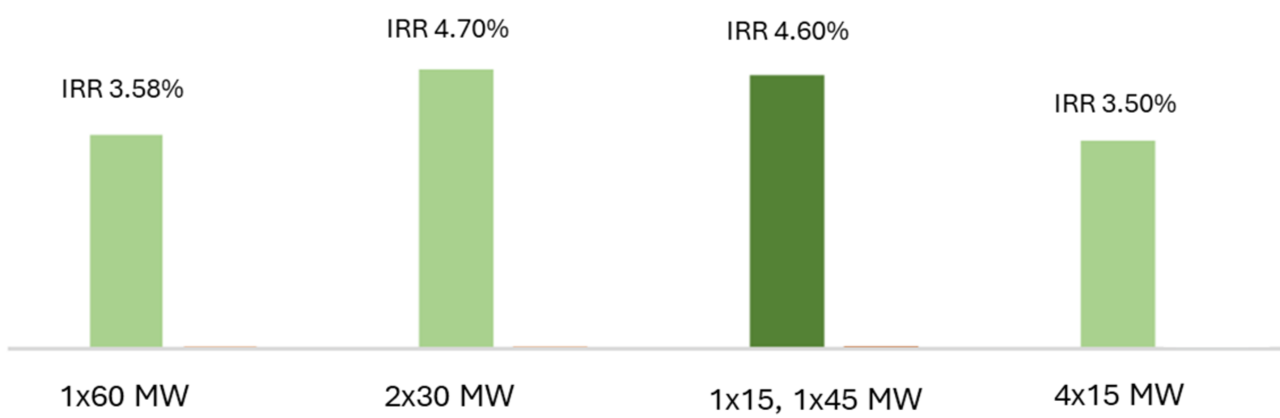


Figure 14. Financial model result for the four scenarios, comparing the IRR for each scenarios.

The reason for this is because of the current electricity price as regulated in the Presidential Decree 112 / 2022. As shown in Figure 12, the development size bigger than 50 MW will have lower ceiling tariff. This shows that while larger plants benefit from economies of scale in operations, they are also subject to a lower tariff ceiling, which could affect their overall revenue potential. This complex interplay between capacity, pricing, and location underscores the need for a nuanced approach to the development of geothermal energy projects in varying regional contexts. Moreover, the ceiling tariff for Eastern Indonesia for development size >60 MW is significantly lower than previous tariff scheme (Figure 15). Thus, it shows that the bigger development in Eastern Indonesia can be less attractive compared to the previous tariff scheme. It explains why the 1x60 MW scenarios fare worse than the 2x30 MW despite having significantly lower CAPEX/MW.

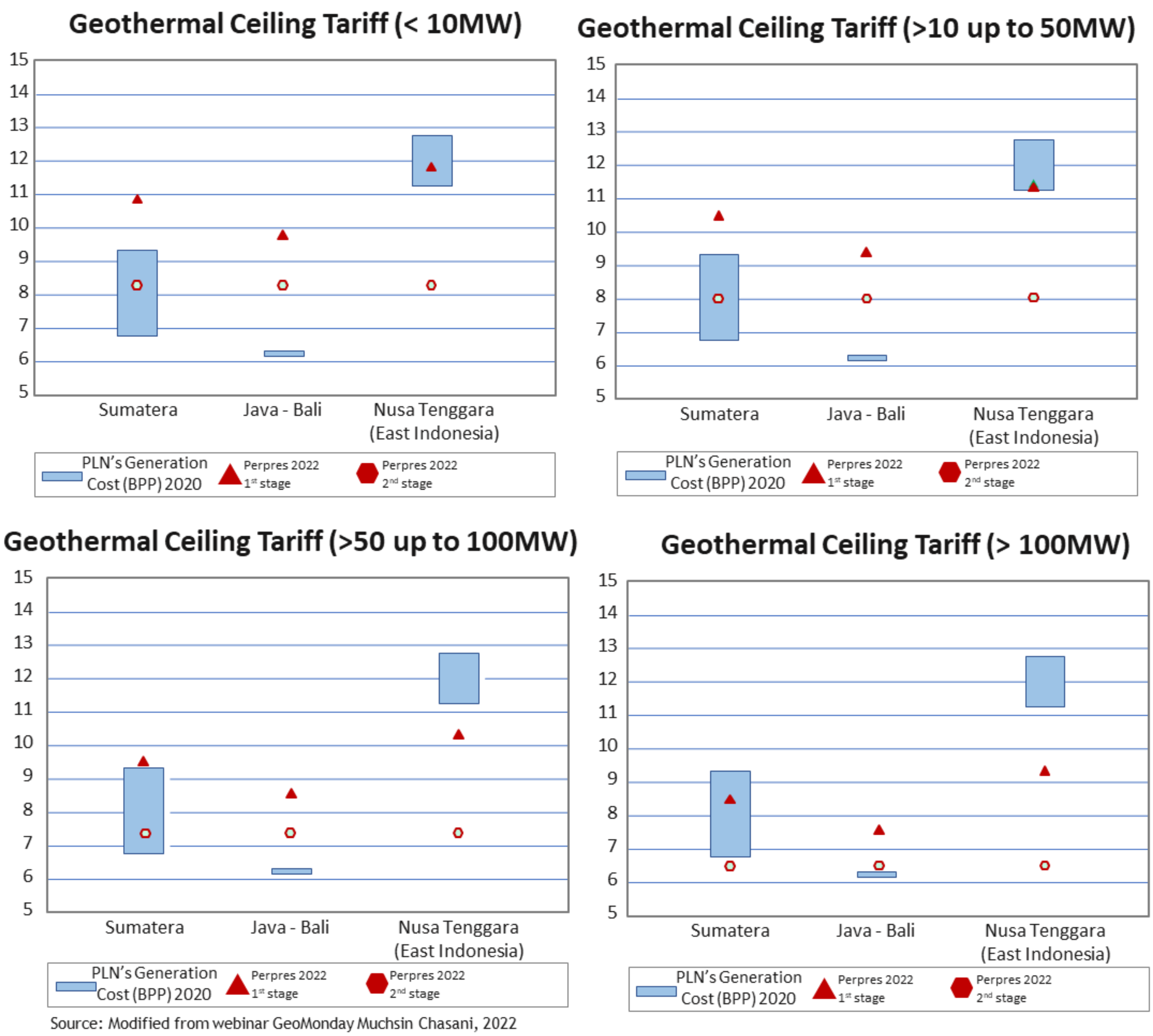


Figure 15. Geothermal ceiling tariff comparison with previous tariff scheme (modified from Chasani, 2022).

6. SUMMARY AND CONCLUSION

The exploration and development of geothermal energy entail complex phases, significant risks, and substantial capital requirements. This paper has examined geothermal development project strategies, with a special focus on the Indonesian landscape, which is governed by stringent regulations and presents unique challenges and opportunities.

The summary and conclusion draw attention to the critical aspects of geothermal development:

- **Staged Development Costs**: Developing geothermal projects in stages with lower MW size can lead to an accelerated revenue stream, as early phases of the project begin to generate income sooner. However, this approach is likely to increase the capital expenditure (CAPEX) overall. This could be due to the costs associated with scaling up, duplicated efforts in each stage, or inefficiencies that come with phased construction and operation.

- **Pricing Scheme Impact on Project Sizing**: The existing tariff structure may inadvertently discourage project development that falls at the lower end of a capacity threshold. For example, projects that are just above 50 MW or 100 MW might be economically less viable due to the price scheme, potentially leading developers to either upscale or downscale their projects to fit more advantageous tariff brackets.

- **Limitations of Financial Models**: Solely relying on financial models for project decision-making could be misleading, as these models may not fully account for the uncertainties associated with geothermal resource exploration. There is a risk that developers might be guided towards either directly initiating large-scale projects or expediting exploration efforts without adequate data, both of which could result in financial and operational risks.

- **Comprehensive Decision-Making**: A more robust decision-making process that incorporates resource uncertainty is recommended. This process should include a thorough assessment of the geothermal resource potential, risks, and variability. This comprehensive approach would ensure that decisions are not solely based on financial projections but are also grounded in geological and technical realities.

The geothermal projects' performance will depend on the ability of developers to balance these factors, ensuring sustainable and profitable exploitation of geothermal resources.

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