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Techno-economic Analysis in Developing Low to Intermediate Temperature Geothermal System in the Eastern Region of Indonesia

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ABSTRACT

The Government of Indonesia has started to expand geothermal energy development in the Eastern Indonesia region to achieve the country's target in 2025. Despite its enormous potential, the Eastern Indonesia region has distinctive fundamental challenges compared to other regions, primarily in engineering design, as the region is dominated by low to intermediate temperature systems. That leads to sluggish geothermal development in those areas. The study aims to provide techno-economic analysis of the low to intermediate temperature geothermal system in Indonesia's eastern area. Some solutions are suggested, namely high-temperature pumps and binary power plant technology, to exploit low-medium temperature systems with specific regard to Eastern Indonesia's context of technology and challenges. To that end, a set of models will be generated to deliver resources assessment of generation capacity, production capacity in MW/well, and the number of wells. Finally, the result will be integrated with the financial analysis to allow a better understanding of commercially viable development approaches for the aforementioned geothermal systems by comparing generation tariff results to the current government tariff in Indonesia. The resource and financial model were simulated using Monte Carlo and JIWA System. The following conclusions can be drawn from this study. Firstly, the production capacity median of eastern Indonesia's low to intermediate temperature system lies between 2.5 MW - 8.9 MW/well, limited to this study data. Secondly, there is a high chance that 65% of those projects are feasible to be developed within the required tariff from Indonesia's government, mostly contributed from temperature ranging 145 ºC - 230 ºC with Productivity Index (PI) at least in low classes at 2 (kg/s-bar). Thirdly, the temperature is the primary indication to deliver the most significant influence among all parameters of area, PI, CAPEX, and OPEX. To conclude, it is identified that the development of low to intermediate geothermal systems in the eastern part of Indonesia can be technically feasible and economically attractive.

1. INTRODUCTION

The Government of Indonesia has committed to developing geothermal resources in the eastern region of Indonesia as an acceleration strategy achieving the 8,007.7 MW electricity generation target from geothermal energy between 2020 and 2030. Over the thirty-seven years of Indonesian geothermal development, the projects are centralized in the western part covering Sumatra, Bali, and Java. It is shown that only 132.5 MW (i.e. approximately 6.2% from total development of 2130 MW) is located in the eastern part of Indonesia until 2020 (MEMR, 2019; PT SMI, 2020). Geologically, a large part of eastern Indonesia has a geothermal system with a non-volcanic environment. The non-volcanic geothermal type is associated with low to intermediate temperature resources (<200 ºC) (Kasbani, 2009). It was justified by the temperature distribution of 131 total geothermal prospects in Indonesia's eastern region in Figure 1. It is clearly seen that Indonesia's eastern region has the abundant potential of low to intermediate temperature resources, accounting for 68% of the total prospects. However, none of those potentials have yet been developed in Indonesia. By the fact of that underutilization, the hurdles are clearly complicated from engineering design, uncertainty law, unattractive tariffs, lower demand, lack of reservoir data, social restraint, and geothermal system that leads the development to remain unclear. Among the hurdles, one prominent instance causing the minimum appetite for investments is the lack of feasibility studies for low to intermediate temperature systems, especially in geothermal development in eastern Indonesia. Therefore, it is important to demonstrate the technology and economic feasibility of power generation under numerous low-medium temperature resource conditions in the eastern region of Indonesia.

According to Sanyal (2005), low to intermediate temperature resources are classified into three categories, very low temperature (100-145 ºC), low temperature (145-190 ºC), and moderate temperature (190-230 ºC). Generally, the resource with low-intermediate temperature contains liquid water. In terms of temperature <145 ºC, the resource has inadequate energy to be self-flowed. Thus, it requires a downhole pump and a binary power plant to be developed. A few resources in this range of temperature were commercially developed. However, current technological advancement in a downhole pump and binary plant is potentially making power generation from this resource more attractive. For temperature <190 ºC, the reservoir at the upper end of the temperature range might be self-flowing (for relatively large flow capacity). However, most of the resources from this range of temperature need a downhole pump to achieve a commercial rate. In terms of temperature greater than 190 ºC, free steam saturation may be present in the reservoir at the temperature above 230 ºC. However, it is hardly found below 230 ºC. Although the wells in this range must be self-flowed, the natural flow rate of these wells is likely to decline over time resulting in the use of well pumps more attractive. Hence, pump technology operated in this range of temperature has been offered by major companies (Molloy, 2009). Therefore, this paper analyses geothermal resources with the temperature < 145 ºC, 145 ≤ temperature < 190 ºC, and ≥ 190 ºC. In fact, the development of low-medium temperature resources has a long operating history, such as East Mesa: 1980, Herber: 1985, Steamboat:1986 (Febrianto, 2019). Those cases indicate that low-intermediate temperature resources are potentially commercial to be developed when the reliable reservoir properties meet a compatible technology. Therefore, this paper offers a technology feasibility study of power generation under numerous resource characteristics of low-medium temperature resources.

When the wells do not flow naturally, or production rates are low, downhole pumping is required to enhance the fluid recovery. In other words, the pump is set in the downhole below the water level and discharges the hot brine at greater rates than natural flow rates, thereby producing additional power generation. There are two main types of pumps widely used around the world: Line Shaft Pump (LSP) and Electrical Submersible Pump (ESP). The distinction between LSP and ESP is the construction, obviously the position of the motor. LSP uses an electric motor on the surface connected to a downhole pump by a rise tube and driveshaft, while ESP uses an electric motor, which is directly coupled with the pump in the downhole. LSP can be set up to 700 meters. Theoretically, it is capable of lifting the fluid up to 260 °C with a maximum flow rate of up to 186.8 L/s. In actuality, the field experience has an operating range between 194-216 °C (Frost, 2010). Conversely, ESP has a greater setting depth up to 1 km. This pump is designed for high temperatures with a limited flow rate. The application of ESP in geothermal has been found in well less than 149 °C (Frost, 2010). The study of well pump performance in low-intermediate temperature resources has been conducted by Sanyal (2007). It has been found that the pump with a set depth at 457 meters and maximum flow rate at 160 L/s can produce net capacity per well up to 7.3 MW irrespective of how high the productivity index is. However, this study has yet evaluated the financial aspect of the project. Hence, Hochwimmer et al (2013) presented a technical and-

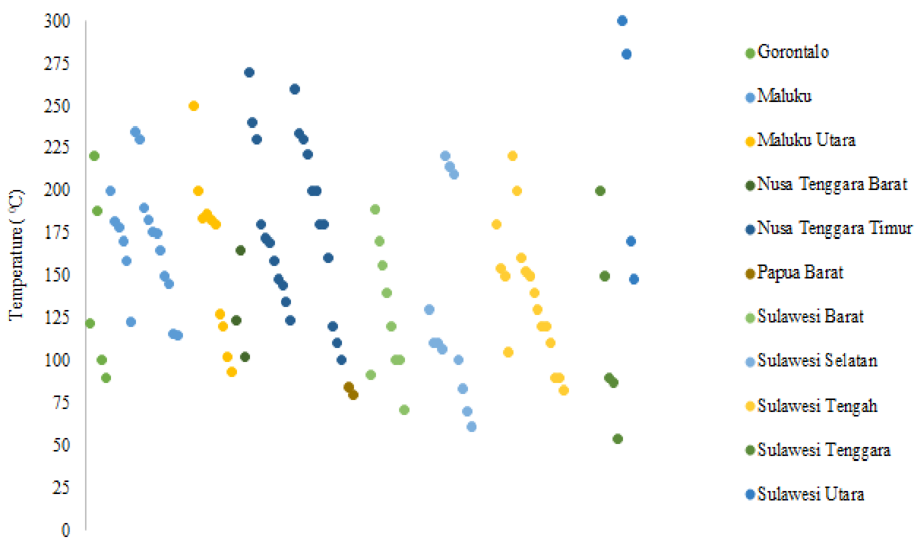


Figure 1: Temperature distribution of total geothermal prospects in Eastern Region of Indonesia (rearranged from Ministry of Energy and Mineral Resources (2017))

financial analysis of well pump performance in the lateral outflow of liquid dominated systems. However, this study still used a single flow calculation. Thus, it is difficult to assess the risk of the project. In Indonesia, the feasibility of the application of pump technology for developing geothermal resources with temperatures below 210 °C has been studied by Febrianto (2019). Nevertheless, this study has yet assessed the net electricity tariff resulting difficulties in evaluating project feasibility based on regulation imposed by the government. Therefore, this paper identifies the range of net capacity of a pumped well for low to intermediate temperature resources coupled with Monte Carlo Simulation. The multiple values of reservoir properties (temperature and productivity index) were substituted to provide a better understanding of the effect of reservoir properties on the net capacity of a pumped well. After that the electricity tariff was estimated to assess the financial feasibility of the project in respect to regulation applied.

Indonesia's government regulates the latest electricity generation cost to date in PP No.55/2019 called BPP (Biaya Pokok Pembangkitan). It stipulated the price cap of each energy in every region in Indonesia and the national average BPP. The national average BPP is 7.86 cents US$/kWh. Suppose the generation project is located in an area where the regional BPP is lower than the national average BPP. In that case, the negotiated price should be based on an agreement with the only one off-taker in Indonesia, Perusahaan Listrik Negara (PLN). On the other hand, if regional BPP is higher than the national average BPP, then the price cap cannot exceed either 85% or 100% of the regional BPP, depending on the technology. Most renewable energy prices are capped at 85%, except for geothermal and waste-to-energy, which are allowed up to 100%. That means that developers are advised to generate costs lower than BPP to make the project viable. The eastern part of Indonesia covers around fifty regions designated tariff, including Nusa Tenggara, Kalimantan, Sulawesi, Maluku, and Papua. In those areas, geothermal ceiling generation cost lies between 8.22 – 21.34 cent US$/kWh. Therefore, that range will be the cutoff for this research model to determine which projects are viable and lies in the range.

2. MODEL

2.1 Process Flow

2.1.1 Process Chart

Overall, the process of the study is divided into two major parts, resource and financial analysis as illustrated in the process flow diagram in Figure 2. The resource analysis consists of estimating resources, developing numerical modeling of pumped flow, determining electrical power generation, and simulating a plan of development. The result of the development simulation is used as an input for further analysis in financial analysis. The financial analysis involves constructing financial modeling and assessing economic feasibility based on BPP applied in the eastern region of Indonesia.

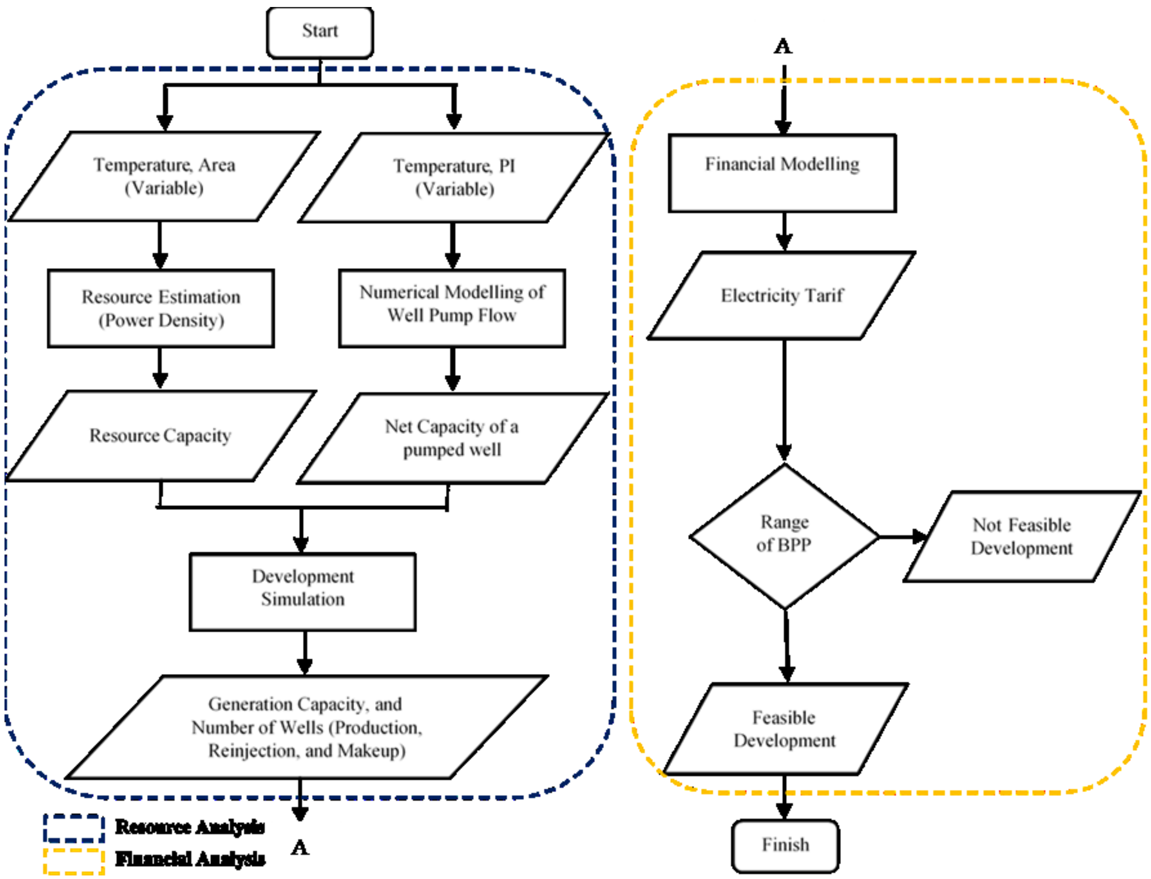


Figure 2: Flow chart of the study

2.1.2 Objectives and Limitations

This study generally aims to assess the technology and financial feasibility of medium temperature resource development. Specifically, the objectives of the study are described as follows:

1. Estimate the productivity range of a pumped well and identify the effect of reservoir properties (temperature and productivity index) on the net capacity of a pumped well.
2. Estimate the range of electricity tariff and investment/MW and the chance of projects being feasible.
3. Determine the range of technical parameter (temperature, productivity index, and area) values required to achieve feasible medium temperature development.
4. Evaluate the significance of technical parameters (temperature, productivity index, and area) and financial parameters on project feasibility.

Several limitations and boundaries to this research study need to be acknowledged. Firstly, the net capacity of a pumped well is evaluated using the pump specification by Frost (2010). The net capacity of a pumped well may increase if the technology is improved. Secondly, the tariff feasibility range will refer to the current national tariff at 8.22 – 21.34 cent US$/kWh that might change corresponding to government regulation. Thirdly, financial modeling sets the IRR at one expected attractive number in Indonesia (Randle, 2019) whereas it can be varied depending on the developer.

2.2 Resource Analysis

This section covers the process of calculation range of net capacity of pumped wells and investigating how reservoir properties (temperature and productivity index) affect the net capacity value. In addition, the resource capacity and the number of wells (production, re-injection, and makeup) are necessary as the input of the financial model in the next sub-chapter. Therefore, the process involves estimating resource capacity, numerical modeling of a well pump, and simulating development plan.

2.2.1 Resource Estimation

Resource capacity in low to intermediate temperature systems was estimated using power density. This method is usually used in the exploration, and development stages of geothermal projects, or even in the early production phase where the availability of data and model are limited (Wilmarth, 2014). The power density as a function of the resource type and temperature is presented by Wilmarth (2020). However, in this paper, the correlation of power density for the low to intermediate temperature geothermal system was re-calculated to avoid overestimation of resource capacity as shown in Figure 3. In terms of calculation, the minimum and maximum temperature is defined at 100 and 230 °C, respectively. Likewise, the maximum and minimum production areas are set at 4 km^2 and 47 km^2, respectively.

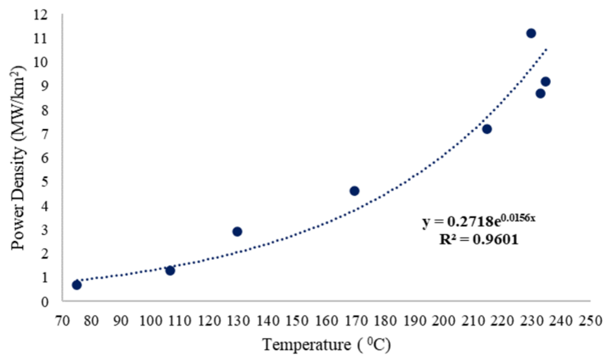


Figure 3: Power density as function of temperature for low-intermediate temperature geothermal system (recalculated from Wilmarth (2020))

2.2.2 Numerical Modeling of Well Pump Flow

The net capacity for a pumped well is estimated by developing a numerical model of well pump flow. The detail of the model input is shown in Table 1. It is clearly seen that Line Shaft Pump (LSP) is used for the model by considering maximum operating temperature range, 194-260 °C and flow rate of the hot brine lifted, 186.8 l/s (Frost, 2010). In the end, the net capacity was analyzed from 10,000 iterative calculations in numerous productivity index values. The range of productivity index is calculated from geothermal rock permeability grouped by Wallis et al (2015). The productivity index is classified into five classes as illustrated in Table 2.

Parameter	Value	Unit
Productivity Index	Variable	
Reservoir Temperature	Variable	
Well Depth	1200	m
Static Reservoir Pressure	Hydrostatic	
Maximum Pump Setting Depth	700	m
Maximum Rated Flow Rate	186.8	l/bar
Rejection Temperature	70	deg C
Power Plant Efficiency	12%	
Power Plant Auxiliary Parasitic Load	11.5%	

Table 1: Parameter input of numerical model of well pump flow (Frost (2010); Wallis et al (2015); Hochwimmer et al (2013); Zarrouk and Moon (2014)

Productivity Index Classes	Value (kg/s-bar)	
	Min	Max
Very Low	1	2
Low	2	7
Medium	7	13
Good	13	23
Very Good	23	42

Table 2: Productivity index classes (calculated from Wallis et al (2015))

2.2.3 Development Simulation

The resource capacity and net capacity of pumped well were used as a basis to simulate development strategy. It was assumed that the resource capacity is fully utilized to generate electricity. Hence, the production wells were drilled to meet full resource capacity development. In terms of power generation, it is commonly found that pumped well with temperature <190 ^oC is coupled with a binary power plant while above 190 ^oC is combined with a flash-cycle or hybrid-cycle power plant (Sanyal, 2007). However, in this study, the binary power plant is used to convert the energy from hot brine into electricity. Following this, the cool brine from the power plant was re-injected to the formation, which has lower fluid deliverability through the re-injection well. It was assumed that the injection index of the formation is 80% of the production index. Then, the maximum capacity of the formation was estimated when the wellhead pressure is 5 bar. In fact, the production rate naturally declines over time. Thus, make-up was drilled to maintain the production rate. In this study, the number of make-up wells was calculated with the assumption that the production rate will decline 3% per year.

2.3 Financial Analysis

In this section, the feasibility of development plans from resource analysis was assessed based on a finance point of view. The development plan is feasible if the electricity tariff lies in the range of BPP applied in the eastern region of Indonesia. Hence, a financial model was developed to calculate the electricity tariff for each development plan. The development plan including electricity generation and the number of wells (production, re-injection, and make-up) became the input of the model.

2.3.1 Financial Modelling

The financial model was developed using three cores which are an income statement, a cash flow statement, and a balance sheet (Pignataro, 2013). Those statements were connected in excel using function and formula to set up reliable financial modeling.

First of all, the income statement measures the profit or loss of the company for a specific period. The net income is defined as gross revenue subtracted by expense, depreciation, interest, investment allowance, production bonus, and tax. In more detail, the gross revenue is generated from the sales of electricity. The revenue depends on the performance of the power plant throughout the year. In this paper, the multiple values in the range of 90-97% was simulated to capture the uncertainty in power generation. In addition, geothermal installation costs cover all costs associated with the availability of hot brine and power generation. The cost component and range of the cost are summarized in Table 3. The cost component and range of the cost are summarized in Table 3. It is known that geothermal costs are very sensitive to the site (IRENA, 2017). The cost of installation of a capacity in an existing field can be less expensive than in a challenging field. Therefore, the multiple values of the cost were assigned to Monte Carlo Simulation to assess the probability of the feasible development plan. Other parameters involved in the calculation of net income including project duration, technical, and financial assumptions are presented in Table 4.

Another fundamental statement is a cash flow statement. The cash flow statement records how much has a company raised and expended over the project life. For simplicity, the revenue and expenses are assumed in cash. Consequently, the cash flow is expressed as the sum of net income, loan capital, investment allowance, and depreciation, deducted by total capital, and principal payment. Knowing that depreciation and investment allowance are never actually paid, those expenses are added back to net income from the income statement.

Equally importantly, the balance sheet shows the financial position of the company. In other words, this statement reveals the company's total assets and how these assets are financed. As its definition, the balance sheet consists of three major categories which are assets, liabilities, and equity. In this study, it was envisaged that the assets are only from non-current assets or fixed assets, tangible and intangible assets. The tangible assets include 30% of wells, piping, well pump, steam/hot water gathering system, power plant and SAGS cost while the rest is intangible assets. Likewise, the liabilities of the project are on long-term debt, 70% of the total capital. However, the rest is assigned to equity.

Parameter	Unit	Price per Unit		
		Min	Most	Max
STEAM FIELD DEVELOPMENT				
Capital				
Land cost, access and site work (included Env. Study and Civil Work)	Activity	$ 1,000,000		$ 5,000,000
Exploration Well Drilling	Well	$ 4,000,000	$ 6,000,000	$ 8,000,000
Production Well Drilling	Well	$ 4,000,000	$ 6,000,000	$ 8,000,000
Reinjection Well Drilling	Well	$ 4,000,000	$ 6,000,000	$ 8,000,000
Make-up Well Drilling	Well	$ 4,000,000	$ 6,000,000	$ 8,000,000
Piping for Make-up Well			(25% Well Cost)	
Well Pump	Well	$ 350,000	$ 450,000	$ 550,000
Steam/Hot Water Gathering System	Activity/MW	$ 200,000	$ 320,000	$ 440,000
Expense				
Detailed G-G-G Survey	Activity	$ 1,000,000	$ 2,000,000	$ 3,000,000
Core holes	Activity	$ 1,000,000		
Resource study & Modelling	Activity	$ 100,000		
Feasibility Study	Activity/MW	$ 100,000	$ 140,000	$ 200,000
Operation and Maintenace of Well Pump			50% Well Pump Cost	
Operating cost (Upstream)	Activity/MW	$ 30,000		
PLANT DEVELOPMENT				
Capital				
Power Plant				
a. Temperature <= 129 deg C		$ 4,500,000		
b. 129 deg C < Temperature < 190	Activity/MW	(0.6874 (Temperature)2 - 259.4 (Temperature) + 26493) x 1000		
c. Temperature >= 190		$ 2,000,000		
SAGS (Piping and Production Facilities)	Activity/MW	$ 325,000	$ 350,000	$ 400,000
Expense				
Operating cost (Downstream)	Activity/MW	$ 50,000		
Other Cost (Administration/Management)	Activity/MW	$ 250,000		

Table 3: Summary of cost components (Gehringer and Loksha (2012); UNFCCC (2012); Hochwimmer et al (2013); Henneberger (2013); Antonaria et al (2014); Purwanto et al (2018); Wahjosoedibjo (2018); Febrianto (2019); Randle (2019).

Parameter	Value			Unit
	Min	Most likely	Max	
PROJECT DURATION				
Planning and Construction Phase		7		Years
Operation Phase		30		Years
TECHNICAL				
Number of Exploration Well		3		Well
Exploration Well Success Ratio		59%		
Production Well Success Ratio		80%		
Reinjection Well Success Ratio		100%		
Capacity Factor	90%		97%	

FINANCIAL		
Tangible Cost	30%	
Depreciation Period	8	Years
Depreciation Rate (Decline Balance)	25%	
Loan : Equity	70 : 30	
Loan Period	20	Years
Interest	4%	
Interest During Construction	4%	
Production Bonus	0.5%	
Tax Rate	25%	
Investment Tax Allowance (for 6 years)	5%	
Discount Rate	12%	

Table 4: Summary of financial model input parameters (Danar (2010); International Finance Coorporation (2013); Sarmiento (2013); Quinlivan et al (2015); Wahjosoedibjo (2018); Randle (2019); Law No. 36/2008; Ministry of Finance Regulation No. 21/PMK.011/2010; Government Regulation No. 28/2016).

2.3.2 Financial Parameters

The indicators for financial evaluation used as criteria to decide the corresponding feasibility of geothermal generation are Investment/MW, IRR, and electricity tariff. Electricity tariff is derived from 10,000 iterative calculations by setting IRR at 16.5% as an attractive return of investment from the private sector point of view in Indonesia (Randle, 2019). Furthermore, the other two parameters of IRR and Investment/MW are formulated as follows:

$$Investment/MW = \sum_{t=1}^{t} \frac{Cost}{Generation\ (MW)} \quad (1)$$

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_0 \quad (2)$$

Where C_t, r, t, C_o are net cash inflow during the period t, discount rate, number of time periods, and total investment cost, respectively.

3. RESULT AND DISCUSSION

This section presents findings and discussion of this research, focusing on the interaction of reservoir properties (temperature and productivity) and area on resource feasibility and financial feasibility.

3.1 Net Capacity of a Pumped Well

Figure 4 illustrates the median of the net capacity of a pumped well vs three ranges of temperature for different productivity index classes. At a glance, the net capacity increases as the reservoir temperature and productivity index increases. However, it is noticeable that the median of the net capacity is relatively constant at 2.5 MW for temperature < 145 °C, 5.9 MW for 145 ≤ temperature < 190 °C, and 8.9 MW for temperature ≥ 190 °C irrespective of how high the productivity index is. This capacity is limited by the maximum flow rate of the pump, accounting for 186.8 l/s. The capacity might be higher if the pump can improve the limit of the rate. In addition, Figure 5 (left) shows the net capacity of a pumped well vs temperature for different productivity index classes. Interestingly, the net capacity increases with temperature until it reaches a peak between 190 and 200 °C. Following this, the net capacity gradually declines with temperature. This condition is caused by the increase of vapor pressure with temperature, thus, the pressure drawdown decreasing. Indeed, Figure 5 (right) depicts the net capacity vs productivity index for different ranges of temperature. It is shown that net capacity is sensitive to productivity index at very low to low class. However, it is not too sensitive for medium, good, and very good classes.

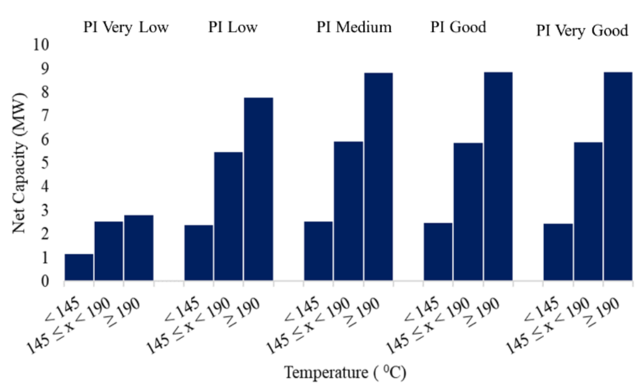


Figure 4: The median of net capacity of a pumped well vs temperature for different ranges of productivity index classes.

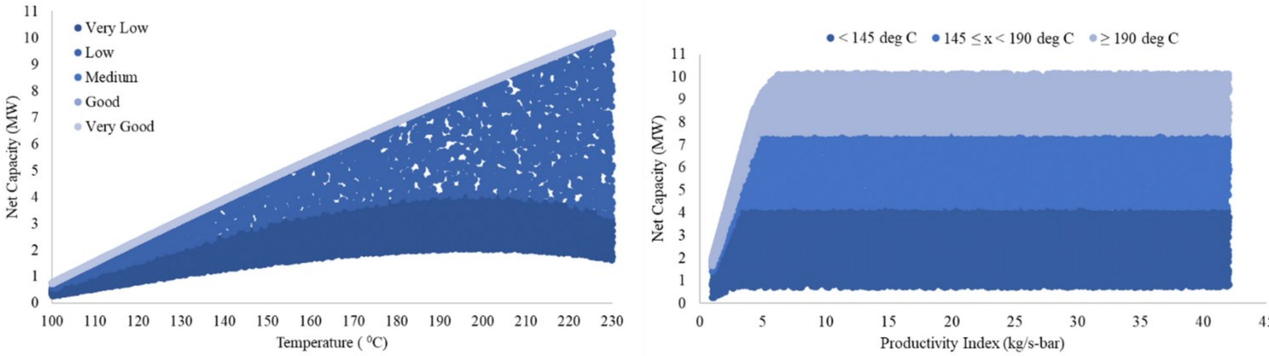


Figure 5. The net capacity of a pumped well vs (left) temperature for different productivity index class (right) The net capacity of productivity index for different temperature groups.

3.2 Electricity Tariff and Investment/MW

This study found interesting results as shown in Figure 6. The tariff range of each category median was 0.112 USD/kWh - 0.450 USD/KW with 4 - 19 million Investment/MW. Comparing this tariff to the current project status quo in Indonesia at 0.0679 - 0.1338 USD/kWh and 3 – 5 million Investment/MWe (LIPI, 2014; World Bank, 2019; ADB, 2015), is not on par due to different geothermal systems and other economic factors such as electricity demand. It is also interesting to note that electricity tariff and investment/MW remains constant at the same temperature from medium to very good class productivity index. This condition has a similar pattern with the net capacity trend which is affected by the limitation of a maximum flow rate of the available pump. Thus, the electricity tariff and investment/MW are sensitive to the productivity index at very low and low class. Knowing that electricity tariff largely depends on resource quality and generation capacity, it was evaluated at multiple values of temperature, productivity index, and area as shown in Figure 7. It can be seen that those parameters have a strong influence on electricity tariff. The result implied that 65% from the Monte Carlo simulation indicates the possibility of tariff lies in the current feasible BPP area. Hence it can be concluded that there is a higher chance to make the projects viable in developing the eastern part of Indonesia.

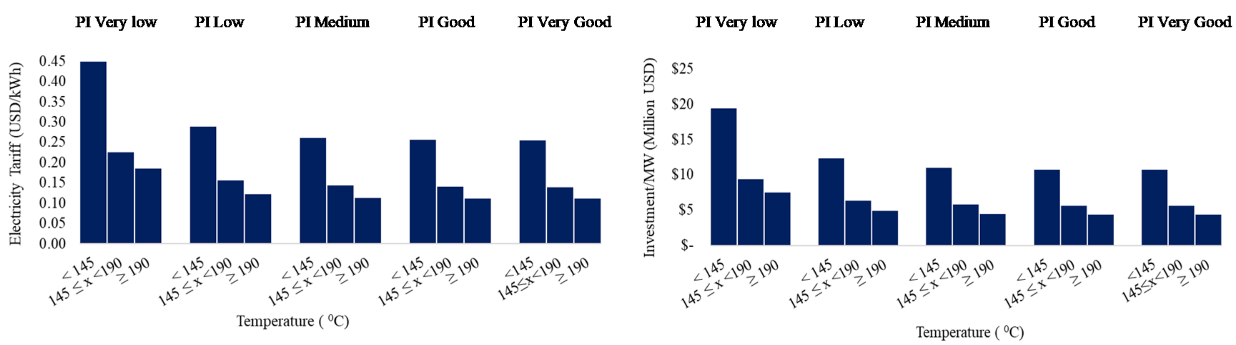


Figure 6: The median of (left) electricity tariff and (right) investment/MW vs temperature for different productivity index class

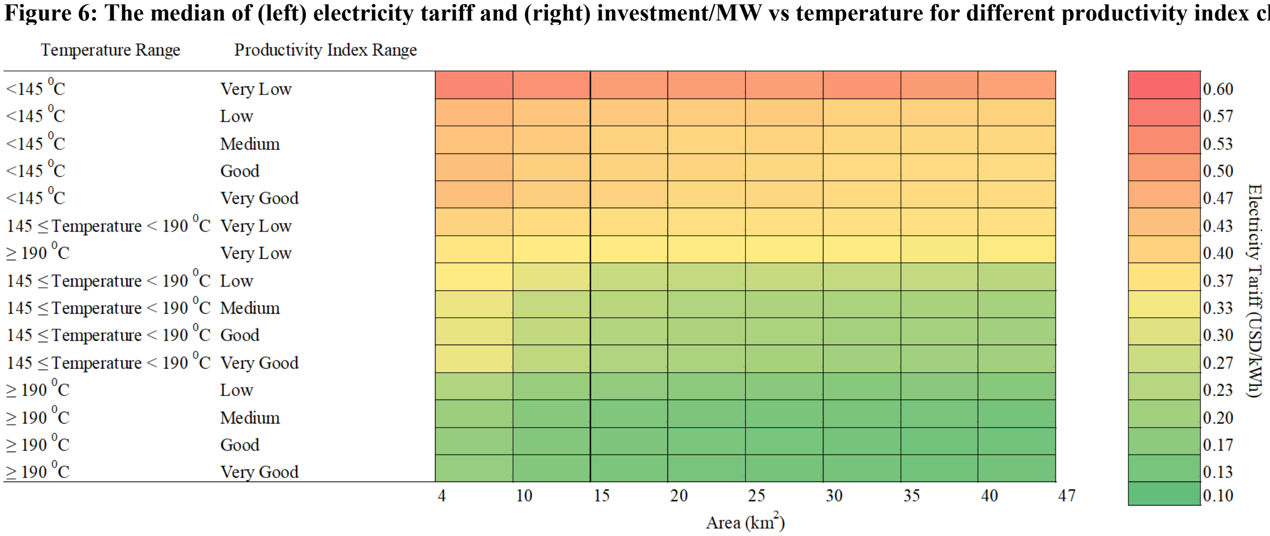


Figure 7: The electricity tariff with a combination of range of temperature, productivity index, and area.

3.3 Financial Feasibility

The financial feasibility of the low to intermediate temperature resources is evaluated based on the BPP range in the eastern region of Indonesia. The resource quality of the feasible development is analyzed to get a preliminary indication of feasible development. Figure 8 shows the probability of feasibility of the low to intermediate temperature resource development with respect to area, one of these research findings showed that the larger the area the more likely generate a feasible tariff. To consider the possibility of tariff changing, the maximum value is changed to see increments per 1 cent tariff changing which can be explained in blue (price cap 0.19 USD/kWh) and yellow (price cap 0.22 USD/kWh) bar in that figure. It can be concluded that every 1 cent tariff reduced will decrease 15% of feasibility percentage on average.

Figure 9 showcases granular views from the previous chart to analyze the relation of temperature, productivity index, and electricity tariff area to feasible tariff range. It is apparent that fields with temperatures ranging from 145 ^{0}C to 230 ^{0}C could be viable to be developed as long as the productivity index (PI) value indicates more than low class at 2 kg/s-bar regardless of size area. Furthermore, in many instances, a debate is taking place to determine which factor of temperature and PI is more prominent in deciding the continuity of the project. It is clearly seen that temperature is more sensitive to deliver more varied results compared to other factors, hence it is advisable to consider temperature as the most prominent factors. This analysis is also supported by sensitivity test results in the next subchapter.

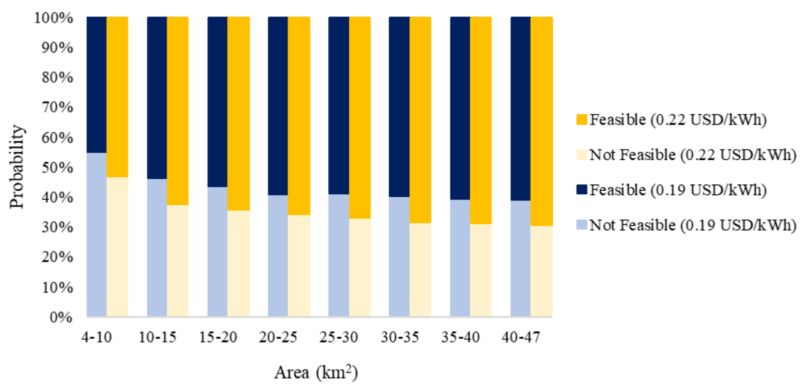
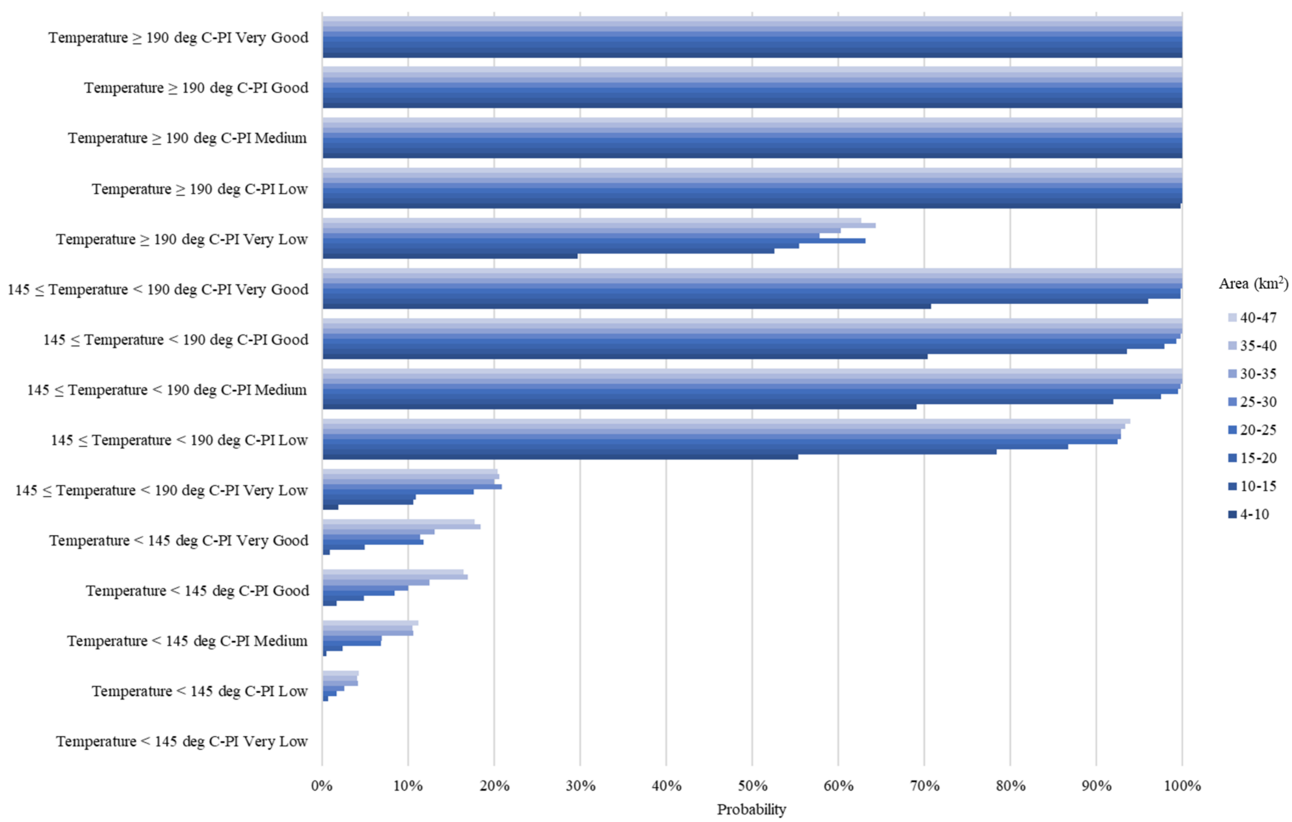


Figure 8: The probability of feasible low to intermediate temperature resource development vs area.



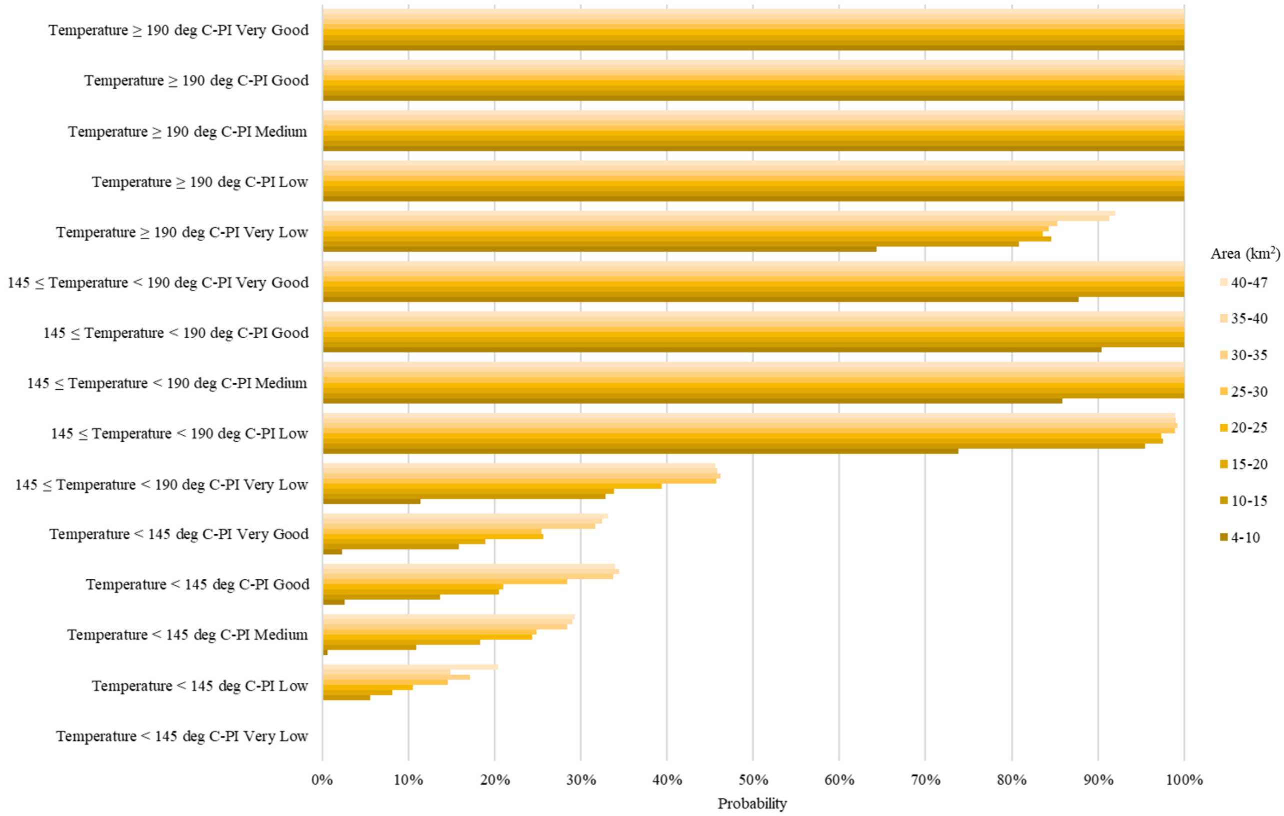


Figure 9: The effect of temperature, productivity, and area on the probability of low to intermediate temperature resource feasibility with cutoff (above) ≤ 0.19 USD/kWh (below) ≤ 0.22 USD/kWh

3.4 Sensitivity Analysis

Figure 10 is comparing the sensitivity of technical parameters (temperature, productivity index, and area), and financial parameters (CAPEX, and OPEX) on electricity tariff. It can be noted that the effect of temperature is much higher in comparison with other technical parameters. Likewise, the effect value of CAPEX also exceeds its counterparts.

Overall, an increase in temperature, productivity index, and area results in a decrease in electricity tariff. However, the sensitivity of those parameters declines as the parameter's value increases. Temperature is the key parameter for estimating resource capacity, net capacity of pumped well, number of wells, and power plant cost. Undoubtedly, the temperature has the strongest effect compared to other parameters. It is also noticeable that the electricity tariff decreases sharply at a lower temperature. This condition is caused by the pattern of the net capacity of a pumped well vs temperature for different ranges of productivity index. The net capacity rose significantly before reaching peak between 190 and 200 ^{o}C. After that, the net capacity gradually decreased until the temperature hit 230 ^{o}C. The net capacity directly involves the calculation of the number of wells which is a major cost component in CAPEX. Indeed, the temperature also contributes to determining the cost of a power plant. It is known that resources at lower temperatures are more cost intensive. As a result, electricity tariff at lower temperature fell dramatically while at higher temperature slowly decreased. In terms of the productivity index, it is also the key in estimating the net capacity of a pumped well. The value of net capacity is relatively constant at medium, good, and very good productivity index class due to the maximum fluid lifted by a well pump. Thus, the sensitivity of productivity index on electricity tariff is lessened at the lower productivity index. Lastly, the area is an essential parameter in estimating resource capacity. However, the electricity tends to be relatively constant at greater generation capacity.

In terms of financial parameters, an increase in CAPEX and OPEX results in an increase in electricity tariff. Capital Expenditure (CAPEX) has a greater effect compared to Operation Expenditure (OPEX). CAPEX mostly is dominated by two major cost components which are well cost and power plant cost. In fact, both expenditures are associated with the technical parameters. The resource capacity and net capacity per pumped well will determine the number of wells. In the same way resource temperature also will determine the power plant cost. In addition, in this study, the drilling success ratio of the production well is assumed to be 80%. The lower success ratio potentially increases CAPEX. In other words, poor exploration might require additional drilling. Conversely, the OPEX is lower and more predictable. The annual operating and maintenance of steam and plant development are relatively stable over time. Therefore, the operational costs for geothermal plants are less significant because the fuel, geothermal steam, is mostly developed during the investment stage.

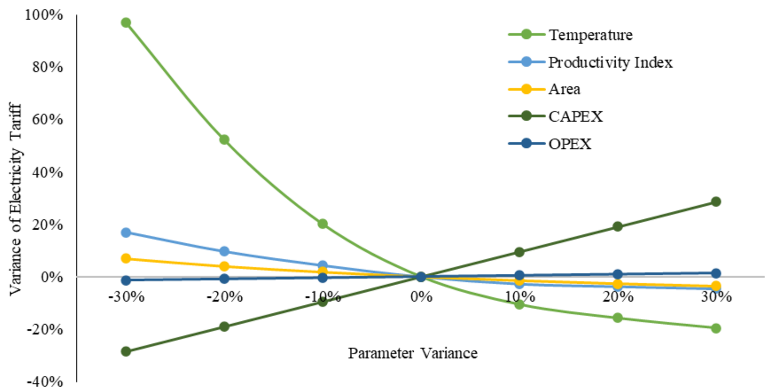


Figure 10: The sensitivity of technical parameters (temperature, productivity index, and area), and financial parameters (CAPEX, and OPEX) on electricity tariff.

4. CONCLUSION AND FURTHER RESEARCH

4.1 Conclusion

Reflecting on the objective and analysis conducted in this study, several conclusions can be drawn as follows: Firstly, regarding well capacity, at PI higher than 7 kg/s-bar, the median or P50 of a pumped well remains constant accounting for 2.5 MW for temperature < 145 °C, 5.9 MW for 145 ≤ temperature < 190, and 8.9 MW for temperature ≥ 190 °C. The net capacity rises in accordance with temperature before hitting the peak between 190 and 200 °C. After that, it falls gradually with temperature. In terms of productivity index, it has a significant effect on net capacity at very low and low class while has a weak effect at higher productivity index. Secondly, in terms of economical tariff, the tariff range of each category median was 0.112 USD/kWh - 0.450 USD/kWh with 4 - 19 million Investment/MW. The Monte Carlo Simulation result indicates that 65% of the tariff lies in the current feasible BPP area at 8.22 – 21.34 cent US$/kWh. Thirdly, limited to this study data, in overall the most viable range is low to moderate temperature class system with productivity index at least in low classes. However, there is a possibility of variance according to a specific case. Lastly, Reservoir temperature has the most significant influence on the feasibility of the project, followed by productivity index and area. Likewise, CAPEX has a greater effect than OPEX on feasibility of the project.

All in all, those learnings above conclude that the development of low to intermediate geothermal systems in the Eastern Indonesia can be technically feasible following the suggested technical profile and economically attractive compared to the current government tariff.

4.2 Further Research

This study concentrates on technical and financial analysis of low to intermediate temperature resources. However, there are other fundamental challenges including supply and demand, regulations, grid connections, and social restraints influencing the feasibility of the geothermal project. Therefore, further studies fleshing out those aspects are suggested to provide a comprehensive understanding of geothermal development in the eastern Indonesia.

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