Approach for Pre-Feasibility Study of Medium Enthalpy Geothermal Field, Case Study: Danau Ranau, Indonesia

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Abstract. The development of geothermal fields in Indonesia is carried out under the provisions of the applicable laws and regulations, namely Geothermal Law No. 21 of 2014 and Environmental Protection and Management Law No. 32 of 2009. Based on Law No. 21 of 2014, geothermal business activities consist of preliminary surveys, exploration, and exploitation. After the exploration phase (a detailed geological, geochemical, and geophysical study), a pre-feasibility study is needed to determine the feasibility of exploration drilling. The pre-feasibility study is done to manage project risks. Danau Ranau geothermal field is one of the 166 medium enthalpy geothermal prospects in Indonesia. Activities carried out in this field were geoscience studies. This research was conducted to determine how feasible the Danau Ranau medium enthalpy geothermal field was developed for direct and indirect utilization by looking at the acceptance of technical, financial, environmental, and risk studies. The study can be a tool for the developer to decide whether to continue the next development stage. The result shows that applying the approach for Danau Ranau Geothermal Field is feasible to develop with consideration. Plant of Development by cascade model with leveling utility of energy for Danau Ranau Geothermal Field shows optimal value both in the operational and financial sides. The first level is technically designed for electricity with ORC conversion technology and the cascade level for indirect use by Lindal Diagram and community empowerment in economic and social. In financial analysis, the cascade model has optimum profitability value expressed in NPV and equity IRR.

1. Introduction
The development of geothermal energy for electricity generation in Indonesia is still focused on high-temperature hydrothermal reservoirs. Thus, the development of medium-low enthalpy geothermal fields is still not favored. However, more than 50% of the identified geothermal prospects are characterized by low to medium enthalpy. From 17 (seventeen) fields that have been developed and utilized, all of them have high enthalpy characteristics. It means no medium enthalpy geothermal field has been developed yet. Various factors are behind the slow progress in the utilization of low to medium enthalpy geothermal fields, including difficulties in choosing conversion technology and the level of acceptance of financial risks in the exploration, exploitation, and utilization stages.

One of the medium enthalpy geothermal fields in Indonesia is Danau Ranau. Danau Ranau geothermal field is located in two provinces, namely Lampung Province and South Sumatra Province.
Lampung Province is in Sukau and West Lampung District, while South Sumatra Province is in the area of Banding Agung Oku Selatan District. As one of the medium enthalpy geothermal fields in Indonesia, this field has been officially made one of the development prospects according to Geothermal Working Area (GWA) Decree number 1551K/30/MEM/2011 dated 21 April 2011. The Danau Ranau field exploitation has entered into RUPTL 2019-2028 [1] with a target capacity of 20 MW, COD in 2030, and assignment to PT PLN. Geology, Geochemistry, and Geophysics (GGG) study estimated that Danau Ranau’s geothermal system is a system with a hydrothermal volcanic system where the heat source location is around Mount Semining. The reservoir is water-dominated with a temperature in the range of 200°C-220°C. The prospect has a hypothetical reserve potential of 25 MW for a 10% probability [2].

According to Geothermal Law No. 21 of 2014 [3], geothermal business activities consist of preliminary surveys, exploration, and exploitation. The exploration stage consists of pre-feasibility studies and exploration activities. The pre-feasibility study has a vital role in deciding to proceed or not with the exploration drilling. The purpose of the pre-feasibility study is to elaborate on all data and project prospects, so the risk of exploitation can be controlled. As is well-known, drilling exploration wells require a significant budget of around US$6-7 million for one well. This research was conducted to develop a pre-feasibility study with an indirect and direct utilization scheme. Uncertainty condition mitigation and probabilistic approaches are both technical and economical [4,5] with sensitivity analysis to manage a project’s uncertainty. Besides, the pre-feasibility study results are expected to be a tool for PLN management or other geothermal developers to decide whether to continue or not the next development stage, namely exploration well drilling.

2. Methodology
The research began by conducting a literature study, determining the research field, and collecting field data such as geological, geochemical, geophysical, and baseline data and 3G field integration analysis. After the field data is collected, the next step is to re-evaluate the geothermal resources in the research field, and the results will be an input in making a Plan of Development (POD). The POD will be assessed based on environmental studies, risk studies, exploratory risk studies, and the probability of success (POS). The results of the studies are then elaborated as a consideration of whether the field can be developed. The next stage is creating a POD technical design that includes direct and indirect production facilities and geothermal fluid utilization facilities. This technical design will be an input parameter for determining costs in a financial study. The last stage of this research workflow is sensitivity analysis. It is hoped that the series of workflows can be a company development tool in considering the Danau Ranau geothermal field development process’s sustainability.

![Figure 1. Workflow of Research.](image-url)

The limitation of this research is no further analysis of geoscience and resource assessment. The electrical system follows the transmission network provision plan at the RUPTL 2019-2028 [1]. This study does not determine the drilling location, so it refers to the documents from PLN in 2017 [6]. The geothermal potential is classified as a possible reserve that covers the Lumbok-Kota Batu prospect area.
Indirect utilization is assumed to use the binary system/Organic Rankine Cycle (ORC) technology. Baseline information on environmental conditions uses regional data within the last 5 (five) years. Development risk analysis uses the ISO 31000 risk management system with risk acceptance adjusted to the risk appetite developer company level. The economic study assumptions refer to the PLN Group’s project funding patterns and financial ratios.

3. Field Development Plan
The intended study and analysis of POD include exploration risk and POS studies, the concept of POD, environmental studies, and risk assessments of field exploitation plans. After obtaining all data, an integrated analysis was conducted to assess the acceptance level criteria’ suitability to continue the Danau Ranau concession project.

3.1. Exploration Risk and POS Studies
A large number of uncertainties and the high investment costs at the early stages of geothermal field development make the process of exploration risk quantification necessary. According to Schulz et al. [7], the exploration risk concerning geothermal wells is the risk of not achieving a geothermal reservoir by one (or more) well(s) with sufficient quantity or quality and the risk of not successfully achieving (economically acceptable) minimum levels of thermal water production (minimum flow rates) and reservoir temperatures. The term quantity is defined by the (thermal) power, which can be achieved by one well (or more wells). In contrast, the term quality in the definition can, in general, be interpreted as fluid composition (fluid chemistry). Components (gas, salinity, oil) can appear in the fluid, which, if they exceed specific limiting values, hinder, or complicate the thermal utilization [7]. The POS can be defined most by merely determining each risk’s probability separately and multiplying the single probabilities. By neglecting water quality risk, geothermal well’s exploration risk depends on temperature and flow rate [7].

3.2. This study calculates the range of thermal power per well with the following conditions
1. The density of the geothermal fluid (ρ) is the density of compressed liquid fluids at reservoir temperatures of 200°C (T min) and 220°C (T max).
2. Compressed liquid geothermal fluid’s specific heat capacity is taken from the Steam Table at WHP 6 bar isobaric conditions.
3. The mass flow rate is taken from the reference data to develop the Lumut Balai geothermal field, taking into account Lumut Balai Geothermal Field’s location in the same cluster as Danau Ranau’s geothermal field.
4. Input reservoir temperature is taken from Afiat et al. [2] with a range of 200°C (T min) and 220°C (T max).
5. The output temperature is taken from Sarmiento [8], which is 120°C.

The thermal power per well’s calculation ranges from 1.5 MW to 3.65 MW per well from the above provisions. Because the Danau Ranau field’s development status has only reached the stage of detailed geoscience studies and does not yet have exploration wells or delineation wells, the POS calculation uses the reference well approach. Reference wells were selected based on consideration of the similarity of field characteristics, location of geothermal fields adjacent/one cluster to the Danau Ranau field. Both of calculation POS using a reference well approach from Lumut Balai Geothermal field, taking into account the location of the Lumut Balai geothermal field located on the same Sumatra geothermal cluster as Danau Ranau geothermal field [9]. POS calculation results show, the POS value of mass flow rate (Q) is 79%, and the POS reservoir temperature is 99.6% so that the overall POS is 78.6%. It means the chances of a successful exploration well drilling in the Danau Ranau geothermal field, containing 21.4% risk of failure to reach a reservoir temperature of 200°C-220°C with a mass flow rate of 50-100 kg/s.
3.3. Plant of Development

The POD is designed by considering baseline data, interpretation of 3G data, calculation of possible reserve potential, and exploration and POS risk studies. The design of the POD concept of the production facilities part includes determining the number and location of wells. Because the Danau Ranau field is a greenfield, which does not yet have exploration wells or delineation wells, for the first stage, the number of wells proposed after the project was stated to proceed to the drilling well stage is 3 (three) wells (Figure 2). These three wells can act as exploration wells and delineation wells. Determination of the point of exploration well drilling is based on the interpretation of the location of permeable zones obtained from geological, geochemical, and geophysical studies. The geological studies, supported by geochemical data, indicate a structure at the drilling location, which shows anomalous Hg and CO$_2$ (above the average) in the area. Besides, the MT data shows a low resistivity value, which can be interpreted as a rock cap or caprock in the area. The drilling location was also chosen due to the ease of infrastructure coverage.

![Figure 2. Well pad location design.](image)

![Figure 3. Design of FCRS.](image)

The Fluid Collecting Reinjection System (FCRS) design includes piping systems as geothermal fluid flow paths from wells to utilization facilities and reinjection systems (Figure 3). Geothermal fluid pipeline systems include flow pipes from well pads to separators, separators, brine flow pipes to the ORC system, and brine flow pipes from the ORC system to the direct utilization station. In the design of brine flow pipes, the possibility of calcite scaling and silica scaling is also a concern. The formation of calcite scaling can occur due to decreased working temperature from the well to Level 1 (ORC) to Level 4. Simultaneously, the formation of silica deposits can be affected by the speed of water in the pipe. Alternative reinjection systems on the proposed POD concept utilize unproductive wells as reinjection wells and flow the brine output from the utilization facility to the lake or river near the development site. Brine, which will be distributed, will ensure its quality standard does not negatively impact the surrounding environment.

In this study, a multilevel cascade model [10,11] is designed to optimum use the produced geothermal fluid (Figure 4). Each level of utilization is designed based on the suitability of the Lindal diagram. At the first level, it is allocated for electricity generation using a binary system of ORC technology with a brine temperature entering the system of approximately 180°C.
Cascade models are designed into four levels. Indirect use is at the first level, while the second level is for direct use up to the fourth level (Figure 5). The model’s design is based on consideration of geothermal fluid flow effectiveness, which in direct use does not require higher geothermal fluid temperatures than for indirect utilization. Direct utilization is designed based on the results of the baseline study. The direct utilization scheme aims to support the empowerment of local commodities and local community tourism objects.

Figure 4. Concept of Cascade model.

Figure 5. Design of Cascade model.
At the first level of this cascade model, the geothermal fluid used is a fluid with a temperature of 180°C with a WHP design set at 7 bars, and the total mass flow is 160 kg/s. The plant’s development uses a phased scheme where the mass flow rate of 3 production wells is 160 kg/s with the initial assumption according to POS that the mass rate/well is 70 kg/s. The reason is to maintain and mitigate the sustainability risk issues of the Danau Ranau geothermal field. In the ORC generation potential analysis, engineering simulations are carried out. The design of brine utilization with ORC has been simulated. The parameters and the outputs, as base values, are listed in Table 1.

At Level 2, the cascade model is designed for drying coffee where the geothermal fluid (brine), the ORC plant’s output, has a temperature of 80°C flowing to the heat exchanger. In the heat exchanger, heat transfer occurs between brine with cold water. Coldwater that has been heated by brine in the heat exchanger is then channeled to the second heat exchanger. There is heat transfer from the cold water heated with air fanned by a blower in the second heat exchanger. In the second heat exchanger, heat output air flows to the pepper drying chamber. Whereas at Level 3, the cascade model is designed for drying coffee. Level 2 output brine has a temperature of 65°C. Brine is then channeled into a winding pipe, which is then fanned by the blower. The results of hot air then flowed into the coffee dryer. The total power needed for Level 2 and Level 3 drying systems is 74.5 kW.

### Table 1. Design of ORC

| Parameter               | Value         |
|------------------------|---------------|
| Turbine Eff            | 85%           |
| Feed Water Pump Eff    | 75%           |
| P Condenser            | 1.4 Bar       |
| P Atmospheric          | 1 Bar         |
| T Ambient              | 21°C          |
| P Brine                | 7 Bar         |
| T Brine                | 180°C         |
| T Output               | 80°C          |
| m brine                | 160 kg/s      |
| m Isopentane           | 160 kg/s      |
| T Recuperator          | 50°C          |
| T Condenser            | 45°C          |
| dP Fan                 | 52 Pa         |
| Fan Eff                | 70%           |
| U Evaporator           | 1.600 kW/m²°C |
| U Preheater            | 1.000 kW/m²°C |
| U Recuperator          | 0.400 kW/m²°C |
| U Condenser            | 0.800 kW/m²°C |
| Pinch point            | 5°C           |
| W<sub>fw</sub> (W feed water pump) | 0.17 MW |
| W<sub>f</sub> (W fan) | 0.046 MW     |
| W<sub>t</sub> (W turbine bruto) | 6.87 MW |
| W<sub>nt</sub> (W turbine netto) | 6.67 MW |

Coffee drying output brine with a 50°C temperature is channeled through an open brine channel to the pond. Temperature control is needed to keep the pool’s temperature at a comfortable level for warm water baths. A temperature sensor was installed in the pool water and set at a specific temperature. The pond/pond’s design considers the mass flow rate of the brine Level 3 Coffee Drying output of 5 kg/s. The proposed pool size details are 40m x 20m x 4m, assuming it can hold brine output for 7 (seven) days.
3.4. Environmental Studies

After the POD concept was designed, including production facilities, distribution facilities, and geothermal fluid utilization facilities, an environmental study was carried out. The environmental study was made to control negative impacts and increase the positive impacts resulting from the operations carried out, as listed in (Figure 6). The formulation of environmental management uses several approaches, such as technology, socioeconomics, and institutions. The technological approach taken is to formulate the application of ways or technologies to manage significant environmental impacts. The socio-economic approach formulates steps to cope with significant impacts through actions based on social interaction and government assistance. Simultaneously, the institutional approach is the formulation of institutional mechanisms that will be taken to cope with significant environmental impacts.

![Figure 6. Workflow of Environment Study.](image-url)

Holistic evaluation of environmental quality includes mapping of impact areas, significant impacts, and sources of impact based on business activities ranging from pre-construction, construction, operations, and post-operation activities. Construction consists of exploration wells, production wells, injection wells, and production facilities (indirect and direct uses). The impact areas are classified according to the socio-economic aspects of culture, physics - chemistry, biology, and other impacts. The impact areas are also broken down into sub-areas covering air, water, land, economy, and public health quality. The mapping of the impact area and 34 impacts can occur due to concessions carried out. From the mapping of impact areas, significant impacts, and sources of impact, success indicators are formulated as targets for environmental management guidelines, which will then become a reference in making environmental management and monitoring programs. From the study results, 63 environmental management programs and 26 environmental monitoring programs were designed.

3.5. Risk Assessment

Geothermal development risk assessment uses the Risk and Control Self-Assessment (RCSA) method based on ISO 31000 Risk Management Standard. This method aims to identify, assess, control, and reduce the possibility of risks that will arise during exploration and stages of field development. The study stages include setting activity targets and alternative achievement targets, testing activity targets, identifying risks, and analyzing and evaluating risks. This section’s risk assessment is taken from the development company’s perspective and is based on technical data, infrastructure data, accessibility, and socio-economic data. However, in analyzing the risk in the Danau Ranau geothermal field, not all data is analyzed, but only data has the potential risk. The first element in risk assessment is risk identification. Risk identification is carried out to explore incidents in the implementation of actions and activities that might hamper the achievement of goals or objectives. The step of risk assessment, as seen in (Figure 7).

In other words, risk identification is an activity to find and register risks related to the organization’s objectives and activities (business process). The risk identification output is a risk profile consisting of a list of risks containing information about risk events, causes, and impacts. After the risk is identified, the next step is the analysis and evaluate risk. Risk analysis is a systematic process to determine how often an event and the impact of risk might occur and how serious the consequences arise when the
events occur. Risk evaluation is the process of comparing the level of risk found during the analysis process with the risk criteria previously determined. The risk evaluation process will determine which risks require treatment and how priority is treated for those risks by referring to the “risk criteria”. In other words, the results of the risk evaluation indicate a risk rating that requires further mitigation concerning an acceptable level of risk. From this assessment, 26 risks are identified due to a development model with 4 (four) risks being accepted, and 22 risks need mitigation program. The risk mitigation plan is a risk management step. Risk management is defined as the process undertaken to minimize the level of risk faced to an acceptable level. Quantitatively, efforts to minimize risk are carried out by applying measures to decrease the measurement results obtained from risk analysis and evaluation. From the results of the study, 24 mitigation programs have been designed to manage 22 unacceptable risks.

Figure 7. Risk Assessment Steps.

3.6. Elaborating Data and Acceptance Project Criteria
Determination of project acceptance level is a stage of decision-making in determining the Danau Ranau concession project’s sustainability. The data elaboration is in the form of merging highlights from studies that have been carried out starting from the calculation of potential field reserves, exploratory and POS risk studies, POD concepts, environmental studies to risk studies. Project acceptance level criteria (acceptance criteria) are designed based on field conditions and the developer company’s management capabilities. The criteria for the level of project acceptance and fulfillment of the results of data elaboration are as follows:

1. The calculation result of $P_{10}$ reserve potential is at least 200% of the target capacity of the PLTP referring to 2019-2028 RUPTL [1]
   **Suitability criteria**: Based on the potential reserve calculation, $P_{10}$ obtained from the heat stored method with Monte Carlo simulation is 25 MW. Danau Ranau geothermal power plant capacity target, according to RUPTL 2019-2028 [1], is 20 MW. The reserve potential of $P_{10}$ is 125% of the target or does not meet the level of acceptance criteria.

2. The value of Exploration Risk and POS is at least in the value of the “encouraging” range according to the criteria for risk assessment by Otis and Schneidermann [12].
   **Suitability criteria**: The risk assessment value lists the range of exploration risk values according to Figure 8.
In Figure 8, the range of encouraging values is 60 to 70%. The POS value obtained in this study is 78.6%, and it can be interpreted that the POS value meets the project acceptance level criteria.

3. The developer company can manage the environmental impacts arising from the stages of undertaking undertaken.

**Suitability criteria:** As the environmental study results, an environmental management and monitoring program has been designed to overcome the negative impacts and increase the positive impacts on operations carried out on the Danau Ranau field. It can be concluded that the development company has the capability and capacity in environmental management.

4. The development company can manage the risks arising from the stages of exploitation undertaken.

**Suitability criteria:** The risk assessment results show that 22 risks were not initially accepted based on the developer’s risk appetite. However, a mitigation plan has been made for these 22 risks with adjusted treatment priorities. The results of the assessment of the 22 risk acceptance levels after mitigation have been moderate and accepted. It concludes that although there are 22 risks to the proposed business plan, the development company can control the impact of these risks through a set of mitigation measures.

Data elaboration results show that one criterion is not met from the four criteria of acceptance levels, namely the large percentage of potential reserve values. According to the calculation results, $P_{10}$ obtained only meets 125% of the capacity target developed from the 2019-2028 RUPTL [1]. Because the Danau Ranau field reserve status is a possible reserve, this research concludes that further studies and studies are needed to ascertain the magnitude of the Danau Ranau field's potential. Besides, considering that Danau Ranau has entered into the target of new renewable energy generation following RUPTL 2019-2028 [1] with COD in 2030, a feasible project decision can be taken further the technical development planning and financial study stage. The consequence of this decision is to conduct further studies and studies on geological, geochemical, and geophysical studies before drilling exploration wells and delineation wells. The cost of study and advanced 3G studies will be included in the financial study’s CAPEX calculation.

4. **Financial Study**

The study assumes that project funding comes from 70% Debt and 30% equity, where debt funds come from soft loans with loan interest of 1.7%. Other than that, the assumption related to the useful life is 30 years, and the electricity tariff value calculated through iteration with the tariff scheme is a feed-in tariff according to Minister of Energy and Mineral Resources No. 17 of 2014 [3]. For the calculation of direct use, the income is calculated from tonnage sold of pepper and coffee produced for one year. The pepper’s price is 3$/kg, and the coffee price is 2 $/kg.

In determining Capex’s cost component, the aspect to consider is the design and technical study of development. Transmission costs are not included in the cost component because the allocation will go to the PLN investment budget of the transmission and network. CAPEX cost components, as listed in Table 2.
Table 2. Capital Expenditure.

| No | Cost Category for Initial Investment | % Contribution | Value ($) | Reference |
|----|--------------------------------------|----------------|-----------|-----------|
| 1  | Recommendation adding Survey and Study | 0.4%           | 218,476   | PLN 2017 [6] |
| 2  | Initial Set-up for Exploration Infrastructure | 1.4%       | 700,000   | PLN 2017 [6] |
| 3  | Feasibility Study                      | 2.0%          | 970,188   | PLN 2017 [6] |
| 4  | Project Management                     | 5.9%          | 2,467,162 | PLN 2017 [6] |

| Asset |
|-------|
| 5     | Well Drilling Campaign                | 55.5%         | 27,240,000| PLN 2017 [6] |
| 6     | FRCS                                  | 8.6%          | 4,204,000 | PLN 2017 [6] |
| 7     | Power Plant                           | 26.1%         | 12,818,845| PLN 2017 [6] |
| 8     | Transmission and Switchyard           | 0.0%          |           |           |
| 9     | Direct Use                            | 0.1%          | 47,264    | Banjarnahor, 2016 [10] |

Total Capital Expenditure ($) 100% 49,075,898

The variable cost component contains the costs required to carry out operation and maintenance (O&M) activities for field operations. Starting from O&M for wells, power plants up to direct utilization. Details of variable costs can be seen in Table 3. The results of economic calculations using assumptions, CAPEX, and OPEX values are obtained in Table 4.

Table 3. Operational Expenditure.

| No. | Category                                   | Unit | Value   |
|-----|--------------------------------------------|------|---------|
| 1   | Field O&M Expense, Yr 1                    | $/MWh| $21.00  |
| 2   | Plant O&M Expense, Yr 1                    | $/MW | $227,063|
| 3   | Calcite Antiscalant                        | $/year | $1300 |
| 4   | Silica inhibitor                           | $/year | $1100 |
| 5   | Direct use                                 | % O&M Plant O&M | 10% |

Table 4. CAPEX and OPEX data.

|                          | $ Million |       |
|--------------------------|-----------|-------|
| Total Revenue            | 291.53    |       |
| Revenue Indirect Use     | $ Million | 222.55|
| Revenue Direct Use       | $ Million | 68.99 |
| Revenue from Pepper Drying | $ Million | 39.42 |
| Revenue from Coffee Drying | $ Million | 29.57 |
| Total Project Cost       | 142.25    |       |
| Project Expenses         | $ Million | 4.77  |
| Project CAPEX            | $ Million | 44.31 |
| O&M Cost                 | $ Million | 93.09 |
| Royalty                  | $ Million | 0.08  |
| Depreciation             | $ Million | 44.31 |
| Interest                 | $ Million | 2.63  |
| Tax                      | $ Million | 28.18 |
| EBITD                    | $ Million | 149.28|
| EBIT                     | $ Million | 104.97|
Sensitivity analysis is carried out to see how much influence the changes in specific financial parameters on project profitability value. PLN, as a development company, has criteria in assessing a feasible project. Two criteria determine the project’s feasibility, namely the value of equity IRR = WACC and NPV = positive. However, in terms of profitability on the shareholder side, the project’s IRR equity value is expected to be no smaller than 12%. The sensitivity analysis carried out in this study includes the economic component parameters assumed to change with time, Capital Expenditure Costs, Operating Costs, Debt Rate or loan interest, and the portion of Debt to capital. Besides these four parameters, the number of wells to be drilled will also be simulated as an independent parameter to the IRR equity value. The number of wells drilled to accommodate the value of the range of thermal power per well. The sensitivity analysis does not include tariff parameters. According to the Minister of Energy and Mineral Resources No. 17 of 2014 [3] with the scenario of feed-in tariff according to the maximum tariff limit is the ceiling price determined by the government. The changes in parameter values that can still be accepted with IRR value constraints equal to the WACC Market value is as follows:

1. The combination of the maximum change in CAPEX value and the number of Sr Debt Rate for IRR = WACC is 130% and 1% to 2%.
2. The combination of the maximum change in CAPEX value and the portion of Capital Structures for IRR = WACC is 130 and 70% to 80%
3. The combination of the maximum change in CAPEX value and the O&M Cost per year escalation for IRR = WACC is 130% and 1%
4. The combination of the maximum change in O&M cost/year and the capital structure for IRR = WACC is 1% and 70% to 85%
5. The combination of changes in the maximum number of wells and Sr Debt Rate for IRR = WACC is 4-5 and 1% to 5%
6. The combination of changes in the maximum number of wells and capital structure for IRR = WACC is 4-5 and 70% to 90%

![Tornado Diagram Analysis of Equity Sensitivity IRR = WACC](image_url)

**Figure 9.** Tornado Diagram Analysis of Equity Sensitivity IRR = WACC.
In addition to using a combination of changes in the value of 2 parameters to the IRR value, this sensitivity analysis measures each parameter’s sensitivity to the equity IRR value. The sensitivity of each of these parameters is shown in the tornado diagram (Figure 9 and 10). The tornado diagram shows that CAPEX has the most sensitive value. A change of +/- 10% of the CAPEX value will cause the IRR equity value to change by 12.02%. When comparing two scenarios to IRR sensitivity, it shows the sensitivity limit of parameters shifts more comprehensively in the IRR scenario ≥ 12%. The reason is the tariff’s adjustment to boost the IRR equity at a 12% minimum. Unlike the IRR = WACC market scenario, the tariff used is the baseline tariff even with the feed-in tariff scheme. In the sensitivity analysis for IRR ≥ 12%, the CAPEX parameter’s sensitivity value with a 10% change limit changes the IRR equity to 8.8%.

![Figure 10. Tornado Diagram Analysis of Equity Sensitivity IRR ≥ 12%](image)

5. Conclusion
Danau Ranau geothermal field is a medium enthalpy field with a reservoir temperature of 200°C – 220°C, reservoir fluid in the form of 1 water phase, and an estimated geothermal potential ($P_{10}$) of 25 MW. The results of exploration risk calculations show the value of thermal power per well is in the range of 1.5 MW to 3.65 MW, and the probability of successful drilling (POS) exploration of 78.6%. The design of developing the results of the study is as follows:

1. Drilling 4 (four) wells, assuming an 80% success rate. The distance between the well pad and the utilization facility is 2.5 km. The brine will be used from successful flowing wells with a temperature of 180°C with a total mass flow of 160 kg/s. In comparison, wells that are not flowing will be used for reinjection wells.

2. Implement a cascade model with 4 (four) levels of utilization
   - Level 1 utilizes a 180°C brine and a mass flow rate of 160 kg/s for the ORC technology (binary power plant) with a total capacity of 6.59 MW.
   - Level 2 utilizes an ORC output brine with a temperature of 80°C and a mass flow rate of 5 kg/s for drying pepper.
   - Level 3 utilizes a Level 2 output brine with a temperature of 65°C and a mass flow rate of 5 kg/s for coffee drying.
   - Level 4 utilizes Level 3 brine output for bathing pools. The pool is set to have a temperature of 35°C - 40°C.

3. The environmental study results identified 35 impacts due to exploitation and designed 63 environmental management programs and 26 environmental monitoring programs.
4. The risk assessment results identified 26 risks where 4 (four) risks were accepted, and 22 risks were accepted with a mitigation program. A total of 24 mitigation programs are designed.

5. The financial study and sensitivity analysis are carried out, assuming the utilization period is 30 years. Details of the financial study results are equity IRR is 7.04%, NPV is 49.23, and the payback period is 9.5 years.

6. The CAPEX parameter is the most sensitive value. A change of +/- 10% of the CAPEX value will cause the IRR equity value to change by 12.02%.

7. By considering the profitability side, sensitivity analysis is also tested for IRR equity value 12%. The sensitivity analysis results show that the sensitivity limit of parameters shifts wider in the IRR scenario ≥ 12%, and the sensitivity value of the CAPEX parameter with a 10% change limit gives the effect of changing the IRR equity value to 8.8%.

From the financial study results, appropriate business project decisions can be made to proceed to the stage of exploration well drilling and delineation wells.

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