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Financial Feasibility Analysis of Pumped Storage Hydropower Plants Considering Uncertainty Factors Using the Value at Risk (VaR) Method

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Abstract

The year 2023 is confirmed as the hottest calendar year in global temperature data records since 1850. One of the causes of global warming is the production of carbon emissions. To promote a low-carbon future globally, the Paris Agreement was adopted on December 12, 2015, and signed by all countries. Indonesia is one of the countries with a large energy reduction target of 30-41%. One of the challenges to realize this is Indonesia's large energy demand, which is one of the largest emission-contributing sectors. Through PLN's long-term plan, Indonesia targets a large increase in the number of hydropower plants until 2030 as one of the best energy source options. One of the breakthroughs made is the use of pumped storage hydropower plants. However, pumped storage hydropower plants are new in Indonesia and the investment value to build pumped storage hydropower plants is very large. With various uncertainty or risk factors from the financial aspect, a study is needed that further assesses the financial feasibility of building a pumped storage hydropower plants by considering factors. Based on the research results, it is found that 3 risk factors can affect the financial feasibility of pumped hydropower development, namely selling price, investment cost, and operational and maintenance cost.

Keywords
Pumped storage, Risk, Monte Carlo, VaR.

Introduction
The year 2023 was recorded as the hottest year in global temperature records since 1850, with the global average temperature reaching 14.98°C (Copernicus Climate Change Service 2024). This temperature increase had significant impacts, particularly on sea ice in Antarctica and the Arctic, as shown in Figure 1. The extent of Antarctic sea ice reached a record low with an average of 3.79 million square miles, while Arctic sea ice coverage was among the 10 lowest years on record (National Oceanic and Atmospheric Administration 2024).

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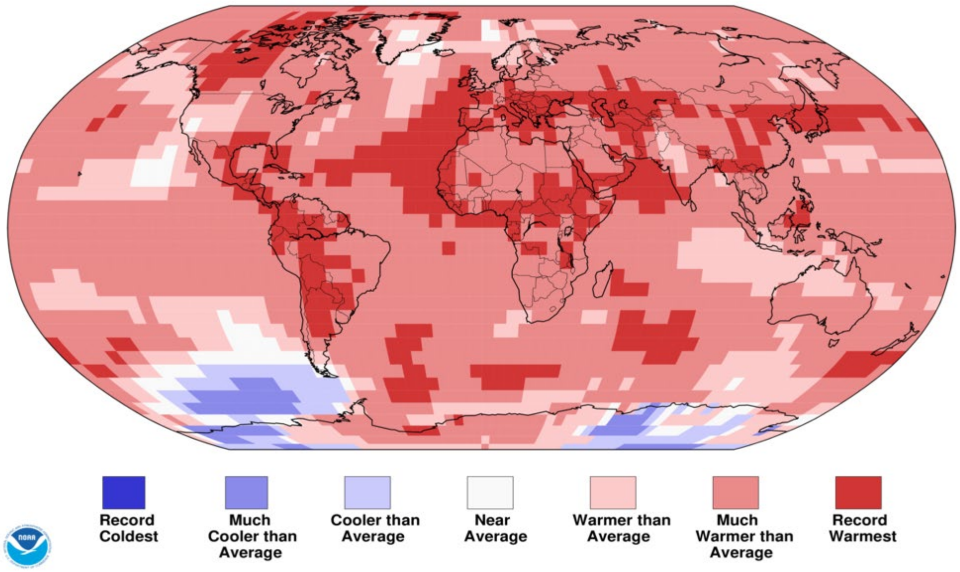

Figure 1. Land & Ocean Temperature Percentiles Jan-Dec 2023

The primary cause of global warming is human activity, particularly the burning of fossil fuels that release greenhouse gases into the atmosphere. Each year, more than 50 billion metric tons of CO_2 are released into the Earth's atmosphere. China, the United States, and India contribute 42.6% of total global emissions. The main sectors contributing to global greenhouse gas emissions in 2019 include (United States Environmental Protection Agency 2024):

- Electricity and heat production (34%)
- Industry (24%)
- Agriculture, forestry, and other land use (22%)
- Transportation (15%)
- Buildings (6%, increasing to 16% if electricity use is included)

The Paris Agreement, adopted on December 12, 2015, represents a significant step in global efforts to address climate change. This agreement aims to limit the increase in global average temperature to below 2°C above pre-industrial levels, with an ideal target of 1.5°C

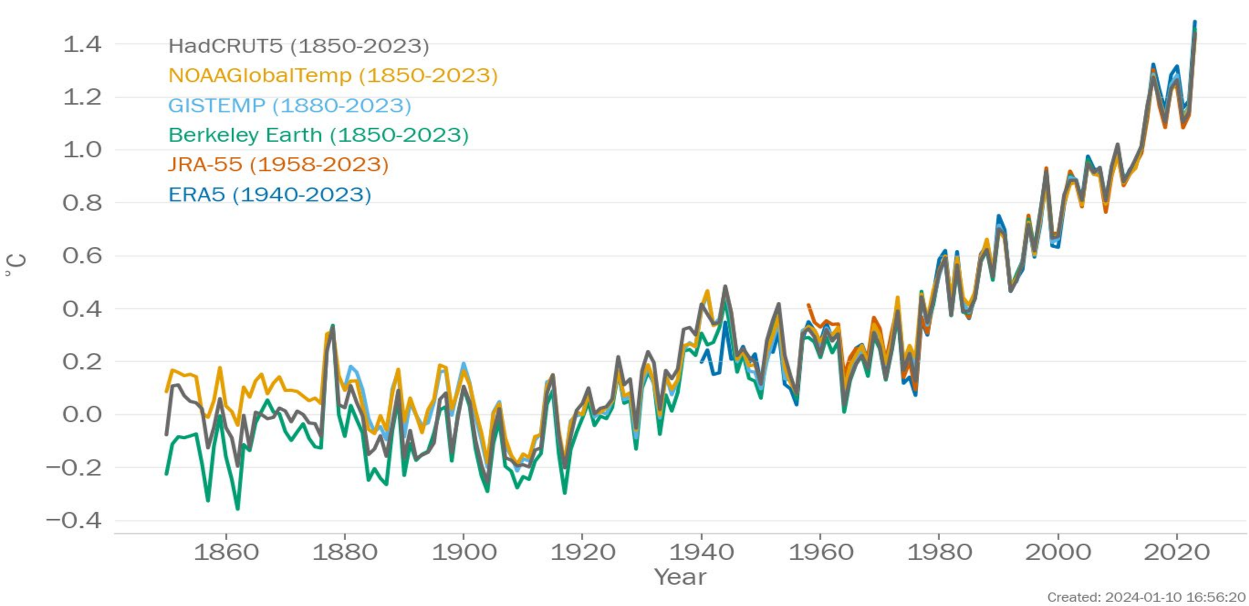

Figure 2. Global Average Temperature Difference

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The agreement requires all countries to report their emission reduction commitments through Nationally Determined Contributions (NDCs) every five years (Karim et al. 2020). The Paris Agreement also emphasizes the importance of climate finance from developed to developing countries. development and transfer of technology to enhance resilience to climate change, and climate-related capacity building in developing countries.

Indonesia has committed to reducing emissions by 29-41% by 2030 through its NDC submitted under the Paris Agreement (Al-Amin et al. 2020). This target is relatively larger compared to some neighboring countries such as Malaysia, Thailand, and Singapore.

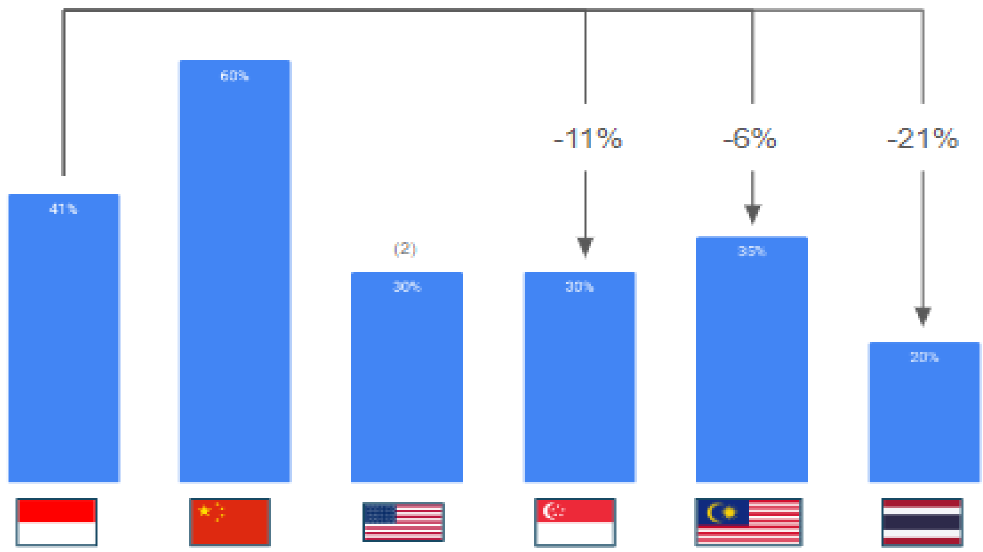

Figure 3. Differences in Emission Reduction Targets of Several Countries

However, these emission reduction efforts require substantial costs, estimated at around Rp4000 trillion, exceeding Indonesia's annual state budget (CNBC Indonesia 2023). The Indonesian government is focusing its emission reduction efforts on the energy sector, which has larger budgets, subsidies, and Public Service Obligations (PSO) compared to other sectors.

Sektor	Total Anggaran + Subsidi dan PSO (Rp Miliar)		
	2018	2019	2020
Energi	12.867,21	9.724,48	6.103,15
Industri	38,73	24,95	14,07
Kehutanan & Gambut	1.381,46	3.306,84	2.080,94
Pertanian	660,74	642,22	624,26
Limbah	71,88	43,88	147,78
Pesisir & Kelautan	43,50	46,22	440,82
Transportasi	19.450,69	21.085,82	14.033,08

Figure 4. Emission Reduction Budget per Sector

The energy sector is targeted to reduce GHG emissions by 13.2% by 2024 (LCDI Indonesia 2020). This focus aligns with projections of increasing energy demand in Indonesia, where electricity sales are expected to increase by 53.90% from 2021 to 2030 (PLN, 2021), as shown in Figure 4. PLN's 2021-2030 Electricity Supply Business Plan (RUPTL) allocates a larger portion (52%) to New and Renewable Energy (NRE) power plants compared to fossil fuel power plants (48%). The total additional generating capacity is projected to reach 40,575 GW, with 51.6% coming from

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NRE. In the 2021-2030 RUPTL, Hydroelectric/Micro/Mini-hydro Power Plants have the largest planned capacity addition (10,391 GW) among other NRE sources (Ministry of Energy and Mineral Resources 2023).

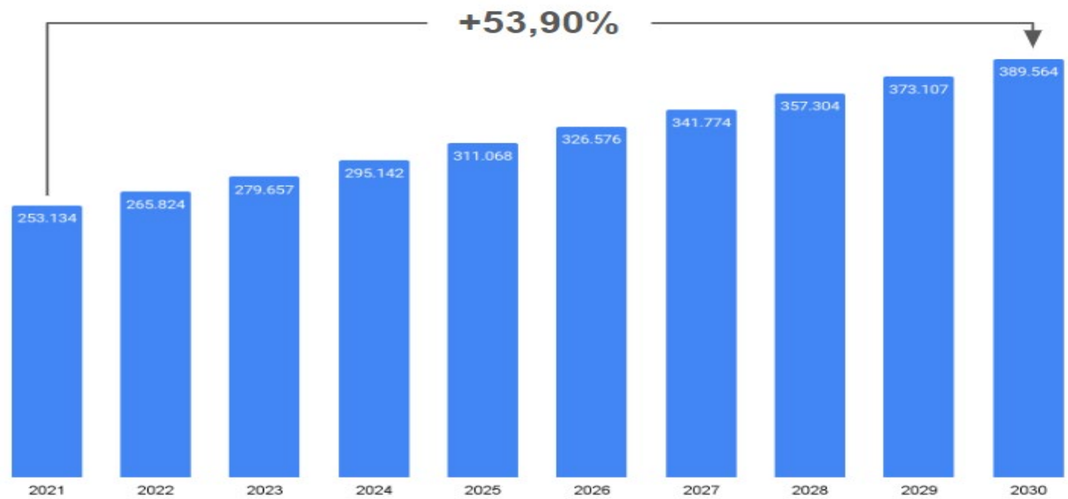

Figure 5. Projected Electricity Sales in Indonesia (GWh)

It is projected that 45% of Indonesia's electricity production composition from NRE sources in 2030 will come from hydropower. Hydroelectric power plants are also considered one of the types of power plants with the lowest emission values in their construction activities. The construction of 1GW of hydroelectric power plants only produces emissions of 1,035,752 tons of CO_2, much lower than wind power plants (Hartono et al. 2020). PLN is making a breakthrough by building a Pump Storage Hydroelectric Power Plant in Cisokan, which is the first of its kind in Indonesia with an investment of USD 850 Million (PLN, 2022). Given that this technology is new, various risks can affect the feasibility of its investment.

1.1 Objectives

The objective of this study is to provide an in-depth and comprehensive analysis of the feasibility of pumped storage hydropower plants investments in Indonesia, taking into account various risk factors and uncertainties. More specifically, this study aims to identify and categorize various uncertainty factors that can affect the feasibility value of pumped storage hydropower plants investments. This will include an analysis of internal and external factors that can impact project success. Furthermore, this research will conduct pumped storage hydropower plants valuation calculations considering the identified risks and uncertainties, using relevant and up-to-date financial valuation methods. This study also aims to measure the potential financial loss value of pumped storage hydropower plants, providing a better understanding of the financial risks that investors may face. Lastly, this research will attempt to identify and rank the most influential factors in the feasibility of pumped storage hydropower plants investments, providing valuable insights for stakeholders in prioritizing risk management and investment decision-making.

2. Literature Review

2.1 Pumped Storage Hydropower (PSH)

Pumped Storage Hydropower (PSH) is an energy storage system that involves transferring water between two reservoirs at different elevations to store and generate electricity (Rehman et al. 2015). This system was first implemented in 1909 in Schaffhausen, Switzerland, with a capacity of 1.5 MW (Deane et al. 2010). PSH contributes significantly to global energy storage capacity, accounting for 95% of grid-scale energy storage capacity in the United States and 98% globally (Nasir et al. 2022). PSH operations can be classified into three types: daily, weekly, and seasonal (Selcuk et al., 2022). The system can also be divided into closed-loop (CLPHSP) and open-loop (OLPHSP) based on its water source (Vilanova et al., 2020). Zhao et al. (2022) identified 3 main types of PSH:

- Conventional Pumped Storage Hydropower (C-PSH): The most mature and widely used model, with 70-85% efficiency.

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- Adjustable Speed Pumped Storage Hydropower (AS-PSH): Improves input power control capability and rapid adaptation to power fluctuations. Costs 25-30% higher than C-PSH.
- Ternary Pumped Storage Hydropower (T-PSH): Has independent turbines and pumps, can run pumping and generator modes simultaneously. Offers high flexibility but at a higher cost.

PSH uses low-cost electricity to pump water to a higher reservoir during low demand periods and releases water to generate electricity during high demand periods (Nasir et al., 2022). This system can also be integrated with batteries to increase efficiency

2.2 Discounted Cash Flow (DCF)

DCF is a valuation method that determines the value of an investment based on future cash flow expectations adjusted for the time value of money concept (Damodaran 2002). These cash flows are discounted back to present value using a specific discount rate (Brealey et al. 2011). This method is used to assess the attractiveness of an investment or project (Copeland et al. 2000). There are several financial parameters to calculate within the Discounted Cash Flow, which are Net Present Value (NPV), Internal Rate of Return (IRR), and Debt Service Coverage Ratio (DSCR).

NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period (Brealey et al. 2011). NPV is used to assess the profitability of an investment (Ross et al. 2010) and represents the value of money today from a sum of money in the future, taking into account the cost of money (Yescombe, 2014). An investment is considered feasible if NPV > 0 (Yescombe 2014). IRR is the discount rate that makes the NPV of all cash flows from a particular project equal to zero (Ross et al., 2010; Brealey et al. 2011). IRR is used to evaluate the profitability of potential investments (Brigham & Ehrhardt, 2013). An investment project is accepted if the cost of capital is less than the IRR (Brealey et al. 2011). Meanwhile, DSCR is a measure of a business's ability to pay its debt. It is typically calculated based on annual or interim financial statements. DSCR is used to estimate a borrower's ability to repay long-term debt in the future (Grady, n.d.). Historically, commercial lenders sought a minimum DSCR of 1.2x, which then increased to 1.3x after 2007 (Grady, n.d.).

2.3 Value at Risk (VaR)

Value at Risk (VaR) is a statistical measure used to assess the level of financial risk over a specific time period (Jorion 2007). VaR estimates the maximum potential loss that an investment portfolio can bear with a certain probability, usually 95% or 99%, over a specific period (Hull, 2018). VaR is widely used in finance to measure the potential risk of loss in investments (Dowd 2002).

2.4 Monte Carlo Simulation

Monte Carlo simulation is a statistical technique used to model the probability of different outcomes in a process that cannot be easily predicted due to the intervention of random variables (Metropolis & Ulam 1949). This technique uses repeated random sampling to obtain numerical results (Rubinstein & Kroese 2016). It is often used to assess the impact of risk and uncertainty in predictive models and forecasts (Glasserman 2003).

3. Methods

This study employs the Value at Risk (VaR) method to assess the feasibility of investing in a pumped-storage hydroelectric power plant project. VaR, a statistical measure of asset value decline risk, summarizes risk impact in a single, easily understood value. It also represents the worst-case outcome in Monte Carlo simulations. The researcher reviews previous studies to formulate the problem statement, research objectives, scope, methodology, and research object. Several steps are taken to obtain VaR results. Initially, a discounted cash flow (DCF) model is created in Excel using financial data and assumptions from various sources, including documents and interviews. The model incorporates relevant financial parameters and serves as the baseline "business as usual" scenario, without considering risks.

Monte Carlo simulation is utilized to account for potential risks. This incorporates risk factors determined through expert interviews. Python programming and Jupyter Notebook facilitate numerous simulations in a short timeframe. The researcher specifies the simulation count, uncertainty variables, and their respective values and distribution types. Results are temporarily stored in the Jupyter Notebook for visualization and interpretation. The VaR output is observed by considering the chosen confidence interval. These simulation results also identify which uncertainty variables most significantly impact financial parameter outputs.

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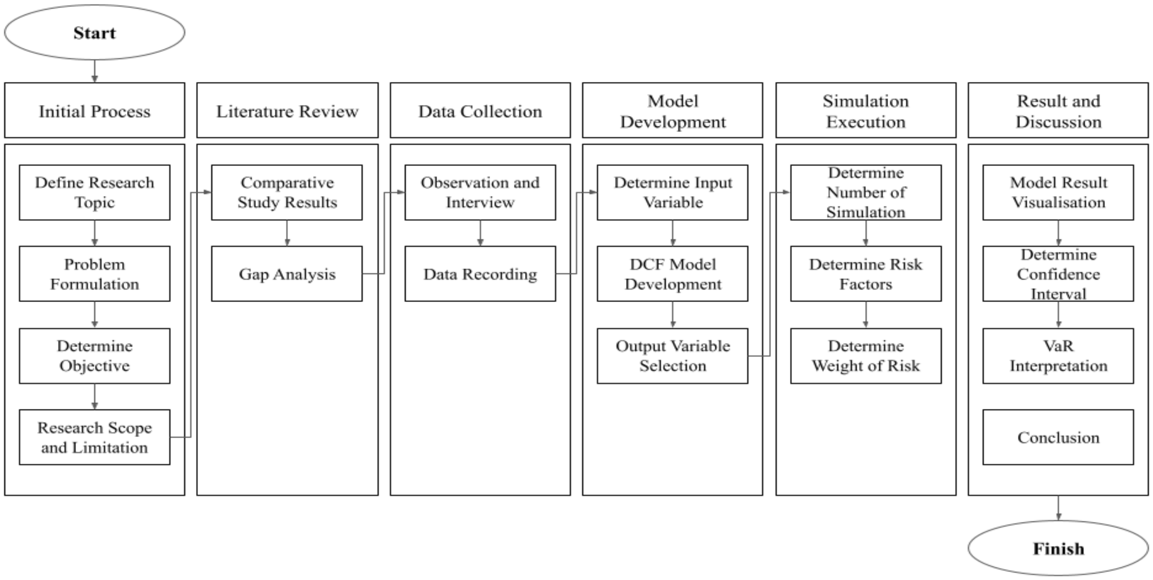

Figure 6. Research Methodology

This approach allows for a comprehensive risk assessment of the pumped-storage project, providing valuable insights for investment decision-making. The combination of DCF modeling and Monte Carlo simulation offers a robust framework for evaluating complex infrastructure investments under uncertainty.

4. Data Collection

Based on the data collection process, it was found that the construction of the pumped storage hydropower plants in West Java involves two scenarios. The first scenario, or base scenario, entails purchasing electricity directly from PLN (the state electricity company) to pump water back to the higher reservoir. The second scenario involves using a portion of the electricity generated by the plant itself to pump water back up. These two scenarios naturally lead to different cost structures.

Figure 7. Location of PSH Construction

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In the base scenario, the plant relies on the grid for its pumping energy needs, which may offer operational simplicity but could result in higher operational costs depending on electricity prices. The second scenario represents a more self-reliant approach, potentially reducing ongoing electricity expenses but possibly requiring additional initial investment in energy storage or management systems.
The choice between these scenarios would likely depend on various factors including initial capital availability, long-term operational cost projections, grid stability, and overall project economics. This dual-scenario approach allows for a comprehensive analysis of the project's feasibility and profitability under different operational strategies, providing valuable insights for decision-makers and investors in the renewable energy sector.

Results and Discussion

5.1 Numerical Results

The base model for Scenario 1 yielded an NPV of -Rp3,457,147,251,529, an IRR of -0.8%, and a DSCR of 0.7. These figures indicate that the project is not financially viable under the initial assumptions. Scenario 2, which included additional costs for battery installation, performed even worse financially. It resulted in an NPV of -Rp6,972,597,351,642, an IRR of -5%, and a DSCR of 0.5.

Table 1. Risk Analysis Results

Scenario	Risk Type	NPV at Risk	IRR at Risk	DSCR at Risk
Scenario 1	PLN electricity purchase price risk	-Rp9,029,874,087,590 (161% lower)	22.9% (22.1% lower)	0.318865513 (143% lower)
	Operational and Maintenance Cost Risk	-Rp5,461,646,726,561 (58% lower)	8.2% (7.4% lower)	0.383857221 (151% lower)
	Investment Cost Risk	-Rp5,660,230,440,759 (64% lower)	6.8% (6% lower)	0.43503848 (42% lower)
	Combined Risk	-Rp9,093,779,590,103 (7.7% lower)	22.9% (22.1% lower)	0.317868130 (143% lower)
Scenario 2	PLN electricity purchase price risk	-Rp10,811,365,792,890 (55% lower)	21.7% (16.7% lower)	0.07014213 (43.9% lower)
	Operational and Maintenance Cost Risk	-Rp12,108,711,705,398 (74% lower)	26.1% (21.1% lower)	0.092209532 (60.1% lower)
	Investment Cost Risk	-Rp10,932,703,346,155 (57% lower)	19.1% (14.1% lower)	0.10118514 (47.8% lower)
	Combined Risk	-Rp11,331,279,991,342 (63% lower)	23.7% (18.7% lower)	0.0280806 (53.7% lower)

When accounting for risk factors, the project's financial outlook further deteriorated as shown in Table 1. For Scenario 1, considering all combined risks, the NPV at risk (95% confidence interval) decreased to -Rp9,093,779,590,103, the IRR at risk fell to -22.9%, and the DSCR at risk dropped to -0.317868130. Similar trends were observed in Scenario 2, with the NPV at risk declining to -Rp11,331,279,991,342, the IRR at risk falling to -23.7%, and the DSCR at risk decreasing to -0.0280806.

5.2 Graphical Results

The Monte Carlo simulations provided crucial visual representations of the risk analysis, offering insights beyond point estimates. For both scenarios, probability distribution curves were plotted for NPV, IRR, and DSCR, clearly illustrating the range of possible outcomes and the probability of achieving specific financial targets.

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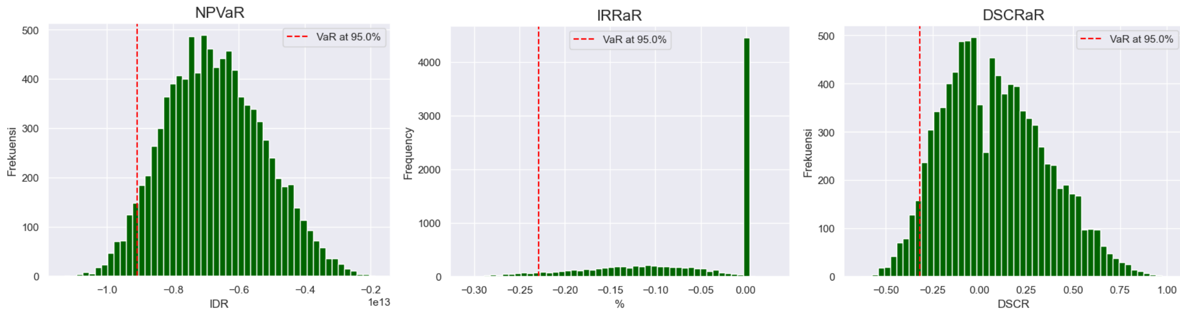

Figure 8. NPV, IRR, and DSCR at Risk Scenario of Combined Risks in Scenario 1

In combined risk of scenario 1, the NPV distribution is widespread, with the majority of outcomes falling in the negative range. The peak of the distribution occurred around -Rp7 trillion, indicating that this level of loss is the most probable outcome. The IRR distribution is similarly skewed towards negative values, far below the typical hurdle rate for energy projects. The DSCR is also falls at around -0.317868130, making the project unfeasible.

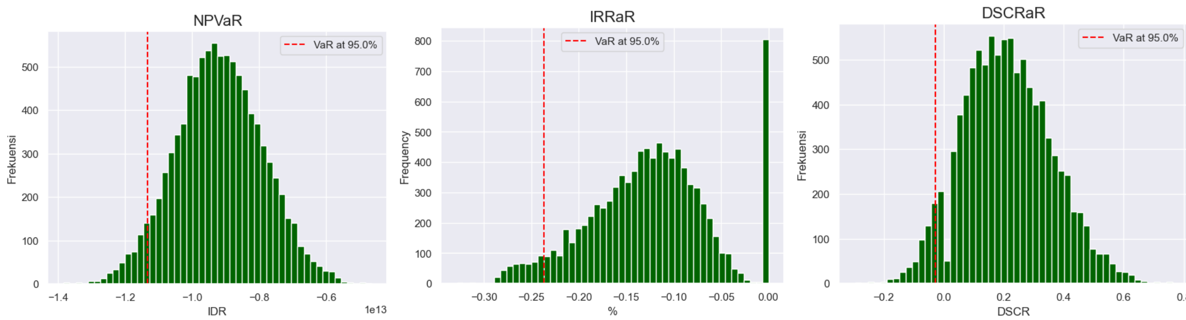

Figure 9. NPV, IRR, and DSCR at Risk Scenario of Combined Risks in Scenario 2

In combined risk of scenario 2, the NPV distribution shifts further into negative territory, with the peak around -Rp11 trillion. The IRR distribution shows a broader spread of negative outcomes, reflecting the increased uncertainty introduced by the battery storage component. The DSCR is around -0.0280806, highlighting the extreme financial stress this scenario will likely face.

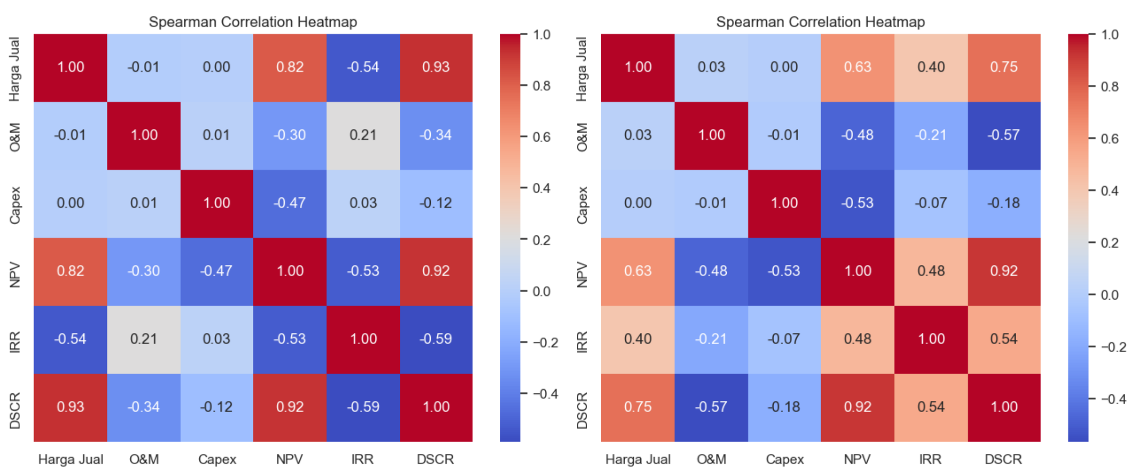

Figure 10. Spearman Correlation of Scenario 1 (Left) and Scenario 2 (Right)

Sensitivity analysis using Spearman correlation coefficients revealed critical insights into the factors driving these poor financial outcomes. For both scenarios, the electricity purchase price by PLN (the state electricity company) emerged as the most influential factor on NPV, IRR, and DSCR. In Scenario 1, this factor had a strong positive correlation coefficient of 0.82, indicating that increases in the purchase price would significantly improve financial outcomes. In Scenario 2, while still the most important factor, the correlation was somewhat weaker at 0.63, suggesting that other factors, likely related to battery costs, were also playing a significant role.

5.3 Proposed Improvements

Given that the electricity purchase price by PLN was identified as the most critical factor affecting project viability, our improvement strategy focused on determining the minimum price required to make the investment attractive. This approach recognizes the need for policy intervention to create a viable market for pumped-storage hydroelectric power in Indonesia.

Table 2. Improving the Feasibility of PSH Development

Scenario	PPA Term	PLN Electricity Purchase Price Required for IRR 12%
Scenario 1	15 Years	Rp2.903
Scenario 1	20 Years	Rp2.691
Scenario 2	15 Years	Rp4.666
Scenario 2	20 Years	Rp4.206

For Scenario 1, assuming a 15-year Power Purchase Agreement (PPA), the analysis shows that the required electricity purchase price by PLN needs to reach Rp2,903 per kWh to achieve an IRR of 12%. This target IRR is chosen based on expert interviews, which indicate that it is generally considered the minimum acceptable return for power plant developers in the region, accounting for the risks involved. Recognizing the potential for longer-term contracts to improve project economics, a 20-year PPA scenario is also analyzed. Under these conditions, the required purchase price can be reduced to Rp2,691 per kWh while still achieving the 12% IRR target. This demonstrates the potential for longer contract periods to enhance project viability.

For Scenario 2, which includes battery storage, the required prices are significantly higher, reflecting the additional capital and operational costs involved. With a 15-year PPA, the electricity purchase price needs to be Rp4,666 per kWh to achieve a 12% IRR. Extending the PPA to 20 years allows this price to be reduced to Rp4,206 per kWh. These higher prices highlight the current challenges of integrating large-scale battery storage into pumped hydro projects, suggesting that further technological advancements or cost reductions in battery technology may be necessary to make this option viable.

5.4 Validation

The validity of the model and results is ensured through a multi-faceted approach, combining expert input, statistical rigor, and sensitivity analysis. The foundation of the risk assessment is built on expert interviews, particularly with experienced professionals from PLN. These interviews provide crucial insights into the relevant risk factors, their potential distributions, and realistic ranges for key variables. This expert validation ensures that the model reflects the current realities and challenges of the Indonesian energy market. The use of Monte Carlo simulation with 10,000 iterations provides a robust statistical foundation for the findings. This large number of iterations helps ensure that the full range of possible outcomes is captured, reducing the impact of outliers or extreme scenarios. The choice of a 95% confidence interval for VAR calculations aligns with industry standards, offering a balance between capturing significant risks and avoiding overly conservative estimates.

The sensitivity analysis using Spearman correlation coefficients offers additional validation of the relative importance of different risk factors. By quantifying the relationship between input variables and financial outcomes, it is confirmed that the model behaves in line with economic theory and industry expectations. The strong correlation between electricity purchase prices and financial outcomes, for example, aligns with the fundamental economics of power generation projects. The proposed improvements, particularly the suggested electricity purchase prices, derive from using the Goal Seek function in Excel. This approach ensures mathematical accuracy in determining the precise price points needed to achieve the target IRR. However, it is important to note that while these calculations are mathematically sound, they represent a significant departure from current market conditions.

To further validate the findings, results are compared with similar studies in other emerging markets. While the specific numbers differ due to local conditions, the general trend of pumped-storage hydro projects requiring significant price support aligns with experiences in countries like India and Brazil. This international comparison provides additional confidence in the overall direction of the findings, even if the specific values are unique to the Indonesian context.

6. Conclusion

Through discounted cash flow analysis and Monte Carlo simulations, this study examined two operational scenarios under various uncertainty factors for the evaluation of the financial feasibility of pumped storage hydropower plants in Indonesia, focusing on a proposed site in West Java. Key uncertainty factors influencing financial feasibility were identified as PLN's electricity purchase price, capital expenditure, and operational and maintenance costs. To achieve financial viability, the analysis suggests that electricity purchase prices would need to be set at Rp2,903 and Rp4,666 for the first and second scenarios, respectively. This research provides valuable insights for stakeholders in Indonesia's energy sector. However, we acknowledge the limitations of our study and recommend future research to incorporate broader socio-environmental factors and a wider range of uncertainty variables. Additionally, the findings can serve as a foundation for developing risk management strategies and informing government policies on renewable energy support schemes.

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