ECONOMIC VALUATION ANALYSIS OF FLOATING PHOTOVOLTAIC POWER PLANTS USING MULTIVARIABLE RISK-BASED FINANCIAL MODELING

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Abstract. *Indonesia has set an ambitious target to reduce carbon emissions in the energy sector to 358 million tons of CO2 by 2030, as stated in the press release of the Ministry of Energy and Mineral Resources (ESDM). This target aligns with the international commitment under the Paris Agreement, which aims to limit global warming to 1.5°C by significantly reducing greenhouse gas emissions. Therefore, Indonesia must transition to renewable energy sources, such as solar energy, to meet the growing energy demand while supporting global climate control efforts. This study aims to analyze the risks and economic feasibility of the floating solar photovoltaic (FPV) project at the Mrica Reservoir using literature data and Monte Carlo-based economic simulations. The evaluation focuses on feasibility indicators such as NPV, IRR, and PIR with a 95% confidence level. The risk analysis results identify 8 potential risks that could impact the project's economic value, with the most significant risks being Trash, Flood, and Sedimentation, Electricity Sale, and Degradation Performance.*

Keywords: *Economic Risk Analysis, Floating Solar PV, Monte Carlo Simulation, Value at Risk.*

1. INTRODUCTION

Indonesia has committed to reducing carbon emissions in the energy sector to 358 million tons of CO_2 by 2030 through initiatives such as clean coal technology, renewable energy, energy efficiency, and low-carbon fuels. This aligns with the Paris Agreement's goal of limiting global warming to 1.5°C by reducing greenhouse gas emissions. The energy sector is a major contributor to global emissions, with fossil fuel combustion accounting for nearly 80% of greenhouse gases, driving climate change significantly (Gur, 2023). Indonesia, blessed with abundant natural resources, including renewable energy sources like solar power, has immense potential to transition from fossil fuels. The National Energy Council aims to increase the renewable energy mix from 23% in 2025 to 66% by 2060, yet the current growth rate of only 0.55% annually highlights the need for improved policies and investments (Wahyudi et al., 2024). Provinces like Central Java have shown a strong commitment to renewable energy through initiatives like the "Jateng Solar Province," striving to achieve renewable energy targets of 21.32% by 2025 and 28.82% by 2050.

Central Java stands out with significant potential for floating solar photovoltaic (FPV) systems, as identified by a study from the Institute for Essential Services Reform (IESR). The study highlights various reservoirs with substantial FPV potential, including Mrica Reservoir which managed by PT PLN Indonesia Power Mrica Power Generation Unit (PGU), ranks fourth with a technical potential of 72.80 MWp, equivalent to 87.36 GWh of annual energy production. While technical potential is promising, realizing such projects requires addressing techno-economic, social, regulatory, and environmental risks. The reservoir, originally built for flood control and hydroelectric generation, has an installed capacity of 3 x 60 MW and generates approximately 800 GWh annually. However, sedimentation challenges threaten its storage capacity and energy efficiency. To counter this, Mrica PGU aims to enhance production by adopting rooftop and floating solar PV systems.

Floating solar PV systems, which involve installing solar panels on water bodies like reservoirs, offer a promising solution for Mrica. The reservoir's expansive water surface is ideal for this technology, potentially enhancing renewable energy capacity while utilizing existing infrastructure. However, as highlighted by the Solar Energy Research Institute of Singapore, a thorough risk analysis is essential for planning, construction, and operation phases. This study aims to identify potential risks and evaluate the economic feasibility of the FPV project at Mrica Reservoir. The economic analysis will cover initial investment, operational costs, and long-term economic benefits to ensure the project's viability. The goal is to balance significant environmental benefits with economic returns, management by attracting further investment and support for sustainable energy development.

2. LITERATURE REVIEW

One of the key step developers must undertake before realizing a project is assessing feasibility, including accounting for uncertainties, to minimize risks of failure due to technical and economic factors. Therefore, a floating solar power plant must meet the criteria for a viable project based on its technical and economic aspects. This study will conduct a technical feasibility analysis to ensure the project can be budgeted appropriately. Various literature on technical and economic feasibility has been reviewed as references, and the literature review will be divided into three sections. Subsection 1.1 will discuss technical feasibility, Subsection 1.2 will cover financial models and indicators for evaluating economic viability, and Subsection 1.3 will focus on Monte Carlo Model Simulation, which incorporates uncertainties that may affect the project's future feasibility.

2.1 Technical Feasibility

The main source of the photovoltaic power plant is the solar irradiation. Solar irradiation is the accumulation of the solar energy per certain area (W/m2). While the Solar Irradiation provides an estimate of the solar energy available, not all of it is effectively captured and converted by the photovoltaic (PV) system. Various losses occur throughout the system, which can significantly reduce the actual energy output. These losses can be broadly categorized into three types: optical losses, which involve energy lost due to reflection, shading, or dirt on the solar panels; array losses, which occur within the photovoltaic array due to temperature effects, mismatched modules, or suboptimal orientation; and system losses, which arise from inefficiencies in components such as inverters, modules, cables, and other balance-of-system elements (T. Mahachi, 2016). Power output is calculated by following equation.

$$P = A \times H \times \eta total$$

H = Solar Irradiation (W/m^2)
A = Area (m^2)
ηtotal = Total efficiency (%)

The energy output is estimated by simulating data using PVsyst.

2.2 Financial Model

The annual energy production will be multiplied by the Power Purchase Agreement (PPA) tariff to estimate the project's yearly revenue. However, alongside the yearly revenue, the project also incurs both initial and ongoing costs that must be accounted for throughout its lifecycle. These costs can be categorized as follows:

A. Initial Cost

The initial cost, also known as the capital expenditure (CAPEX), represents the upfront investment required to acquire the necessary equipment and infrastructure. This cost is typically calculated by multiplying the per-watt price of the photovoltaic system by its direct current (DC) capacity (Ogunnubi et al., 2015).

$$IC_0 = PVC_0 \; x \; DC \; Power \; Rating$$

IC_0 = Initial Cost
PVC_0 = Cost required

B. Yearly Cost

Yearly costs, commonly referred to as operational expenditure (OPEX), include the ongoing expenses required to operate and maintain the solar power plant. These typically cover operation and maintenance (O&M) costs, administrative expenses, and any other recurring charges. Over time, these costs are expected to rise due to inflation, which impacts labor, material costs, and other operational factors (Goswami et al., 2019). Therefore, accurate forecasting of yearly costs is essential to ensure the long-term financial sustainability of the project.

$$C_{OM_n} = C_{OM_1} \, (1 + r_{OM})^{n-1}$$

C_{OM} = Operation and Maintenance Cost
r_{OM} = Operation and Maintenance Escalator factor

Economic analysis is a systematic evaluation of the feasibility of a project or business venture, with a primary focus on its financial aspects. This analysis typically employs various financial metrics to determine whether an investment is worthwhile. The key indicators used in such evaluations include Net Present Value (NPV)**,** Internal Rate of Return (IRR)**,** and Profitability Index Ratio (PIR) (Arifandi et al., 2022; Zhang, 2022). These key indicators will be calculated using Microsoft excel by following methods below.

1. Net Present Value (NPV)

The Net Present Value is calculated by assessing the cash flow generated each year, comparing the annual income with the annual expenditures. This method discounts future cash flows to their present value using a specific discount rate. A positive NPV indicates that the project's earnings exceed its costs, making it financially viable. It is a widely used tool for evaluating the profitability of long-term investments and provides a clear measure of added value.

2. Internal Rate of Return (IRR)

The Internal Rate of Return represents the discount rate at which the present value of the project's future cash inflows equals the present value of its initial investment. In simpler terms, it is the rate that makes the Net Present Value (NPV) equal to zero. The IRR is a critical indicator for comparing potential investment opportunities, as it reflects the efficiency or yield of the investment (Shah, 2023). Projects with an IRR higher than the cost of capital are typically considered desirable.

3. Profitability Index Ratio (PIR)

The Profitability Index Ratio measures the relative profitability of a project by calculating the present value of returns for every unit of currency invested in the initial cost. It is expressed as a ratio of the present value of future cash flows to the initial investment. A PIR greater than 1 indicates that the project generates more value than its cost, making it a compelling option for investors. This metric is particularly useful for ranking projects when resources are limited, as it highlights the return per unit of investment.

2.3 Monte Carlo Model Simulation

Monte Carlo Simulation, uncertain variables are treated as random variables with a range of possible values, independent of each other and unaffected by changes over time. Conducting an effective MCS involves several key steps as follows below (Raychaudhuri S, 2008):

1. Develop a deterministic or base model.
2. Select a probability distribution for each uncertain variable.
3. Perform iterations using pseudo-random numbers generated according to the probability distribution functions of the uncertain variables for a specified number of iterations (n).
4. Conduct sensitivity analysis and make decisions based on the output of the model.

Determining the appropriate probability distribution for each uncertain variable requires careful consideration. Probability distributions can be derived through distribution fitting based on available data. However, in many construction projects, data on costs and other variables may be scarce or unavailable. In such cases, probability distributions are often determined using previous studies or expert judgment (Salling & Leleur, 2006).

By this simulation Value at Risk can be measurable. Value at Risk (VaR) is commonly used to estimate the maximum potential losses within a portfolio under a given confidence level, but it also serves as a valuable tool for assessing project feasibility, especially in uncertain conditions. By incorporating a confidence level, VaR aids decision-making by quantifying risk in a more structured manner. By integrating VaR into project evaluation, stakeholders can gain a clearer understanding of the risk exposure associated with uncertain variables. This method helps ensure that decisions are grounded in rigorous financial analysis, providing confidence that the project can withstand potential adverse conditions while still delivering acceptable returns.

3. RESEARCH METHODS

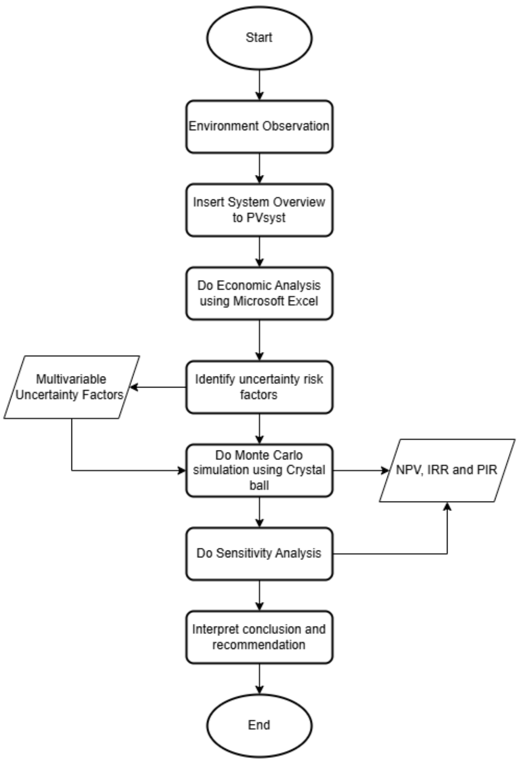

Figure 1. Research Stages Diagram

Context of the Study, this research was conducted in the context of evaluating the technical and economic feasibility of a floating solar photovoltaic project at the Mrica Reservoir in Banjarnegara, Indonesia. The location was chosen because of its strategic importance as a reservoir managed by PT PLN Indonesia Power, offering a significant potential for renewable energy development due to the water surface availability and favorable policy.

Duration and Timing of Fieldwork, the fieldwork for the study was planned to take place over two months, including environmental observations, data collection, and preliminary analysis. This duration was chosen to ensure comprehensive data collection under literature data, expert interview and environmental conditions, as well as to align with project planning timelines.

The study primarily used technical and economic data related to the floating solar PV system. The materials include:

- Solar irradiation data: Collected from the Meteonorm database integrated into PVsyst software.
- Financial Cost: Gathered from solar market report by Solar Energy Research Institute of Singapore, prior research, and expert opinions.
- Performance data: Based on literature for solar modules, inverters, and system efficiency. The involvement of expert consultants, such as engineers and financial analysts, is also essential for validating assumptions and simulation inputs.

This study used a combination of software tools (e.g., PVsyst, Microsoft Excel, and Crystal Ball) and literature reviews for data collection and modeling:

- PVsyst: Used to model system performance and energy output.
- Microsoft Excel: Utilized for economic analysis, including NPV, IRR, and PIR calculations.
- Crystal Ball: Applied for Monte Carlo simulations to account for uncertainties and variability in key parameters.

Based on the explanation above, this study had some stages as follows:

1. System Modeling: Inputting system design and location data into PVsyst to simulate energy output under various conditions.
2. Economic Analysis: Calculating NPV, IRR, and PIR using Excel based on cost and revenue data.
3. Uncertainty Analysis: Performing Monte Carlo simulations in Crystal Ball to evaluate the impact of variable factors were identified by fitting the best probability distribution based on smallest average deviation.
4. Sensitivity Analysis: Identifying the most influential factors affecting project feasibility.
5. Conclusion and Recommendation: Interpreting results to provide actionable insights for decision-making.

4. RESULTS AND DISCUSSION

4.1 Location and Potential Data

According to the annual report of PT PLN Indonesia Power, the total zoned area of the Mrica Reservoir is 1,288 hectares, with the water body covering 52.95% of the area, equivalent to 682 hectares. Based on Regulation No. 7 of 2023 by the Ministry of Public Works and Housing (PUPR), specifically Article 105, Paragraph 6, only 20% of the water body area within a reservoir is permitted for the development of floating solar power plants. Therefore, the water body area available for a floating solar power plant project at the Mrica Reservoir is approximately ±136.4 hectares. Utilizing this permissible area, the potential generation capacity can be calculated based on solar irradiation conditions and the designed system efficiency.

Table 1. Weather Data

Month	Global Horizontal Irradiation (W/m²)	Horizontal Diffuse Irradiation (W/m²)	Temperature (°C)	Wind Velocity (m/s)	Relative Humidity (%)
January	202.8	112.6	27.1	1.69	81.7
February	214.7	120.7	26.9	1.7	82.9
March	207	116.4	27.4	1.49	80.7
April	214	109.9	27.2	1.2	77.3
May	203.9	99.9	27.1	1.4	77.9
June	200	79.2	27.1	1.61	77.3
July	201.1	83.9	26.9	1.8	74.7
August	213.2	99.3	26.8	2.1	71.6
September	217.1	110.7	26.9	2.05	73.2
October	231.7	123.9	27.4	1.5	72.2
November	210.3	124.4	27.2	1.31	79.4
December	200.9	108.6	27.2	1.5	81.3
Year	208.8	107.4	27.2	1.6	78

(Source; Meteonorm PVsyst, 2024)

The Global Horizontal Irradiation (GHI) data used in the calculations is obtained from the Meteonorm 8.2 database integrated with PVsyst software. According to literature, the efficiency of each system component is as follows: solar module efficiency = 22% (Jinko Solar, accessed in 2024), inverter efficiency = 97%, cable efficiency = 98%, and environmental factor efficiency = 95% (Deshmukh & Chandrakar, 2022; Ekici & Kopru, 2017; Saeed & Zohaib, 2021). The total combined efficiency is calculated as 0.19886 or 19.88%. The potential power calculated using the following calculation methodology.

$$P = A \times H \times \eta total$$
$$P = 1364000\ m^2 \times 208.8 W/m^2 \times 0.198$$
$$P = 56635964.35\ Wp$$
$$P = 56.635\ MWp$$

This efficiency results in a potential generation capacity of floating solar power plant can reach 56.635 MWp. By using this result, the energy output can be estimated using PVsyst simulation. The energy output is showed on figure 2 below.

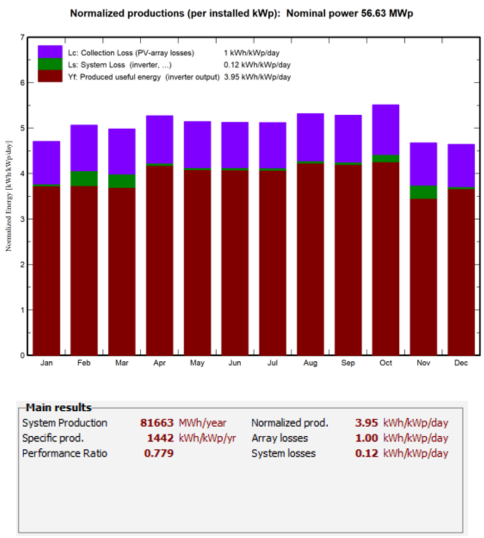

Figure 2. Energy Output of Floating Solar Power Plant

4.2 Economic Analysis

Financial data in this study is categorized into cash outflows and cash inflows. Cash outflows are expressed in terms of USD/Wp, representing the cost per unit of installed plant capacity, a standard metric used in financial modeling for the feasibility of solar power systems. All financial data were gathered through interviews with external company stakeholders to estimate the cost.

Table 2. Capital Expenditure

Component	Unit	Value	Price (USD)
Module	USD/Wp	0.25	$ 14,158,991.09
Inverter	USD/Wp	0.08	$ 4,530,877.15
Floating and Anchoring, Mounting System	USD/Wp	0.15	$ 8,495,394.65
Balance of System (BoS)	USD/Wp	0.13	$ 7,362,675.37
Design, Construction, Testing & Commisioning	USD/Wp	0.14	$ 7,929,035.01
Wiring	USD/Wp	0.016	$ 906,175.43
Total Estimated	USD/Wp	0.766	$ 43,383,148.69

(Source: World Bank (2019); Kinanti (2021); personal communication (July, 2024))

Table 3. Operational Expenditure

Component	Unit	Value	Price (USD)
Office Operation	USD/Wp/year	0.00167	$ 94,582.06
SPV Operation Salary	USD/Wp/year	0.00196	$ 111,006.49
Operational and Maintenance Cost	USD/Wp/year	0.00269	$ 152,350.74
Trash, Flood and Sedimentation maintenance	USD/Wp/year	0.008	$ 566,359.64
Insurance	USD/Wp/year	0.00269	$ 152.35
Total Estimated O&M	USD/Wp/year	0.01901	$ 1,076,649.68

(Source: World Bank (2019); Kinanti (2021); personal communication (July, 2024))

In addition to the cash inflow and outflow data over the project's lifecycle, several external parameters may influence the economic feasibility of the floating solar PV system. These external factors include trends in the solar energy market, shifts in government policies, and changes in monetary policies. These elements may can significantly impact project costs, revenues, and overall financial performance. To provide a comprehensive analysis, these external parameters will be integrated with the financial data to evaluate the project's viability. The feasibility assessment will be conducted using key financial indicators such as Net Present Value (NPV), Project Internal Rate of Return (IRR), and the Profitability Index Ratio (PIR). This integrated approach ensures that both internal financial factors and external market conditions are accounted for, providing a robust framework for determining the project's potential success.

Table 4. Financial Factor

Component	Unit	Value
Inflation	%	3.45
Interest Rate	%	3
Discount Rate	%	5
Debt to Equity Ratio	%	80:20

Component	Unit	Value
Tariff Growth rate	%/year	0.53
Electricity Sale	USD/kWh/year	0.071
Taxes	%/year	22

4.3 Uncertain Factors

The uncertain factors in this study refer to external variables that are independent of each other and not influenced by time. Some of the probability distributions for these variables were derived from previous studies, while other site-specific data, such as the annual global horizontal irradiation, were obtained through historical satellite data available for the specific site location from Meteonorm 8. Additional data were gathered through expert interviews to provide further insights and ensure the relevant factors that affecting the project. Uncertain factors in this sub discussion were mentioned as Risk Variable.

Table 5. Uncertain Factors

Risk Variables	Distribution Probability	Value
Annual GHI	Logistic	Mean: 205.29, Scale:5.38
Degradation Performance	Triangular	Min: 0; Most likely: 0.5, Max: 0.8
Module Price	Triangular	Min: 0.22, most likely: 0.25, Max: 0.42
Inverter Price	Triangular	Min: 0.08, Most Likely: 0.1, Max: 0.12
Trash, Flood and Sedimentation Maintenance	Triangular	Min: 0.008, Most Likely: 0.03, Max: 0.087
OpEx	Lognormal	Location: 0.0, Mean: 0.02, st Dev: 0.0
CapEx	Uniform	Min: 0.7, Max: 0.8
Electricity Sale	Uniform	Min: 0.071, Max: 0.089
Inflation	Max Extreme	Likeliest: 0.0272, Scale: 0.0113
Interest Rate	Lognormal	Location: 0.0, Mean: 0.02, st Dev: 0.02

(Source : Meteonorm; Sukarso et al Year 2020; NREL year 2017; SERIS year 2019; Penetapan-Penyesuaian-Tarif-Tenaga-Listrik PLN.co.id year 2024; Untoro year 2021.)

4.4 Monte Carlo Analysis

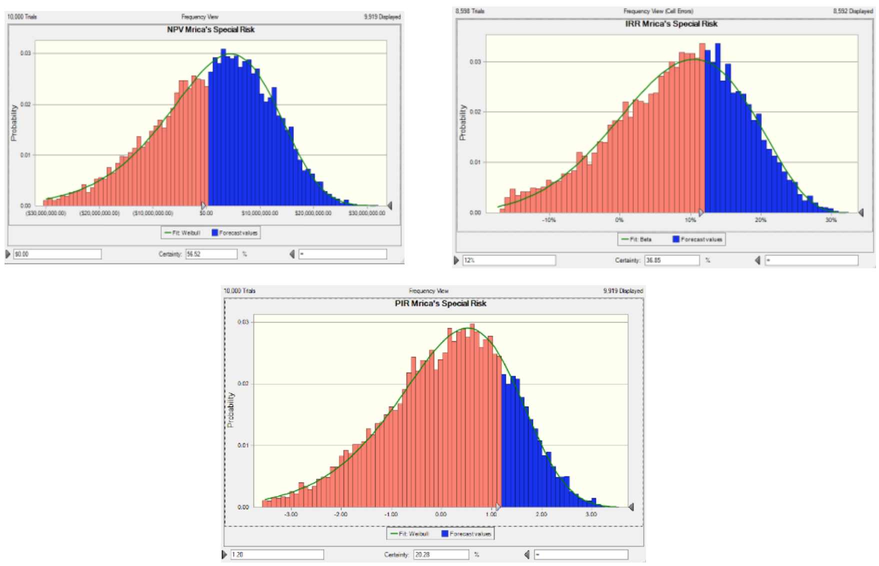

Figure 3 Monte Carlo Result

The net present value (NPV) that is acceptable for a project is generally considered positive, indicating that the project's returns are profitable and viable (Yukio et al., 2023). The IRR value in this simulation were set with a minimum value of 12%. The IRR range in this Monte Carlo simulation is based on the requirement of an Internal Rate of Return (IRR) of 12-15% for renewable energy projects funded by multilateral institutions such as the World Bank, stemming from the need to ensure the project's sustainability. This threshold reflects the high capital costs and risks associated with renewable energy projects, often exacerbated by budget constraints and limited access to traditional financing (Kim & Lee, 2021). Meanwhile, the Profitability Index Ratio (PIR) is set between 1.2 and 1.5 because it is often considered necessary to ensure adequate returns, particularly in high-risk environments. This threshold serves as an important benchmark for decision-makers, guiding them in evaluating the feasibility of projects amid uncertainty. The PIR were set above 1.2, based on long-term viability, as projects with a PIR below 1.2 may not cover costs, leading to unsustainable investments (Rijnen, 2018). The simulation results, as shown in Figure 4, with NPV > 0, have a certainty value of 56.52%, IRR > 12% at 36.85%, and PIR > 1.2 at 20.28%, indicating the percentage of the project's value considered feasible, Suggesting that the project can proceed, with special attention to reducing and optimizing the most influential factors based on sensitivity analysis.

4.5 Sensitivity Analysis

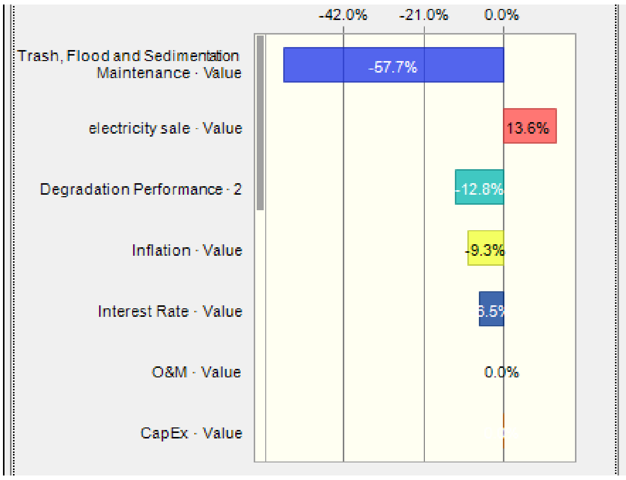

Figure 4. Sensitivity Analysis Result

Figure 4 illustrates the contribution analysis of risk variables to changes in the Net Present Value (NPV) of the floating solar PV project. The variable with the largest negative impact is Trash, Flood, and Sedimentation Maintenance, contributing -57.7%. This highlights that maintenance costs related to waste management, flooding, and sedimentation pose a significant potential to reduce the economic feasibility of the project. This factor is attributed to the unique characteristics of the location, which require intensive efforts to ensure the operational continuity of the floating solar PV system. The electricity sale variable provides a positive contribution of 13.6%, indicating that an increase in electricity prices or sales volume plays a crucial role in improving the project's profitability. Meanwhile, other variables such as Degradation Performance (-12.8%), inflation (-9.3%), and interest rates (-6.5%) have a moderate impact on feasibility.

CONCLUSION

This study concludes that there are eight uncertainty factors affecting the investment feasibility of floating photovoltaics. The identified uncertainty factors can be categorized into mitigable and non-mitigable risks. Mitigable uncertainty factors consist of factors that can be controlled internally by the company such as performance degradation, electricity sales, interest rates, inverter prices, module prices, and maintenance costs for trash, flood, and sedimentation.

For this floating solar PV project, it is recommended to use the profitability index ratio as a criterion to anticipate worst-case scenarios by considering the mitigable uncertainty factors. Mitigation actions should minimize maintenance costs for trash, flood, and sedimentation, optimize electricity sales, and control performance degradation through regular maintenance. Although other factors, such as interest rates, inverter costs, and module prices, contribute less significantly, but they should still be monitored and managed effectively.

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