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Floating solar power plant planning based on electricity price fluctuations in Towuti, south Sulawesi

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Abstract

A company located in South Sulawesi, intends to mitigate emissions from the Power Plant by constructing an environmentally friendly alternative, namely the Floating Solar Power Plant (FSPP), in Towuti. The development plan involves a feasibility analysis for each configuration of the FSPP, considering technological, economic, and environmental criteria. The selection of the preferred configuration is determined using the Analytical Hierarchy Process (AHP) method, based on input from experts. According to this method, the chosen configuration is the on-grid non-battery Floating Solar Power Plant, with a Net Present Value of Rp. 1,431,159,245,752, an Internal Rate of Return of 9.46%, a Payback Period of 8.916 years, a Profitability Ind ex of 1.299, a system efficiency of 21.56%, a carbon footprint of 35,003 kg CO_2, and an emission reduction of 9,136,808,273 kg CO_2. Decision analysis, involving open and abandonment scenarios based on fluctuations in industrial electricity prices, was conducted using Monte Carlo simulation, yielding a volatility value of 31.2%. The real options analysis recommends abandonment in the twentieth year, with a decision success potential of 38%, based on the results.

Keywords: Dedieselization; Floating Solar Power Plant; Feasibility Study; Real Option Analysis

1. Introduction

Energy is crucial and needed by all people worldwide. According to the Indonesia Ministry of Energy and Mineral Resources, in 2020, Indonesia's energy supply came from 35.36% coal, 34.38% petroleum, 19.36% natural gas, and 10.9% Renewable Energy Sources (RE) (Ministry of Energy and Mineral Resources, 2021). Fossil energy includes oil, natural gas, and coal as the main commodities used to fulfill the nation’s energy needs. The rise in demand for energy correlates with the growth in population and quality of life.

Solar Photovoltaic (PV) Power Plants are one of the alternatives used by the government to achieve its target of net-zero emissions using renewable energy is one of the government's efforts to achieve net-zero emissions by utilizing renewable energy.The use of Floating Solar Power Plant can be used in various region in Indonesia as a part of the government efforts in renewable energy. The utilization of floating models is suitable for Indonesia, which comprises 62% of its territory as marine and water areas covering 7.32 million km^2. The utilization of Mixed Renewable Energy with floating PV systems aligns with the Power Supply Business Plan (RUPTL) of the National Electricity Company (PLN) 2021-2030, targeting a 23% share of RE generation by 2025, compared to 14% realization in 2020. FSPP construction utilizes photovoltaic (PV) technology, capable of generating 50 grams per kilowatt-hour from solar radiation. FSPP is considered as one of the best options in renewable energy due to it’s higher efficiency compared to landed solar power plant. This is a result because FSPP is placed above water thus having a better heat distribution in the system.

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In the development of FSPP, various aspects can affect the feasibility of the project, requiring substantial investment costs. These factors include depreciation costs, efficiency degradation of solar panels, environmental costs, technological aspects, determination of FSPP construction schemes, and electricity price fluctuations. Solar panels experience efficiency degradation annually in their capacity to convert solar energy into electricity, impacting the generated electricity capacity and the depreciation-induced decrease in the panel's value. In FSPP construction, marine flora and fauna may be affected due to water surface coverage by solar panels, hindering sunlight access to underwater plants. This outcome may incur additional costs to mitigate potential environmental damage caused by the project's construction. These aspects can affect the company's revenue and profitability, as well as the time required to break even on the investment. Despite the high costs involved, solar energy usage can provide opportunities to reduce CO_2 emissions by 200-300 kilograms per year.

Therefore, analysis is necessary to determine the feasibility of FSPP development. A company, located in Towuti, South Sulawesi, plans to construct a 400MWp FSPP. In developing the project, the company aims to assess the feasibility and construction scheme of FSPP in economic aspects. Based on the exposition above, this research aims to analyze the feasibility of FSPP development in Towuti for diesel power plant dedieselization. This study will employ process simulation calculation using Microsoft Excel software and economic evaluation using the real option binomial lattice method to determine the best investment decision scenario.

2. Literature Review

2.1. Solar Energy in Indonesia

Indonesia is an archipelagic nation located along the equator. This geographic positioning results in high exposure to sunlight. The tropical climate signifies stability in solar radiation and temperatures that remain relatively consistent throughout the year (Ministry of Energy and Mineral Resources, 2021). Solar energy uses radiation and sunlight, converting it into electrical energy that can be stored in batteries or used directly for operational needs. The solar energy potential in Indonesia is relatively high, with South Sulawesi averaging radiation of 5.88 kWh/m2/day (Fathouni et al, 2014).

Indonesia holds significant potential in renewable energy, with a total potential of 3,686 Gigawatts in renewable energy sources. Solar energy covers more than 80% of renewable energy potential in Indonesia, amounting to 0.27 Gigawatts. However, the actual utilization of solar energy in Indonesia lags behind other types of renewable energy sources, despite its largest potential within the renewable energy spectrum (Ministry of Energy and Mineral Resources, 2023).

2.2. Floating Solar Power Plant

Floating Solar Photovoltaic Power Plant (FSPP) is one of the environmentally friendly electricity generators that utilize floating solar modules to convert solar energy into electrical energy. FSPPs can be deployed on various water surfaces including lakes, reservoirs, or seas (Ministry of Energy and Mineral Resources, 2020). In the construction of FSPPs, there are various main components including:

- Solar panel modules: components that function to convert sunlight into electrical energy. Consisting of photovoltaic solar cells to capture sunlight and produce direct current (DC) electricity.
- Inverter: a component that converts the DC electricity from the solar panels into alternating current (AC) electricity to match the typical electrical grid used.
- Support structure: a component used to support the solar panels above water and is suitable for environmental conditions.
- Battery: used to store the electrical energy produced by the solar panels.
- Wiring and control system: components used to connect all components and manage energy distribution and control systems.
- Floater: a component used to keep the solar panels and other components floating on the water.
- Monitoring system: used to supervise the performance of the FSPP including energy production, battery status, and system conditions.

There are two types of FSPPs used in Indonesia, namely on-grid and off-grid. On-grid FSPPs provide electrical energy from both the PLN electrical grid and electricity generated from solar panels, while off-grid FSPPs use all electrical energy sourced from solar panels (Ibáñez-Rioja, et al., 2023).

2.3. Technology Parameter

Technology analysis is a methodological approach used to determine the level of optimization within a project (Ronay & Dumitru, 2015). This analysis is conducted by assessing the efficiency levels based on the components utilized in a Floating Solar Photovoltaic Power Plant (FSPP) system. It serves to ascertain the effectiveness and the most optimal configuration for generating electrical energy.

2.4. Environment Parameter

Environmental analysis is a methodological approach used for strategic planning to monitor environmental sectors and impacts that can determine opportunities or threats to a company (Glueck & Lawrence, 2003). When conducting analysis for feasibility in environmental aspects, emission levels are one of the factors considered as feasibility parameters in the environmental aspect.

Carbon footprint and emission reduction are used as parameters in assessing environmental feasibility. Carbon footprint is a method used to determine the amount of emissions generated by each component within a system, including during the production process of each component (Caetano et al., 2024). The calculation for carbon footprint is performed by summing the emissions generated by the system during the production process. Emission reduction is a calculation method used to determine the level of reduction in emissions produced (Susilowati et al., 2023).

2.5. Economic Parameter

Economic analysis is a methodological approach used to analyze the technical and economic performance of processes, products, or product systems (Zimmermann et al., 2020). In conducting techno-economic analysis, various parameters are required to determine the feasibility of the investment or project, including Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI), and Payback Period.

Net Present Value is a model that calculates the overall cash flow pattern of an investment, in relation to time, based on a specific Discount Rate (Dong et al., 2023). If the NPV is positive, it can be concluded that at the prevailing interest rate, the investment generates profit. On the other hand, if the NPV is negative, the investment, if pursued, would result in a loss. Comparison using NPV can only be utilized if the project's lifespan is of equal duration.

Internal Rate of Return (IRR) is an interest rate that indicates the Net Present Value (NPV) equals the total investment amount (Mellichamp, 2017). The primary function of calculating IRR is to measure whether an asset will experience an increase or not. Another benefit of calculating IRR is to determine the rate of return on investment so that operational activities can be evaluated accurately in terms of the rate of return.

The Profitability Index, also known as the profit-to-cost ratio, is the ratio of the present value of future cash flows to its initial outlay (Djakman, 2000). The criterion of the net present value of investment provides a measure of project feasibility in absolute monetary terms, while the profitability index provides a relative measure of its future net profit against the initial cost. This method calculates the comparison between the present value of future cash flows and the current investment value. The Profitability Index must be greater than 1 to be considered feasible.

The Payback Period is one of the analyses used to determine the feasibility of a proposed investment project. The Payback Period is the length of time required to recover the investment expenditure through the profits gained from a planned project (Djuhatmoko, 2019). The quicker the payback, the more favorable and attractive the investment.

2.6. Analytical Hierarchy Process

According to Saaty (2004), AHP is a theory of pairwise comparisons and prioritized measurements based on expert judgment. AHP is also commonly used to determine strategic priorities that have many criteria, plans, resource allocation, and competitive situations (Saaty, 1988). AHP is an analysis method with a systems approach used for decision making. The principle of the AHP method simplifies something that is complex, unstructured, strategic, and dynamic problems by organizing variables into a hierarchy consisting of parts. The importance of a variable is then given a subjective number regarding the weight of its relative importance compared to other variables.

2.7. Real Option Analysis

Real option analysis is employed to make decisions regarding asset valuation in dynamic conditions characterized by fluctuations, which result in complexity in decision-making (Mbolo et al.,2008). Real option analysis uses the volatility to determine to each option success rate on every time duration.

3. Material and method

The initial stage in this research is problem identification. During this stage, the company aims to construct a Floating Solar Photovoltaic Power Plant (FSPP) in the Towuti Area as a means of self-sufficient energy supply and to support the government's diesel reduction program. This phase involves conducting preliminary research based on previous studies.

Subsequently, the research objectives are determined, aligned with the company's needs, which include assessing the feasibility and decision-making process throughout the FSPP project development.

Preliminary and literature studies are conducted through scholarly articles, journals, books, and previous research. The literature review encompasses foundational aspects of the research such as components and variables in FSPP construction, solar panel specifications and efficiency, as well as government regulations regarding FSPP usage.

Economic analysis evaluation is employed to assess the feasibility of constructing the FSPP in the Towuti Area. Economic analysis tools used include Monte Carlo simulation with Microsoft Excel software. The analysis method involves estimating cash flows throughout the project's duration using the Discounted Cash Flow (DCF) method.

Cash flow analysis is conducted to assess the project's feasibility using Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), and Profitability Index (PI). Economic evaluation is conducted based on the fluctuation of energy levels obtained from solar energy in the Towuti area. Investment risk analysis is performed using the real option analysis method with the binomial lattice method. This method enables the determination of NPV for each year considering fluctuating electricity prices, which can indicate the best decision-making scenario for each year.

Technology analysis evaluation is employed to assess the technical aspects of FSPP construction in the Towuti Area. The evaluation utilizes literature studies of each scheme based on the components used by simulating the operation of the system along with the energy produced.

During this phase, a scheme for constructing the FSPP in the Towuti Area is determined based on the potential electricity generated, economic costs, and efficiency of the selected construction scheme. The FSPP construction scheme is selected based on economic, technological, and environmental parameters.

Analysis of processed data based on real option is conducted in this phase to understand the factors influencing project lifespan risks. This analysis is obtained by determining the volatility of electricity prices using Monte Carlo simulation, followed by the binomial lattice calculation method. The results at each node on the binomial tree are compared with decision-making parameters for opening or abandoning, thus obtaining the success percentage of each option throughout the project's lifespan.

This phase concludes with conclusions drawn from the analysis and data processing conducted in this research. Recommendations are also provided regarding the research conducted and the findings obtained.

4. Results and Discussion

In conducting the analysis, this research utilizes three criteria to determine the best configuration to be used: economic viability with feasibility analysis parameters, technology with efficiency and amount of electricity generated parameters, and environmental considerations with emission reduction and carbon footprint parameters.

Table 1 Solar Power Plant Efficiency

Floating Solar Power Plant	Solar Panel	Inverter	Battery	Total
On-grid battery	22%	98%	99%	21.344%
On-grid no battery	22%	98%		21.560%
Off-grid battery	22%	98%	99%	21.344%

Environmental feasibility analysis is a process conducted to assess the environmental impact of a project on the environment. In this study, environmental aspects are evaluated based on carbon footprint and emission reduction of each alternative. Carbon footprint calculates the amount of carbon generated from the production process of each component in the system. Emission reduction is an indicator that shows the reduction in emissions produced by the system.

Based on the calculation results, the carbon footprint of the on-grid non-battery floating solar photovoltaic power plant (FSPP) configuration is the lowest compared to other alternatives, at 35,003 kg CO_2. This is because this alternative does not use batteries that generate significant carbon emissions during production compared to the on-grid battery FSPP with a carbon footprint of 41,491 kg CO_2 and the off-grid battery FSPP with a carbon footprint of 37,288 kg CO_2. This is also influenced by the frequency of battery replacement in the FSPP, which causes higher carbon emissions in other configurations compared to the second configuration.

Based on the calculation results, the emission reduction of the second configuration is the largest compared to other alternatives, at 9,136,808,273 kg CO_2. This is because the second configuration has the highest efficiency and generates the least emissions during the production process of components in the system compared to other alternatives, where the on-grid battery FSPP has an emission reduction of 9,045,433,352 kg CO_2 and the off-grid battery FSPP has an emission reduction of 9,045,437,555 kg CO_2. This is also influenced by the calculation results regarding the amount of electricity sold by the system.

Table 2 Emission Reduced

Emission reduced	**kg CO_2**
FSPP *on-grid battery*	9.045.406.840
FSPP *on-grid non battery*	9.136.808.273
FSPP *off-grid battery*	9.045.411.043

Technological feasibility analysis is an activity that examines aspects related to the production process along with the quality of the system. The technological feasibility analysis in this study includes the efficiency of each configuration. The calculation is based on existing literature studies on efficiency based on the components used in the system.

Based on the simulation results, the second configuration or alternative 2 has the best efficiency compared to other alternatives. This is because this alternative does not use batteries, reducing the amount of electrical energy dissipated compared to other configurations. The dissipated energy increases when batteries are used due to losses in the transfer of electrical energy from the system to the batteries and vice versa.

The efficiency of the alternative is 21.56% of the solar energy, which comprises heat and sunlight energy. Based on this efficiency value, the electrical energy produced in the first year is 542,468,800 kWh. This efficiency is higher compared to the on-grid battery floating solar photovoltaic power plant (FSPP) configuration with an efficiency value of 21.344% and the off-grid battery FSPP configuration with an efficiency value of 21.344%.

Table 3 Economic Feasibility Analysis

Parameters	**FSPP On-grid Battery**	**FSPP On-grid No Battery**	**FSPP Off-grid Battery**
NPV	IDR 1.365.943.179.205	IDR 1.431.159.245.752	IDR 1.474.377.296.852
IRR	9.31%	9.46%	9.64%
PP	9.002	8.910	8.800
PI	1.286	1.299	1.316

Investment feasibility analysis is an in-depth study of a business or venture to determine its viability. Economic feasibility analysis considers four indicators: net present value (NPV), profitability index (PI), payback period, and internal rate of return (IRR).

All three configurations have a positive cumulative cash balance around the 9th year of the project, with relatively constant income throughout the year. In the final year of the project, there is an increase in the cash balance due to the addition of salvage value from the assets owned during the project's lifespan.

Based on the calculations, the off-grid battery floating solar photovoltaic power plant (FSPP) configuration, or alternative c, has the highest NPV compared to the other alternatives: Rp1,365,943,179,205 for alternative a, Rp1,431,159,245,752 for alternative b, and Rp1,474,377,296,852 for alternative c. This is because alternative c has a lower investment cost than the other two alternatives. NPV uses the income generated by a system during the project's lifespan and the investment cost as a feasibility reference influenced by prevailing interest rates. The indicators are deemed feasible if the NPV is positive.

Based on the calculations, alternative c has the highest IRR compared to the other two alternatives: 9.31% for alternative a, 9.46% for alternative b, and 9.64% for alternative c. This is because alternative c has a lower investment cost than the other two alternatives. IRR uses the income generated by a system during the project's lifespan and the investment cost as a feasibility reference to determine the rate of return the system has during the project's lifespan. The values are considered feasible if the IRR is greater than the Minimum Acceptable Rate of Return (MARR), which is 6%.

Based on the calculations, alternative c has the shortest payback period compared to the other two alternatives: 9.002 years for alternative a, 8.910 years for alternative b, and 8.800 years for alternative c. This is because alternative c has a lower investment cost than the other two alternatives, requiring a shorter time to recover the initial capital used. The payback period does not consider the present value of income.

Based on the calculations, alternative c has the highest profitability index compared to the other two alternatives: 1.286 for alternative a, 1.299 for alternative b, and 1.316 for alternative c. PI uses the income generated by a system during the project's lifespan and the investment cost as a feasibility reference. It calculates the NPV for each year during the project's lifespan and compares the NPV in the final year of the project with the present value of the initial capital. The indicators are considered feasible if the PI value is greater than 1.

In using the Analytical Hierarchy Process (AHP) method, the inconsistency value should not exceed 1. If the value exceeds this limit, the opinions and questionnaire inputs cannot be used for analysis. In this study, all questionnaire results can be used because they have an inconsistency value less than 1.

Table 4 Chosen Floating Solar Power Plant Based On AHP

Chosen FSPP	
On grid battery	0.118243
On grid non battery	0.579184
Off grid battery	0.302573

Based on the calculation results, the selected configuration is the second configuration. The weighted criteria results are 0.09791 for economic criteria, 0.63110 for technological criteria, and 0.27099 for environmental criteria. The weighted sub-criteria results are 0.124 for carbon footprint and 0.875 for emission reduction. The weighted alternative results are 0.118243 for the first configuration, 0.579184 for the second configuration, and 0.302573 for the third configuration.

The decision-making recommendation is carried out using real option analysis, which is a method for decision-making recommendation during the project's lifespan. This method utilizes Monte Carlo simulation to determine the volatility of electricity prices set by the State Electricity Company (PLN) and the binomial lattice calculation method to determine the value of each possibility during the project's lifespan. The inputs used for real option analysis are depicted in the following graph.

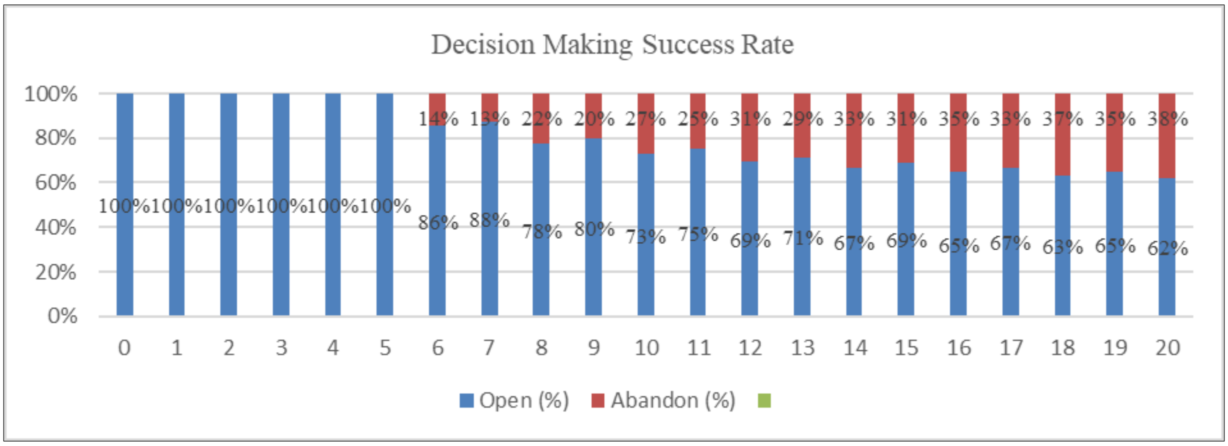

Figure 1 Decision Making Success Rate Based On Real Option analysis

The decision-making recommendation is conducted using real option analysis, which is a method for recommending decisions throughout the project's lifespan. This method employs Monte Carlo simulation to assess the volatility of electricity prices set by PLN and the binomial lattice calculation method to ascertain the value of each possibility during the project's duration.

Based on the calculations, the blue-colored nodes depict the percentage of options within the range to either proceed or abstain, indicating that the management does not take action regarding the Floating Solar Photovoltaic Power Plant (FSPP) and allows the project to proceed. The calculation results indicate that the project can be executed with a success rate of 100% from the first year to the fifth year, thus enabling the project to proceed without delay.

Abandonment is executed if the value of a node on the binomial tree is less than or equal to 20% of the NPV value, depicted in orange on the graph. This indicates a recommendation and the possibility of success for abandoning the project, which is advantageous. The higher the percentage value, the greater the likelihood of higher profits if this option is pursued. Based on the calculation results, the optimal recommendation for abandonment is in the 20th year, with a potential abandonment impact of 38%. This suggests that the project is still deemed feasible to continue for more than 20 years, with a 62% chance.

5. Conclusion

Based on the calculation results, the recommended floating solar photovoltaic power plant (FSPP) configuration to be used, according to the calculation results and using the Analytical Hierarchy Process (AHP) method, is the on-grid FSPP configuration without batteries. For providing recommendations using the real option method, inputs include the NPV of the selected configuration with abandon option parameters if the value at the node on the binomial tree is 20% of the NPV, volatility of electric price at 31.2%, and the risk-free rate in Indonesia for the year 2023 at 6.49%. Based on these inputs, the largest abandon option is identified in the 20th year, with a potential decision-making impact of 37%. For the option to open/abstain, it applies to every node with a value outside the abandon boundary. These options are derived from the results of the binomial tree, which depicts every possibility stemming from fluctuations in electricity prices, offering two choices each year: whether the electricity price increases or decreases. The likelihood of success is determined by how many nodes meet the criteria for each option available.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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