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Feasibility Study of an on Grid Floating Solar PV Extension at the Lontar Coal Fired Power Plant for Self Consumption Using the SROI Method

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Abstract

This study analyzes the technical, financial, and social feasibility of a 3 MWp on grid Floating Solar Photovoltaic (FPV) extension planned for the ash pond area of the Banten 3 Lontar coal fired power plant. The objective is to evaluate its contribution to reducing internal power consumption, assess economic performance, and estimate social benefits using the Social Return on Investment (SROI) approach. Methods include PVsyst simulation, financial analysis (NPV, IRR, Net B/C, Discounted Payback Period, and LCOE), and scenario based SROI evaluation. Results show annual energy production of 4,590,668 kWh, contributing only 1.36% of total auxiliary demand, indicating a complementary role and implying that approximately 227 MWp would be required for full substitution. Financially, the project is infeasible, with a negative NPV, IRR below the 10% discount rate, Net B/C <1, LCOE higher than coal, and payback exceeding 25 years, based on assumptions including a 10% discount rate, Rp 786.88/kWh tariff, and CAPEX of $889.65/kWp. The SROI is 0.63 under the base scenario, increasing to 1.06 without coal subsidies and 1.29 with international carbon pricing, highlighting the importance of policy. This SROI represents an ex-ante evaluation of potential social value.

Keywords: *Floating Solar PV; Coal-Fired Power Plant; Self-Consumption; Financial Feasibility; Social Return On Investment.*

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INTRODUCTION

The growing energy demand in Indonesia presents increasing challenges, driven by sustained economic development and population growth, while the national energy mix remains heavily dependent on fossil fuels such as coal and oil (Alisjahbana & Murniningtyas, 2018). To accelerate the shift toward a cleaner and more sustainable energy system, the government has established renewable energy targets of 23% by 2025 and 31% by 2050, as outlined in Government Regulation No. 79/2014 and Presidential Regulation No. 22/2017 (Adrianti et al., 2025). Within this context, coal fired power plants including the Banten 3 Lontar Power Plant must undergo technological and operational transformation to support national decarbonization efforts and improve efficiency. One relevant option is the utilization of solar photovoltaic (PV) technology, given Indonesia's solar potential exceeding 200 GW, despite its still limited deployment in the power generation sector (Ditjen EBTKE, 2024).

Large-scale solar PV development requires substantial land availability, making the ash pond area at PLTU Lontar a promising site for floating solar PV expansion, particularly as only 1 MWp has been installed and significant surface area remains available. The ash pond functions as a containment basin for fly ash and bottom ash (Pandey & Singh, 2010), which may pose environmental risks if not properly managed (Lokeshappa & Dikshit, 2012); however, its extensive and generally underutilized water surface makes it well suited for floating PV installation while simultaneously enhancing the sustainability profile of the plant (Warto & Tobing, 2024).

Solar photovoltaic systems, which convert solar radiation into electricity using PV modules and represent the fastest-growing renewable energy technology globally (IEA, 2023), are generally classified into on-grid and off-grid systems (Halim, 2025). Technological advancements continue to expand their applicability, including floating solar PV, which offers enhanced efficiency and strong deployment potential in Indonesia's archipelagic regions

(Sukarso & Kim, 2020; Esparza et al., 2024). Accordingly, solar PV particularly floating PV has become a strategic solution in supporting Indonesia's clean energy transition and its Net Zero Emission 2060 target.

Several research works have explored floating solar PV implementation in Indonesia, including the 145 MW floating solar power plant in Cirata, the 48 MW FPV project at Lake Singkarak, and the 100 kWp installation in Muara Nusa Dua, all demonstrating strong techno-economic feasibility (Rifansyah & Hakam, 2024; Abiyasa & Sihombing, 2024). In addition, the Levelized Cost of Electricity (LCOE) for FPV has decreased to 0.05–0.07 USD/kWh, making it increasingly competitive relative to conventional power generation (Wei et al., 2025). However, prior studies in Indonesia predominantly focus on techno economic feasibility and grid connected performance, with limited attention to plant-level integration strategies, particularly the use of FPV for auxiliary load self consumption in coal-fired power plants, as well as the interaction between energy policy instruments and project value creation.

Beyond techno economic assessments, numerous studies have also evaluated energy projects using Sustainable ROI and Social Return on Investment (SROI), methods that quantify both financial performance and the social value generated by a program (Kim & Ji, 2020). Research on solar PV in Cyprus indicates that Sustainable ROI is an effective indicator for long-term renewable energy investment viability (Therapos, 2020). Positive socio economic impacts have also been observed in renewable energy based CSR projects in Thailand (Promuppatum et al., 2018) and in Indonesia, such as the CSR program at PLTGU Cilegon, which achieved an NPV of IDR 1.9 billion, an IRR of 109%, and an SROI of 20.39 (Yana & Nainggolan, 2023), as well as PT Berau Coal's briquette project, which reported an SROI of 27.03 (Hermawan, 2022). The effectiveness of SROI has also been demonstrated in the Trenggulunan Agro View (TAV) program near PLTU Rembang, which achieved an SROI of 2.23 (Apriyanto et al., 2025), and in Nature Based Solutions (NBS) projects across Europe, which have improved environmental quality and social engagement (Kouchakkapourchali, 2024). Nevertheless, existing SROI applications in the energy sector rarely incorporate policy-sensitive variables, such as Indonesia's Domestic Market Obligation (DMO) and Harga Batubara Acuan (HBA) mechanisms, or explicitly model carbon pricing scenarios within the valuation framework.

This study addresses these gaps by proposing a comprehensive evaluation of Floating Solar PV deployment in a coal fired power plant environment that integrates technical performance, economic feasibility, and social value creation. The novelty of this research lies not only in this integration but also in the development of a policy sensitive SROI framework, which explicitly incorporates coal price variability (DMO vs HBA) and carbon pricing scenarios. Furthermore, this study introduces a measurable threshold analysis, demonstrating the conditions under which the SROI value transitions from less than 1 to greater than 1, thereby identifying the tipping point at which the project becomes socially and economically viable under different policy regimes. By doing so, this research provides a more nuanced understanding of how regulatory and market dynamics influence the sustainability of FPV investments in coal-based power systems.

METHOD

Study Area and Site Conditions

This study evaluates on the planned extension of the existing 1 MWp Floating Solar PV (FPV) system installed on the settling basin ash pond of PLTU Banten 3 Lontar, Tangerang, Banten (–6.058874, 106.4643). The ash pond offers a substantially large water surface area, with less than 20% currently utilized, making it highly suitable for further FPV capacity expansion (Warto & Tobing, 2024). In addition to the availability of unused water surface, the site exhibits favourable and stable solar resource characteristics, with an annual Global Horizontal Irradiation (GHI) of 1,804 kWh/m²/year and monthly values ranging from 140.7 to 172.9 kWh/m², based on the Meteonorm 8.0 database. The reliance on Meteonorm 8.0 data in this study is primarily due to the absence of long term on site solar irradiation measurements, which is a common limitation in early stage feasibility assessments. However, it is acknowledged that Meteonorm data are derived from interpolated typical meteorological year datasets and may introduce uncertainty in representing actual site-

specific conditions. These conditions reflect the typical solar profile of tropical regions and provide strong support for the deployment of floating photovoltaic systems. Furthermore, FPV-specific modelling assumptions are incorporated, including reduced module temperature due to water induced cooling effects, lower soiling losses compared to ground mounted systems, and adjusted albedo values representing water reflectivity, all of which influence system performance estimation.

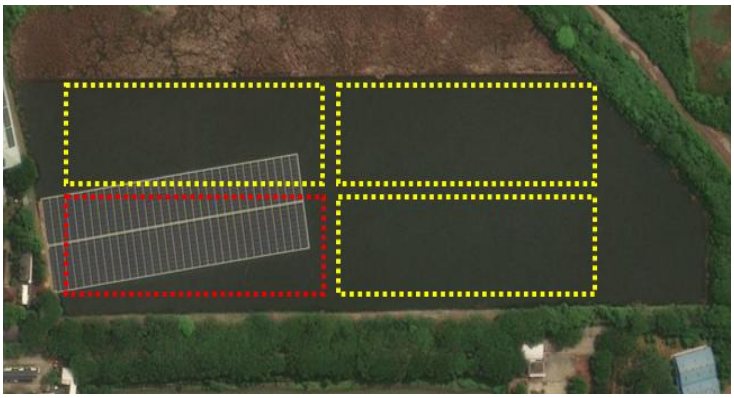

Figure 1. Satellite imagery and the projected FPV extension

Technical performance analysis and energy yield estimation in this study were conducted using the PVsyst software, which enables hourly simulation over an annual cycle and provides a comprehensive evaluation of system configuration, energy output, and associated losses (Sanjaya & Hiendro, 2025). The proposed FPV extension has a planned capacity of 3 MWp, resulting in a total installed capacity of 4 MWp on the ash pond area of PLTU Banten 3 Lontar.

Table 1. Annual climate and solar irradiation data (Meteonorm 8.0 in PVsyst)

Month	Global Horizontal Irradiation [kWh/m²/month]	Temp. [°C]	Wind Speed [m/s]	Humidity [%]
1	141.6	26.8	1.50	83.2
2	144.0	26.7	1.39	84.3
3	159.6	27.1	1.49	82.4
4	149.5	27.0	1.20	81.2
5	146.1	27.5	0.89	81.9
6	141.6	26.7	0.89	82.5
7	149.0	26.7	0.89	79.5
8	155.0	27.0	0.91	76.6
9	156.1	26.9	1.09	77.6
10	172.9	27.9	1.36	77.1
11	147.9	27.0	1.09	81.3
12	140.7	27.0	1.49	81.5
Cummulative / Mean	1804.0	27.0	1.2	81.0

Internal power consumption in a coal-fired power plant (CFPP) refers to the portion of electricity generated by the plant that is used to operate its auxiliary equipment and is therefore not exported to the grid. The magnitude of this internal consumption determines the net capacity defined as the difference between gross and net generation and serves as a key indicator of operational efficiency. At PLTU Banten 3 Lontar, internal electricity consumption exceeds 30,000 MWh per month, accounting for approximately 6% of total generation. Efficiency enhancements can be attained by deploying high efficiency equipment, optimizing the operation of pumps and fans, and integrating renewable energy sources, including rooftop and floating solar photovoltaic systems. Electricity generated by the FPV system is delivered directly to the plant's auxiliary loads, thereby reducing internal electricity consumption.

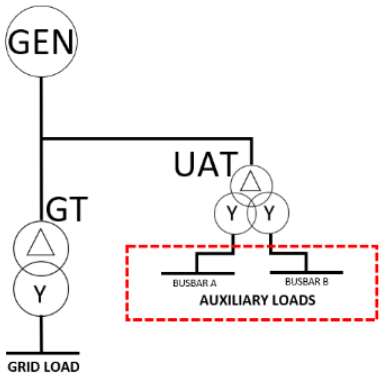

Figure2. Power Plant Generator Transformer Configuration

System Design and PVsyst Simulation

Technical performance analysis and energy yield estimation in this study were conducted using the PVsyst software, which enables hourly simulation over an annual cycle and provides a comprehensive evaluation of system configuration, energy output, and associated losses (Sanjaya & Hiendro, 2025). The proposed FPV extension has a planned capacity of 3 MWp, resulting in a total installed capacity of 4 MWp on the ash pond area of PLTU Banten 3 Lontar.

To enhance methodological transparency and replicability, several key system design parameters are specified. The PV system utilizes mono-crystalline modules (efficiency >20%) and standard inverter configurations, with an assumed DC/AC ratio in the range of 1.1–1.3. The modules are installed at a low tilt angle (approximately 5–10°) and oriented toward the equator (azimuth 0°), consistent with FPV design practices in tropical regions.

The PVsyst simulation incorporates detailed loss components, including incidence angle modifier (IAM) losses, thermal losses, ohmic wiring losses, module mismatch losses, inverter losses, and system availability losses. However, curtailment and export limitations are assumed negligible, as the system is designed under a self-consumption scheme where electricity is directly utilized by auxiliary loads.

The resulting Performance Ratio (PR) of 0.867 is relatively high compared to typical PV systems. This value is partly attributable to the cooling effect of the water surface in FPV systems, which reduces module operating temperature and improves efficiency. Nevertheless, in the absence of a detailed PVsyst loss diagram, this PR value should be interpreted cautiously as an upper-bound estimate under favorable operating conditions.

Self-Consumption Contribution Analysis

Internal power consumption in a coal-fired power plant (CFPP) refers to the portion of electricity generated by the plant that is used to operate its auxiliary equipment and is therefore not exported to the grid. The magnitude of this internal consumption determines the net capacity defined as the difference between gross and net generation and serves as a key indicator of operational efficiency. At PLTU Banten 3 Lontar, internal electricity consumption exceeds 30,000 MWh per month, accounting for approximately 6% of total generation. Efficiency enhancements can be attained by deploying high efficiency equipment, optimizing the operation of pumps and fans, and integrating renewable energy sources, including rooftop and floating solar photovoltaic systems. Electricity generated by the FPV system is delivered directly to the plant's auxiliary loads, thereby reducing internal electricity consumption.

In this study, the parameter is explicitly defined as the amount of electrical energy utilized by internal auxiliary loads, rather than energy exported to the external grid. This clarification is essential to ensure consistency with the self-consumption scheme applied in the analysis.

The average contribution of FPV to auxiliary consumption is calculated at 1.36%. Furthermore, the estimation that approximately 227 MWp of FPV capacity would be required to fully offset internal consumption is based on a linear scaling assumption. This estimation does not account for practical constraints such as limited available surface area, temporal mismatch between solar generation and load demand, and intermittency of solar resources.

Therefore, it should be interpreted as a theoretical approximation rather than a practically achievable deployment target.

Solar PV planning

In the design of a photovoltaic (PV) system, the number of modules required is determined by the target installed capacity (watt peak) and can be calculated as follows (Priyono et al., 2019):

$$N = \frac{P_{wp}}{P_{max}} \quad (1)$$

Where: n is the number of PV modules (units), P_{wp} the desired installed capacity (watt-peak), and P_{max} is the maximum output power of a single PV module (W).

The required land area for the PV installation can be calculated as follows:

$$A = N \times A_{panel} \quad (2)$$

Where: A s the total land area (m²), N is the number of PV modules, and A_{panel} is the surface area of a single module (m²).

The annual energy yield of the PV system can be estimated as follows (Kurtz et al., 2013):

$$E = Ppv \times H \times PR \quad (3)$$

Where: E represents the annual energy output (kWh/year), P_{pv} is the installed PV capacity (kWp), H is the annual solar irradiation at the site (kWh/m²/year), and PR is the performance ratio.

Financial Feasibility Study

The financial feasibility assessment in this study is conducted based on key economic indicators, including Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and Payback Period (PBP). These indicators are employed to evaluate the project's financial performance based on projected cash flows, incorporating capital expenditures (CAPEX), operational expenditures (OPEX), electricity tariffs, applicable incentives, and the Levelized Cost of Electricity (LCOE) as an economic benchmark for solar PV systems (Rifansyah & Hakam, 2024) (Sinaga et al., 2023). To ensure methodological consistency and avoid ambiguity, the formulation and labeling of financial equations have been revised and standardized.

The evaluation follows a discounted cash flow (DCF) approach, with NPV serving as the primary indicator to determine the net economic benefit of all discounted revenues and costs over the project lifetime. NPV is calculated as the difference between the total discounted benefits and the combined investment and operational costs, which a positive NPV indicates its financial feasibility (Yuniar, 2024). The NPV value can be calculated using the following equation (Mulyani et al., 2020).

$$NPV = \sum_{t=0}^{n} N\,B\,(1+i)^{-n} \quad (4)$$

Where NB_t is the net benefit (benefit minus O&M cost) in year, n is the project lifetime in years, and i is the discount rate (%).

In addition to NPV, the Internal Rate of Return (IRR) serves as a key indicator in evaluating the financial attractiveness and performance of the proposed FPV project. IRR is defined as the discount rate at which the net present value (NPV) equals zero, representing the project's internal yield based solely on its projected cash flows (John, 2019) (Speranda & Speranda, 2019). This metric is particularly useful for comparing renewable energy investments because it incorporates both the magnitude and timing of cash flows, enabling investors and decision-makers to evaluate whether the project meets or exceeds required return thresholds. The IRR applied in this study is calculated using the following formulation (Mulyani et al., 2020):

$$IRR = i + \frac{NPV_1}{(NPV_1 - NPV_2)} \times (i_2 - i_1) \quad (5)$$

Where: i_1 is the discount rate that yields a positive NPV, i_2 is the discount rate that yields a negative NPV, NPV_1 is the positive NPV, and NPV_2 is the negative NPV.

$$BCR = \frac{Benefit}{Cost} \quad (6)$$

One financial metric utilized in this study is the Benefit Cost Ratio (BCR), which serves as a comparative measure of the economic efficiency of the proposed Floating Photovoltaic

(FPV) project. The BCR is defined as the ratio of the present value of all discounted benefits to the present value of all discounted costs, effectively capturing the degree to which the project generates net economic value under specified financial conditions (Effendy et al., 2024). A BCR greater than 1 indicates that the economic benefits surpass the associated costs, suggesting that the project is financially viable and meets the standard criteria for investment justification in renewable energy initiatives. The BCR is calculated as follows:

$$PBP = \frac{I_0}{\sum_{i=1}^{n} \frac{CF}{(1+i)^n}} \quad (7)$$

Where: PBP is the discounted payback period, I_0 is the initial investment, CF_i represents the annual cash flow, i is the discount rate, and n is the project lifetime.

The Discounted Payback Period (PBP) is utilized in this study as a key financial feasibility indicator to assess the time required for the project to recoup its initial capital investment when cash flows are evaluated in present value terms. Unlike the simple payback period, the PBP accounts for the time value of money, facilitating a more realistic evaluation of investment risks. A shorter PBP typically indicates lower financial uncertainty and a more robust economic profile for the project, particularly in the context of renewable energy investments, where significant upfront capital expenditures are involved and long-term returns can be affected by performance degradation and market fluctuations (Delapedra-silva et al., 2022). The PBP is calculated as follows. The LCOE is given by:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{Ct}{(1+r)^t}}{\sum_{t=0}^{n} \frac{Et}{(1+r)^t}} \quad (8)$$

Where: C_t denotes the annual cost, E_t the annual energy output, and r the discount rate.

Table 2. Financial Analysis Input

Parameter	Value	Reference
Capacity	3,000 kWp	Adjusted to ash pond potential
Exchange Rate	IDR 16,400/USD	(Trading Economics, 2025)
Solar PV Tariff	IDR 786.88/kWh	(PLN, 2024)
Investment Cost	889.65 USD/kWp	(Rifansyah & Hakam, 2024)
O&M Cost	14.50 USD/kWp/year	(Sukarso & Kim, 2020)
System Degradation	0.5% per year	(Jordan & Kurtz, 2012)
Discount Rate	10%	(JETP, 2023)
Construction Period	1 year	Assumption for 3 MWp project
Project Lifetime	25 years	Assumed PLTS operational lifetime

SROI Analytical Framework

In addition to the Discounted Payback Period (DPP), the Levelized Cost of Energy (LCOE) is employed as a comprehensive indicator to assess the average cost of electricity generation over the operational lifetime of the floating photovoltaic (FPV) system. LCOE considers total project costs including capital expenditures (CAPEX), operation and maintenance (O&M) expenses, and costs associated with component replacement by normalizing these figures against the total energy produced by the system over its lifetime. This characteristic makes LCOE a widely recognized benchmark for assessing the economic competitiveness of various power generation technologies, regardless of differences in system size, cost structure, or geographic location (Delapedra-silva et al., 2022; Ahmad et al., 2022).

The Social Return on Investment (SROI) framework is utilized in this study to quantify the broader social, economic, and environmental value generated by the proposed Floating Photovoltaic (FPV) extension project. In contrast to traditional financial evaluation tools that primarily focus on monetary returns, SROI incorporates non-financial outcomes such as enhancements in community well-being, environmental benefits, and changes in behaviour by converting these outcomes into measurable economic values. This approach provides a more comprehensive assessment of project performance (Mitchell et al., 2023). The methodology is anchored in eight core principles established by Social Value International, which emphasize stakeholder engagement, transparency, and rigorous verification to ensure that the estimated impacts accurately reflect actual value creation.

Table 3. Stages of the Social Return on Investment (SROI) Analysis

Stage	Description
1. Establishing Scope and Identifying Stakeholders	Defining the evaluation boundaries, objectives, time horizon, and resources, while identifying stakeholders directly or indirectly affected by the project.
2. Mapping Outcomes	Developing a theory of change that links inputs, activities, outputs, and expected outcomes, describing how the project generates social, economic, and environmental value.
3. Evidencing Outcomes and Assigning Monetary Values	Collecting indicators and data to verify expected outcomes, and converting non-financial impacts into monetary values using appropriate financial proxies.
4. Establishing Net Impact	Adjusting the gross outcomes to remove effects not attributable to the project, through deadweight, attribution, displacement, and drop-off.
5. Calculating the SROI Ratio	Discounting future benefits and comparing them to total investment costs to obtain the SROI ratio.
6. Reporting, Using, and Embedding Results	Presenting findings to stakeholders and integrating insights into organizational decision making and future project improvements.

The SROI ratio is formulated as follows (Nicholls et al., 2012):

$$SROI = \frac{Total\ Present\ Value\ of\ benefits}{Total\ Present\ Value\ of\ Investment\ (Input)} \quad (9)$$

In accordance with the Guide to SROI (Nicholls et al., 2012), two analytical approaches are distinguished: forecast SROI, which estimates anticipated future benefits prior to project implementation, and evaluative SROI, which assesses actual outcomes during or after project execution. Since this research focuses on a planned FPV extension, the forecast SROI approach has been selected. This method is particularly pertinent for renewable energy projects, where it is essential to consider long-term environmental and social benefits, even in the absence of immediate empirical data.

Scenario Design for SROI Analysis

a. Scenario 1: Base Scenario

The base case applies the regulated coal price under Indonesia's Domestic Market Obligation (DMO) scheme set at 70 USD/ton for electricity generation, as stipulated in Ministerial Decree No. 139.K/HK.02/MEM.B/2021 and uses the domestic carbon market price from IDX Carbon, amounting to IDR 58,800 per ton CO_2e (ESDM, 2021) (ICAP, 2023). This scenario represents current policy and operational conditions at PLTU Lontar.

b. Scenario 2: Market Coal Price without DMO Mechanism

This scenario replaces the subsidized DMO coal price with the market-based Harga Batubara Acuan (HBA). The Ministry of Energy and Mineral Resources reports that the HBA for April 2025 is 120.20 USD/ton, equivalent to approximately IDR 1,972 per kilogram (ESDM, 2021). This scenario evaluates the effect of removing fuel-price intervention on the SROI value.

c. Scenario 3: Market Coal Price without DMO and International Average Carbon Price

Scenario 3 integrates the market coal price with the international average carbon price of $32 per ton of CO_2e, as reported in the World Bank's State and Trends of Carbon Pricing 2024 (Group, 2024). This scenario exemplifies a policy environment where carbon externalities are fully internalized in accordance with international standards.

d. Scenario 4: Sensitivity Analysis of Impact Adjustment Factors

The fourth scenario assesses the sensitivity of SROI outcomes to variations in impact-adjustment parameters namely, deadweight, attribution, displacement, and drop off which are core components of the SROI methodology (Nicholls et al., 2012). Adjustment values are varied from 10% to 100% to examine the robustness and responsiveness of the SROI ratio under different assumptions of net impact realization.

RESULTS AND DISCUSSION

This study evaluates the technical, economic, environmental, and social feasibility of a proposed 3 MWp Floating Solar PV (FPV) extension at the Banten 3 Lontar coal-fired power plant as a strategy to reduce the plant's internal power consumption.

Technical Assessment

The site analysis indicates that the 36,125 m² ash pond area at PLTU Banten 3 Lontar has substantial potential for further utilization, as the existing 1 MWp FPV installation currently occupies only approximately 6,000 m², or less than 20% of the total available area. The solar irradiation level of 1,804 kWh/m²/year further confirms that the location is highly suitable for expanding FPV capacity.

The assessment of land requirements for a 3 MWp solar system indicates that the calculated area for the array, initially 13,341 m², increases to 22,235 m² when a packing factor of 0.60 is applied. This adjustment falls within the range recommended by the National Renewable Energy Laboratory (NREL) (Ong et al., 2013). This suggests that the ash pond has ample space to accommodate the planned floating photovoltaic (FPV) expansion without facing any spatial limitations

Meanwhile, the PVsyst simulation estimates a module installation area of 13,932 m² and an annual energy output of 4,590,667 kWh, with a Performance Ratio (PR) of 0.867. This high PR value reflects an optimal system performance under tropical climatic conditions, further supported by the natural cooling effect of the water surface inherent to FPV installations. To further substantiate this high PR value, a detailed PVsyst loss breakdown (including thermal losses, inverter losses, mismatch losses, and wiring losses) should be presented to provide greater transparency and technical validation.

In addition, a time-profile analysis (hourly or diurnal generation profile) should be considered, as the auxiliary load of the coal-fired power plant operates continuously (24/7), while the FPV system generates electricity only during daylight hours. This mismatch may limit the effective contribution of FPV to internal consumption despite adequate annual energy production.

Table 4. Comparison of Self-Consumption Energy and Solar PV Contribution

Month	Lontar *Auxiliary Power (kWh)*	FPV *E_Grid (kWh)*	Ratio (%)
January	29,562,195.20	380,838.00	1.29%
February	26,824,161.00	380,714.00	1.42%
March	23,698,644.00	409,614.00	1.73%
April	27,828,052.80	371,050.00	1.33%
May	33,160,525.21	352,912.00	1.06%
June	31,692,511.20	336,466.00	1.06%
July	32,909,304.22	356,418.00	1.08%
August	33,993,799.76	381,855.00	1.12%
September	23,208,963.22	395,528.00	1.70%
October	21,918,051.28	450,813.00	2.06%
November	29,869,272.30	395,265.00	1.32%
December	33,023,779.84	379,195.00	1.15%
Total/Average	347,689,260.03	4,590,668.00	1.36%

The plant's internal power consumption at PLTU Lontar is recorded at 347,689,260 kWh per year, representing 5.37% of total electricity generation. In comparison, the 3 MWp FPV system contributes only 1.36% annually toward meeting the internal power demand. This indicates that 3 MWp is insufficient for full substitution of internal consumption, which would require a capacity of approximately 227 MWp.

The technical assessment indicates that while the 3 MWp floating photovoltaic (FPV) system can operate efficiently and help decrease internal electricity consumption, its overall impact is still relatively small in scale. These findings serve as a basis for further economic and social analyses, including an evaluation of Social Return on Investment (SROI) under various coal and carbon pricing scenarios.

Financial Feasibility Analysis

The financial assessment reveals that the total capital expenditure (CAPEX) required for the development of the 3 MWp Floating Solar PV (FPV) system at PLTU Banten 3 Lontar is approximately Rp 43.77 billion. This estimate is based on the FPV investment cost of $889.65 per kWp (Rifansyah & Hakam, 2024), using an assumed exchange rate of Rp 16,400 per USD. Additionally, the annual operation and maintenance (OPEX) cost, estimated at $14.50 per kWp (Sukarso & Kim, 2020), results in a total yearly O&M expenditure of Rp 713.4 million. These cost components are essential financial inputs for evaluating the project's overall economic feasibility.

Based on a cash-flow analysis conducted over a 25-year system lifetime, which considers an annual module degradation rate of 0.5% (Jordan & Kurtz, 2012) and applies a 10% discount rate in line with the CIPP 2023 recommendations (JETP, 2023), the total present value of benefits is estimated at Rp 25.13 billion. When this value is compared to the total investment cost, it results in a Net Present Value (NPV) of –Rp 18.64 billion. The negative NPV indicates that the revenue generated from floating photovoltaic (FPV) electricity production, calculated using the applicable solar tariff of Rp 786.88 per kWh (PLN, 2023), is insufficient to cover both the capital and operational expenditures over the project's lifetime. However, this valuation approach should be revisited to align with a self-consumption scheme, where the economic benefit is better represented by avoided cost of electricity rather than tariff-based revenue. Therefore, the proposed 3 MWp FPV extension is considered financially unfeasible under the current baseline scenario.

The financial evaluation of the 3 MWp Floating Solar PV project at PLTU Banten 3 Lontar reveals a concerning result. The Internal Rate of Return (IRR) is significantly lower than the benchmark discount rate used in this analysis. Over a projected 25 year system lifespan, the calculated IRR is –5.70%, indicating that the project is expected to yield a negative internal rate of return based on baseline assumptions.

To further validate the results, an interpolation approach between two discount rates was used, resulting in an adjusted Internal Rate of Return (IRR) estimate of approximately 4.11%. This apparent discrepancy between the negative IRR and the interpolated IRR should be clarified to ensure consistency in reporting methodology, as IRR values should be derived from a single coherent cash flow framework. This figure is significantly lower than the assumed discount rate of 10%. Consequently, it confirms that the project does not meet the minimum acceptable return necessary for financial feasibility.

The IRR analysis highlights that the FPV extension project is not financially viable under the current baseline scenario. To make the project align with conventional investment standards, significant improvements are necessary. These could include reducing capital expenditures (CAPEX), raising electricity tariffs, or introducing additional financial incentives.

The Benefit Cost Ratio analysis indicates that the present value of benefits generated by the 3 MWp Floating Solar PV extension project amounts to IDR 31.60 billion, while the present value of total costs including discounted CAPEX and OPEX reaches IDR 50.25 billion. Consequently, the resulting BCR value of 0.628 (<1) demonstrates that the economic benefits produced by the project do not exceed its total investment and operational costs over the 25-year lifetime. A BCR below the feasibility threshold signifies that the project is not economically viable under the baseline conditions and would require additional interventions, such as CAPEX reductions, fiscal incentives, or enhanced valuation of solar-generated energy, to achieve financial feasibility.

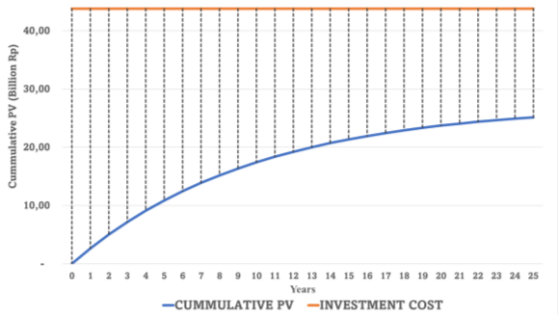

Figure 3. Comparison of LCOE for Floating Solar PV and Coal-Fired Power Plant

The Discounted Payback Period (DPP) analysis indicates that the total cumulative discounted cash inflows over a period of 25 years amount to only IDR 25.13 billion, which is significantly lower than the initial investment of IDR 43.77 billion. With a discount rate of 10%, the project fails to reach its break-even point within its operational lifetime. This lack of achievement in the DPP further emphasizes that the net annual cash inflows generated by the Floating Solar PV (FPV) system are insufficient to recover the initial investment costs. These findings confirm that, based on the current assumptions, the 3 MWp Floating Solar PV project is not financially viable without major cost reductions or supportive policy measures.

For the FPV system, the total discounted cost consists of an initial capital investment (CAPEX) of Rp 43.77 billion, along with a present value of annual operation and maintenance (O&M) expenses amounting to Rp 6.48 billion. Together, these elements lead to a total discounted project cost of Rp 50.25 billion over the project's 25 year lifespan. By applying a discount factor of 9.077 and a total discounted energy output of 41.68 million kWh, the resulting LCOE for the FPV system is calculated at Rp 1,205.83/kWh (USD 0.0735/kWh). This relatively high cost reflects the capital-intensive nature of FPV technology, coupled with a modest annual energy yield.

The LCOE (Levelized Cost of Energy) calculation for the PLTU Banten 3 Lontar Coal Fired Power Plant (CFPP) shows significantly lower production costs. The plant has a capital expenditure (CAPEX) of Rp 10.70 trillion, with fixed and variable operations and maintenance (O&M) costs amounting to Rp 288.97 billion annually, and annual fuel costs of Rp 3.04 trillion. When these costs are discounted over a 30-year operational period, the present value of the total system costs is Rp 42.09 trillion. With a discount factor of 9.427 and a discounted lifetime energy production of 61.02 billion kWh, the resulting LCOE is Rp 689.73 per kWh (USD 0.0421 per kWh). This indicates that electricity generation from the coal-fired plant is significantly more economical under the current baseline conditions.

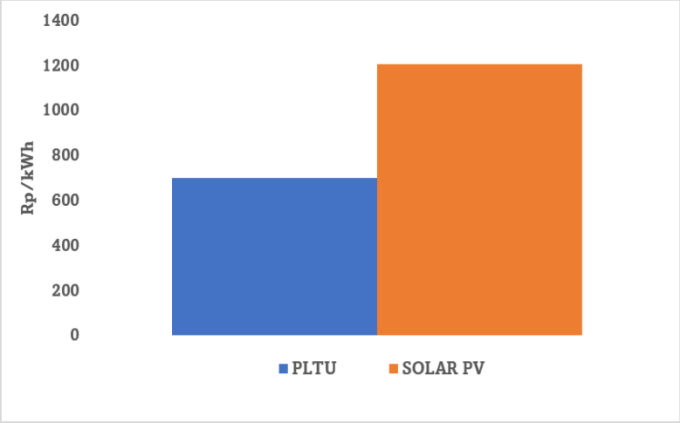

Figure 4. Comparison of LCOE for Floating Solar PV and Coal-Fired Power Plant

The comparison highlights that the floating photovoltaic (FPV) system is currently not cost-competitive with coal-fired power plants (CFPPs). The levelized cost of energy (LCOE) for FPV is nearly double that of its coal-fired counterpart. This difference is primarily due to high initial investment costs and lower energy output. To improve the financial viability of FPV deployment, significant cost reductions, performance enhancements, or policy interventions such as increased renewable energy tariffs, capital subsidies, or carbon pricing mechanisms would be necessary. These findings emphasize the need for comprehensive economic and regulatory strategies to facilitate the wider adoption of FPV technologies in Indonesia's transition to a more sustainable power sector.

Social Return on Investment (SROI) Analysis

In the Social Return on Investment (SROI) assessment, the first step is to define the analytic boundaries and identify the stakeholders who are either directly or indirectly affected by the project. This study specifically focuses on the planned development and operation of a 3 MWp floating solar photovoltaic (PV) extension at the PLTU Banten 3 Lontar, located in Tangerang Regency, Banten Province. This project aims to diversify the energy portfolio of the plant while contributing to the broader transition toward cleaner electricity generation.

Stakeholder identification encompasses groups with varying degrees of influence and exposure to the project's outcomes. The primary stakeholders include:

- PLTU Management, who oversee operational planning and strategic decision-making within the power plant;
- PLTU Workers, who may experience changes in work conditions, job responsibilities, or skill requirements due to technological integration; and
- Local Communities, who are potential recipients of social, economic, and environmental impacts stemming from the project's implementation.

These stakeholders form the basis for mapping value creation pathways and determining the social outcomes to be quantified in the subsequent SROI analysis stages.

The outcome mapping stage aims to establish a clear causal pathway between inputs, outputs, and the resulting outcomes generated by the 3 MWp floating solar PV extension at PLTU Lontar. This process enables a systematic identification of the positive and unintended changes experienced by key stakeholders, thereby providing a structured foundation for evaluating the project's social, economic, and environmental contributions. By articulating how the project's resources translate into measurable outputs and meaningful stakeholder outcomes, this stage strengthens the validity of the subsequent SROI valuation.

For PLTU management, the main input is a capital investment of Rp 43,770,780,000, which enables the installation of a 3 MWp floating photovoltaic (FPV) system that produces 4,590,668 kWh annually. This results in improved operational sustainability, characterized by reduced emissions and alignment with national renewable energy goals. PLTU workers invest their time and effort in training and system operations, with ten employees participating in technical capacity-building sessions. The anticipated outcomes include increased workforce adaptability, enhanced technical skills in renewable energy operations, and expanded career development opportunities. Additionally, the surrounding community contributes labor during the construction and operational phases, with approximately 40 individuals involved during the development stage and 10 during operation. The results include improved household income, skill enhancement, better air quality, and potential long-term public health benefits, all of which strengthen social cohesion and overall community well-being.

During the current stage of the SROI analysis, we validate each identified outcome using measurable indicators and assign a monetary value through financial proxies. This process ensures that the social, economic, and environmental impacts of the 3 MWp floating solar photovoltaic (PV) extension at PLTU Lontar are based on verifiable evidence rather than assumptions. By converting outcomes into economic values, we can compare impacts across different domains and calculate the total social value generated. The validated outcomes including fossil fuel savings, reductions in CO_2 emissions, and job creation are systematically documented using indicators, data sources, changes in quantities, benefit durations, and corresponding financial proxies. This information forms the empirical basis for the SROI assessment.

A significant environmental achievement of the project is the reduction in coal consumption due to renewable electricity generation. With an annual energy output of 4,590,668 kWh and a specific fuel consumption (SFC) of 0.65 kg/kWh for PLTU Lontar, the project is expected to decrease coal use by 2,983,934 kg in its first year. Based on PLN's 2023 coal price reference of Rp 999.76/kg (PLN, 2024), this reduction translates to an economic value of Rp 2,983,218,055. Additionally, the project reduces greenhouse gas emissions. Using PLN's emission factor of 0.73 kg CO_2/kWh (PLN, 2023), the annual avoided emissions are calculated to be 3,351,118 kg CO_2e. When monetized at a secondary market carbon price of Rp 58,800 per ton CO_2 (ICAP, 2023), this reduction generates a social value of Rp 197,049,833. The project also brings socioeconomic benefits through job creation. During the construction phase, 40 workers will be employed for six months, with compensation based on the 2024 minimum wage of Tangerang Regency (Rp 4,901,117) (Damenta, 2025), resulting in a total impact of Rp 1,176,268,080. In the operation and maintenance phase, 10 workers will be engaged, and with the same wage reference and an assumed annual wage increase of 6.5%, the socioeconomic value generated in the first year

amounts to Rp 588,134,040. These quantified outcomes provide a strong basis for incorporating social and environmental benefits into the SROI calculation.

In the Building Impact stage of the SROI analysis, the goal is to calculate the net impact generated by each verified outcome. Within the SROI framework, not all observed changes can be solely attributed to the project, as some outcomes may have occurred even without the intervention or may be influenced by external factors. To provide a more realistic and conservative estimate of the project's true contribution, several adjustment parameters deadweight, attribution, displacement, and drop-off are applied. Summarizes the correction factors used in this study: a deadweight of 11.11%, attribution of 13.58%, displacement of 14.32%, and a drop off of 0.50%. The drop-off rate corresponds to the assumed annual degradation rate of the FPV installation.

The reduction in fossil fuel consumption has an initial monetary value of Rp 2,983,218,055, resulting in an adjusted annual impact of Rp 1,953,633,212.89. The reduction in CO_2 emissions, valued at Rp 197,049,833.23, produces a net impact of Rp 129,042,896.50. Regarding employment outcomes, the absorption of labor during the construction phase generates an adjusted impact of Rp 770,307,884.09, while the operations and maintenance workforce contributes Rp 385,153,942.05 annually. Employee training activities, which were initially valued at Rp 50,000,000, now result in a net adjusted impact of Rp 36,155,812.50 per year. These adjusted values reflect the realistic contributions of the FPV project to social, environmental, and economic value creation, taking into account potential external influences and diminishing effects over time.

Scenario 1: Base Scenario

Following the identification of outcomes, valuation, and impact adjustment, the SROI for the 3 MWp floating solar PV project at PLTU Lontar was calculated by discounting the net impact for each stakeholder group over the analysis period. In line with the macroeconomic assumptions outlined in the Comprehensive Investment and Policy Plan (CIPP) under the Just Energy Transition Partnership (JETP, 2023), a discount rate of 10% was applied.

The total present value of benefits amounts to Rp 27,955,733,755.55, whereas the value of inputs (investment cost) is Rp 43,770,780,000. This results in an SROI ratio of 0.634, indicating that every 1 rupiah invested generates approximately 0.634 rupiah in social value. Although the ratio is below the threshold of economic desirability (SROI > 1), the project still offers significant contributions, including reduced carbon emissions, decreased fossil fuel consumption, and enhanced workforce capacity, thereby supporting the broader transition toward sustainable energy systems.

Scenario 2: Market Coal Price without DMO Mechanism

In the baseline scenario, the coal price reflects the Domestic Market Obligation (DMO) policy, which mandates a subsidized domestic coal price of $70 per ton for electricity generation, as outlined in Ministerial Decree No. 39.K/HK.02/MEM.B/2021. In Scenario 2, the subsidy is removed, and the coal price is adjusted to the market-based reference price (HBA) of $120.20 per ton, equivalent to Rp 1,972 per kg (ESDM, 2021). When this unsubsidized coal price is applied, the Social Return on Investment (SROI) increases significantly to 1.06, exceeding the threshold for social value creation. This indicates that government coal subsidies play a major role in diminishing the perceived social benefits of renewable energy investments compared to coal-fired generation. The removal of such subsidies reveals the true economic and social costs of fossil-fuel-based systems, thereby enhancing the comparative social performance of floating solar photovoltaic (PV) systems.

Scenario 3: Market Coal Price without DMO and International Average Carbon Price

In Scenario 3, two adjustments are introduced simultaneously: the implementation of unsubsidized coal prices, as seen in Scenario 2, and the application of the average international carbon price. The domestic carbon reference price used in Scenarios 1 and 2, which is Rp 58,800 per ton of CO_2e (equivalent to 3.66 USD), is significantly lower than global benchmarks. The "State and Trends of Carbon Pricing 2024" report by the World Bank recommends an effective carbon price ranging from 63 to 127 USD, with a global average of 32 USD per ton of CO_2e, equivalent to Rp 524,800 per ton. By incorporating this international carbon price, the Social Return on Investment (SROI) increases to 1.29,

representing the highest ratio among the three scenarios. This finding highlights that the valuation of carbon plays a crucial role in determining the perceived social value of renewable energy projects. Furthermore, applying global carbon pricing standards can significantly enhance the SROI of floating solar PV investments in Indonesia.

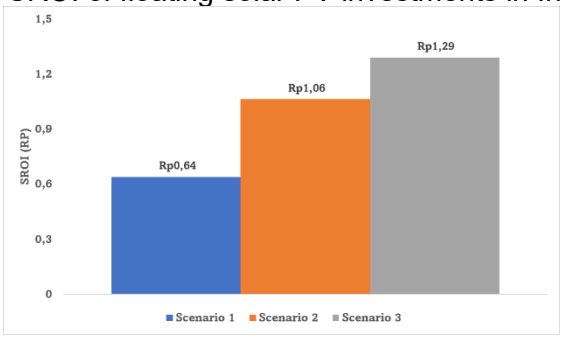

Figure 5. Comparison of Scenario 1, 2, and 3

Scenario 4: Sensitivity Analysis of Impact Adjustment Factors

Scenario 4 presents a sensitivity analysis that examines how variations in the impact adjustment factor (ranging from 10% to 100%) affect the Social Return on Investment (SROI) across all scenarios. The results indicate a consistent upward trend in SROI values as the adjustment factor increases. In Scenario 1, which considers the DMO coal price and domestic carbon price, SROI values range from 0.10 to 0.97, remaining below 1 even at the highest adjustment level. In Scenario 2, which looks at the unsubsidized coal price, SROI values rise to between 0.16 and 1.62, highlighting the significant influence of coal pricing on social value outcomes. Scenario 3, which includes the unsubsidized coal price and international carbon pricing, shows the highest SROI range, from 0.20 to 1.96, confirming that assumptions regarding carbon pricing play a crucial role in determining the magnitude of social benefits.

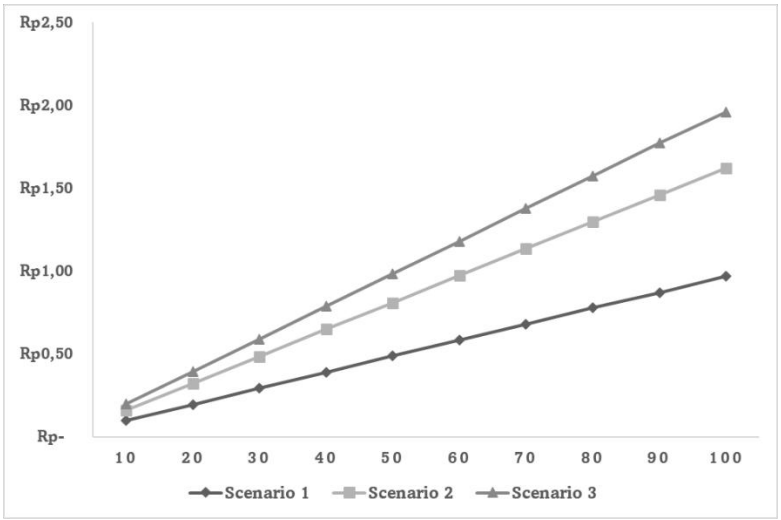

Figure 6. Sensitivity of Impact Adjustment Factors on SROI

The sensitivity analysis indicates that the Social Return on Investment (SROI) outcomes are significantly affected by changes in adjustment factors. Notably, Scenario 3 consistently demonstrates the highest social value across all levels of correction. These findings underscore the importance of accurate carbon pricing and the elimination of fossil fuel subsidies to better reveal the true social returns of investments in renewable energy. However, the interpretation of this sensitivity analysis should be approached with caution, as SROI responses may not be strictly linear due to variations in proxy duration, discounting effects, and the interaction between adjustment parameters such as attribution and drop off.

CONCLUSION

This study concludes that the proposed 3 MWp on-grid floating solar photovoltaic extension at the ash pond of PLTU Banten 3 Lontar is technically feasible but remains limited in its contribution to the plant's internal electricity demand. The PVsyst simulation indicates

that the system can generate approximately 4,590,668 kWh of electricity per year with a Performance Ratio of 0.867. However, this output only accounts for about 1.36% of the plant's annual auxiliary electricity consumption. Therefore, the proposed FPV extension should be understood as a complementary energy source rather than a major substitute for the coal-fired power plant's internal power demand. The estimate that approximately 227 MWp would be required to fully offset auxiliary consumption also needs to be interpreted as a theoretical approximation, since actual implementation would be constrained by available surface area, solar intermittency, and the mismatch between daytime PV generation and continuous auxiliary load.

From a financial perspective, the project is not feasible under the baseline assumptions. The analysis shows a negative Net Present Value of Rp 18.64 billion, a Benefit–Cost Ratio of 0.628, an Internal Rate of Return below the 10% discount rate, and a Discounted Payback Period exceeding the 25-year project lifetime. The Levelized Cost of Electricity for the FPV system is also calculated at Rp 1,205.83/kWh, which is considerably higher than the coal-fired power plant's LCOE of Rp 689.73/kWh. These results indicate that, under the current tariff, investment cost, and policy conditions, the project cannot yet compete financially with coal-based internal electricity supply.

The Social Return on Investment analysis shows that the project can generate environmental, social, and economic value, but this value is highly dependent on policy assumptions. Under the base scenario using the DMO coal price and domestic carbon price, the SROI is only 0.634, meaning that every Rp 1 invested generates Rp 0.634 in social value. When the coal price subsidy is removed, the SROI increases to 1.06, and when international carbon pricing is applied, it rises further to 1.29. These findings indicate that the project's social feasibility improves when fossil fuel externalities are more accurately reflected through market coal pricing and stronger carbon valuation. Thus, the FPV extension becomes more justifiable not because of its baseline financial return, but because of its potential contribution to emission reduction, fuel savings, workforce capacity development, and policy-driven energy transition.

RECOMMENDATION

Based on the findings, the implementation of the 3 MWp floating solar PV extension at PLTU Banten 3 Lontar should not be pursued solely as a conventional commercial investment under the current baseline assumptions. The project is technically promising, but its financial indicators remain weak. Therefore, its development should be positioned as part of a broader decarbonization and energy transition strategy rather than as a stand alone profit-oriented project.

Future project planning should use an avoided cost approach rather than a tariff based revenue approach, because the proposed FPV system is intended for self-consumption by auxiliary loads, not for electricity sales to the grid. This adjustment is important to produce a more accurate economic valuation of the project. The analysis should also clarify the inconsistency in the reported IRR values, since the manuscript presents both a negative IRR and an interpolated IRR of 4.11%. A single coherent cash-flow framework is needed to avoid ambiguity in the financial feasibility result.

Technical validation should be strengthened by using long term on site solar irradiation data, detailed PVsyst loss diagrams, and hourly generation load matching analysis. The current Performance Ratio of 0.867 is relatively high and may be reasonable for FPV because of water cooling effects, but it should be supported by clearer evidence on thermal losses, inverter losses, mismatch losses, wiring losses, and system availability. Since auxiliary load operates continuously while solar generation occurs only during daylight hours, future analysis should include diurnal load profiles to estimate the actual usable contribution of FPV more precisely.

Policy support is necessary if the project is expected to become financially and socially attractive. Relevant interventions include capital expenditure subsidies, preferential financing, carbon credit mechanisms, stronger carbon pricing, and reform of fossil fuel subsidy structures. The SROI results show that the project becomes socially viable only when coal subsidies are removed or when carbon externalities are valued more realistically.

This means that regulatory conditions play a decisive role in determining whether FPV investment at coal fired power plants can create sufficient social value.

Future studies should also strengthen stakeholder engagement in the SROI framework. The current analysis monetizes social outcomes such as job creation, worker training, reduced coal consumption, and avoided carbon emissions, but these assumptions would be more convincing if supported by direct stakeholder consultation, especially with plant workers, local communities, and plant management. This would make the SROI result less dependent on proxy assumptions and more reflective of actual perceived benefits.

Finally, the project should be combined with auxiliary energy efficiency measures at the power plant. Since the 3 MWp FPV system contributes only 1.36% of auxiliary consumption, improving pump, fan, motor, and internal electrical system efficiency may provide a more substantial reduction in internal energy use. A combined strategy of FPV deployment, efficiency improvement, and policy-based carbon valuation would provide a stronger basis for improving the sustainability profile of PLTU Banten 3 Lontar.

REFERENCES

Abiyasa, A., & Sihombing, R. (2024). *Techno-economic Analysis of 100 kWp Floating Solar Photovoltaic for Renewable Energy Mix in Bali – Indonesia Techno-economic Analysis of 100 kWp Floating Solar Photovoltaic for Renewable Energy Mix in Bali – Indonesia*. https://doi.org/10.1088/1755-1315/1344/1/012011

Adrianti, Agung, T. K., Nasir, M., & Anugrah, P. (2025). *A 48-MW floating photovoltaic design and integration to a grid*. *30*(3), 1331–1338. https://doi.org/10.11591/ijeecs.v30.i3.pp1331-1338

Ahmad, M., Khattak, A., Janjua, A. K., Alahmadi, A. A., Khan, M. S., & Ullah, N. (2022). *Techno-economic feasibility analyses of grid- connected solar photovoltaic power plants for small scale industries of Punjab , Pakistan*. (November), 1–22. https://doi.org/10.3389/fenrg.2022.1028310

Alisjahbana, A., & Murniningtyas, E. (2018). Tujuan Pembangunan Berkelanjutan Di Indonesia: Konsep Target Dan Strategi Implementasi. In *UNPAD*. https://doi.org/10.18356/9789210010788

Apriyanto, B., Saputra, E., & Putra, V. P. (2025). *Analysis Of Social Return On Investment (Sroi) In The Community Empowerment Program Related To Integrated Agroculture For Forest Area Management In Trenggulunan Village , Pancur District , Rembang Regency*. *4*(4), 459–470. https://doi.org/10.58344/jws.v4i4.1390

Damenta, U. A. (2025). *KEPUTUSAN GUBERNUR BANTEN NOMOR 471 TAHUN 2024*.

Delapedra-silva, V., Ferreira, P., & Cunha, J. (2022). Methods for Financial Assessment of Renewable Energy Projects : A Review. *MDPI*. https://doi.org/10.3390/pr10020184

Ditjen EBTKE. (2024). *Laporan Kinerja 2024*.

Effendy, M., Nasar, M., Abduh, M., & Ad, A. (2024). *Studi Kelayakan Teknis dan Ekonomi Pembangkit Listrik Tenaga Surya Rooftop di Hotel Rayz Universitas Muhammadiyah Malang*. 95–106.

ESDM. (2021). *Pemenuhan Kebutuhan Batubara Dalam Negeri*.

Esparza, I., Ol, Á., Huang, L., Yang, Y., Budiono, C., Riyadi, S., Hetharia, W., Hantoro, R., Setyawan, D., Utama, I. K. A. P., & Wood, T. (2024). *Floating PV Systems as an Alternative Power Source : Case Study on Three Representative Islands of Indonesia*.

Group, W. B. (2024). *state and trends of carbon pricing*. https://doi.org/10.1596/978-1-4648-2127-1

Halim, L. (2025). *Analisis Teknis dan Biaya Investasi Pemasangan PLTS On Grid dan Off Grid di Indonesia*. *5*(2), 131–136.

Hermawan, R. (2022). *Social Return On Investment (Sroi) Of Coal Briquette Processing Plant For Poultry Farms Master of Business Administration Program School of Business and Management Institut Teknologi Bandung*.

ICAP. (2023). *Compare ETS*. Intenational Carbon Action Partnership. https://icapcarbonaction.com/

IEA. (2023). *Share of renewable electricity generation by technology, 2000-2030 – Charts – Data & Statistics - IEA*. https://www.iea.org/data-and-statistics/charts/share-of-renewable-electricity-generation-by-technology-2000-2030

JETP. (2023). *Comprehensive Investment and Policy Plan (CIPP) 2023*.

John, S. (2019). *Capital Budgeting Techniques : Estimation of Internal Rate of Returns*. *13*(2), 1–10. https://doi.org/10.9734/AJEBA/2019/v13i230167

Jordan, D. C., & Kurtz, S. R. (2012). Photovoltaic Degradation Rates — An Analytical Review. *NREL*, (June).

Kim, D. J., & Ji, Y. S. (2020). The evaluation model on an application of SROI for sustainable social enterprises. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(1), 7. https://doi.org/10.3390/joitmc6010007

Kouchakkapourchali, A. (2024). *u Assessing the Social Return on Investment Approach for Rehabilitation Projects on Urban Spaces : A Case Study of Six*. POLITECNICO DI TORINO.

Kurtz, S., Newmiller, J., Dierauf, T., Kimber, A., Mckee, J., Flottemesch, R., Kurtz, S., Newmiller, J., Dierauf, T., Kimber, A., & Mckee, J. (2013). *Analysis of Photovoltaic System Energy Performance Evaluation Method Analysis of Photovoltaic System Energy Performance Evaluation Method*. (November 2013).

Lokeshappa, B., & Dikshit, A. K. (2012). *Fate of Metals in Coal Fly Ash Ponds*. *3*(1), 1–6. https://doi.org/10.7763/IJESD.2012.V3.185

Mitchell, L., Hardman, M., Goodspeed, T., Atkinson, L., Mitchell, L., Hardman, M., Goodspeed, T., & Atkinson, L. (2023). Social return on investment : reflections on advancing the method within Cities & Health. *Cities & Health*, *7*(5), 677–681. https://doi.org/10.1080/23748834.2023.2192333

Mulyani, M. S., Rochdiani, D., & Setia, B. (2020). *Analysis Of Financial Feasibility Of Aren Flour Agroindustry*. *Vol. 7*, 797–804. https://doi.org/10.25157/jimag.v7i3.4018

Nicholls, J., Lawlor, E., Neitzert, E., & Goodspeed, T. (2012). *Social Return A guide to on Investment Social Return on Investment* (Number January).

Ong, S., Campbell, C., Denholm, P., Margolis, R., Heath, G., Ong, S., Campbell, C., Denholm, P., Margolis, R., & Heath, G. (2013). *Land-Use Requirements for Solar Power Plants in the United States Land-Use Requirements for Solar Power Plants in the United States*. (June).

Pandey, V., & Singh, N. (2010). *Impact of fly ash incorporation in soil systems*. *136*(1–2), 16–27. https://doi.org/10.1016/j.agee.2009.11.013

PLN. (2023). *ESG Performance Report 2023*.

PLN. (2024). *Statistik PLN 2023*.

Priyono, T., Khwee, K., & Yandri. (2019). *Studi Perencanaan Pembangkit Listrik Tenaga Surya Pada Peternakan Ayam Pedaging (Broiler) Di Gang Karya Tani Pontianak Selatan*.

Promuppatum, N., Kongpann, A., Boonpramote, T., Wangnai, C., & Chavalparit, O. (2018). *Evaluation of CSR Project from the Economic, Environmental and Social Performances Monitoring by Using the Case Study of Renewable Energy for a Community Project in Thailand*. (March 2018), 55–58. https://doi.org/10.1145/3208854.32089

Rifansyah, M., & Hakam, D. F. (2024). Techno economic study of floating solar photovoltaic project in Indonesia using RETscreen. *Cleaner Energy Systems*, *9*(February), 100155. https://doi.org/10.1016/j.cles.2024.100155

Sanjaya, W., & Hiendro, A. (2025). *Solar Power Plant (PLTS) Planning Based On Pvsyst Software In The Joint Lecture Building – B Tanjungpura University*. *2*(1), 80–92. https://doi.org/10.26418/telectrical.v2i1.76534

Sinaga, A. S., Sari, M. M., Hutasuhut, A. A., Zahara, S. T., Amanda, A., Fitri, A., & Caesario, M. A. (2023). *Comparison of capital budgeting methods : NPV , IRR , PAYBACK PERIOD*. *19*(02), 1078–1081.

Speranda, I. V. O., & Speranda, Z. (2019). *The Comprehensive Method of Solving the Multiple Internal Rate of Return Problem*. *15*(1), 73–86. https://doi.org/10.14254/1800-5845/2019.15-1.6

Sukarso, A. P., & Kim, K. N. (2020). *Cooling E ff ect on the Floating Solar PV : Performance and Economic Analysis on the Case of West Java*. https://doi.org/10.3390/en13092126

Therapos, N. (2020). *Sustainable ROI as an indicator of renewable energy investments: an application on a solar PV project in Cyprus* (Number February). Bocconi University.

Trading Economics. (2025). *Rupiah Indonesia: Panduan Singkat Indikator Ekonomi dan Keuangan*. https://id.tradingeconomics.com/

Warto, & Tobing, S. (2024). *Techno-Economic Analysis of Floating Solar PV on Reservoir Ash Pond in Coal-Fired Power Plants*. 98–105. https://doi.org/10.36079/lamintang.ijeste-0702.789

Wei, Y., Khojasteh, D., Windt, C., & Huang, L. (2025). An interdisciplinary literature review of floating solar power plants. *Renewable and Sustainable Energy Reviews*, *209*(October 2023), 115094. https://doi.org/10.1016/j.rser.2024.115094

Yana, C., & Nainggolan, Y. A. (2023). *International Journal of Current Science Research and Review CSR Program Social Return on Investment Analysis Case Study : PT PLN Indonesia Power PLTGU Cilegon OMU*. *06*(07), 4396–4408. https://doi.org/10.47191/ijcsrr/V6-i7-54

Yuniar, F. P. (2024). *Metode valuasi ekonomi dalam pengambilan kebijakan lingkungan di sektor pertambangan*. *1*(2), 160–172. https://doi.org/10.61511/jembar.v1i2.2024.504