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Techno-Economic Study of Solar Panel Implementation as the Alternative Energy Source in Mataram City

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ABSTRACT

Mataram City, the capital of West Nusa Tenggara Province, has strong potential for solar energy development due to its favorable geographic and climatic conditions. Indonesia's commitment to reducing greenhouse gas (GHG) emissions by 41% by 2030, along with the province's net zero emission goal by 2050, underscores the importance of renewable energy deployment. This study aims to evaluate the technical and economic feasibility of implementing solar panels as an alternative energy source in Mataram City and to assess their contribution to GHG emission reduction. The analysis uses RETScreen software with secondary data from NASA's Surface Meteorology and Solar Energy (SSE) database. It covers resource assessment, cost analysis, and financial indicators including Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Levelized Cost of Electricity (LCOE). Mataram receives an average daily solar radiation of 5.4 kWh/m²/day, with consistent potential throughout the year. The financial analysis shows that the project is technically feasible and economically viable, supported by positive NPV and IRR values, and provides significant contributions to GHG reduction. Solar panel implementation in Mataram City is proven to be feasible in technical, financial, and environmental terms. The findings serve as a valuable reference for local governments in formulating sustainable and low-carbon energy strategies.

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Introduction

The Provincial Government of West Nusa Tenggara (NTB) is strongly committed to achieving net zero emissions by 2050, which aligns with Indonesia's broader national commitment to reduce greenhouse gas (GHG) emissions by 29% through internal measures and up to 41% with international support by 2030, as agreed under the Paris Agreement (UNFCCC, 2016). Transitioning toward renewable energy is a key strategy to achieve these targets, and utilizing solar panels as a primary energy source in Mataram City represents a strategic step in this direction.

Mataram City, as the capital of NTB Province, has significant potential for solar energy development due to its favorable geographic and climatic conditions. This potential can be leveraged to reduce carbon emissions and dependence on fossil fuels, while supporting local and national renewable energy goals. Conducting a *feasibility study* is a crucial initial step to assess the technical performance and financial viability of solar energy projects in the region.

This type of assessment ensures that the planned investment is well-aligned with both environmental sustainability and long-term energy needs.

The *feasibility study* involves the collection and analysis of data such as solar radiation, air temperature, and energy demand in Mataram. It also considers factors such as government incentives, public support, and relevant policies for renewable energy adoption. Evaluating these elements provides a comprehensive understanding of the opportunities and challenges involved in implementing solar panels as an alternative energy source.

Previous studies have explored solar panel performance in regions with similar tropical climates. For instance, Pratiwi et al. (2021) highlighted Indonesia's average solar radiation range of 4.5–5.5 kWh/m²/day, demonstrating the country's high potential for solar energy. Similarly, Husain & Abdullah (2020) emphasized the feasibility of solar photovoltaic systems in Indonesia, noting their economic and environmental benefits. However, these studies often focus on larger urban areas or national-level analyses, leaving a gap in localized, small-city contexts like Mataram. This study addresses that gap by providing a detailed *techno-economic analysis* tailored to Mataram's unique conditions, leveraging advanced tools like RETScreen software and high-resolution data from NASA's Surface Meteorology and Solar Energy (SSE) database.

What distinguishes this study from existing research is its granular focus on Mataram City, a smaller urban area with specific energy needs and constraints. Unlike broader studies, this research employs a more precise methodology, combining GIS-based site selection, detailed financial modeling (including NPV, IRR, and LCOE), and sensitivity analyses to account for local variables such as humidity, rainfall, and grid integration challenges. Additionally, the study evaluates the impact of local policies and community engagement, aspects often overlooked in larger-scale analyses. By focusing on Mataram, this research offers actionable insights for policymakers and investors, ensuring the findings are directly applicable to the city's energy transition.

This research aims to answer several key questions: Is solar panel energy suitable for implementation in Mataram City? What are the total costs for installation, operation, and maintenance? What is the potential reduction in GHG emissions? Which economic indicators—such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Levelized Cost of Electricity (LCOE)—demonstrate the project's feasibility? Lastly, how does the project perform under sensitivity and risk scenarios? These questions form the foundation for evaluating the viability of solar energy in Mataram.

The study focuses exclusively on Mataram City and utilizes RETScreen software for technical and financial analysis, with data sourced from NASA's Surface Meteorology and Solar Energy (SSE) database. This method allows for precise evaluation of energy production potential, cost structures, and environmental benefits. While the study does not address the actual implementation of solar projects, its findings are intended to serve as valuable input for policymakers, investors, and energy planners.

This research aims to comprehensively evaluate solar panel implementation in Mataram City through multiple critical dimensions. The study will assess technical feasibility by analyzing solar energy potential, optimal system configurations, and grid integration requirements. A detailed economic analysis will be conducted using key financial indicators including Net Present Value, Internal Rate of Return, Payback Period, and Levelized Cost of Electricity to determine project viability. The environmental impact will be quantified through calculation of potential GHG emission reductions compared to conventional energy systems. The investigation will also identify key risks and sensitivities affecting project performance, including cost fluctuations, policy changes, and technical challenges. Ultimately, the research seeks to develop actionable policy recommendations and investment strategies to support solar energy adoption in Mataram and similar small Indonesian cities.

The significance of this research lies in its dual contribution. From an academic perspective, it adds to the body of knowledge on solar energy feasibility in Indonesia, particularly for urban regions with high renewable potential. From a practical standpoint, the study provides strategic guidance for the Mataram City government and other stakeholders in developing policies that support low-carbon energy solutions. By promoting solar energy, the region can reduce reliance on fossil fuels, improve environmental quality, and contribute to Indonesia's climate change mitigation commitments. The findings of this study could also serve as a model for other Indonesian cities seeking to transition toward sustainable energy systems.

Research Method

The methodology used to assess the *techno-economic* feasibility of solar panel implementation in Mataram City centered on RETScreen software, supported by NASA's Surface Meteorology and Solar Energy (SSE) database. This feasibility study relied on secondary data and consisted of two main components: technical feasibility and economic viability.

The first step involved evaluating solar resources in Mataram City. Solar irradiance data were obtained from NASA SSE and supported by findings from Pratiwi et al. (2021), which showed Indonesia's solar radiation ranged between 4.5 and 5.5 kWh/m²/day. This data helped estimate the photovoltaic energy potential in the area.

Site selection was a critical part of the technical assessment. Locations for solar panel installations were identified based on freedom from shading, optimal tilt angle, and roof structural integrity, as emphasized by Chaurey et al. (2016). Geographic Information Systems (GIS) assisted in mapping feasible rooftop or ground-mounted sites throughout the city. The choice of solar panel type was guided by performance, cost, and durability considerations. Monocrystalline panels offered higher efficiency and lifespan but were more expensive, while polycrystalline and thin-film panels provided budget-conscious alternatives (Hosseini et al., 2018). Panel selection influenced both energy output and financial metrics.

The photovoltaic system size was calculated based on Mataram's electricity demand, historical consumption, peak sunlight hours, and anticipated system losses. System configuration and simulations were optimized using RETScreen's modeling tools, enabling accurate projections of energy production under local climatic conditions. Grid integration was also evaluated, focusing on compatibility with the local electricity network managed by PT PLN (Persero). This included assessing net metering schemes, grid capacity, and relevant technical regulations to ensure efficient operation and legal connection (Zhang et al., 2016).

The economic assessment covered capital costs, operational expenses, and key financial indicators. Cost and benefit estimates were modeled with RETScreen, incorporating international and local pricing benchmarks. Capital expenditure (CAPEX) included the initial investment for solar panels, inverters, mounting systems, installation labor, and permits. The formula for CAPEX is:

$$\begin{aligned} CAPEX = {} & Cost\ of\ Solar\ Panels + Cost\ of\ Inverters \\ & + Cost\ of\ Mounting\ Structures + Installation\ Labor \\ & + Permits\ and\ Other\ Costs \end{aligned}$$

According to IRENA (2019), the average global CAPEX for utility-scale solar PV is approximately $1,210/kW, though local conditions may cause deviations.

Operational expenditure (OPEX) includes recurring costs such as maintenance, insurance, and system monitoring. Bazilian et al. (2016) noted that annual OPEX typically ranges from 1% to 2% of CAPEX. The formula is:

$$OPEX = Annual\ Maintenance\ Cost + Insurance\ Cost$$
$$+ Monitoring\ and\ Miscellaneous\ Costs$$

To evaluate the long-term economic viability, several key financial indicators are calculated, including Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PoT), and Levelized Cost of Electricity (LCOE).
LCOE is defined as the average cost per unit of electricity produced over the system's lifetime. It is computed using the formula:

$$LCOE = \frac{Total\ Lifetime\ Cost}{Total\ lifetime\ Energy\ Production}$$

Where:

- Total Lifetime Cost = CAPEX + OPEX + Decommissioning Costs
- Total Lifetime Energy Production = Total kWh generated over the system's operational life

LCOE provides a benchmark for comparing solar PV against other energy technologies. Bazilian et al. (2016) reported global LCOE ranges for solar PV from \$0.03 to \$0.10 per kWh.
The Payback Period (PoT) measures the time needed to recover the initial investment through electricity cost savings. It is calculated using:

$$Pay\ of\ Time\ = \frac{CAPEX}{Annual\ Income}$$

Annual income is derived from the savings on electricity bills resulting from solar generation. Kalogirou (2017) notes that the PoT is a critical metric for small-scale solar investors who prioritize quick returns.
NPV is the sum of discounted future cash flows, subtracted by the initial investment:

$$NPV = \Sigma_{T=1}^{T} \frac{R_t}{(1+r)^t} - C_O$$

Where:
R_t is the net cash inflow during the period
r is the discount rate
t is the time period
C_o is the initial investment
A positive NPV indicates profitability, aligning with investor expectations. The discount rate reflects the cost of capital and investment risk profile.
The IRR is the rate at which NPV equals zero. It is used to compare the profitability of the solar project relative to other investment opportunities. The IRR formula is:

$$O = \Sigma_{T=1}^{T} \frac{R_t}{(1+r)^t} - C_O$$

If IRR exceeds the cost of capital, the project is considered financially sound (Perea et al., 2019). Beyond technical and economic dimensions, environmental and social impacts are fundamental components of this feasibility study. Solar energy reduces dependence on fossil fuels, thus contributing to emissions mitigation. According to Choi et al. (2017), the integration of solar PV can significantly decrease greenhouse gas emissions, supporting Indonesia's climate targets. An environmental impact assessment (EIA) is performed to estimate CO_2 reduction levels and identify potential ecological disturbances. The outcomes feed into policy decisions and stakeholder engagement processes. Social acceptance plays a vital role in successful renewable energy implementation. Public consultations and community outreach are essential for fostering awareness, dispelling misconceptions, and building trust. Wüstenhagen et al. (2017) emphasized that projects with high community involvement exhibit better implementation outcomes. Risk analysis identifies and addresses technical, financial, and environmental uncertainties. Technical risks include equipment failure, poor system performance, and installation errors. These can be mitigated through preventive maintenance and selecting reputable technology providers (Hwang et al., 2017). Financial risks arise from fluctuations in component prices, interest rates, or regulatory changes. Sensitivity analysis enables simulation of various scenarios to assess project robustness. Perea et al. (2019) highlighted the role of long-term contracts and funding diversification in minimizing financial exposure. Environmental and social risks may involve land-use conflicts or opposition from local communities. Proactive dialogue and inclusive decision-making are effective strategies to mitigate these risks (Sovacool et al., 2015).

Results and Discussion

Site Reference Conditions

The environmental characteristics of Mataram City are crucial for evaluating the feasibility of solar photovoltaic (PV) development. Based on data analysis using NASA's Surface Meteorology and Solar Energy (SSE) database, Mataram is located at 116.1° East Longitude and -8.6° South Latitude, with an elevation of 111 meters above sea level. The climate is marked by consistently high temperatures and humidity throughout the year, which significantly influence the efficiency and performance of PV systems. Daily solar radiation in Mataram averages 5.40 kWh/m², with monthly values ranging from 4.91 kWh/m² in January to 6.06 kWh/m² in September. This consistency indicates strong potential for continuous solar energy generation across the year. The average annual air temperature is 26.4°C, which remains relatively stable across months. However, the average humidity level of 80.2 percent can lead to corrosion of components and accumulation of dust on PV surfaces. These conditions require robust system design and scheduled maintenance to preserve efficiency. Annual rainfall reaches 1,558.80 mm, with peak rainfall above 250 mm in January and February, and a low of less than 50 mm in July and August. This variation affects maintenance strategies, particularly cleaning requirements for the PV panels. Atmospheric pressure remains stable at around 99.7 kPa. Average wind speeds reach 3.2 m/s annually, with a maximum of 3.9 m/s in August, indicating limited but possible use for hybrid solar-wind setups using low-speed wind turbines.

Energy Data

Based on the data analysis conducted during this study, a benchmark electricity production cost of $100/MWh was established. Photovoltaic (PV) systems without tracking generally fall within the $75–300/MWh range, making them competitive when well-managed. PV with tracking, while offering higher efficiency, incurs slightly higher costs. Technologies such as hydro and combined cycle gas turbines stand out with costs well below the benchmark, while diesel and coal-based systems remain costlier due to fuel and environmental considerations. PLTS Mataram is projected to generate 10 MW of solar power with a consistent export tariff of $0.057/kWh. This fixed tariff remains stable throughout the year, providing predictable cash flow for financial forecasting. Although the project does not benefit from cost-saving incentives, the consistency in tariff simplifies revenue modeling and sensitivity analysis. The lack of fluctuations allows for more accurate long-term planning, assuming policy conditions remain unchanged. The solar PV system uses a fixed tracking mode, which is cost-effective and suitable for regions with steady sunlight. Panels are tilted at 8 degrees, a slope appropriate for Mataram's near-equatorial location, maximizing sunlight capture during midday. The azimuth is set at 0 degrees, aligning panels along the north-south axis, optimal for installations in the southern hemisphere to achieve consistent daily exposure. The selected technology is monocrystalline silicon (Mono-si) with 20% efficiency, indicating a focus on performance and space optimization (Thompson & Evans, 2017; Garcia et al., 2019). The system does not employ bifacial panels, which are more costly and require specific reflective surfaces to be effective (Miller et al., 2021). Miscellaneous losses are accounted for at 15%, covering efficiency reductions from dust, shading, and wiring. These losses are factored into system design and can be mitigated through regular maintenance (Chen et al., 2020). The inverter in the system operates at 97% efficiency and has a capacity of 9700 kW, indicating its capability to handle large-scale solar power conversion. A 5% miscellaneous loss is expected, reflecting thermal and electrical inefficiencies. This realistic expectation supports accurate yield forecasting and reliable energy delivery planning.

Cost Analysis

The cost analysis covers the initial capital cost and annual operation and maintenance (O&M) cost, which are summarized in Table 5 and Table 6 respectively. These figures are essential for assessing the financial feasibility of the solar PV project in Mataram. The initial investment is estimated at USD 6,318,500. This includes key components such as a feasibility study (USD 100,000), which evaluates the technical and economic aspects of the system (Dobos, 2014; Zhou et al., 2017). A development cost of USD 1,000,000 covers project planning, permits, environmental studies, and legal preparation (Steinhilber et al., 2016). Engineering costs total USD 316,000, including the system's technical design and compliance standards (Bony et al., 2010). The power system, which includes transformers, mounting structures, and grid components, is budgeted at USD 1,500,000 (Breyer et al., 2010). The solar PV panels, representing the system's core, account for USD 3,000,000. Panel selection is based on efficiency and durability, impacting both initial outlay and long-term energy yield (Fu et al., 2018).

Inverter costs, including replacements, are estimated at USD 400,000. Inverters require periodic replacement due to their shorter life compared to panels (Jordan & Kurtz, 2013). Lastly, miscellaneous and balance of system (BoS) costs total USD 2,500, covering monitoring tools and wiring (Breyer et al., 2010).

For long-term performance, O&M costs are set at USD 250,000 per year, with USD 150,000 allocated to maintenance and USD 100,000 to insurance. Regular maintenance, including inspections and cleaning, ensures system reliability and efficiency (Zhang et al., 2018). Insurance safeguards against damage, theft, or natural disruptions, securing the system's financial sustainability (Wiser et al., 2016).

Emission Analysis

The emission analysis reveals the substantial environmental burden associated with fossil fuel-based electricity generation in Mataram. Currently, the energy mix is dominated by coal (60%), natural gas (22%), and oil (7%). As shown in Figure 1, coal and oil exhibit the highest CO_2 emission factors: 94.6 kg/GJ and 73.3 kg/GJ, respectively, while renewables such as solar and wind emit no direct greenhouse gases (Clark et al., 2014; Jacobson et al., 2017). Methane (CH_4) and nitrous oxide (N_2O), both with high global warming potential, further exacerbate the emissions from natural gas use (Alvarez et al., 2018; Saunois et al., 2020). The low efficiency of fossil fuel sources, especially coal at 33.8%, intensifies greenhouse gas emissions due to energy losses during conversion (Paltsev et al., 2015). Transmission and distribution (T&D) losses across all energy types stand at 7%, highlighting inefficiencies within the grid. These losses, combined with the high-emission profile of fossil fuels, result in a total GHG emission factor of 0.845 tCO_2/MWh. Such conditions stress the urgency for transitioning to cleaner, renewable sources (IRENA, 2020; Gellings, 2017). In a comparative analysis of scenarios, the baseline fossil-based electricity system produces 11,612.7 tons of CO_2 annually. In contrast, the proposed solar panel system eliminates direct emissions, resulting in just 812.9 tons of GHG from T&D losses. This is visually captured in Figure 2, where a gross annual reduction of 10,799.8 tons of CO_2 is observed. Additionally, the proposed scenario opens revenue opportunities through GHG credit sales. With a carbon credit rate of $5 per ton over 10 years and a 2% annual escalation, the project generates approximately $53,945. This underscores the dual benefit of emission reduction and financial viability through clean energy investment (Wiser et al., 2016).

Financial Analysis

The financial assessment for the proposed project considers long-term sustainability, capital structure, and potential revenue. Several parameters influence the financial viability, including inflation (3%), discount rate (8%), reinvestment rate (6%), and a 30-year project lifespan. Petroleum costs are assumed constant. These general assumptions form the basis for calculating future revenues, costs, and tax liabilities The financing approach is shown in Figure 3, where the project is funded through 70% debt ($4.42 million) and 30% equity ($1.89 million), with debt serviced over 15 years at a 7% interest rate, requiring annual payments of $485,616. This financing structure, without grants or incentives, necessitates robust cash flow management to ensure financial stability. A 10% income tax rate applies to profits, and the project does not benefit from loss carryforward. A 5-year tax holiday provides early relief, but post-holiday operations must account for increasing tax liabilities. Depreciation uses the declining balance method with a 5% rate and a 100% depreciation basis. This allows higher tax deductions in the initial years, easing the early-stage cash burden. However, these benefits taper over time, requiring strong future revenue to sustain performance. In terms of income, Figure 4 shows that electricity exports are projected at 13,738 MWh per year, sold at $57/MWh, generating $783,063 annually. This amount escalates by 2% annually. Additional income of $53,945 is derived from GHG reduction credits at $5 per ton for the first 10 years, also escalating by 2%. Over 30 years, cumulative GHG reduction reaches 323,669 tCO_2. These two revenue streams—electricity sales and carbon credits—ensure both profitability and alignment with climate goals. The revenue model integrates well with environmental policy mechanisms such as carbon trading, making it adaptable to policy shifts and inflation.

Table 7 consolidates long-term outcomes. The project posts an NPV of $1,062,121, confirming financial viability. Annual life cycle savings are $94,345, while the GHG reduction cost is negative at -$8.74/$tCO_2$, suggesting that emissions mitigation is profitable due to carbon credit revenue. The energy production cost is estimated at $0.066/kWh, placing it competitively below many fossil-based generation options.As Figure 5 illustrates, the first year sees a steep negative cash flow (~-$1.5 million), covering initial capital outlays. Revenue begins recovering by the second year and continues growing. Around year 10, post-tax holiday, the revenue stabilizes and grows significantly. Cumulative cash flow becomes positive near year 15, signaling the break-even point. From year 16 onward, strong cash flows (~$500,000–800,000 annually) mark a phase of high profitability. This steady increase reflects efficient operations, maturing infrastructure, and increasing returns from carbon credits and electricity exports. Taxation becomes more relevant post-holiday, but depreciation and strategic planning mitigate the impact.

Sensitivity and Risk Analysis

NPV Sensitivity Analysis

Figure 6 shows the sensitivity analysis of Net Present Value (NPV) with respect to variations in Initial Cost and O&M Cost. In the base case, the Initial Cost is $6,318,500 and the O&M Cost is $250,000. A 10% change in Initial Cost is equivalent to $631,850, while a 10%

variation in O&M Cost equals $25,000 In the first scheme, where the O&M Cost is reduced by 20%, the NPV outcomes under initial cost variations of -20%, -10%, 0%, +10%, and +20% are $2,959,966, $2,374,211, $1,788,455, $1,202,700, and $616,944 respectively. For the second scheme with a 10% decrease in O&M Cost, the resulting NPVs are $2,596,799, $2,001,044, $1,425,288, $839,532, and $253,777. When the O&M Cost remains unchanged in the third scheme, the NPVs decrease from $2,233,632 to $-109,391. In the fourth scheme (O&M +10%), the values are $1,870,464, $1,284,709, $698,953, $113,198, and $-472,558. The fifth scheme, with a 20% increase in O&M Cost, shows more drastic declines in NPV: $1,507,297, $921,541, $335,786, $-249,970, and $-835,725. These results indicate that increases in both cost variables can push NPV below zero.

Sensitivity analysis

Perform analysis on	Net Present Value (NPV)	
Sensitivity range	20%	
Threshold	0	$

- Remove analysis

Initial costs		O&M $				
$		200.000	225.000	250.000	275.000	300.000
		-20,0%	-10,0%	0,0%	10,0%	20,0%
5.054.800	-20,0%	2.959.966	2.596.799	2.233.632	1.870.464	1.507.297
5.686.650	-10,0%	2.374.211	2.011.044	1.647.876	1.284.709	921.541
6.318.500	0,0%	1.788.455	1.425.288	**1.062.121**	698.953	335.786
6.950.350	10,0%	1.202.700	839.532	476.365	113.198	-249.970
7.582.200	20,0%	616.944	253.777	-109.391	-472.558	-835.725

- Remove analysis

Electricity export rate		Electricity exported to grid MWh				
$/MWh		10.990,36	12.364,15	13.737,95	15.111,74	16.485,54
		-20,0%	-10,0%	0,0%	10,0%	20,0%
45,60	-20,0%	-2.627.289	-1.794.583	-972.699	-158.186	655.352
48,45	-15,0%	-2.209.102	-1.331.214	-463.262	401.121	1.265.505
51,30	-10,0%	-1.794.583	-870.451	45.199	960.428	1.875.658
54,15	-5,0%	-1.382.601	-412.416	553.660	1.519.735	2.485.811
57,00	0,0%	-972.699	45.199	**1.062.121**	2.079.042	3.095.964
59,85	5,0%	-564.954	502.814	1.570.582	2.638.349	3.706.117
62,70	10,0%	-158.186	960.428	2.079.042	3.197.656	4.316.271
65,55	15,0%	248.583	1.418.043	2.587.503	3.756.964	4.926.424
68,40	20,0%	655.352	1.875.658	3.095.964	4.316.271	5.536.496

Figure 1. Sensitivity Analysis performing on NPV

Source: The results of the sensitivity analysis simulation using RETScreen are based on input data from NASA SSE and the author's calculations (2025)

Figure 1 also examines NPV sensitivity to electricity export parameters. The base case assumes an export rate of $57/MWh and an electricity export volume of 13,737.95 MWh. A ±10% change results in $5.7/MWh and 1,373.8 MWh variation, respectively.

In the first scheme, with a 20% reduction in electricity exported to the grid, and export rate varied between -20% and +20%, the NPVs are $-2,627,289, $-1,794,583, $-972,699, $-158,186, and $655,352. In the second scheme, with a 10% reduction in exported electricity, NPVs improve slightly: $-1,794,583, $-870,451, $45,199, $960,428, and $1,875,658. In the third scheme, where the export volume is constant, the NPV ranges from $-972,699 to $3,095,964. The fourth and fifth schemes, with 10% and 20% increases in exported electricity respectively, yield NPVs from $-152,186 up to $4,316,271 and from $655,352 to $5,536,496.

Equity Payback Sensitivity Analysis

Figure 2 presents Equity Payback analysis under the same cost variation scenarios. In the base case, equity payback is 14 years. Under Scheme 1 (O&M -20%), the results for the five levels of Initial Cost are 5.4, 7.2, 9.6, 14.1, and 16.1 years. Scheme 2 (O&M -10%) yields values of 6, 8.1, 11.4, 15.5, and 16.8 years. Scheme 3, with no change in O&M, results in 6.6, 9.2, 14, 16.2, and 17.6 years. Scheme 4 (O&M +10%) results are 7.5, 10.8, 15.5, 17, and 18.5 years. Scheme 5 (O&M +20%) produces longer payback periods: 8.6, 13.8, 16.4, 18, and 19.5 years.

Sensitivity analysis

Perform analysis on: Equity payback
Sensitivity range: 20%
Threshold: 30 yr

Initial costs ($)		O&M ($) 200.000	225.000	250.000	275.000	300.000
		-20,0%	-10,0%	0,0%	10,0%	20,0%
5.054.800	-20,0%	5,4	6,0	6,6	7,5	8,6
5.686.650	-10,0%	7,2	8,1	9,2	10,8	13,8
6.318.500	0,0%	9,6	11,4	**14,0**	15,5	16,4
6.950.350	10,0%	14,1	15,5	16,2	17,0	18,0
7.582.200	20,0%	16,1	16,8	17,6	18,5	19,5

Electricity export rate ($/MWh)		Electricity exported to grid (MWh) 10.990,36	12.364,15	13.737,95	15.111,74	16.485,54
		-20,0%	-10,0%	0,0%	10,0%	20,0%
45,60	-20,0%	> project	24,7	20,6	17,8	15,7
51,30	-10,0%	24,7	20,2	17,2	15,0	9,2
57,00	0,0%	20,6	17,2	**14,0**	8,6	6,4
62,70	10,0%	17,8	15,0	8,6	6,2	4,8
68,40	20,0%	15,7	9,2	6,4	4,8	3,9

Figure 2. Sensitivity Analysis performing on Equity Payback

Source: Project financial data processing with assumptions from IRENA (2019) and the Indonesian Ministry of Energy and Mineral Resources (2021), processed by the author (2025)

Electricity export variations in Figure 7 demonstrate similar patterns. Under a 20% reduction in exported electricity, equity payback durations are above project life when the export rate is -20%, while improving to 15.7 years at +20% export rate. In Scheme 2 (exported energy -10%), payback ranges from 24.7 to 9.2 years. Scheme 3 (no change in export volume) shows payback periods of 20.6, 17.2, 14, 8.6, and 6.4 years. In Schemes 4 and 5, with 10% and 20% export increases, payback shortens further to as low as 3.9 years in favorable conditions.

Energy Production Cost Sensitivity Analysis

Figure 8 explores the sensitivity of Energy Production Cost (or Levelized Cost of Electricity—LCOE), set at a base of 65.53 $/MWh. In Scheme 1 (O&M -20%), the LCOE values are 52.42, 56.47, 60.51, 64.56, and 68.6 $/MWh. Scheme 2 (O&M -10%) results are 54.93, 58.97, 63.02, 67.06, and 71.11 $/MWh. Scheme 3 (no change in O&M) yields 57.44, 61.48, 65.53, 69.57, and 73.62 $/MWh. Scheme 4 (O&M +10%) gives 59.94, 63.99, 68.03, 72.08, and 76.12 $/MWh. In Scheme 5 (O&M +20%), results are 62.45, 66.50, 70.54, 74.59, and 78.63 $/MWh.

Sensitivity analysis

Perform analysis on	Energy production cost	
Sensitivity range	20%	
Threshold	100	$/MWh

- Remove analysis

Initial costs		O&M ($)				
$		200.000	225.000	250.000	275.000	300.000
		-20,0%	-10,0%	0,0%	10,0%	20,0%
5.054.800	-20,0%	52,42	54,93	57,44	59,94	62,45
5.686.650	-10,0%	56,47	58,97	61,48	63,99	66,50
6.318.500	0,0%	60,51	63,02	**65,53**	68,03	70,54
6.950.350	10,0%	64,56	67,06	69,57	72,08	74,59
7.582.200	20,0%	68,60	71,11	73,62	76,12	78,63

- Remove analysis

Electricity export rate		Electricity exported to grid (MWh)				
$/MWh		10.990,36	12.364,15	13.737,95	15.111,74	16.485,54
		-20,0%	-10,0%	0,0%	10,0%	20,0%
45,60	-20,0%	81,91	72,81	65,53	59,57	54,61
51,30	-10,0%	81,91	72,81	65,53	59,57	54,61
57,00	0,0%	81,91	72,81	**65,53**	59,57	54,61
62,70	10,0%	81,91	72,81	65,53	59,57	54,61
68,40	20,0%	81,91	72,81	65,53	59,57	54,61

Figure 3. Sensitivity Analysis performing on Energy Production Cost

Source: LCOE calculation using the RETScreen model with technical parameters from Pratiwi et al. (2021) and NASA SSE meteorological data, processed by the author (2025)

The second part of Figure 3 reflects export variation impact. With a 20% reduction in exported electricity, the cost rises to 81.91 $/MWh. At a 10% export drop, the cost is 72.81 $/MWh. In the base case, cost remains at 65.53 $/MWh, while export increases of 10% and 20% result in reduced costs of 59.57 $/MWh and 54.61 $/MWh respectively.

NPV Risk Analysis

Figure 4 details a Monte Carlo simulation for NPV risk, based on 500 iterations. Parameters include Initial Cost ($6,318,500 ±25%), O&M Cost ($250,000 ±25%), Exported Energy (13,737.95 MWh ±25%), Export Rate ($57/MWh ±25%), Net GHG Reduction (107,890 tCO_2 ±25%), Credit Rate ($5.00/$tCO_2$ ±25%), Debt Ratio (70% ±25%), Interest Rate (7.00% ±25%), and Debt Term (15 years ±25%).

Risk analysis

Perform analysis on	Net Present Value (NPV)
Number of combinations	500
Random seed	Yes

Parameter	Unit	Value	Range (+/-)	Minimum	Maximum
Initial costs	$	6.318.500	25%	4.738.875	7.898.125
O&M	$	250.000	25%	187.500	312.500
Electricity exported to grid	MWh	13.737,95	25%	10.303,46	17.172,44
Electricity export rate	$/MWh	57,00	25%	42,75	71,25
Net GHG reduction - credit duration	tCO_2	107.890	25%	80.917	134.862
GHG reduction credit rate	$/$tCO_2$	5,00	25%	3,75	6,25
Debt ratio	%	70,0%	25%	52,5%	87,5%
Debt interest rate	%	7,00%	25%	5,25%	8,75%
Debt term	yr	15	25%	11	19

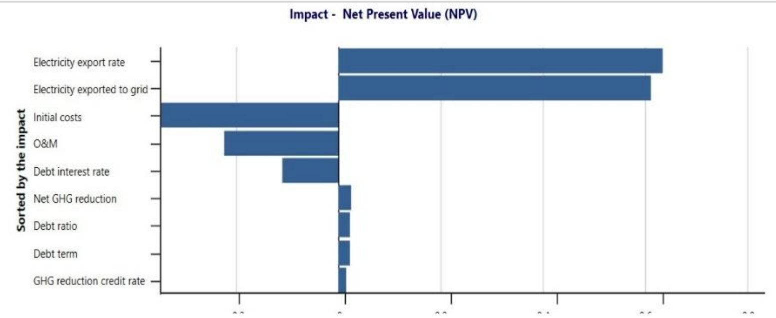

Figure 4. Risk Analysis performing on NPV

Source: Simulation based on 500 iterations with variables from the IRENA (2019) and World Bank (2021) studies, visualized using RETScreen by the authors (2025)

Among all variables, Electricity Export Rate and Exported Grid Energy have the greatest influence on NPV, as seen in the bar graph. Initial Cost and O&M Costs also contribute significantly, while GHG Credit Rate, Debt Ratio, and Debt Term have the least influence.

NPV Distribution Risk

As shown in Figure 10, the simulation's NPV distribution is centered around a median of $1,022,729. With a 90% confidence level, the NPV is expected to fall between -$1,328,184 and $3,346,381. The histogram shows a concentration of scenarios in the $1,359,465 to $1,822,830 range.

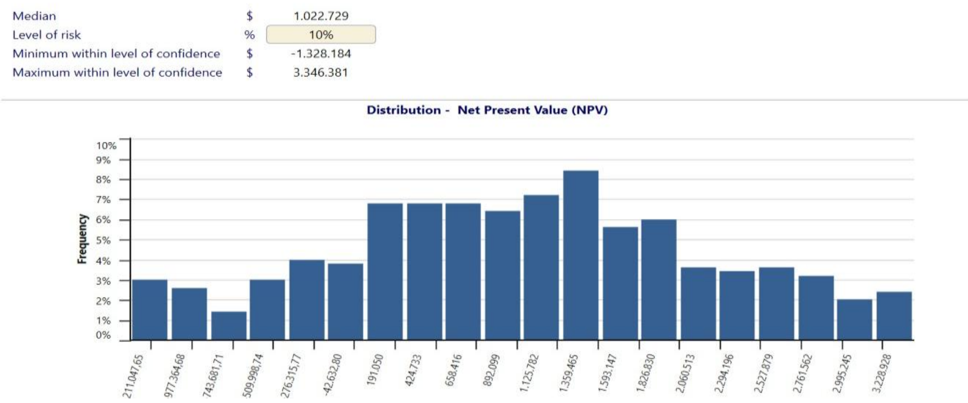

Figure 5. Risk Analysis performing Distribution on NPV

Source: Probability distribution results from Monte Carlo simulations, referring to the financial scenario of Bazilian et al. (2016), processed by the author (2025)

While some scenarios yield negative NPVs, the majority remain positive, confirming robust financial potential with appropriate risk mitigation.

Equity Payback Risk Analysis

Figure 6 presents the equity payback period distribution. The median is 14.1 years, with a 90% confidence interval between 5.8 and 21.8 years. Most scenarios fall between 9 and 17 years, with peak frequency near 15.8 years.

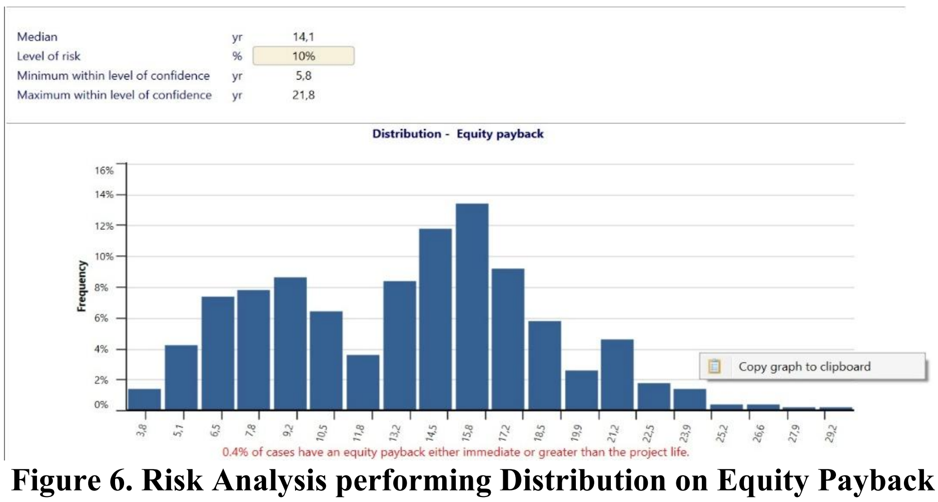

Figure 6. Risk Analysis performing Distribution on Equity Payback

Source: The payback period analysis is based on the financing model of 70% debt (assuming an interest rate of 7%), referring to Perea et al. (2019), processed by the author (2025)

Although some extreme cases show durations as short as 3.8 years or as long as 29.2 years, they are rare.

Energy Production Risk Analysis

As shown in Figure 7, the risk distribution of energy production cost is centered around a median of 65.46 \$/MWh. The 90% confidence interval ranges from 55.86 to 78.45 \$/MWh.

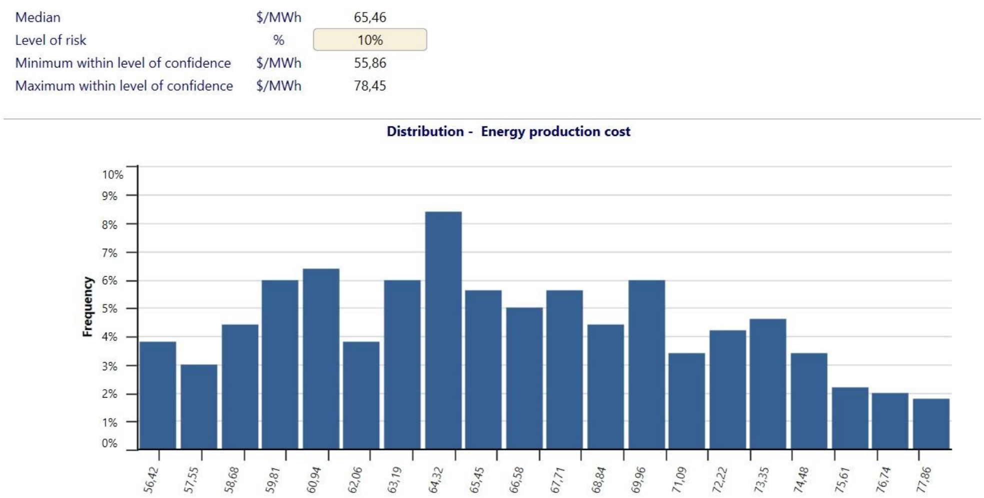

Figure 7. Risk Analysis performing Distribution on Energy Production

Source: Comparison of LCOE with Kost et al. (2018) references for utility-scale PV systems, processed by the author (2025)

The most frequent outcomes fall near 64.32 \$/MWh. The histogram indicates a symmetrical and narrow distribution, suggesting moderate volatility in cost and confirming the base case assumptions.

Conclusion

This study concluded that solar panel implementation in Mataram City demonstrated strong potential for economic feasibility, technical suitability, and significant carbon emission reductions. With an average solar radiation of 5.40 kWh/m²/day and the use of monocrystalline panels, the project showed long-term viability, reflected in a positive NPV of \$1,062,121, an IRR of 11.3%, an LCOE of \$65.53/MWh, and a 14-year payback period. The installation cost totaled \$6,318,500 with annual operating expenses of \$250,000, and the project was estimated to reduce GHG emissions by 323,669 tCO_2 over 30 years, achieving financial gains through carbon credits. Although sensitive to cost and electricity export price fluctuations, risk analysis indicated the project's resilience, endorsing it as a sustainable investment for Mataram and similar Indonesian cities. The study recommends project implementation with ongoing monitoring, optimization of electricity export rates, stakeholder engagement, and continued policy advocacy by local government to enhance feasibility. Future research should explore detailed socio-economic impacts on local communities, the integration of emerging storage technologies, and long-term grid stability to ensure sustainable scaling of solar energy in similar urban contexts.

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