

Simulation of Solar Panel Design as an Energy Source for Catfish Ponds

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Abstract: The increasing demand for sustainable energy solutions has driven the adoption of solar photovoltaic (PV) systems in various industries, including aquaculture. This study designs and simulates a solar power system for small-scale catfish (Lele) pond operations using the System Advisor Model (SAM). The methodology includes assessing energy requirements, selecting system components, conducting simulations, and performing an economic feasibility analysis. The results indicate that the designed 12-panel, 3-battery solar system effectively meets the pond's daily energy demand while ensuring continuous operation during low sunlight conditions. The SAM simulation confirms stable electricity generation throughout the year, with seasonal variations minimally affecting efficiency. The economic analysis reveals that PLTS costs Rp. 150,365 per month, compared to Rp. 151,620 for PLN electricity, showing small but valuable long-term savings. Despite the high initial investment, solar power offers price stability, energy independence, and reduced reliance on fossil fuels. This study demonstrates that solar energy is a viable, cost-effective, and sustainable alternative for aquaculture operations. Future research should focus on optimizing system efficiency and integrating hybrid energy solutions to further enhance performance and financial benefits.

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INTRODUCTION

Aquaculture plays a crucial role in global food security, but its energy-intensive operations lead to high costs and environmental concerns. Traditional energy sources, such as fossil fuels, contribute to carbon emissions and operational inefficiencies. As a sustainable alternative, solar energy has gained attention for its ability to power essential aquaculture components like aeration, water circulation, and monitoring systems. Recent studies demonstrate the effectiveness of solar energy in aquaculture applications. Research by

(Hakizimana et al., 2024), explored the use of solar panels in small and medium-sized farms, highlighting their potential to enhance energy efficiency and sustainability (Hakizimana et al., 2024) Meanwhile (Febriani et al., 2024), assessed the performance of off-grid solar photovoltaic systems for powering water pumps in aquaponics, demonstrating their reliability and cost-effectiveness (Febriani et al., 2024). Economic feasibility remains a key consideration in solar energy adoption. A study by (Jomsri & Prangchumpol, 2024) examined the economic and social benefits of aquavoltaics, finding that integrating solar panels with aquaculture enhances energy conservation and long-term profitability (Jomsri & Prangchumpol, 2024). Additionally, (Moustafa et al., 2024) investigated the potential of solar-enhanced photocatalytic decontamination for aquaculture wastewater treatment, demonstrating its ability to improve water quality while utilizing renewable energy (Moustafa et al., 2024). Considering these advancements, this study aims to design and simulate a solar panel system specifically for catfish (Lele) pond operations. By evaluating energy requirements, system efficiency, and financial feasibility, this research seeks to contribute to the development of sustainable aquaculture practices through solar energy integration.

METHOD

This study aims to design and simulate a solar panel system for catfish (Lele) pond operations using the System Advisor Model (SAM). SAM, developed by the National Renewable Energy Laboratory (NREL), enables detailed performance and financial modeling of renewable energy systems. The methodology consists of five key stages:

Location Determination in SAM

The study location is set directly in SAM's "Location and Resource" module, which automatically retrieves meteorological data based on geographical coordinates. Sungailiat, Bangka Regency is selected within SAM, and the software imports real-time and historical weather data from NASA, NREL, or other global databases. The solar resource data retrieved in SAM includes Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), average annual temperature, monthly temperature variations, wind speed, and humidity, which may affect system performance (AlFaraj et al., 2024). We analyze the electrical load requirements of the catfish pond by identifying key energy-consuming equipment, including water pumps, aerators, and lighting systems. We calculate the total daily energy, this calculation ensures that the solar system can support 24-hour pond operations. Previous studies validate that solar-powered water pumps in aquaponics provide reliable and energy-efficient solutions, minimizing operational costs.

Equipment and Materials Planning

The selection of equipment and materials is based on the estimated energy demand for the catfish ponds and the solar energy potential in Sungailiat, Bangka Regency. The components are chosen to ensure optimal efficiency, cost-effectiveness, and sustainability.

Previous research highlights that selecting the right PV modules, inverters, and energy storage solutions plays a crucial role in maximizing solar energy generation efficiency (Tundwal et al., 2024). We select system components based on energy demand and efficiency considerations. We choose monocrystalline solar panels due to their higher efficiency in tropical climates, and we integrate 12V 200Ah lithium-ion batteries to provide extended lifespan and faster charging capabilities. To ensure stable power conversion, we utilize a 2500W pure sine wave inverter, paired with an MPPT charge controller to maximize energy capture and minimize losses. This selection aligns with best practices in solar energy deployment for aquaculture, ensuring long-term reliability and performance.

Simulation Using System Advisor Model (SAM)

The performance of the solar energy system for the catfish (Lele) pond in Sungailiat, Bangka Regency is simulated using the System Advisor Model (SAM). SAM, developed by the National Renewable Energy Laboratory (NREL), allows for detailed technical and financial analysis of solar photovoltaic (PV) systems based on real-world meteorological data and system parameters. Studies show that simulation-based approaches using software like SAM or PVSyst improve the accuracy of solar system design and optimization (Moustafa et al., 2024). We simulate the solar power system using SAM, allowing us to predict annual and monthly energy production, system efficiency, and power losses. We assess battery performance, discharge cycles, and seasonal energy variations to determine the system's long-term sustainability. Previous research highlights that simulation-based approaches enhance solar system optimization by predicting performance across different environmental conditions, ensuring the feasibility of the designed system.

Cost Estimation and Comparison with PLN Electricity Consumption

The financial feasibility of the solar panel system is assessed by estimating the total installation cost and comparing the cost savings against using PLN electricity for running the catfish pond. Research indicates that while solar PV systems have high initial costs, they offer long-term savings and energy security, making them a sustainable choice for aquaculture (Jomsri & Prangchumpol, 2024). We perform a financial analysis by comparing the total cost of the solar system with PLN electricity expenses over a 10-year period. We calculate the investment cost, operational expenses, and return on investment (ROI) to determine whether solar power is a more cost-effective alternative. Research findings indicate that solar energy systems typically achieve ROI within 7–10 years, making them a viable long-term solution for aquaculture operations.

RESULTS AND DISCUSSION

This section presents the findings from the design and simulation of the solar energy system for small-scale catfish farming in Sungailiat, Bangka Regency. The results include energy demand calculations, system component selection, performance analysis using the System

Advisor Model (SAM), and financial feasibility comparisons with PLN electricity consumption

Energy Demand and Solar System Design

The energy demand of the catfish pond is calculated based on the electrical load requirements of the essential equipment, including lighting, water pumps, and aerators. The total daily energy consumption is determined using the formula:

$$E_{total} = P \times t$$

where:

E_{total} = daily energy consumption (Wh/day)

P = power rating of the equipment (W)

t = daily operating hours (h)

Using this formula, the calculated energy consumption for each component is presented in Table 1.

Table 1. Electrical Load Calculation for the Catfish Pond

Equipment	Quantity	Power (Watt)	Operating Time (h/day)	Total Energy/Day (Wh)
Lighting	2 Units	10 W	12 hours	240 Wh
Submersible pump	1 Unit	80 W	8 hours	640 Wh
Aerator	1 Units	80 W	24 hours	1920 Wh
Total Energy Demand				2800 Wh/day

Since solar energy generation is affected by system losses, the required solar system capacity is adjusted to compensate for efficiency losses (20%) (Hakizimana et al., 2024), calculated as:

$$P_{required} = \frac{E_{total}}{\eta}$$

where:

$P_{required}$ = required system power (W)

η = efficiency factor (0.8 or 80%)

Thus, the solar system is designed for a total output of 3500 Wh to ensure stable and reliable energy supply throughout the day.

Determining System Components

The selection of system components is based on the energy demand of the catfish pond and the solar energy potential in Sungailiat, Bangka Regency. This section determines the required solar panels, battery storage, inverter, and charge controller to ensure an efficient and reliable power supply.

1. Solar Panels (Photovoltaic Cells)

The number of solar panels required is determined using the formula:

$$N_{panels} = \frac{P_{required}}{P_{panel}}$$

where:

N_{panels} = number of solar panels

$P_{required}$ = total required system power (W)

P_{panel} = power output per panel (W)

Given that the required system power is 1,400 W and the selected SunPower SPR-E19-310-COM panel has a 310 Wp output:

$$N_{panels} = \frac{3500}{310} = 11.3 \approx 12 \text{ panels}$$

Thus, a total of 12 solar panels is needed to meet the energy demand.

2. Battery Storage

A battery system is required to store excess energy for use during nighttime and cloudy conditions (Babu & Basher, 2024). The number of batteries required is determined using:

$$N_{batteries} = \frac{E_{total}}{V_{battery} \times C_{battery}}$$

where:

$N_{batteries}$ = number of batteries

E_{total} = daily energy requirement (Wh)

$V_{battery}$ = battery voltage (V)

$C_{battery}$ = battery capacity (Ah)

Using a 12V 200Ah lithium-ion battery, the required number is:

$$N_{batteries} = \frac{3500}{12 \times 200} = 1.45 \approx 2 \text{ batteries}$$

Since batteries should not be fully discharged, a safety factor of 1.4 is applied:

$$N_{batteries} = 2 \times 1.4 = 2.8 \approx 3 \text{ batteries}$$

Thus, 3 batteries (12V 200Ah each) are required to ensure stable energy supply.

3. Inverter Selection

The inverter converts DC power from the solar panels into AC power required by the pond's electrical equipment (Nazir et al., 2024). The minimum inverter capacity is determined by:

$$P_{inverter} \geq P_{peak\ load}$$

where:

$P_{inverter}$ = inverter capacity

$P_{inverter}$ = highest simultaneous power demand

to ensure stability and accommodate future expansions, an inverter with at least 2,500 W capacity is selected. The Schuco USA SWR2500U (2500W, 240V) inverter meets this requirement (Nazir et al., 2024).

4. Solar Charge Controller (SCC)

The charge controller regulates power flow from the solar panels to the battery bank. The required charge controller rating is calculated using:

$$I_{SCC} = I_{SC} \times N_{panels}$$

where:

I_{SCC} = required charge controller current (A)

I_{SC} = short-circuit current of a panel (A)

N_{panels} = number of panels

Given that the short-circuit current (I_{sc}) of each panel is 8.95 A, the SCC rating is:

$$I_{SCC} = 8.95 \times 5 = 44.75 \text{ A}$$

a 60A MPPT (Maximum Power Point Tracking) charge controller is selected to ensure efficient energy transfer (Nazir et al., 2024).

Simulation Using System Advisor Model (SAM)

The performance of the solar energy system for small-scale catfish farming in Sungailiat,

Bangka Regency is analyzed using the System Advisor Model (SAM). SAM, developed by the National Renewable Energy Laboratory (NREL), provides a detailed technical and financial simulation based on real-world solar data and system specifications (Ayadi et al., 2024).

The study location is Kawasan Industri Air Katung, Sungailiat, Bangka Belitung, with geographical coordinates (-1.8448°S, 106.1270°E). The solar resource data is retrieved automatically in SAM from NASA/NREL weather databases.

Figure 1 presents two graphs illustrating the characteristics of the SunPower SPR-E19-310-COM solar module and the ABB PVI-3.0-OUTD-S-US-A [240V] inverter efficiency curve. The left graph shows the current-voltage (IV) curve of the solar panel, where the current remains stable as voltage increases until reaching the Maximum Power Point (MPP), beyond which the current drops sharply towards the Open Circuit Voltage (Voc). This indicates that the module generates maximum power at V_{mp} and I_{mp} . Meanwhile, the right graph displays the inverter efficiency curve, showing that efficiency increases as output power rises, stabilizing above 95% efficiency after around 20% output power. The three efficiency curves (Vdco, Mppt-low, Mppt-hi) represent slight variations based on Maximum Power Point Tracking (MPPT) settings, but overall, the inverter maintains high efficiency across a wide range of power levels. In summary, for optimal performance, the solar module should operate at its MPP, and the inverter should function within its high-efficiency range to maximize energy conversion.

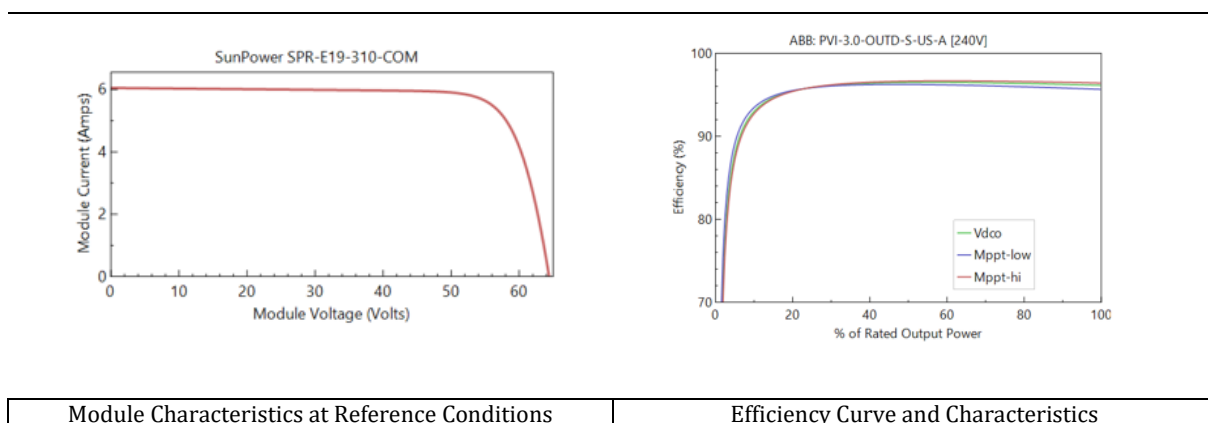


Figure 1. Module Characteristics at Reference Conditions and Efficiency Curve and Characteristics

For Monthly AC Energy in Year show on Figure 2. The x-axis represents the months from January to December, while the y-axis indicates the energy production in kWh. The chart reveals that January and March recorded the highest energy production, exceeding 420 kWh, while the lowest production occurred around June and July, where energy generation dropped to approximately 270–310 kWh. Energy production starts relatively high at the beginning of the year, declines in the middle months, and then recovers towards the end of the year, showing a seasonal variation likely influenced by solar irradiance changes, weather conditions, or system efficiency fluctuations throughout the year.

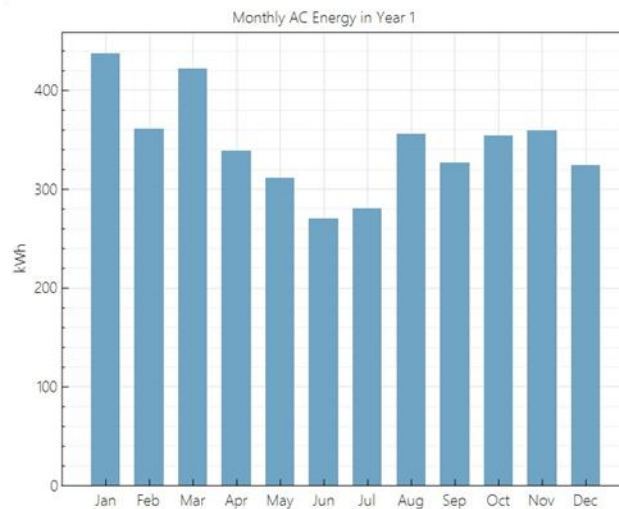


Figure 2. Monthly AC Energy in Year 1

Figure 3 shows how different factors cause energy loss in a solar power generation system, expressed as a percentage of the total generated energy. POA front-side shading reduces energy output the most, accounting for approximately 8% of the total loss, while POA front-side soiling follows with around 6%. Other factors, such as DC tracking, AC inverter efficiency, and AC inverter power consumption, each contribute between 1% and 4%. Additionally, DC wiring, AC wiring, and AC-connected battery losses also lower the system’s efficiency, though to a lesser extent. Understanding these losses helps optimize the solar power system by improving panel placement, reducing shading, keeping panels clean, and enhancing inverter performance.

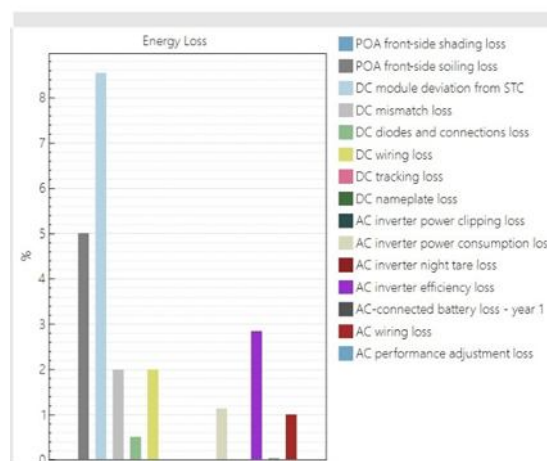


Figure 3. illustrates various sources of energy loss

Figure 4 showed represents the Electricity Net Generation over a 25-year period, measured in kWh. The data shows a gradual decline in net electricity generation over time, which

is expected due to factors such as solar panel degradation, efficiency loss in electrical components, and environmental factors that impact long-term performance. Initially, the system generates close to 4000 kWh per year, but this value slowly decreases as the years progress. This trend highlights the importance of maintenance, panel replacement, and system optimization to sustain energy output over time.

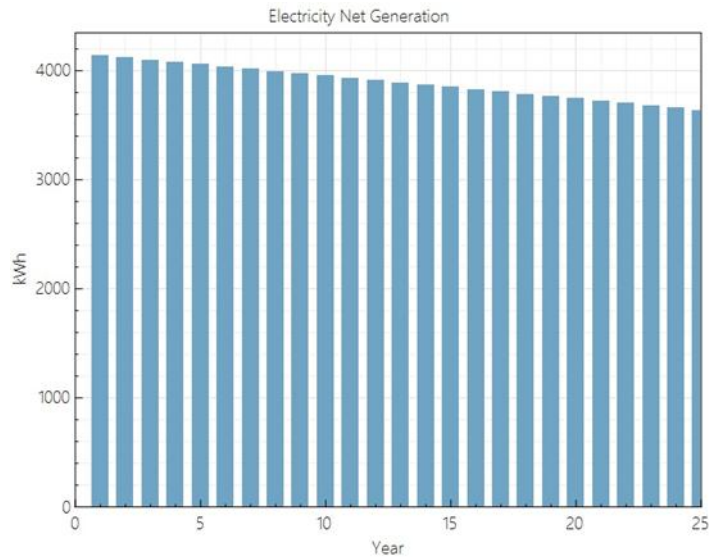


Figure 4. Electricity Net Generation

Explanation of Solar Power System Installation

To install a Solar Power System (PLTS) with a 4500-Watt load, the following equipment is required:

Table 2. Solar Panel System (PLTS) Instalation Cost

Equipment	Quantity	Unit Price (Rp)	Total Investment (Rp)
Solar Panel 310 WP	12 pcs	1529000	18348000
Battery 12V 200 Ah	3 pcs	4700000	14100000
DC to AC Inverter 300 Watt	1 pcs	3451700	3451700
Solar Charge Controller 60A	1 pcs	188000	188000
Total Investment Cost			36087700

Assuming this investment lasts for 20 years of operation, the monthly cost of the solar power system is Rp. 150,365.

Comparison with PLN Electricity Supply

Using PLN (State Electricity Company) electricity, the cost would be calculated based on the average tariff for household electricity in Indonesia.

For a 3500-Watt load, assuming an average monthly usage of 105 kWh, and a tariff of Rp. 1,444 per kWh, the monthly electricity bill would be:

$$105 \times 1444 = \text{Rp. } 151,620 \text{ per month}$$

Comparing the two options:

Solar Power System (PLTS): Rp. 150,365 per month

PLN Electricity: Rp. 151,620 per month

Based on the calculations, using a Solar Power System (PLTS) costs Rp. 150,365 per month, while PLN electricity costs Rp. 151,620 per month, resulting in a small savings of Rp. 1,255 per month with PLTS. Although the monthly difference is minimal, PLTS can provide greater long-term savings, especially if PLN electricity rates increase. PLN electricity prices fluctuate due to government policies and inflation, whereas PLTS offers more stable costs after installation. However, PLTS requires an initial investment for purchasing solar panels, inverters, batteries, and installation, which users can recover over time through lower electricity bills. PLTS also promotes sustainability by reducing dependence on fossil fuels and lowering carbon emissions. In terms of reliability, PLN provides a more consistent power supply through the national grid, while PLTS depends on sunlight and may require a battery system for continuous power. Despite the upfront investment, PLTS offers financial savings, price stability, and environmental benefits, making it a more economical and sustainable choice in the long run for those willing to invest.

Recent research in Indonesia highlights the increasing adoption and benefits of solar power systems. Household-scale Solar Home Systems (SHS) are becoming more widespread due to Indonesia's abundant sunlight and the growing demand for alternative energy solutions (Sundah et al., 2024). Various protection mechanisms for solar power systems, such as lightning protection, grounding systems, and overcurrent control, significantly improve system efficiency and safety, especially when combined with real-time monitoring using Arduino Uno, ESP 32, and PLC technology (Fadli et al., 2024). Additionally, the legal framework for rooftop solar power systems in Indonesia, particularly Minister of Energy and Mineral Resources Regulation No. 26 of 2021, facilitates the integration of solar power with the national electricity grid (PLN), ensuring regulatory support for renewable energy expansion (Jomsri & Prangchumpol, 2024). Although the initial investment in solar power is high, operational costs remain low, making solar energy a financially viable and sustainable long-term solution (Hediati & Azim, 2024). These findings emphasize the economic, environmental, and regulatory advantages of expanding solar energy adoption in Indonesia.

CONCLUSION

This study designs and simulates a solar power system for small-scale catfish pond

operations using the System Advisor Model (SAM). The results confirm that the 12-panel, 3-battery system successfully meets the pond's energy demands, ensuring continuous operation even during periods of low sunlight. The simulation demonstrates stable electricity generation throughout the year, with minor seasonal variations affecting efficiency. The economic analysis highlights that although the initial investment in solar power is high, the system lowers long-term electricity costs compared to PLN. Over 20 years, the PLTS system costs Rp. 150,365 per month, slightly less than PLN electricity costs of Rp. 151,620 per month. While the monthly savings remain small, solar power provides long-term price stability and protects users from fluctuating PLN tariffs. Additionally, PLTS reduces carbon emissions and decreases reliance on fossil fuels, making it a more sustainable energy option. From a reliability perspective, PLN delivers a consistent electricity supply, but PLTS enhances energy independence and operates efficiently when integrated with battery storage. These findings emphasize that solar energy offers a viable, cost-effective, and environmentally friendly solution for aquaculture. Future studies should explore ways to optimize system efficiency and develop hybrid energy solutions to maximize performance and financial benefits.

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