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Original Research Paper

# Techno-Economic Analysis of Floating Solar PV on Reservoir Ash Pond in Coal-Fired Power Plants

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**Abstract**: The increasing global energy demand drives the development of efficient and sustainable renewable energy solutions. Floating Solar PV (FSPV) technology offers a viable solution by utilizing water surfaces such as reservoir ash ponds in coal-fired power plants without requiring additional land. This study aims to analyze the technical and economic aspects of an FSPV system with a capacity of 15.2 kWp using HelioScope and Homer Pro software, assuming Global Horizontal Irradiance (GHI) data from the National Solar Radiation Database. The analysis methods include annual energy production, Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and other economic metrics such as Return on Investment (ROI), Internal Rate of Return (IRR), and Simple Payback Period for various grid electricity price escalation scenarios. The results show that a 5% annual increase in grid electricity prices reduces the simple payback period from 18.2 years to 13 years, with an ROI increase to 6.3% and an IRR of 7.1%. This study concludes that the FSPV system not only supports the transition to clean energy but also offers greater financial benefits under scenarios of rising grid electricity prices.

**Keywords:** Ash Pond, Coal-Fired Power Plant, Floating Solar PV, Renewable Energy, Reservoir.

## 1. Introduction

The global energy demand continues to increase due to population growth and industrialization, making renewable energy a priority to mitigate the environmental impact of fossil-based power plants [1]. Floating Solar Photovoltaic (FSPV) technology offers an innovative solution by utilizing water bodies such as reservoirs without requiring extensive land [2]. FSPV holds significant potential to support global renewable energy targets while contributing to climate change mitigation [3]. Studies have shown that FSPV can enhance solar panel efficiency through the natural cooling effect of water, which reduces the operational temperature of the panels and increases energy output [4] [5]. Additionally, this technology can reduce water evaporation, providing conservation benefits in drought-prone areas [6]. Research conducted in several regions, such as Saudi Arabia, demonstrates that FSPV can replace fossil-based power plants and reduce dependency on energy imports [7]. Despite its potential, challenges such as environmental impacts on aquatic ecosystems, as well as corrosion and biofouling of materials, require special attention [8] [9]. Overcoming these barriers necessitates system designs tailored to local conditions, such as wind speed and water depth, to ensure the sustainability of this technology [10] [11].

The development of FSPV also provides additional benefits by reducing carbon emissions and lowering the operational costs of renewable energy plants [12]. By utilizing available water bodies, FSPV can serve as an efficient clean energy solution in areas with limited land availability [13]. Studies indicate that integrating FSPV with energy storage systems, such as Battery Energy Storage Systems (BESS), can improve efficiency and grid stability, particularly in remote areas [14] [15]. Furthermore, FSPV can enhance water quality by reducing surface warming and protecting water bodies from atmospheric pollution [3] [6]. High initial costs remain a significant barrier to the implementation of this technology, although its operational costs are lower in the long term [16] [17]. Some studies suggest that increasing production capacity and improving structural designs can help reduce installation costs and improve the scalability of this technology [1] [18]. With a comprehensive analysis of its technical efficiency and economic viability, FSPV can emerge as one of the key solutions for the transition to clean and sustainable energy in the future [19].

## 2. Literature Review

The coal power plant, located in Tanah Laut Regency, South Kalimantan, Indonesia, is geographically positioned at a latitude of -3.9271088 and a longitude of 115.1068497. This site serves as the center for a coal-fired power generation unit that uses coal as its primary fuel. The coal power plant spans a total area of 185 hectares, of which only 40 hectares are currently utilized, leaving approximately 145 hectares of unused land.

Figure 1 illustrates the reservoir ash pond at the coal power plant site, which presents significant potential for the installation of Floating Solar Photovoltaic (FSPV) systems without requiring additional land.


Figure 1. Floating Solar PV System on the Reservoir Ash Pond of a Coal-Fired Power Plant

This eliminates potential land-use conflicts in the surrounding industrial areas. Additionally, the water surface of the reservoir provides a natural cooling effect [4] [5], which enhances the operational efficiency of solar panels [20], while also reducing water evaporation [6], thereby supporting water resource conservation efforts. By utilizing existing infrastructure, the integration of FSPV into the reservoir ash pond not only optimizes renewable energy utilization but also supports the clean energy transition while mitigating the environmental impacts of fossil-based power plants. This makes the system an innovative and sustainable solution that aligns with global efforts to reduce carbon emissions and address climate change challenges.

## 3. Methodology

The office electricity load profile at the coal power plant, illustrated in Figure 2, indicates peak consumption during working hours, particularly between 9 AM and 3 PM, with an average daily consumption of 829 kWh and a peak load of 61.88 kW. The Floating Solar PV system connected to the power grid can effectively meet the majority of energy demands during daytime hours, reducing grid electricity consumption, lowering operational costs, and decreasing dependency on fossil-based energy. This integration provides an efficient and sustainable solution to meet office energy requirements in an environmentally friendly manner.

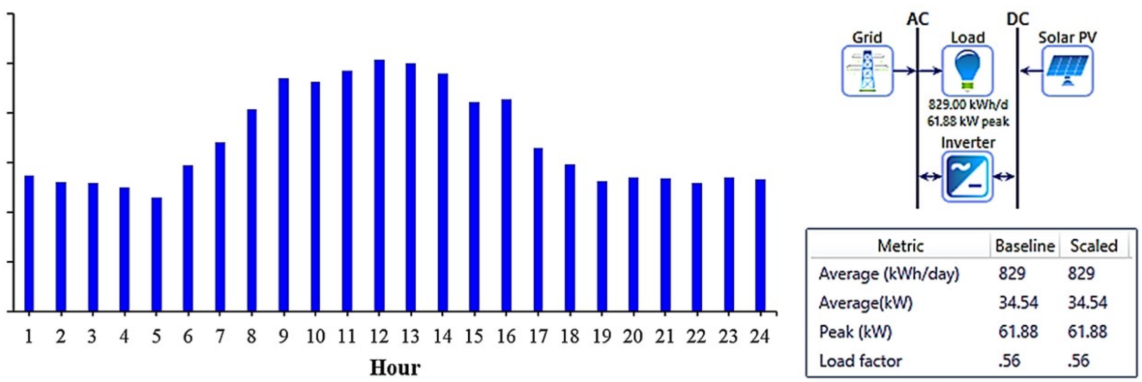


Figure 2. Office Load Profile of the Coal-Fired Power Plant

Based on the data presented in Figure 3, the Floating Solar PV system has an installed capacity of 15.2 kWp.

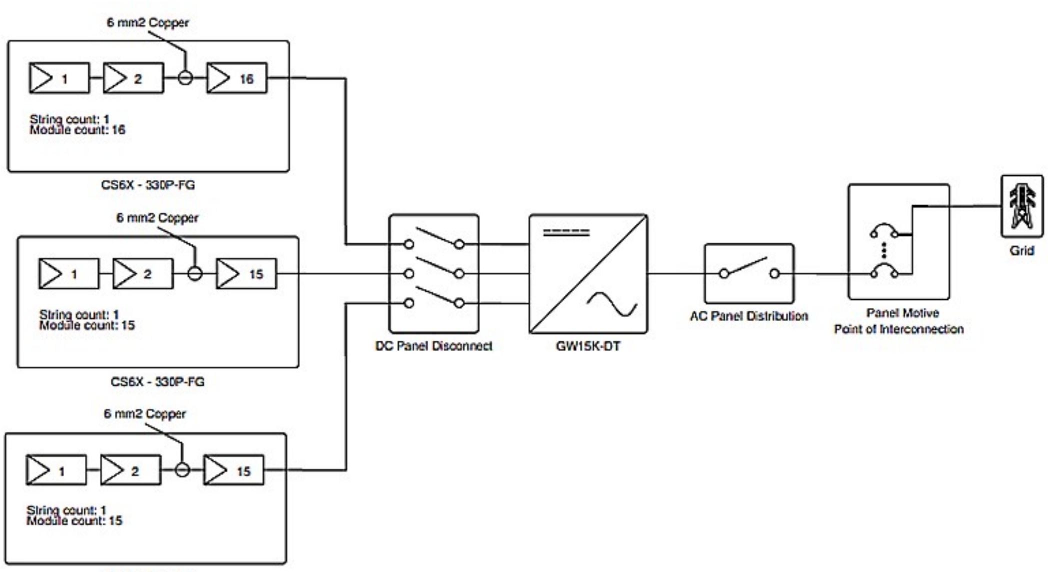


Figure 3. Schematic Diagram of the Floating Solar PV System

This system utilizes 46 solar panels, each with a capacity of 330 Wp, with detailed specifications provided in Table 1. These panels are divided into three strings, each consisting of 15 or 16 modules connected in series. The string configuration is optimized to ensure voltage and current align with the inverter's specifications. The system is equipped with a 15 kW inverter, as detailed in Table 1, designed to efficiently convert DC power to AC power. The solar panels are mounted with a fixed tilt at a 10-degree angle in a horizontal orientation to maximize sunlight absorption.

Table 1. PV Module and Inverter Characteristics

| Electrical Specification | CS6X-330P-FG |
|---|---|
| Rated Power ($P_{mpp}$) | 330 Wp |
| Rated Current ($I_{mpp}$) | 8.88 A |
| Rated Voltage ($V_{mpp}$) | 37.2 V |
| Short Circuit Current ($I_{sc}$) | 9.45 A |
| Open Circuit Voltage ($V_{oc}$) | 45.6 V |
| Panel Dimension (H/W/D) | 1971x995x24.1 mm |

| Electrical Specification | GW15K-SDT20 |
|---|---|
| Nominal Output Power | 15,000 W |
| Nominal Output Voltage | 400V 3L/N |
| Mppt Operating Voltage | 140-950 V |
| Max. Input Voltage | 1100 V |
| Max. Input Current | 30 A |
| Number of String per MPPT | 2 |

The technical and economic aspects were analyzed using Homer Pro and HelioScope software to compare the energy output generated. The solar radiation input for both HelioScope and Homer Pro simulations was standardized using data from the National Solar Radiation Database. The solar PV system is assumed to have a 25-year project lifespan, with a grid electricity price of $0.098/kWh and an annual grid price escalation rate of 5%. The nominal discount rate and expected inflation rate in Indonesia as of December 2024 are 6% and 1.55%, respectively. The floater's tilt angle is set at 10°, with an azimuth direction of 0°.

Table 2. Floating Solar PV System Component Costs

| Component | Quantity | Unit Price | Total Price |
|---|---|---|---|
| **Floating Solar PV Installation Costs** | | | |
| Solar PV Module ($) | 46 panel | 200 | 9,200 |
| Floater PV system 15 kWp ($) | 1 system | 6,920 | 6,920 |
| Floater Accessories (Mooring, metal clip, etc) ($) | 1 system | 400 | 400 |
| Service & Installation 15 kWp ($) | 1 system | 7,400 | 1,400 |
| *Total Cost of Floating Solar PV ($)* | | | *24,920* |
| **Inverter and Wiring Costs** | | | |
| Inverter ($) | 1 unit | 3,900 | 3,900 |
| Cabel &Accessories ($) | 1 sistem | 6,520 | 6,550 |
| DC & AC Switchgear ($) | 1 system | 1000 | 1000 |
| Grouding & Lighting Protection ($) | 1 system | 2,830 | 2,830 |
| *Total Cost of Inverter and Wiring ($)* | | | 14,280 |
| **Total Initial Capital ($)** | | | **39,200** |

Table 2 provides a detailed breakdown of the component costs for the Floating Solar PV system, divided into two main categories: the installation costs for the Floating Solar PV system and the costs for the inverter and wiring. In the first category, the costs include 46 Solar PV modules totaling $9,200, a 15 kWp floater system costing $6,920, floater accessories such as metal clips and other components costing $400, and installation services priced at $1,400, resulting in a total cost of $24,920. The second category includes an inverter priced at $3,900, cables and accessories costing $6,550, DC & AC switches priced at $1,000, and grounding and lightning protection systems costing $2,830, amounting to a total of $14,280. The total initial capital cost for this project is $39,200.

## 4. Finding and Discussion

Based on the comparative data, Figure 4 illustrates the energy simulation results of the Floating Solar PV system installed on a reservoir ash pond at a coal-fired power plant using HelioScope and Homer Pro software, with Solar GHI input derived from the National Solar Radiation Database. HelioScope (represented by red bars) estimated an annual total energy output of 21,241 kWh, while Homer Pro (green bars) estimated a higher energy output of 21,977 kWh. These results indicate that Homer Pro provides consistently higher predictions compared to HelioScope for nearly every month, with the most notable differences occurring in April, May, and July when solar irradiance reaches its peak.

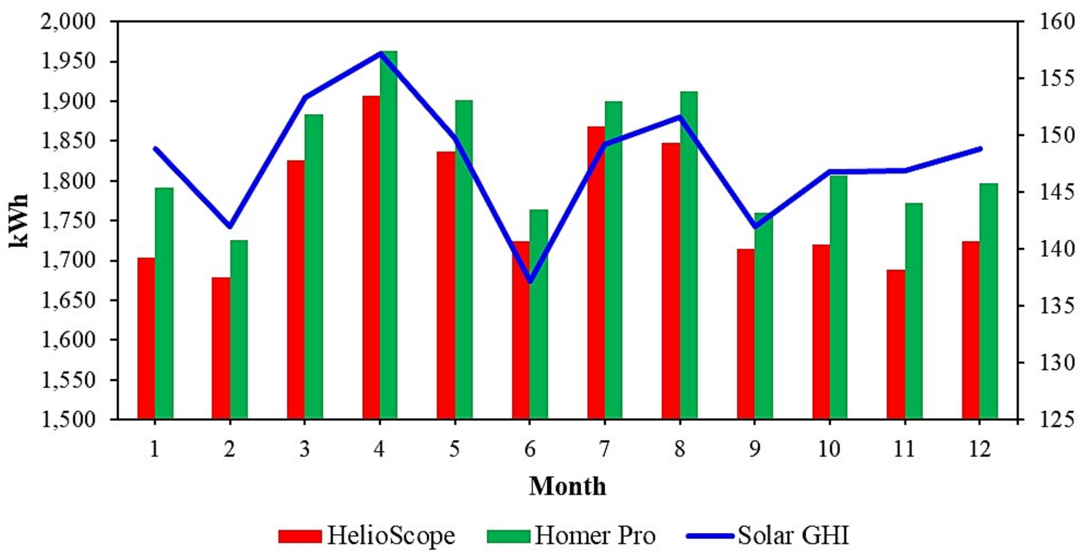


Figure 4. Comparison of Output Energy in Floating Solar PV Systems

The total annual energy difference between the two software simulations is 736 kWh, with Homer Pro offering a more optimistic estimate. On a monthly basis, the average energy difference ranges from 30 to 60 kWh, with the highest difference in April at 56 kWh and the lowest in February at 48 kWh. This discrepancy reflects the differing approaches of the two software programs, where HelioScope tends to be more conservative by accounting for system losses, while Homer Pro adopts a more optimistic perspective by focusing on the maximum potential of Solar PV. These insights provide valuable guidance for energy system planning, particularly in evaluating conservative and optimistic scenarios for Floating Solar PV performance.

Table 3 presents a summary of the costs for the Floating Solar PV system with a capacity of 15.2 kWp under various scenarios of grid electricity price escalation, ranging from 0% to 5% per year.

Table 3. Floating Solar PV System Cost Summary

| Grid Price | NPC | Initial Capital | O&M | LCOE |
|---|---|---|---|---|
| ↑ 5% | $750,365 | $39,200 | $47,380/yr | $0.165/kWh |
| ↑ 4% | $672,861 | $39,200 | $42,216/yr | $0.148/kWh |
| ↑ 3% | $605,904 | $39,200 | $37,755/yr | $0.133/kWh |
| ↑ 2% | $547,955 | $39,200 | $33,895/yr | $0.121/kWh |
| ↑ 1% | $497,704 | $39,200 | $30,547/yr | $0.109/kWh |
| 0 | $454,039 | $39,200 | $27,638/yr | $0.100/kWh |

With a 5% annual increase in grid prices, the Net Present Cost (NPC) reaches $750,365, while the Levelized Cost of Energy (LCOE) is $0.165/kWh. Conversely, under a scenario with no grid price escalation (0%), the NPC is lower at $454,039, with an LCOE of $0.100/kWh. Operation and Maintenance (O&M) costs also show an increasing trend corresponding to grid price escalation, ranging from $27,638 per year under the 0% scenario to $47,380 per year under the 5% scenario. This indicates that while higher grid price escalation increases the overall system costs, it also positively impacts the system's long-term economic viability.

Table 4 presents the economic metrics of the Floating Solar PV system, including Return on Investment (ROI), Internal Rate of Return (IRR), and Simple Payback. Both ROI and IRR show improvements with grid price escalation, with an ROI of 6.3% and an IRR of 7.1% under a 5% grid price increase scenario, compared to an ROI of 2.5% and an IRR of 2.5% under a flat grid price scenario.

Table 4. Economic Metrics of Floating Solar PV System

| Grid Price | ROI | IRR | Simple Payback |
|---|---|---|---|
| ↑ 5% | 6.3% | 7.1% | 13 year |
| ↑ 4% | 5.0% | 6.2% | 14 year |
| ↑ 3% | 3.8% | 5.2% | 15 year |
| ↑ 2% | 2.6% | 4.3% | 16 year |
| ↑ 1% | 1.3% | 3.4% | 17 year |
| 0 | 0 | 2.5% | 18 year |

The Simple Payback period also reflects better economic efficiency under grid price escalation, decreasing from 18 years with a flat grid price to just 13 years with a 5% annual grid price increase. This highlights that rising grid electricity prices significantly accelerate the return on investment for the Floating Solar PV system.

Overall, both tables demonstrate that the Floating Solar PV system becomes more economically viable and attractive with grid price escalation. Rising grid electricity prices provide greater incentives to transition to renewable energy, particularly through reduced Levelized Cost of Energy (LCOE) and shorter payback periods. This data offers valuable insights for renewable energy project planning, emphasizing the importance of incorporating external variables such as grid price escalation into economic analyses.

The comparison of the economic performance of the 15.2 kWp Floating Solar PV system demonstrates significant differences between the assumptions of a flat grid price and a 5% annual grid price escalation, as illustrated in Figures 5 and Figure 6.

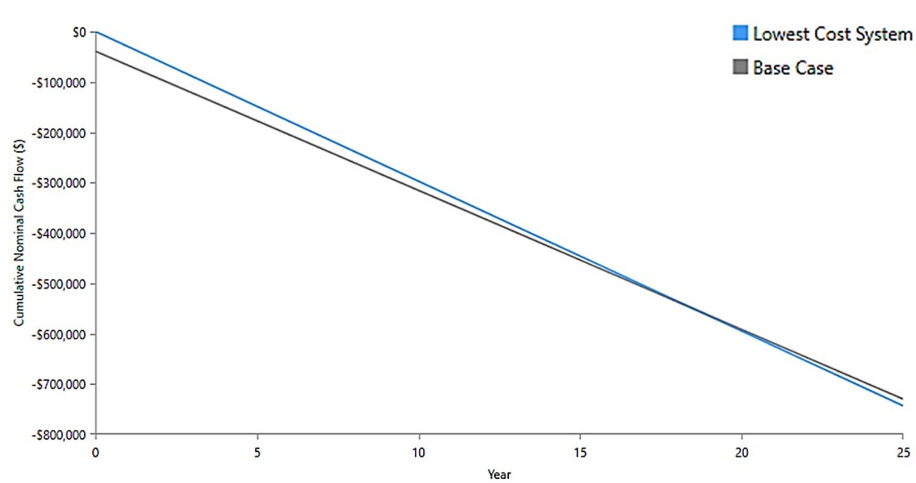


Figure 5. Economic Analysis of the Floating Solar PV System with a Flat Grid Price Scenario

Under the flat grid price assumption, the system has a simple payback period of 18.2 years, indicating a longer time required to break even. However, with a 5% annual grid price escalation, the simple payback period is reduced to 13 years. This reduction reflects the greater economic benefits of the Floating Solar PV system as grid electricity costs continue to rise. This condition suggests that investments in renewable energy systems, such as Floating Solar PV, become more financially attractive in the future if the trend of increasing grid electricity prices persists. It also underscores the importance of incorporating energy cost projections into the economic analysis of renewable energy projects to better evaluate their long-term feasibility and financial viability.

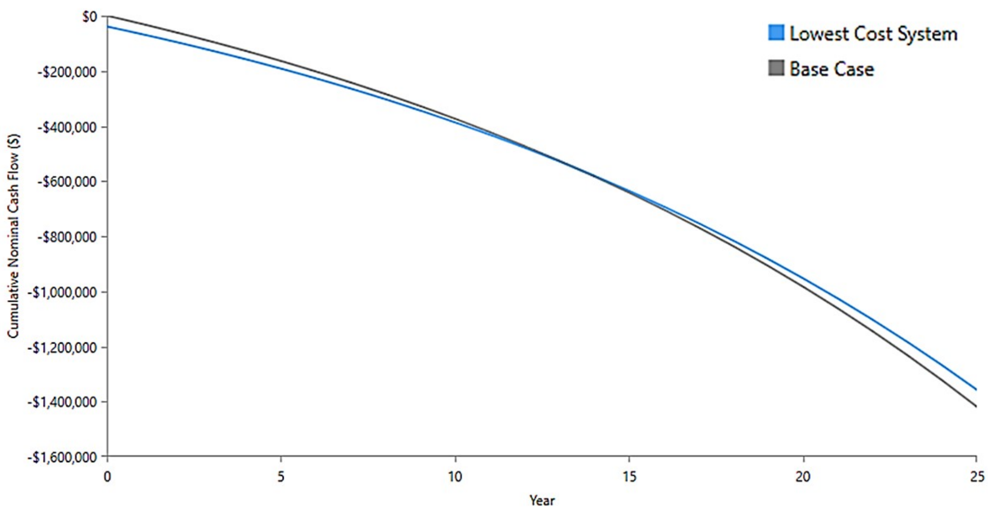


Figure 6. Economic Analysis of the Floating Solar PV System with a 5% Annual Grid Price Escalation Scenario

## 5. Conclusion

This study demonstrates that the Floating Solar PV system on a reservoir ash pond holds significant potential as a sustainable and economical renewable energy solution. With a capacity of 15.2 kWp, the system generates annual energy output ranging from 21,241 kWh to 21,977 kWh, depending on the simulation software used. The economic analysis indicates that under a scenario of a 5% annual grid price escalation, the system becomes more financially advantageous, with an ROI of 6.3%, an IRR of 7.1%, and a shorter simple payback period of 13 years compared to 18.2 years under a flat grid price scenario. This study emphasizes that increasing grid electricity prices can enhance the investment appeal of FSPV systems while accelerating the transition to clean energy. Future recommendations include developing modular designs to improve efficiency and reduce implementation costs across various locations.

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