Feasibility Study on Floating Solar Photovoltaic Systems: A Case Study with reference to Kanigiri Reservoir, Buchireddy Palem, SPS Nellore District, Andhra Pradesh

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***Abstract*—This study investigates the feasibility of Floating Solar Photovoltaic (FSPV) systems in the Nellore district, focusing on their energy potential, economic viability, and environmental benefits. FSPV systems, which deploy solar panels on water bodies, address land-use challenges posed by traditional ground-mounted systems while leveraging natural cooling effects to enhance efficiency and reduce water evaporation. In this work, feasibility studies on energy generation potential and cost-benefit analysis for deployment of FSPV in Nellore district, including the Kanigiri reservoir, have been carried out. It was estimated that Nellore district has aninstallation capacity for 3,519MW across 11,614 acres of usable water area. Thus, FSPV systems can generate 46,25,477.46 MWh annually, with competitive payback periods ranging from 12.5 to 16.9 years. By integrating FSPV technologies, the region can reduce its ecological footprint, conserve water resources, and contribute to India's renewable energy targets. A case study on the Kanigiri reservoir, with a projected annual energy output of 6,04,570.84 MWh, exemplifies the scalability and economic feasibility of FSPV systems. This research work indicates that FSPV systems can be a sustainable and economically viable alternative for advancing renewable energy solutions in water-abundant, semi-arid regions like Nellore.**

***Index Terms*—Floating solar photovoltaic systems, energy potential, economic analysis, environmental benefits, renewable energy**

I. INTRODUCTION

The global energy landscape is undergoing a paradigm shift due to the escalating demand for clean and renewable energy. With concerns over fossil fuel depletion and the adverse impacts of greenhouse gas emissions, [1] renewable energy sources have emerged as pivotal solutions. Among renewable energy sources, solar photovoltaic (PV) have gained prominence for their scalability, sustainability, and environmental compatibility [2]. However, traditional ground-mounted solar PV systems pose significant challenges, particularly in terms of land usage, which often conflicts with agricultural and urban demands [3].

Floating Solar Photovoltaics (FSPV) systems offer a promising alternative to address these challenges[2]. By deploying solar panels on the surface of water bodies, FSPV systems minimize land requirements while benefiting from natural cooling effects, which enhance energy efficiency and give higher yield compared with ground mounted solar panels. These systems also mitigate water evaporation rates and leverage underutilized water surfaces, making them a multifaceted solution for sustainable energy generation.

India's vast network of water bodies and favourable sunny days make it an ideal candidate for FSPV deployment. Within India, Nellore district in Andhra Pradesh presents unique advantages for adopting FSPV systems [4]. The district boasts a significant number of reservoirs and tanks, coupled with high solar irradiance, creating a conductive environment for renewable energy projects.

Nellore's water resources, including the Kanigiri reservoir and several large tanks, span over 19,000 hectares of surface area [4]. This extensive network of water bodies offers tremendous potential for integrating FSPV systems to meet local energy demands sustainably. Furthermore, FSPV deployment in these water bodies could reduce the evaporation of precious water resources, which is critical in semi-arid regions like Nellore.

The environmental and economic benefits of FSPV systems extend beyond energy generation. FSPV technologies minimize the ecological footprint by avoiding large-scale land alterations[5]. They also align with India's renewable energy targets and its commitments under the Paris Agreement, contributing to the reduction of carbon emissions and fostering energy security.

Despite the promising potential of FSPV systems, challenges remain. Environmental factors such as water salinity, material degradation, and resilience against cyclonic storms necessitate robust engineering solutions[6]. Additionally, the initial capital investment and long-term maintenance costs require a thorough economic feasibility analysis to ensure the financial viability of large-scale FSPV installations.

This study evaluates the technical, economic, and environmental feasibility of deploying FSPV systems in Nellore district. By estimating the energy generation potential, analyzing environmental impacts, and proposing an implementation roadmap, the study aims to provide a comprehensive framework for adopting FSPV technologies in the region.

II. OVERVIEW OF WATER BODIES IN NELLORE DISTRICT

Nellore district, located in the southeastern part of Andhra Pradesh, is endowed with an extensive network of water bodies, including reservoirs, lakes, and numerous irrigation tanks. These water bodies collectively span a vast surface area of approximately 116,140 acres, contributing significantly to the district's agricultural and ecological sustenance [7]. As highlighted in Table 1, major reservoirs such as Somasila, Sarvepalli, and Kanigiri form the backbone of the district's hydrological resources, with Kanigiri alone covering 15,181.824 acres. These reservoirs not only support irrigation and drinking water needs but also present untapped potential for renewable energy initiatives like floating solar photovoltaic systems. Smaller tanks and ponds scattered across the district further enhance its hydrological richness, enabling effective water resource management and supporting aquaculture activities under the guidance of local fisheries departments.

This extensive water network makes Nellore an ideal location for exploring sustainable energy solutions such as floating solar systems.The integration of floating solar projects, particularly in reservoirs like Kanigiri, highlights Nellore's capacity to transition towards a green energy future while maintaining its traditional reliance on water bodies for agriculture and fisheries, ensuring a balanced approach to sustainable development.

Table 1: Major Reservoirs and its Area

S.No	Name of Reservoir	Area in Acres	Reference
1	Somasila	52456	[8]
2	Sarvepalli	4351.431	[9]
3	Kanigiri	15181.82	[4]

III. METHODOLOGY FOR ESTIMATION OF ENERGY GENERATION POTENTIAL AND COST

Floating Solar Photovoltaic (FSPV) systems leverage the untapped potential of water bodies for renewable energy generation. To estimate the energy generation potential in Nellore district, the study considers the available water surface area, system efficiency, and local climatic conditions [4]. This revised section assumes a more conservative approach, considering only 10% of the total water surface area for FSPV deployment, ensuring minimal ecological impact.

3.1 Energy Generation Potential and Cost Estimation Methodology

The estimation methodology for evaluating the feasibility of floating solar photovoltaic systems involves a structured approach to assess energy potential, economic viability, and environmental benefits of utilising water bodies in Nellore district. The process starts with determining the usable water surface area for each reservoir, accounting for technical constraints such as system design and spacing requirements, with an allocation of 3.3 acres per megawatt of installed capacity[10]. The energy potential is calculated based on the installed capacity, a capacity factor of 15%, and annual operational hours, while also factoring in a 0.5% annual degradation in panel efficiency. Economic analysis includes evaluating capital expenditure (Capex), operational expenditure (Opex)[11], annual revenue at a tariff of ₹3.2 per kWh[12], and the resulting payback period. This comprehensive methodology ensures a reliable assessment of the technical and financial feasibility of implementing floating solar systems in the region.

Fig.1 illustrates the energy estimation process for deploying floating solar photovoltaic (FSPV) systems. The work flow begins with determining the usable water surface area of reservoirs, followed by calculating the installed capacity based on available area and system design. Subsequent steps involve estimating annual energy generation considering operational hours and capacity factors, factoring in panel efficiency degradation, and conducting an economic analysis covering capital expenditure (CAPEX), operational expenditure (OPEX), and revenue. This systematic methodology ensures a comprehensive assessment of energy potential and financial feasibility for FSPV deployment.

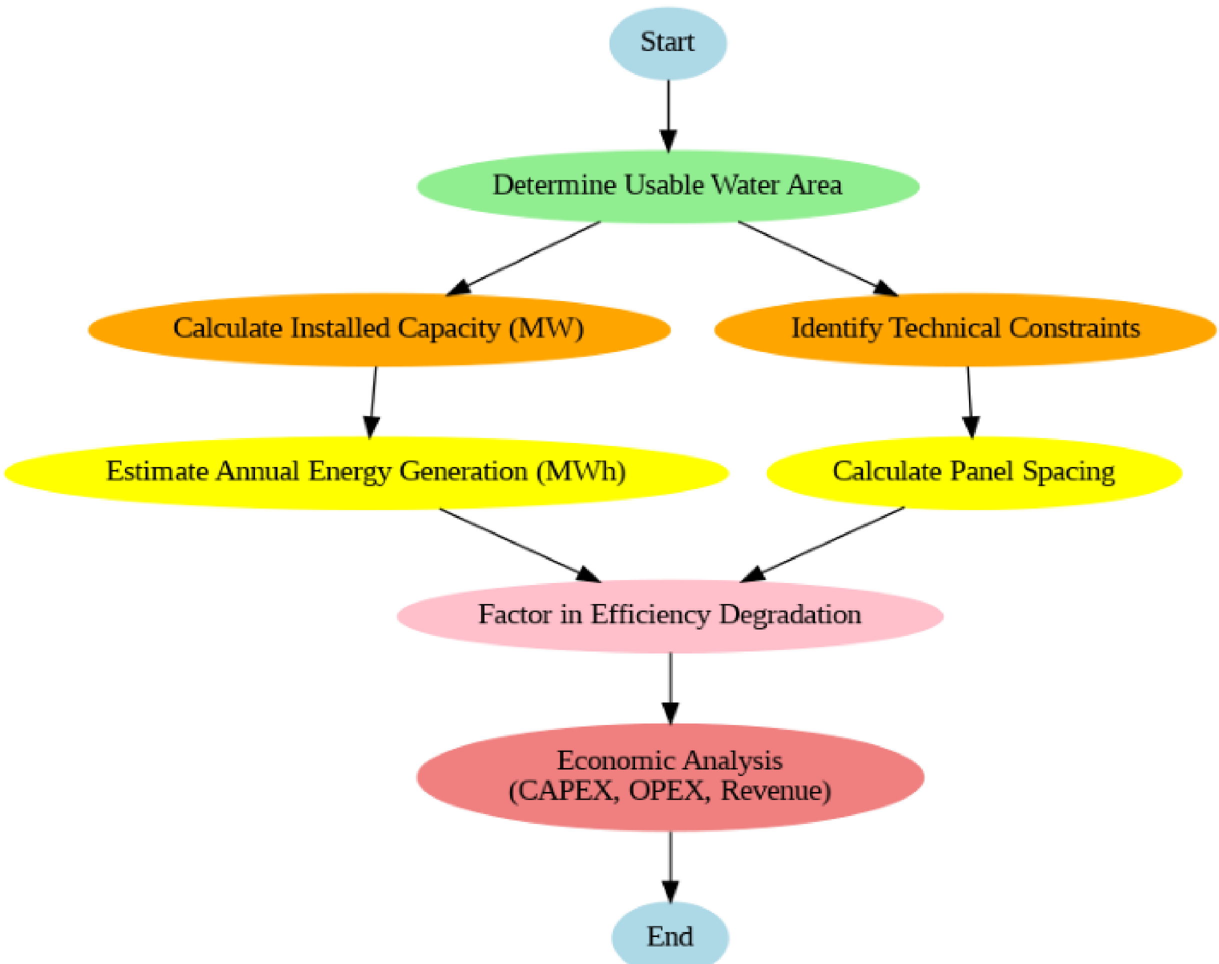

Fig. 1: Energy Estimation Process flowchart

3.2 Comparison between land mount and FSPV

The methodology for comparing the cost-effectiveness of floating solar photovoltaic (FSPV) systems and ground-mounted solar systems involves evaluating various financial and operational parameters. As shown in Figure 2, the process includes assessing key components like capital expenditure (CAPEX), operational expenditure (OPEX), and land acquisition costs, along with additional benefits such as evaporation savings and cooling efficiency improvements. This approach provides a clear framework to highlight the financial viability and environmental advantages of FSPV systems over traditional ground-mounted installations.

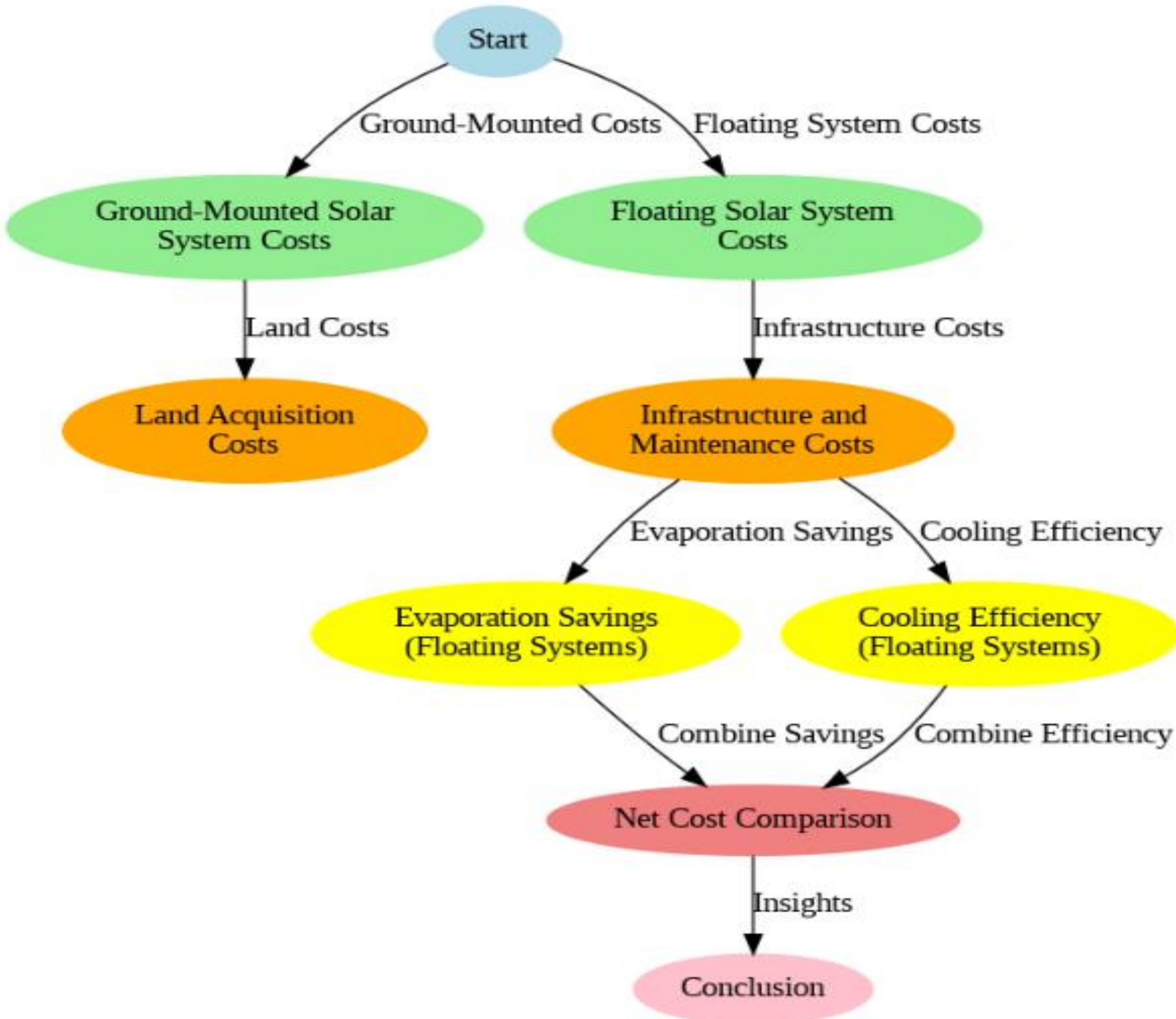

Fig. 2: Methodology for Cost-Effectiveness Comparison between floating solar and ground-mounted systems

IV. RESULTS AND DISCUSSION

In this section results of energy generation potential and economic cost benefit analysis of Nellore district and a case study of Kanigiri reservoir are presented. Also, a comparison between land and water mount solar FSPV is made.

4.1 Energy Generationpotential and Cost-Benefit Analysis of Water Bodies of Nellore District

The energy generation potential of water bodies in Nellore district demonstrates the region's capacity for large-scale deployment of Floating Solar Photovoltaic (FSPV) systems, offering a sustainable solution to meet growing energy demands

Table 2: Estimated Energy Generation Potential for Nellore District

Parameter	Value
Total Water Area (acres)	1,16,140
Usable Water Area (acres)	11,614
Installed Capacity (MW)	3,519.39
Capacity Factor (%)	15
Annual Operating Hours	8,760
Annual Energy Generation per MW (MWh)	1,314
Total Annual Energy Generation (MWh) (Year 1)	46,25,477.46

The energy generation potential of Nellore district's water bodies is summarised in Table 2, providing a comprehensive overview of the district's renewable energy prospects. With a total water area of 1,16,140 acres and a conservatively estimated usable area of 11,614 acres, the district has an installed capacity potential of 3,519.39 MW for Floating Solar Photovoltaic (FSPV) systems. Assuming a capacity factor of 15% and annual operating hours of 8,760, the total annual energy generation for the first year is calculated to be 46,25,477.46 MWh. This significant potential highlight Nellore's suitability for large-scale FSPV deployment, contributing to both regional energy demands and sustainability goals.Floating Solar Photovoltaic (FSPV) systems offer significant environmental benefits and present a compelling economic case for renewable energy deployment. This section delves into the environmental advantages and conducts a detailed economic analysis of implementing FSPV systems in Nellore district, Andhra Pradesh.

The cost-benefit analysis for renewable energy systems in Nellore district is detailed in Table 3, offering insights into the economic feasibility of deploying floating solar photovoltaic (FSPV) systems. For a single 1 MW system, the annual energy generation is estimated at 1,314 MWh, generating a revenue of ₹0.42 crore per year, with a CAPEX of ₹4–5 crore and an OPEX of ₹0.10–0.125 crore. Scaling to the district's full potential of 3,519.39 MW, the total annual revenue increases to ₹1,480.15 crore, with a payback period ranging from 12.5 to 16.9 years. This analysis underscores the financial viability of FSPV systems, highlighting their scalability and potential for substantial energy generation and economic returns in the region.

Table 3: Cost-Benefit Analysis for Nellore district

Parameter	1 MW System	Total Project (3,519.39 MW)
Installed Capacity (MW)	1	3,519.39
Annual Energy Generation (MWh)	1,314	46,25,477.46
Annual Revenue (₹ crore)	0.42	1,480.15
CAPEX (₹ crore)	4–5	14,077.56–17,596.95
OPEX (₹ crore)	0.10–0.125	351.94–439.92
Net Annual Revenue (₹ crore)	0.30–0.32	1,040.23–1,128.21
Payback Period (Years)	12.5–16.9	12.5–16.9

4.2. Energy Generation potential and Cost-Benefit Analysis of Kanigiri Reservoir

The Kanigiri Reservoir showcases significant potential for renewable energy generation through Floating Solar Photovoltaic (FSPV) systems. As presented in Table 4, the reservoir's total water area of 15,181.82 acres includes a conservatively estimated 1,518.18 acres (10%) usable for solar installations, supporting an installed capacity of 460.06 MW. At a capacity factor of 15%, and with annual operating hours of 8,760, the reservoir is capable of generating 6,04,570.84 MWh of clean energy annually. This highlights the feasibility of FSPV systems in optimising underutilised water surfaces, offering a sustainable and scalable solution to meet energy demands. Additionally, the deployment of these systems supports India's renewable energy targets while conserving water resources by mitigating evaporation, particularly in semi-arid regions like Nellore. The findings underline the dual advantage of energy production and environmental sustainability, positioning Kanigiri Reservoir as a benchmark for similar renewable energy projects.

Table 4: Estimated Energy Generation Potential for Kanigiri Reservoir

Parameter	Value
Total Water Area (acres)	15,181.82
Usable Water Area (acres)	1,518.18
Installed Capacity (MW)	460.06
Capacity Factor (%)	15

Annual Operating Hours	8,760
Annual Energy Generation per MW (MWh)	1,314
Total Annual Energy Generation (MWh)	6,04,570.84

The economic feasibility of deploying Floating Solar Photovoltaic (FSPV) systems in the Kanigiri Reservoir is comprehensively analysed in Table 5. For a 1 MW system, the annual energy generation is estimated at 1,314 MWh, with an annual revenue of ₹0.42 crore. The capital expenditure (CAPEX) ranges from ₹4 to ₹5 crore, while operational expenditure (OPEX) is estimated at ₹0.10 to ₹0.125 crore per year. These figures yield a net annual revenue of ₹0.30 to ₹0.32 crore, resulting in a payback period of 12.48 to 16.92 years. Scaling this to the reservoir's total capacity of 460.06 MW highlights a substantial revenue potential of ₹193.46 crore annually, with a CAPEX of ₹1,840.24 to ₹2,300.30 crore and an OPEX of ₹46.01 to ₹57.51 crore. This analysis underscores the financial viability of FSPV systems, demonstrating their ability to generate substantial economic returns while contributing to sustainable energy generation. The competitive payback period further emphasises the attractiveness of these systems as a long-term investment in renewable energy.

Table 5: Cost-Benefit Analysis for Kanigiri Reservoir

Parameter	1 MW System	Total Project (460.06 MW)
Installed Capacity (MW)	1 MW	460.06 MW
Annual Energy Generation (MWh)	1,314 MWh	6,04,570.84 MWh
Annual Revenue (₹ crore)	0.42	193.46
CAPEX (₹ crore)	4–5	1,840.24–2,300.30
OPEX (₹ crore)	0.10–0.125	46.01–57.51
Net Annual Revenue (₹ crore)	0.30–0.32	135.96–147.46
Payback Period (Years)	12.48–16.92	12.48–16.92

4.3 Comparative Analysis Between Land Mount and Floating Solar Photovoltaics

The comparative analysis evaluates the potential of the Kanigiri Reservoir for floating solar photovoltaic (FSPV) systems against traditional ground-mounted solar systems and other reservoirs in the region. Key aspects such as land utilisation, energy generation, operational efficiency, and environmental impact are considered to highlight the advantages and limitations of the FSPV approach.

1. Land Utilisation: Floating solar systems utilise the water surface area of reservoirs, avoiding the need for large-scale land acquisition, which is a major constraint for ground-mounted systems. For Kanigiri Reservoir, only 10% of the total water surface area is considered usable, equivalent to 1,518.18 acres, with an installed capacity of 460.06 MW. This efficient use of water bodies makes FSPV systems particularly suitable for regions like Nellore, where agricultural land is crucial for local livelihoods.

2. Energy Generation: The annual energy potential of the Kanigiri FSPV system, based on a capacity factor of 15%, is approximately 604,570.84 MWh. This is comparable to traditional ground-mounted systems in similar climatic conditions but offers additional benefits such as panel cooling due to water, which improves efficiency. Additionally, the Kanigiri system's scalability ensures energy output comparable to or exceeding smaller reservoirs like Sarvepalli (4,351 acres) and Saromasila (52,456 acres).

3. Operational Efficiency: Unlike ground-mounted systems, floating solar systems minimise issues such as dust accumulation and overheating, leading to reduced maintenance and operational costs. For Kanigiri, operational expenditure is limited to 2.5% of the capital expenditure annually, translating to ₹46.006–₹57.5075 crore for the entire project.

4. Environmental Impact: Floating systems significantly reduce land degradation and avoid the ecological disruption caused by land clearing. Additionally, the shade provided by solar panels reduces water evaporation, which is beneficial for reservoirs like Kanigiri in semi-arid regions. This dual utility enhances the environmental sustainability of FSPV systems.

5. Economic Viability: The payback period for Kanigiri's FSPV system ranges from 12.48 to 16.92 years, depending on the capital expenditure. This is

competitive with ground-mounted systems, particularly when factoring in the reduced land acquisition costs and additional water conservation benefits.

6. The cost-effectiveness comparison of floating solar photovoltaic (FSPV) systems and ground-mounted solar systems is summarised in Table 7, highlighting the advantages of FSPV systems. While the capital expenditure (CAPEX) for both systems is comparable, FSPV systems eliminate land acquisition costs, which range from ₹0.5 to ₹1 crore per MW for ground-mounted systems. Additionally, FSPV systems provide benefits such as 50% reduction in water evaporation and 10–15% higher panel efficiency due to cooling effects. With an energy yield of ~1,314 MWh per MW annually and a shorter payback period of 12.5–16.9 years compared to 15–18 years for ground-mounted systems, FSPV systems are both financially and environmentally advantageous. These features make FSPV systems a more sustainable and cost-effective solution for large-scale solar energy deployment.

Table 6: Cost-Effectiveness Comparison

Parameter	Floating Solar Systems	Ground-Mounted Solar Systems
Capital Expenditure (CAPEX)	₹4–5 crore per MW	₹4.5–6 , crore per MW
Land Acquisition Costs	₹0 (utilises water bodies)	₹0.5–1 crore per MW[13]
Infrastructure and Maintenance Costs	2.5% of CAPEX annually	3% of CAPEX annually
Evaporation Savings	50% reduction in water evaporation	No savings
Cooling Efficiency Benefits	10–15% higher panel efficiency	Standard efficiency
Energy Yield (MWh/MW)	~1,314 MWh/year	~1,200 MWh/year
Annual Revenue (₹/MW)	₹42.05 lakh	₹38.4 lakh
Payback Period (Years)	12.5–16.9	15–18
Environmental Impact	Minimal land disruption, water-saving	Significant land disruption

V. CONCLUSIONS

The study concludes that floating solar photovoltaic (FSPV) systems present a sustainable and economically viable solution for renewable energy generation in water-abundant regions like Nellore district. By utilizing the extensive network of reservoirs, including the Kanigiri reservoir, FSPV systems address land scarcity issues while leveraging natural cooling effects to enhance energy efficiency. The research demonstrates the potential of FSPV systems to generate 46,25,477.46 MWh annually across 11,614 acres of usable water area, with competitive payback periods ranging from 12.5 to 16.9 years. The Kanigiri reservoir alone offers an annual energy output of 604,570.84 MWh, showcasing the scalability of this technology. FSPV systems significantly reduce water evaporation, conserve land resources, and align with India's renewable energy goals under the Paris Agreement. The economic analysis indicates that FSPV systems offer a lower ecological footprint and competitive capital and operational expenditures compared to ground-mounted systems. Despite challenges like material degradation and resilience to environmental factors, the study highlights the feasibility of implementing FSPV systems in semi-arid regions. Integrating FSPV technologies can reduce reliance on fossil fuels, enhance energy security, and foster sustainable development, making them a pivotal component in addressing the global energy crisis while conserving vital natural resources.

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