Adapting Floating Solar Power Projects: A Study of Sustainability and Economic Viability in Tamil Nadu, India

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Abstract. The pursuit of sustainable energy sources has become imperative in mitigating climate change and addressing India's growing energy demand. Floating solar power projects offer a promising solution, particularly in regions with limited land resources, such as Tamil Nadu. This study investigates the sustainability and economic viability of floating solar power projects in Tamil Nadu, India, and to propose policy and investment decisions. The research employs a multidisciplinary approach, combining environmental and economic perspectives to evaluate the feasibility of floating solar projects in the state. It begins by examining the environmental impact, focusing on factors like water quality, aquatic ecosystems, and carbon emissions. Results indicate that floating solar arrays have a minimal environmental footprint and can even have positive effects on water quality and biodiversity. Economic viability is a central concern in the context of renewable energy projects. The study analyses the initial capital costs, operational and maintenance expenses, and energy generation potential of floating solar systems. The study concludes that floating solar power projects represent a sustainable and economically viable solution for Tamil Nadu. Their low environmental impact, combined with the potential for long-term financial returns, underscores their promise in addressing the state's energy needs while contributing to environmental preservation. This research offers insights and recommendations for policymakers, investors, and local communities interested in harnessing the benefits of floating solar power in Tamil Nadu. By embracing this renewable energy technology, the state can contribute to the broader sustainability and economic development goals of India, ultimately reducing its carbon footprint and bolstering energy security.

Keywords: Sustainable energy, Floating solar power plant, Economic viability.

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1 Introduction

The world faces a twin challenge, one being the escalating demand for energy to power economic growth and the other challenge is to curtail greenhouse gas emissions to combat climate change. In the response to these challenges, renewable energy sources have emerged as a guiding light, offering both sustainability and economic viability. Among these sources, floating solar power projects have captured attention as an innovative and adaptable solution, especially in regions with limited land resources. This theoretical paper delves into the dynamic realm of "Adapting Floating Solar Power Projects: A Study of Sustainability and Economic Viability," with a particular focus on Tamil Nadu, India.

As the global population burgeons and urbanization accelerates, energy demand continues to soar. Meeting this demand is no longer a choice but an essential prerequisite for modern society's functioning. However, this energy production must coexist with environmental sustainability and ecological harmony. The conventional energy paradigm, largely reliant on fossil fuels, has propelled the world toward a climate crisis. Thus, it is increasingly clear that renewable energy sources must lead the way, and solar energy, in particular, stands out as a key factor in the transition toward a more sustainable future.

Within the domain of solar energy, floating solar power projects have emerged as a novel concept that holds tremendous promise. By deploying photovoltaic panels on water bodies, these projects tap into the dual resource of direct sunlight and reflected light from the water's surface, amplifying their energy capture capacity. Furthermore, the cooling effect of the water mitigates the temperature-related efficiency losses often observed in terrestrial solar installations. Floating solar power projects can have a localized impact on reducing water evaporation. This combination of factors positions floating solar projects as a compelling and sustainable means of energy production.

Tamil Nadu is a state situated in the southern region of India, presents an intriguing research proposal for the adaptation of floating solar power projects. Known for its rapidly expanding industrial and urban landscape, Tamil Nadu is also grappling with the pressing need for sustainable energy solutions. With limited land availability and a climate conducive to the deployment of solar power, the state becomes a fertile ground for investigating the feasibility, sustainability, and economic viability of floating solar projects.

This theoretical paper embarks on a journey to explore the interplay between sustainability and economic feasibility in the context of floating solar power projects in Tamil Nadu. It seeks to assess the environmental impact, economic potential and social implications of these projects, guided by a multidisciplinary framework that integrates environmental science, economics, and community development. This study provides valuable insights, policy recommendations, and a deeper understanding of how floating solar projects can serve as a pivotal catalyst for sustainable energy transitions in Tamil Nadu and beyond.

Floating solar projects utilize innovative solar panels, making them a highly inventive means of harnessing solar power. These panels, akin to conventional solar devices, harness direct sunlight but possess the unique capability to capture reflected light from the water's surface.

A key distinguishing feature of floating solar installations is their interaction with the surrounding water, significantly altering the environment by lowering ambient temperatures. Notably, this cooling effect on the panels' operating temperature renders floating solar projects up to 15% more efficient than their terrestrial counterparts, as reported by the Environmental and Energy Study Institute.[7]

Furthermore, the integration of cutting-edge technology in the design of these solar panels enhances their energy production capabilities. This heightened efficiency is a central factor contributing to the growing popularity of floating solar projects in the nation.

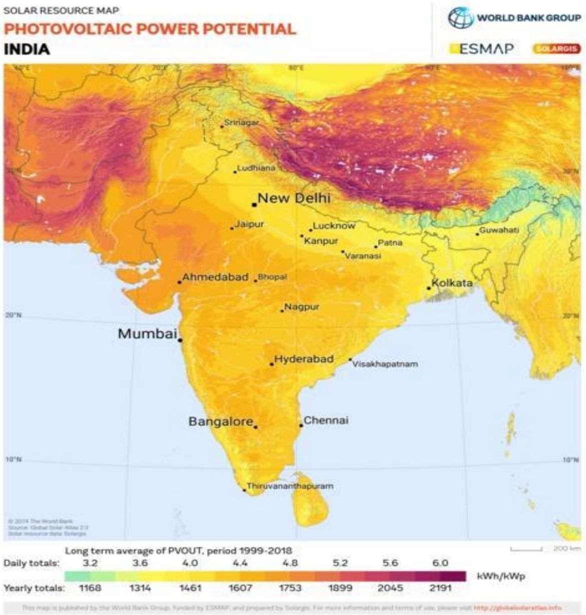
India, standing as the second-largest global contender in hosting expansive floating solar projects, underscores the nation's commitment to embracing and leading in the adoption of this innovative renewable energy solution.

2 The Importance of Renewable Energy

The importance of renewable energy, with a particular emphasis on innovative solutions like floating solar power projects, cannot be overstated in the context of addressing global energy needs and sustainability goals. As the world confronts a multitude of interconnected challenges, from escalating energy demands to the urgent imperative of mitigating climate change, renewable energy sources emerge as a beacon of hope and a linchpin for a sustainable future.

At the forefront of the global agenda is the dire need to combat climate change. Traditional energy sources, primarily fossil fuels, have been the principal reasons for the emissions of the greenhouse gas. The primary cause for the global warming and the climate disruptions are these emissions. Renewable energy, including solar power, offers a clean and environmentally responsible alternative, helping to curtail emissions and mitigate the impacts of climate change.

Fig. 1. Solar Radiation Map of India (World Bank, Global Solar Atlas & Solargis)[8]



The figure shows that India is the recipient of high level of solar energy that can be utilized in solar power generation. Floating solar power projects have a distinct advantage in terms of reducing their environmental footprint. By utilizing water bodies for energy generation, they minimize land use and preserve terrestrial ecosystems. This approach aligns seamlessly with sustainability goals, helping to protect natural habitats, conserve biodiversity, and safeguard water resources.

The sun, as an energy source, is virtually limitless. Solar energy, when harnessed effectively, can provide a substantial portion of the world's energy needs. Floating solar projects leverage both direct sunlight and reflected light from water surfaces, maximizing energy capture. This abundant and renewable resource ensures long-term energy security and contributes to global sustainability.

Renewable energy technologies, including floating solar, offer the prospect of enhancing energy access, particularly in regions where traditional grid infrastructure is lacking or unreliable. These projects can be deployed swiftly, making them invaluable in addressing energy poverty and promoting economic development. The economic appeal of renewable energy cannot be overlooked. Floating solar projects, through innovations in technology and economies of scale, have become economically competitive with traditional energy sources. They offer the potential for substantial energy cost savings and job creation, contributing to local and global economic stability.

Reducing reliance on a single energy source, especially one as environmentally taxing as fossil fuels, is vital for energy security. The diversification of energy sources through renewables, including floating solar, reduces vulnerability to supply disruptions and price fluctuations. Countries and global institutions have established ambitious objectives for sustainability, exemplified by the United Nations Sustainable Development Goals and the Paris Agreement. Renewable energy, including floating solar, plays a pivotal role in achieving these objectives, offering a sustainable and equitable path to prosperity.

Renewable energy, exemplified by innovative solutions like floating solar power projects, is pivotal in addressing the pressing global challenges of energy security and sustainability. By harnessing the power of the sun, reducing environmental impact, and promoting economic development, these projects offer a compelling pathway towards a more sustainable and resilient future for our planet.

3 The need for Floating Solar Power Project in Tamil Nadu

Tamil Nadu is situated in the southern part of India, and due to its geological location it presents a unique and compelling context for the proposal of floating solar PV projects. The region has a distinct set of conditions and needs that make floating solar a particularly attractive and relevant solution.

One of the primary drivers for adopting floating solar projects in Tamil Nadu is the scarcity of available land for large-scale solar installations. As the state grapples with rapid urbanization and industrial growth, suitable land for utility-scale solar farms has become increasingly scarce. Floating solar projects, deployed on water bodies like lakes, reservoirs, and ponds, provide a viable alternative to make efficient use of available resources without competing with other land uses.

Tamil Nadu is endowed with numerous lakes, ponds, and reservoirs, offering a wealth of water resources. The main lakes in Tamil Nadu are Ayanambakkam Lake, Chembarambakkam lake, Puzhal Lake, Valankulam Lake, and many more these water bodies often serve multiple purposes, such as irrigation and water supply. By deploying floating solar panels on these water surfaces, the state can maximize land utility and create a dual-purpose infrastructure that generates renewable energy without compromising the water's primary functions.

Tamil Nadu enjoys a high level of solar irradiance that makes Tamil Nadu as an ideal location for the generation of solar power. Throughout the year the state receives abundant amount of sunlight due to its geographical location, providing an optimal environment for solar energy projects. Floating solar power projects, harnessing both direct sunlight and reflected light from water surfaces, can capitalize on these favourable climatic conditions to generate clean energy efficiently.

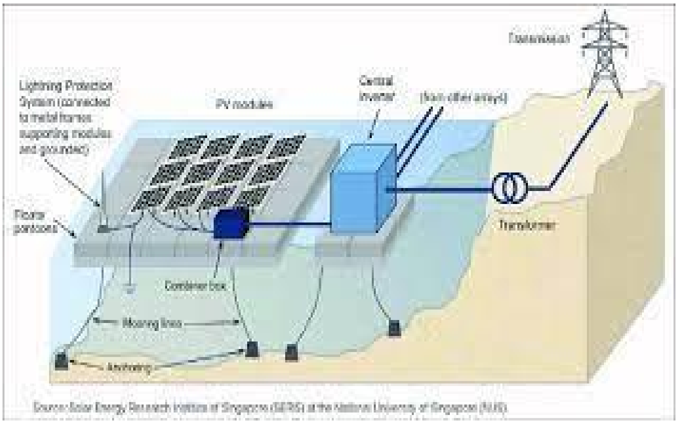
Tamil Nadu, like the rest of India, faces the growing need for sustainable and reliable energy sources. The state's energy demand is escalating due to its burgeoning population and expanding industrial and urban sectors. At the same time, Tamil Nadu is committed to meeting sustainability goals and reducing its carbon footprint. Floating

solar projects offer a tangible means to align energy needs with environmental objectives, fostering a more sustainable and resilient energy future.
In a region with a warm and arid climate, water evaporation from reservoirs and water bodies can be a significant concern. Floating solar projects, with their shading effect and cooling properties, can help reduce water evaporation, thereby aiding in water conservation efforts in Tamil Nadu, where water resources are often under stress.

4 Key Components of Solar PV System

The Floating Solar PV (FSPV) comes into existence with the combination of Solar PV technology and the floating system. This solution comprises four fundamental components:

Fig. 2. Floating PV system (NUS & SERIS)[9]



A. Floating Module: The floating module serves as a sturdy support structure capable of bearing heavy loads. It provides the platform for the installation of PV panels.
B. Mooring System: The mooring system is a permanent structure designed to assist the floating modules in adapting to fluctuations in water levels while maintaining their orientation, typically facing south to maximize sun exposure.
C. PV Modules: Photovoltaic (PV) modules are responsible for harnessing solar energy to generate electricity. In some cases, these PV modules may consist of multiple arrays of PV panels to enhance efficiency. They may also incorporate inverters, tracking units, and batteries for improved performance.
D. Cables: Durable cables are employed to transmit the generated electrical power. These cables are engineered to withstand harsh environmental conditions, ensuring reliable power transfer in FPVS installations.

5 Advantages and Disadvantages of Floating Solar PV system

Floating solar PV system represents an innovative approach to harnessing solar energy. This method involves the deployment of solar panels on buoyant structures, enabling them to gracefully float on the surface of water bodies. Typically, such floating solar installations find their home on tranquil lakes and dams, as these settings are generally more stable than the tumultuous open oceans.

5.1 Advantages of Floating Solar:

Optimal Land Utilization: Floating solar mitigates the loss of valuable land space often associated with traditional ground-mounted solar panels. It effectively utilizes underutilized areas on Aquatic facilities like wastewater treatment plants, potable water reservoirs, and hydroelectric dam reservoirs. This not only maximizes land efficiency but also eliminates the need for land clearing, thus contributing to environmental conservation.

Environmental Benefits: Floating solar panels offer multiple environmental advantages. One of which is the cooling effect due to the surrounding water that can enhance the performance and efficiency of photovoltaic modules, particularly in areas prone to high temperatures. Moreover, these installations reduce water evaporation, a significant benefit in regions susceptible to drought. By floating solar panels on water bodies, the growth of algae is curtailed, helping preserve the quality of freshwater sources and safeguarding aquatic ecosystems. Additionally, by generating clean energy from renewable sources, floating solar reduces dependence on fossil fuels, effectively lowering greenhouse gas emissions.

Enhanced Solar Performance: Traditional solar panels can experience a reduction in efficiency as temperatures rise. However, floating solar panels benefit from the cooling effect of the water surface, which helps maintain and potentially enhance their efficiency.

5.2 Disadvantages of Floating Solar:

Higher Installation Costs: One notable drawback of floating solar installations is the relatively higher initial costs compared to traditional photovoltaic systems. This increased expense can be attributed to the technology's relative novelty, necessitating specialized knowledge and equipment for installation. Nonetheless, as the technology matures and gains wider adoption, it is anticipated that installation costs will become more competitive.

Limited Applicability: Floating solar technology primarily suits large-scale applications that provide electricity to sizeable communities, corporations, or utility companies. This specialization means that for individual homeowners or smaller-scale operations, conventional rooftop or ground-mounted solar installations remain the more practical and cost-effective choice.

In summary, floating solar power projects represent an innovative and environmentally friendly approach to energy production. These installations optimize land utilization, provide various environmental benefits, and can enhance solar panel efficiency. However, they come with higher upfront costs and are most applicable to large-scale applications, making them an ideal solution for specific contexts and energy needs.

6 Review of Literature

Singh et. al.[4] conducted a study comparing the hybrid hydel – floating solar photovoltaic and land based photovoltaic and concluded that the floating solar PV system generates 81.39 GWH more energy along with the increased energy yield of 2.4% in comparison with the land based PV system. The overall water that is conserved is 69.4 mcm as well as 123,454.53 tons of Carbon di Oxide has been reduced due to the corresponding reduction in carbon. The average cost of energy generation is 3.24 $/W that is in comparison with the current price of electricity is less than by 2.3%. From the study it was implicit that floating solar photovoltaic does not only helps in attaining sustainable development goals but also protects the ecological system.

Sahu[3] depicts that the aquatic facilities ranging from oceans, lakes, lagoons, and reservoirs to irrigation ponds, waste water treatment plants, wineries, fish farms, dams, and canals, play diverse and critical roles in various aspects of our environment and are utilized for the installation of solar PV systems that offers a dual alluring solution that will conserve both the resources land and water. Because of the water beneath the panels keep the temperatures of the floating solar PV power plant at a lower point, these results in the increase of the power generation efficiency of the power plant. Additionally floating solar power plant is not only beneficial to human being, it has a positive impact on the aquatic environment also like it reduces excessive water evaporation, it also limits the growth of algae in water that results in enhancing the water quality.

Channi et. al. [6] concludes that with floating solar power project, electricity can be acquired from two renewables sources of energy at the same time and in the same location. Floating solar energy has replaced the traditional ways of pumping back the water to a hydroelectric power station. By 2050 the ratio of renewable energy in the total output of primary energy will rise up to 63% from 15% in 2015.

Fereshtehpour et. al.[1] conducted a comprehensive assessment of floating solar photovoltaic (PV) systems within Iran's five major reservoir dams reveals their superior performance across multiple key metrics, including energy generation, evaporation reduction, economic viability, and environmental benefits. In-depth cost-benefit analyses were carried out to compare various energy generation and water conservation approaches, unequivocally demonstrating that floating solar PV systems outshine alternative methods in terms of efficiency and effectiveness. Since the initial investment in the floating solar PV system is large, therefore, it will take five to six years for the return on investment. Iran is having high energy demand and their water situation is perilous, hence Iran can take advantage of its geographical location due to which it receives high solar radiations. Iran can effectively convert solar energy with the help of floating solar PV system consequently tackling the dual problem by producing energy and conserving water.

Solomin et. al.[5] suggests to enhance the technological and economic competitiveness of floating solar PV system installations, the hybrid floating solar PV systems offers a captivating alternative that potentially deliver greater benefits than the conventional floating solar PV system. The hybrid floating PV systems are growing substantially, particularly when the other emerging technologies like off-shore aqua-voltatics, tide, wind and wave are considered. It is expected that the dual mode of power plants that combines wind, wave, tide and thermal energy with floating solar power plants will increase the energy generation very efficiently.
Goswami et.al.[2] reveals that the FSPV plant boasts a 10.2% higher generating capacity when compared to land-based PV systems, resulting in a surplus generation of 28.38 MU over the plant's life cycle. This remarkable outcome not only enhances energy production but also contributes to significant cost savings. Explicitly, the FSPV plant averts the need for substantial land costs, amounting to USD 352,125, and eliminates water cess expenses totalling USD 47,600. As a result, the rate for the Floating Solar PV plant is reduced to a highly competitive USD 0.026/kWh, which is 39% lower than that of traditional PV power plants that are based on land. Along with these financial advantages, the FSPV plant also makes a substantial environmental impact. It conserves 92,945.92 metric tons of coal and reduces total CO2 emissions by an impressive 340,801.74 metric tons. This contribution to carbon reduction is invaluable in the context of global environmental preservation and climate change mitigation.

7 Success Stories

Floating photovoltaic (PV) solar projects have been implemented in various countries, primarily in response to land scarcity and a desire to maximize the use of water bodies for energy generation[13]. Here's an overview of some of these projects:

7.1 Japan:

The Aichi project in Japan, initiated in 2007, was the world's first floating PV project and served as a pilot to introduce this technology globally. The project was executed by the National Institute of Advanced Science and Technology in Japan and funded by the Ministry of Environment. Hyogo has the highest concentration of floating PV projects, thanks to numerous reservoirs used for agriculture. Kagawa boasts the second-largest floating PV capacity, with notable projects like the 13.5 MW Yamakura floating solar plant. Japan has around 73 floating PV projects with a total capacity of 130.5 MW, mostly on reservoirs, lakes, and ponds. Many projects in Japan are funded in local currency by local banks, with attractive feed-in tariffs driving their growth[13].

7.2 China:

As of January 2019, China had six floating PV projects generating a total of 78.36 MW of power. Two significant projects in Anhui, China, produce nearly 60 MW of power.

The Chinese government repurposed flooded and collapsed mines into floating PV solar farms to improve air quality and working conditions for former mine workers. China also integrated land-based solar farms with the Longyangxia hydropower plant in Qinghai, enhancing overall energy production efficiency. The Chinese government has converted the environmental and social disaster into an opportunity[13].

7.3 India:

India has been implementing floating PV projects for several years, primarily in Kolkata, Kerala, and Chandigarh, with capacities around 10 kWp. In early 2018, India installed its largest floating PV project with a floating substation in Wayanad, Kerala, with a capacity of 500 kWp.[12] In 2022, in Ramagundam Telangana 100 MW floating solar PV project was operationalized. Sanjay Dubey, Principal Secretary of Renewable Energy Department have announced that in 2022-23 that in Khandawa, Madhya Pradesh, world's largest floating solar power plant will be built on the Narmada river which will generate 600 MW power and the project will cost around 3000 Crores INR.

7.4 Iran:

Iran implemented a floating PV project on the 15-Khordad dam in Delijan to combat water evaporation and improve water quality. The initial capacity of the project was 1.45 MW. As a test only small portion was covered but the outcome was surprising. There was a dual benefit, on one hand; significant amount of water was conserved annually due to the floating solar PV plant and on the other hand; efficiency of solar plant was increased due to the cooling effect of the water.[10]

7.5 South Korea:

The Korean Water Resource Corporation (K-Water) installed a 100 kWp floating PV project on the Hapcheon dam, using moisture-resistant structures. Another project was installed in Cheongju, South Korea, featuring special structures capable of withstanding extreme cold.

7.6 United States:

The first grid-connected floating PV project in the United States was set up by Far Niente Wineries in Napa Valley, California. This project used modular crystalline PV panels with built-in walkways for easy maintenance.[11]

Floating PV solutions have gained popularity due to their ability to make efficient use of water bodies and their cooling effect, resulting in higher panel efficiency, making them a promising alternative in regions with limited available land. These projects help address environmental concerns and contribute to clean energy generation.

8 Conclusion

In conclusion, the study on "Adapting Floating Solar Power Projects: A Study of Sustainability and Economic Viability in Tamil Nadu, India" underscores the tremendous potential of floating solar power installations in addressing both sustainability and economic considerations. Tamil Nadu, with its abundant water bodies and high solar irradiance, is a promising region for the adoption of this innovative technology.

The findings of this research emphasize the numerous advantages of floating solar systems, including their ability to conserve valuable land and water resources, improve energy efficiency, and enhance power generation efficiency due to the cooling effect of water. Additionally, the shading provided by these installations contributes to reduced water evaporation and improved water quality, benefiting the aquatic environment.

Moreover, the study recognizes the growing importance of hybrid floating photovoltaic systems, which integrate various renewable energy sources, further amplifying the prospects for sustainable and efficient power generation.

As Tamil Nadu strives to meet its energy needs while minimizing its environmental impact, the introduction of floating solar power projects emerges as a viable and forward-thinking solution. However, it is essential to consider the specific challenges, such as maintenance, anchoring systems, and environmental impact assessments, when implementing these projects.

In sum, this study underscores the potential of floating solar power projects in Tamil Nadu, emphasizing their sustainability, economic viability, and their role in contributing to a cleaner and more energy-efficient future for the region. These findings offer valuable insights for policymakers, investors, and stakeholders seeking to harness the power of solar energy in a responsible and sustainable manner.

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