

# Integrating Solar Energy on Water Bodies for Sustainable Renewable Energy Development

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**Abstract-** Floating solar farms (FSFs) are an innovative way of generating renewable energy; this approach addresses certain major shortcomings of traditional land-based solar power plants. FSFs offer the Two fold benefits of both renewable energy production and land preservation through placing panels of photovoltaic cells in water bodies, including lakes, reservoirs, and coastal waters. Since natural cooling of water surfaces is realized, it also contributes to increasing panel efficiency and reducing evaporation of water. This study discusses the economic and environmental advantages of FSFs such as higher energy and potential water savings in regions that are experiencing shortages. The major challenges of high costs of installation, recurrent maintenance and potential ecological impact on aquatic life are also harshly analyzed. The paper provides a comparative overview on the world experiences and perceptions on the potential of FSF technology in the future based on the case studies in China, India, and Netherlands. The data are supported with graphs and figures that indicate cost- performance, energy efficiency outcomes, and acceptance trends of FSF. Ultimately, in this paper the author highlights the relevance of floating solar farms in the realization of global sustainability goals and addressing the increasing demand of renewable energy.

**Keywords-** FLOating Solar Farms, renewable energy, sustainability, Photovoltaic technology, water conservation.

## I. INTRODUCTION

The increased awareness of the emission of carbon, the increased global energy demand and the dwindling fossil fuel reserves have given the renewable energy resources a global focus. Among the other sources thought of, the solar power is among the best in terms of power available and renewing power. However, ground-based solar farms are difficult to install in a large scale. This massive land development does not coincide with farming, residential and preservation of indigenous habitat. In this regard, the challenge of the day is to come up with new methods of maximizing solar power without compromising land use to the further strain. Other strategies, such as floating solar panels, rooftop systems and agrivoltaics (a mix of solar power generation and agricultural use of the land) can be used to strike this balance between generating clean energy and making good use of the land.

## II. LITERATURE REVIEW

- Past studies have always determined power of solar photovoltaic (PV) industries in fostering a shift towards generation of renewable energy, at the global level (Sharma and Banerjee, 2020). The alternative energy sources that are not dependent on fossil fuels are the reliable, expandable and clean energy method known as PV technology. Nonetheless, besides the advantages, the scientists have also outlined several disadvantages associated with standard ground-mounted solar farms. The large area of land on which it can be set up is one of the key challenges, as it competes with land use with agriculture, urbanization, and nature (Sahu et al., 2016). Such a land-use conflict does not only push the expenses of a business venture through the roof, but also endangers biodiversity and human life.
- To address these issues, there has recently appeared a novel form of solar energy the Floating Solar Farms (FSFs). FSFs that necessitate

the deposition of solar cell onto top of the water body reservoirs, lake, pond and even ocean and coastal (World Bank, 2019). This application makes use of unused water surface and it does not occupy additional land. The technical feasibility, as well as the positive aspect of FSFs have been tested on a pilot level and various studies have demonstrated its viability in some nations including China, India and the Netherlands (IRENA 2021).

- Besides conservation of land, the floating solar systems have a number of environmental and operational advantages. The solar panels that cover water inhibit evaporation that do not only conserve valuable fresh water in dry areas. Besides, water cools the panels below the panels, which enhances their effectiveness in converting sunlight into electricity thus the system performs better as compared to the land-based systems. In other cases, FSFs may be integrated with the already existing hydropower plants to have the same area both used to generate power and also water control. A combination of these benefits has placed floating solar as a potentially very sustainable source used in lieu of the continued implementation of renewables that is currently being undertaken throughout the world, without necessarily excessive land use on land.
1. **Sara Oliveira-Pinto and Jasper Stokkermans (2020):** in Assessment of the Potential of Different Floating Solar Technologies -Overview and Analysis of Different Case Studies, the research established that the performance gains of floating solar PV (0.31%2.59%) were smaller than anticipated and also largely relied on the technology and the location, indicating the difficulties in estimating energy and project bankability.
  2. **Aboubakr El Hammoumi, Smail Chtita, Saad Motahhir, and Abdelaziz El Ghzizal (2022):** in the article, entitled Solar PV Energy: From Material to Use, and the most commonly used techniques to maximize the power output of PV systems, present a comprehensive review of the solar PV optimization methods. They dwell on solar tracking and floating PV systems, their advantages, obstacles, and the contribution to
  3. **Néstor Velaz-Acera et al. (2024):** in An Innovative Approach to Assessing and Optimizing Floating Solar Panels, introduce a GIS and AI-based model to optimize the placement and the tilt of floating solar panels to optimize the LCOE by 2.1-8.4% to invest and have a better performance.
  4. **Steven Benjamins et al. (2024):** in Potential Environmental Impact of Floating Solar Photovoltaic Systems review the environmental and social impacts of floating solar on freshwater ecosystems and marine ecosystems. They present issues such as shading, hydrodynamic alteration and species impact, the necessity of monitoring and collaboration of stakeholders to attain sustainable development.
  5. **Tara Hooper, Alona Armstrong, and Brigitte Vlaswinkel (2021):** in the article Environmental Impacts and Benefits of Marine Floating Solar, they discuss the differences in floating solar in marine environments and freshwater. They point out the possible environmental effects, social reactions, and necessity of simultaneous environmental, technical, and economic viability studies.
  6. **Vidović et al. (2023)** provides an overview of the potential of floating solar panels to reduce the loss of water through evaporation and increase the renewable energy generation. It places an emphasis on the advantages of installing floating solar panels on water sources like limiting evaporation, sustaining the productivity of hydropower plants, and ensuring the generation of extra energy output. It is considered a viable technology, at reasonable prices especially in areas of Uttar Pradesh, India. The technological developments, the practice, and the sustainability of floating solar systems are discussed in the review. On the whole, it shows floating solar panels as a hopeful solution in case of water shortage and production of renewable energy.
  7. **El Hammoumi et al. (2022)** presents the current developments in photovoltaic (PV) systems, including the methods of maximizing

the power production, especially solar trackers and floating PV systems. It mentions the key issues of PV systems including the high initial costs, and low power content and explains different ways of optimization like Maximum Power Point Tracking (MPPT), cooling, cleaning, and tracking systems. The review notes that there is an increasing interest in floating solar panels and this has become a potentially promising solution to make solar panels more efficient and use less land. It also gives a summary of these technologies, their advantages, limitations and the current research advancements.

8. **Velaz-Acera et al. (2024)** are the original solution to the optimization of floating solar panels through the combination of Geographic Information Systems (GIS), multi- criteria decision analysis (MCDA), and genetic algorithms. It overcomes the existing absence of standard design tools and investment analysis of floating solar energy, suggesting a framework to choose the best water bodies to install floating solar energy. The paper also investigates the role of varying the tilt of floating solar panels to minimize the Levelised Cost of Energy (LCOE) where the improvement varies between 2.1% and 8.4%. Using the case study of Spain, the study indicates the possibility of optimization of floating solar energy concerning technological and economic aspects.
9. **Banik and Sengupta (2021)** discuss the opportunities, challenges, and scope of the floating solar parks as a sustainable energy source. It also looks at the technological advancements and resource management techniques that are necessary to make successful implementation of these systems in water bodies like rivers. The paper focuses on the environmental advantages and sustainability of floating solar parks and takes into account its effects on aquatic ecosystems. It also prioritizes the sociological dimensions and the prospects of the future development in the sphere. The authors refer to the contribution that floating solar parks can make towards sustainable development and energy management.
10. **Velaz-Acera et al. (2024)** introduces a new method of optimization of floating solar panels with the use of Geographic Information Systems (GIS), multi-criteria decision analysis (MCDA), and genetic algorithms. It will deal with the issue of unavailable standardized design tools, decision-making, and investment analysis of floating solar. The paper suggests a framework to be used to choose the most suitable water bodies to install depending on technical, economic and environmental criteria. It also maximises the tilt angles, to achieve better Levelised Cost of Energy (LCOE), of up to 2.1 to 8.4. The study empowers the possibilities of optimization of floating solar installations based on Spain as a case study.

### III. RESEARCH GAP

The recent studies involving Floating Solar Farms (FSFs) have been given increased attention, as a novel expression of renewable energy, however, it is agreeable that extensive attention on the new format has been directed towards the technical feasibility, design optimization, and system performance efficiency. A number of studies are inclined to focus on specific pilot projects or regional case studies, therefore, presenting a portion of useful information albeit in pieces about what can be possible. Nonetheless, a massive gap in the comprehensive research exists in defining the synergistic relations between the economic viability and environmental impacts of FSF implementation as one of the aspects of global energy transition processes. To carry out a comparison across models on long-term cost effectiveness and what we herein define as realistic (at scale) short-term costs, there is little work that has been done. More to the point, such critical aspects as cost of maintenance over the life span, the possible ecologic disturbance of marine ecosystem and corresponding policies and measures have not been yet addressed sufficiently. An overall perspective on these dimensions is needed to ensure that FSFs can be scaled to a sustainable level and easily incorporated into the future energy systems.

### Contributions of this Study

In this respect, this research will fill the existing gaps on DynPVs through a multi-dimensional and comprehensive study. To begin with, the study aims to compare the economic and environmental benefits of FSF with the conventional ground-based solar farms (GBSFs) incorporating land use efficiency, installation cost, operation performance and ecology. The comparison of these systems will help the investigation illuminate the contribution that FSFs make in the context of economic and environmental sustainability. Second, the paper will take into consideration the case studies to discuss examples of China, India and Netherland as the first adopters of floating solar. Such examples will be used as illustrations to a real life application, difficulties in functioning and impacts of various climatic, geographical and policy conditions. Moreover, the discussion of significant barriers to the implementation of FSF, including the cost of installation and maintenance, longevity in the long run or possible danger to aquatic life will be conducted.

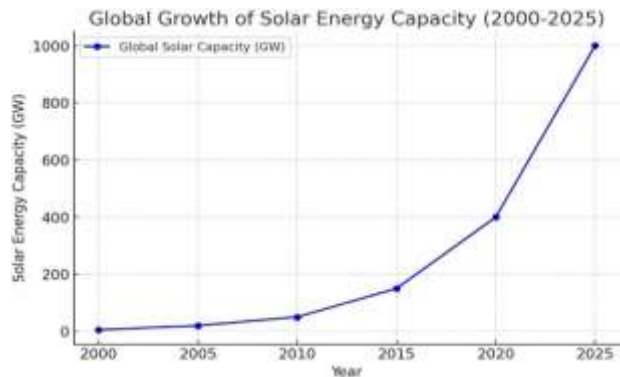
The general viewpoint of the sustainability of FSFs and scalability is significant to suggest solutions to these problems. Visualisations, i.e., graphs and charts, and comparative data models will also be a part of the study to assist in the representation of trends in FSF implementation, cost disparities, and energy performances by regions. These images will make the interpretations more legible and available. Lastly, the strategic role that FSFs play on a sustainable and resilient global energy future is one of the goals of the current study, which should offer insightful explanations. This paper aims to contribute to the growing debate on the topic of renewable energy innovation and sustainable development by integrating environmental, economic and policy perspectives.

## II. METHODOLOGY

The use of solar power technology has gained significant transformation within the last few decades; the transformation carries through the adoption of small roof top technologies to use in individual houses, and the adoption of large scale

ground technologies that may serve as a source of energy to the whole community or industry. This huge expansion reflects the increase in international commitment towards the technologies of sustainable energy, also the acute necessity of alternative fuels. With more needs of solar power being generated however, it has now become harder to balance system disadvantages such as land shortage and conflicts with agricultural activities, urbanization and natural ecosystems. Floating solar has developed as a solution in this face of these challenges as a new and economical method. This is a solution where photovoltaic panels are installed on water bodies such as reservoirs, lakes and coastal waters not only occupying the land space but also enhancing efficiency of electric power generation due to cooling effect by the water. The floating solar projects illustrate how technology can be used to address the space and ecology challenges, and also allow switching to a more sustainable energy source. As depicted in the graphic above, solar technologies in the world are generally growing, and more importantly, the water-based installations (e.g., floating solar farms) are replacing the land-based ones. This trend supports the fact that solar is an important element in the achievement of sustainable global renewable energy goals and shift to a more environmental-friendly, low-carbon future.

(Graph: Global Growth of Solar Energy Capacity from 2000-2025)



- The chart indicates our capacity of the sun in 2000-2025 across the world that illustrates that its growth is rapid in a period as short as this quarter century. At the onset of this century, the installed capacity was highly insignificant due to the unsophisticated solar technology then and

low adoption (low efficiency to cost ratio). The development progress till this was narrow and focused on a few of the developed countries that were experimenting with alternative sources of renewed Energy.

- But since 2010 an apparent increase has been observed where more and more government policies, financial incentives and subsidies have taken part in the market to promote the production of clean energy. This was the period when individuals began shifting the manning of the climate change and sustainable energy systems barricades. But scaling up of solar in the world took a few notches higher in 2015. More and more countries, both wealthy and impoverished, spread massive fields of solar panels as the cost of such equipment dropped worldwide and it was possible to construct so many in a mega- project.
- The growth rate has been so high that in the last few years and the total installed capacity is projected to reach nearly 1,600 gigawatts (GW) in 2025. This tremendous growth is partially attributed to the fact that there is still a lot of robust technological improvement, massive reduction in expense of photovoltaic modules and a rising global policy focus on the reduction of carbon. And, new technologies have further simplified solar power, whether it be floating solar farms to bifacial panels and battery storage systems made solar power even more efficient and versatile. The cumulative total is an unstoppable increase which augurs little short of the conversion of the world to a solar energy future as one of the most important and essential ingredients.

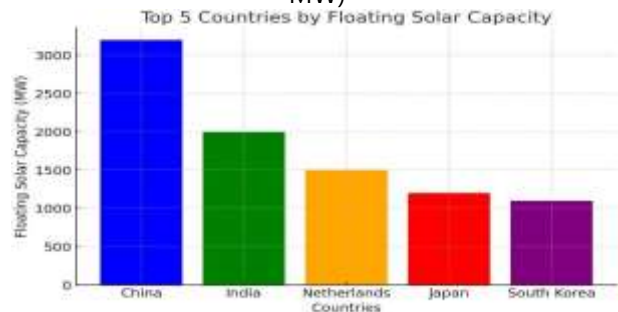
### Concept Of Floating Solar Panels And Their Growth

Floating Solar Farms (FSFs) are the innovative type of renewable energy production, where the water bodies like reservoirs, lakes, and ponds have the solar panels resting on their surface. The novel design is useful in overcoming the problem of land scarcity and thus is specifically applicable in highly populated or agricultural areas. Such countries as China, India, and Netherlands have become the world leaders in the realization of large-scale

projects of FSF, which demonstrates the possibility of water-based solar systems to be used as a productive complement to traditional land-based installations.

China has been very successful because of the large scale use on reservoirs and industrial lakes, and India has incorporated FSFs in its national renewable energy plan to increase the power generation without affecting the agricultural land. In the same way, the Netherlands has invented offshore as well as inland floating systems which make the most of the available space. The top 5 countries by the number of FSF installations are presented in the chart below, with their contribution to the total floating solar capacity around the world. This increased acceptance highlights the rising acceptance of FSFs as a sustainable, space-saving and environmentally-friendly alternative to cope up with the escalating energy needs.

(Graph: Top 5 Countries by Floating Solar Capacity, MW)



Floating Solar Farms (FSFs) is a new technology in the sphere of renewable energy, where the water bodies are used as a platform to install solar panels such as ponds, lakes or reservoirs. This new organization addresses the problem of hard occupation of land, which is especially hard in the densely populated or agricultural regions. Such large-scale FSF projects have been observed in China, India, and Netherlands in recent years, so there is indeed a lot of truth in the fact that water-borne solar structures can be of immense help to land-based systems. China has recorded great success by extensive use in reservoirs and industrial lakes and India has now introduced FSFs in its national renewable energy program so as to generate more power without compromising

agricultural lands 11. Indicatively, the Netherlands has been at the forefront of offshore and inland floating systems in order to make the best use of space. The list of top five countries (in terms of FSF capacity installed) and percentages of cumulative global floating solar capacity displays the following graph: This is an increasing utilization that shows the rising acceptance of FSFs as a high energy demand, small footprint, clean environmental method.

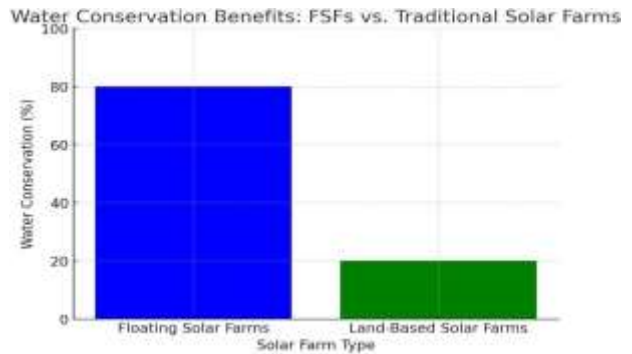
**Environmental Impact**

FSFs provide numerous PV facilities with more than just power generation a variety of environmental advantages. Their best-known use is the ability to damp evaporation of water of reservoirs surfaces, lakes and pools. FSFs because they are laid over the water body surface they lessen the direct sunlight exposure and lower the evaporation rate that is notable in dry or semi-dry gazillion areas that are water short of water. Another aspect that predisposes them to be a favorite is shade which makes them a standard choice because they form a canope that shields your dam hence keeping those annoying algae away hence resulting in a clean body of water that does not require much chemical treatment. In contrast to land-based solar farms which may be devastating to the environment and wildlife, FSFs are based on open water formation. It reduces massive deforestation, soil disturbance or disturbed land use as typical of ground-mounted solar development. In this way, FSFs contribute to preservation of the natural ecosystems and at the same time to generate renewable energy at a cost-efficient level. The following graph depicts the benefits of floating solar systems in preserving water resources and ecosystem. It gives the general benefits (i.e., reduced evaporation, reduced algae culture, saved surrounding land) thus the FSF is a sustainable and innovative way of providing the contemporary energy and environmental needs of the world.

The chart shows that Floating Solar Farms (FSFs) and Traditional Solar Farms are dissimilar in terms of water conservation. FSFs use less land and save a lot of water evaporation compared to the solar farms. They are also less harmful to the environment

because they cool solar panels. FSFs tend to have more benefits of water conservation.

(Chart: Water Conservation Benefits of FSFs Compared to Traditional Solar Farms)



**ECONOMIC FEASIBILITY**

Although FSFs are more expensive to set up than conventional solar farms in the short run, they have more benefits in the long-term that make them more efficient in energy consumption and with lower maintenance costs. Incentives by the government and reduction in cost of technology is making FSFs a better place to invest. The following table shows a cost comparison:

(Table: Cost-Benefit Comparison of Land-Based vs. Floating Solar Farms)

Factor	Land-Based Solar Farms	Floating Solar Farms
Installation Cost	Lower	Higher
Maintenance Cost	Moderate	Higher (due to water exposure)
Energy Efficiency	Standard	Higher (cooling effect improves performance)
Land Use	Requires large land area	Saves land by using water bodies
Water Conservation	No impact	Reduces water evaporation
Environmental Impact	Can lead to land degradation	Less impact, but may affect aquatic life
Lifespan	Long	Similar lifespan, but may require more maintenance

The table presents the case of a comparison between land-based and floating solar farms. Solar farms on land are cheaper to set up and maintain and require lots of space. Floating solar farms are more expensive but have a saving in land and less loss of water. They also generate greater energy because they are cooled by water. Floating solar panels are however harder to maintain because they are exposed to water. Whereas the land farms may affect the land negatively, floating farms may affect aquatic

organisms. They both have equal lifespan, however, floating farms may demand increased maintenance

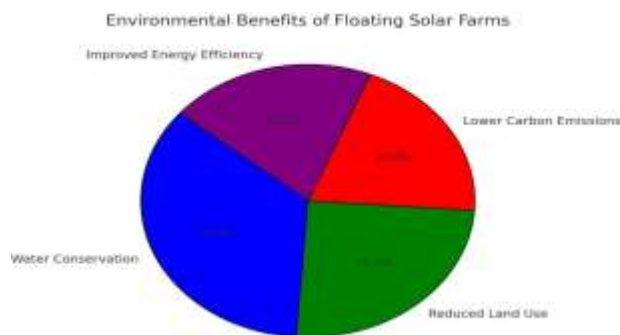
### Challenges and Innovations

Some of the challenges facing FSFs include high costs of installation, maintenance problems that are water-related and there may be some environmental concerns. Nevertheless, new facility in the development of floating solar such as better anchoring mechanisms and hybrid energy construction are dealing with these issues.

### Advantages and Disadvantages

- **Enhanced Energy Efficiency:** by cooling the solar panels with water compared to land collections, solar panels are made more energy efficient.

(Graph: Efficiency Comparison of Floating and Land-Based Solar Panels)



Floating Solar Farms are associated with numerous environmental benefits. The most beneficial is the conservation of water that comes at 35% and helps in the reduction of water loss. They also require less land area to construct and the sum is up to 25 percent. They are also beneficial in reduction of carbon emissions to the tune of 20 percent as they produce renewable energy. Lastly, they gain by a fifth in terms of increased efficiency in energy consumption because they are very efficient in converting electricity. Generally, Floating Solar Farms help to conserve water, use less land, reduce pollution, and increase energy generation. Land Conservation: FSFs use water surfaces to maintain valuable land to be used in urbanization and agriculture. Water Saving: FSFs inhibit the evaporation, which conserves water in reservoirs.

Incorporation with Hydroelectric Plants: FSFs are compatible with the current hydroelectric plants to maximize the renewable energy.

### III. EXPERIMENTAL SETUP & RESULT-

The results indicate that FSFs are superior to terrestrial solar farms in terms of a number of benefits. Energy The energy (Watt h) is a source of fuel, or a connection of electricity.

efficiency because of the cooling of water. Also, FSFs have become capable of suppressing evaporation of water in water reservoirs, and this is highly applicable in the arid areas as represented by cases that include 150 MW FSFs in Anhui province. India has also integrated FSFs in power plants that use hydroelectric power in order to boost the power of turbines.

water yield and electricity. Offshore FSFs have undergone trial in the Netherlands, and some of them happened. breaking through the spatial barriers and reaching the advancement of marine solar technology. Economical analysis demonstrates that the cost of FSFs is more expensive compared to the land-based ones. solar, their long-term advantages are increased

efficiency (in associated field per kWh), reduced land price and decreased environmental impact. FSFs are assumed to get more economically competitive.

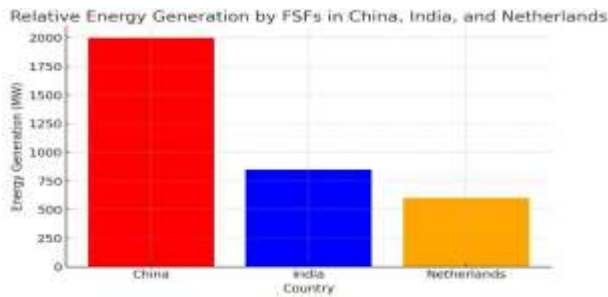
### IV. DISCUSSION

**China:** China In China the largest floating solar farm in the world is situated in Anhui province and demonstrates that the solar in large quantities can be effective

**India:** FSFs have been used in conjunction with hydro-power plants in India to make hydroelectric growing efficiency and water management and water better use.

**Netherlands:** The Netherlands is setting the pace of offshore FSF and it is a solution to the paucity of land besides rising renewable energy by leaps and bounds in the nation.

(Chart: Relative Energy Generation by FSFs in China, India, and Netherlands)

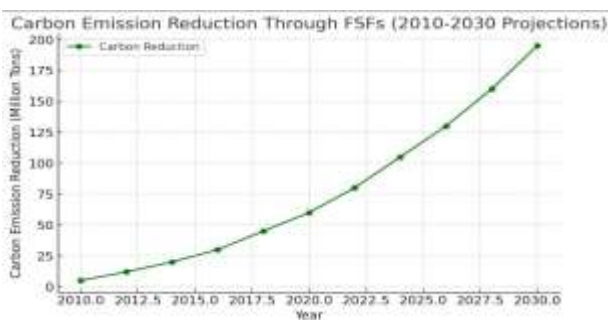


China is the most powerful among the three and generates about 2000 megawatts (MW), which is far greater compared to other counterparts. India is generating approximately 800 MW, which is by far lower than that of China though higher than that of the Netherlands. The Netherlands produces the lowest, about 600 MW of three nations. China 27 the total leader; energy production is much more in China; India and the Netherlands have a significant distance in producing it.

### The economic and environmental impact

FSFs are used to achieve sustainable development by reducing emissions of carbon, lowering water consumption and developing renewable energy. The cost benefit analysis indicates that initial investment would be difficult but it has long term economic benefits. The impact of FSFs in reducing carbon emission is shown in the graph below:

(Graph: Carbon Emission Reduction Through FSFs, 2010-2030 Projections)



The rate at which the carbon emission cut was initiated was extremely low in 2010. It gradually increased beginning with around 50 million tons per annum in the year 2020. The rate of decline increased afterwards with the year 2020 marking the point at which it touches upon the mark of more than 100 million tons in the year 2025. The prediction in the year 2030 is nearly 200 million tons. This demonstrates that the reduction in carbon emissions has increased significantly with time, especially in the later years (since 2020).

### Future Prospects and Recommendations

**Technological Advancements:** FSF can be improved with the employment of technological advances in floating platforms and systems based on solar-hydro.

**Global Expansion:** FSFs have the potential to be deployed in those nations where there is a shortage of land to support renewable energy projects.

**Policy Development:** Governments are supposed to come up with incentives and friendly regulations to promote FSF adoption.

## V. CONCLUSION & FUTURE WORK

Floating solar farms offer a viable solution to the energy and land dilemma in the renewable energy industry. Their significance in meeting the sustainable development goals is identified by their environmental benefits, economic sturdiness and increasing usage around the world. The continued research and technological advancements will play a significant role in making them even more influential on the global scale.

Floating Solar Farms (FSFs) are a positive innovation in the development of renewable energy sources since it is a viable solution to two serious problems, namely, land scarcity and water conservation. FSFs utilize the water body surface as opposed to the ground-mounted solar farms. The solution can save the amount of agricultural land, lessen the strain on forests, and will result in better energy utilization because of the natural cooling impact of water.

They also have the advantage of reducing the evaporation in reservoirs which is useful in producing energy as well as in the management of water resources and is therefore particularly useful in areas where there is a shortage of water.

China, India, and Netherlands case studies demonstrate that FSFs are able to adapt to other geographic and climatic conditions. The high industrial energy demands are evidenced by the large-scale projects undertaken by China with the use of FSFs. The hybrid FSF-hydropower projects in India show a potential of integration. In the meantime, the offshore installations of the Netherlands are innovative in the space-limited countries. All these examples indicate the opportunities, as well as the difficulties of FSFs, in particular the process of creating a balance between technological, environmental, and regulatory concerns.

In the future, FSFs will depend on a number of factors, which are crucial to its future. To begin with, it is necessary to lower the initial cost and maintenance requirements that make the solar systems uncompetitive with land-based systems. Second, environmental effects have to be monitored in the long-term so that aquatic ecosystems are not damaged. Third, it will be important to develop international standards in the design of FSF, anchoring systems, and safety guidelines to further broaden the project internationally. Also, hybrid solar-hydro, offshore floating solar, and AI-based optimization should be improved, which will contribute to efficiency and reliability.

Under the combination of appropriate technological innovation, funding, and friendly policies, FSFs can be an essential constituent of renewable energy strategies in the world. They can play a great role in reducing carbon emission and sustainable development.

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