International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 06 | June - 2022 Impact Factor: 7.185 ISSN: 2582-3930

WATER FLOATING SOLAR SYSTEM

HIMANSHU SAONERKAR, AVI GUPTA, CHAITALI AKHARE, CHETNA BANGADE,

SHWETA VAIDYA

1. INTRODUCTION

1.1 General

The biggest problem in our country is power crisis. Around 70% coal is used for generation of electric energy. Irrigation and industry production is get affected due to load shedding, daily shutdown, etc. So we need to move towards renewable energy sources to generate electricity.

Now a days renewable energy sources are growing fast not in just India but many other countries. Solar energy is clean, efficient and abundant source of alternative energy. The use of solar energy Solar energy decreases greenhouse effect. Area wise seventh largest country is India and has good sunshine. Solar energy is energy produced by sun created through a thermonuclear process and this process crates heat and electromagnetic radiations. These electromagnetic radiations have the energy that reaches the earth. Solar energy is the indirect source of energy so we need two main components: firstly the collector to collect radiations which are coming from the sun and convert it into the electrical energy form, secondly storage unit as radiations are varying in nature. To solve the energy crisis solar energy will be an excellent solution but to use land mounted solar system is the requirement of land which is very costly and less available to get it. India will generate up to 1.75 GW solar powers from renewable energy sources and 1 GW of solar power in upcoming 10 years. As per the Jawaharlal Nehru National Solar Mission around 5000 MW has been commissioned till date in different parts of the country. To make the country consuming green power in world, the progress is not just sufficient and needs hard efforts by every state and state departments.

Floating solar system has PV concentrator which is very light weight and it floats on water bodies, mounted on anchored rafts float on the surface of irrigation canals, water reservoirs, quarry lakes, and tailing ponds. Some of systems exist in France, India, Japan, Korea, the United Kingdom and the United States.

The floating solar system reduces the need of costly land area, it also saves the drinking water that would otherwise be lost due to evaporation, reduces the growth of algae. The solar system shows a higher efficiency as the panels are kept in cooler temperature than they would be on land area. The floating platforms are 100% recyclable, utilizing high density polyethylene which can withstand ultraviolet rays and corrosion. Floating solar is also called as ‘SOLAR ARRAY ‘or ‘FLOTOVOLTAIC’ or ‘FLOATING PV’.

2. LITERATURE SURVEY

2.1 Floating solar photovoltaic plants in India — A rapid transition to a green energy market and sustainable future — J. Charles Rajesh Kumar and Mohammed Abdul Majid — SAGE Publication (2021)

The Review examines the viable means of exploiting the enormous resource confined in India’s inland water bodies (reservoirs) by installing FSPV. The renewable energy market share of FSPV is anticipated to expedite as the technology evolves. As the technologies mature, the deployment of FSPV seems to commence to hasten. FSPV prepares a new frontier of global renewable power growth and introduces possibilities to various nations and businesses. FSPV is expected to be an attractive alternative when paired with other confirmed advantages, such as producing tremendous power, lessened evaporation, and enhanced water quality. Even though the market is still young, exceptionally qualified suppliers make well-defined competitive tender and build a funded commercial project. The extra expenses tend to be minimal and are swiftly decreasing. Though FSPV is in the initial phase of its development in the country and before running into the extensive FSPV implementation, several questions need answers, notably its long-term influence on the local region’s climate and ecosystems. The production of FSPV energy has increased exponentially, while the cost has decreased tremendously. These cost reductions and the increased investment and acceptability are beginning to have a broad impact on power markets, utilities, and laws. The decrease in FSPV costs and subsequent increase in deployment has been amazing, but considerable obstacles remain in reaching the solar penetration levels required to decarbonize our power grid. To successfully manage distribution voltage, high penetrations of distributed solar will necessitate the employment of increasingly complex inverters. Benchmarking and tracking LCOE versus MNRE targets, investigating approaches to lower LCOE, and understanding LCOE determinants to help guide R&D and investment decisions. R&D should improve their understanding of costs and markets, as well as look into various cost-performance trade-offs. Investing in R&D to lower costs and scale up operations to take advantage of economies of scale has long been touted as a solution to these issues. Companies and government-sponsored research initiatives in India must continue to invest in advanced R&D and build larger, more advanced manufacturing facilities. On the other hand, manufacturing facilities in India are restricted to small processing units and solely focus on replicating existing technologies.

Prioritize strategic installations of FSPV at sites where it is already economical over the next few years. The strategic plan must incorporate the deployment of FSPV at locations where the financial situation already exists and the enforcement of the precautionary policy for FSPV's influnces on the climate and social issues. The strategic plan may require establishing fundamental boundaries on the protected water surface and avoidance of installations in the shore area of the lake or pond, where there could be a greater aquatic flora and fauna life in abundance. If initial installations are closely examined, the constituent technologies' expansion and awareness of negative and positive outcomes will improve considerably, resulting in some public investment. Adding "monitoring" to the potential increased cost of capital would make initial installations in developing countries such as India the right candidate for concessional climate funding. Efficient communication is required between all parties concerned, public and private, to encourage global understanding of the technologies of FSPV and spread lessons learned from earlier ventures into a wider area to encourage business growth. The government, financiers and investors, policy developers such as MNRE, NITI Aayog, developers of the project, agencies executing the project, and the researchers must act together to widen the market for FSPV. Furthermore, this will help decrease the cost, grid integration support, optimize ancillary advantages, and mitigate adverse environmental or social consequences. The present need is formulating FSPV-specific criteria and project implementation directives. Reaping this technology's real value without damaging the local climate and ecosystem. At this beginning period, the emphasis is on FSPV's ability to survive as a technology rather than the tariff. Therefore, it is vital to observe and check FSPV's progress and put it into the public domain.

2.2 Floating photovoltaic system for Indian artificial reservoirs — an effective approach to reduce evaporation and carbon emission — N. Ravichandran, N. Ravichandran and B. Panneerselvam — International Journal of Environmental Science and Technology (2021)

The present study investigates the performance of FPV technology in Indian reservoirs with HEPP. Implementing these innovative FPV systems on reservoirs not only generates solar power but also helps in reducing water loss due to evaporation and carbon emission. The saved water can also be conveniently used to increase hydropower generation. Numerical analyses of a preliminarily designed 5-MW FPV plant in the 20 largest reservoirs in India were carried out. The electrical performance of the model plant, along with its environmental and economic benefits, was studied. The results show that the implementation of these 20 model FPV plants in Indian reservoirs will generate 159.64 GWh of power annually. The power produced per km^2 from these fixed tracking PV systems was 38% more efficient than the land-based PV system. Further, the FPV system with a single-axis tracking mechanism results in a 3.65% gain in energy density than the fixed mount FPV system.

Eventually, the FPV plants acting as a covering system for reservoirs help save 1.40 million cubic meters of water every year. The saved water can be effectively used to produce additional hydropower. The implementation of this renewable technology will also avoid 3.30 million tons of CO_2 emissions annually. Altogether, this hybrid FPV-HEPP technology helps increase the renewable power production in the nation without affecting the environment. The results of this detailed investigation highlight the suitability of Indian reservoirs for FPV implementation. With a large number of reservoirs and open water bodies all over the country, this sustainable technology is the most suitable solution to meet the energy requirement and water crisis in India. With the identified advantages of innovative hybrid technology, the future research by the research group is focused on detailed operation simulation of the hybrid FPV-HEPP systems, static and dynamic interconnection topologies, and DC–DC converter configurations.

2.3 Feasibility study of floating solar panel over lakes in Bengaluru City, India — Yashas Venkatesh, Bagrecha Aman and Dhanush S — ICE Publishing (2021)

Solar energy is the most readily available source of clean energy over most parts of India. Using FSPV systems, this energy can be harnessed on areas that have no competitive use and is often closer to areas of consumption compared to conventional power plants. Bengaluru City's widespread lake network and ambient climatic conditions for PV modules can contribute towards harnessing clean energy and lead the city towards a sustainable future. A conservative assessment of the feasibility of such systems carried out in the present study is summarised in the following points :

a. The 3924 ac of land considered over 32 lakes within the city at a coverage ratio of 0.5–0.6, amounted to an annual average output of 459 MW of power. An average of 8.5 ac is needed per megawatt, compared to 7 ac/MW at the state's biggest terrestrial solar park in Pavagada, Tumkur, Karnataka, India.
b. The FSPV systems adopted in the city would meet an average of 26% of the city's power demand, and due to the spatial spread of the lakes being within the vicinity of the city, this would significantly reduce the transmission losses and costs.
c. The floating solar plants would also save water due to evaporation, resulting in annual savings of approximately 22 866 million litres.
d. By moving towards FSPV integration into the city, the community could benefit in the following ways:
e. FSPV systems encourage a faster and more economic development of solar projects, as it reduces the burden of land acquisition on the governments and encourages timely competition of projects (due to the less probability of prolonged legal disputes regarding acquisition) by contractors.
f. Given the spatial spread of the lakes, PV-EV-based charging stations can be established, reducing the payback period of the plants, enhancing accessibility for electric vehicle users in urban areas and encouraging start-ups, as well as addressing mobility issues using micro-mobility vehicles.

Despite all the positive impacts, there is a need for detailed studies on the impact of floating solar systems on the aquatic ecosystem, stratification of lakes and food chain disruptions. Since most of the floating solar plants are in their nascent stages of operation, a simulation of their biological activities and studying their behaviour would ensure the holistic suitability of FSPV systems. There is a need to scientifically relate the biotics of an ecosystem with the coverage ratio of solar panels to ensure a balanced trade-off between energy production and environmental protection. Another aspect is to quantify the visual pollution of FSPV systems and ensure that they can be incorporated by preserving the aesthetics of the surroundings. Lastly, with increasing solar projects across the nation, hazardous PV waste is estimated to reach 0.04 Mt by 2030 and 4.5 Mt by 2050. It is vital for stringent recycling policies to be enacted to ensure the lifetime sustainability of solar projects.

2.4 Floating solar opportunities and way ahead- Deepak Singhal, Sangeetha Suresh, Shipra Arora, Surbhi Singhvi, Vinay Rustagi – Bridge to India (2018)

Floating solar technology has a huge potential to scale up and replicate the success of ground-mounted systems in India. It is imperative that policy makers and procurement agencies - BIS, NISE, SECI, NTPC and others - make specific market intervention to exploit this potential :

2.4.1 Quality standards and technical specifications should be made more robust

High moisture content adversely impacts modules and other system components. Appropriate quality standards for water vapour transmission rate and UV blocking capabilities must therefore be adopted to survive the harsh operating environment. Standards should be formulated to ensure use of non-hazardous material to prevent water contamination. These measures would have a marginal cost but go a long way in providing quality assurance to users.

2.4.2 More domestic manufacturing capacity for floats need to be encouraged

Better visibility of floating solar project pipeline would help in attracting investment in domestic manufacturing capacity for floats. This would help in reducing capital cost and improving floating solar's cost competitiveness.

2.4.3 Site studies should be speeded up

Detailed site assessments should be undertaken in advance and speeded-up, where possible, to accelerate project development timelines.

2.5 Floating Solar Photovoltaic (FSPV): A Third Pillar to Solar PV Sector ? – Mohit Acharya and Sarvesh Devraj – TERI (2019)

With the rate of capacity additions growing almost 3.5 folds, and reaching 84.4 GW within the last 5 – 6 years, the journey of renewable energy capacity additions in India is being phenomenal so far. With scheme like Saubhagya, providing last mile connectivity, the regulatory structure in place is geared towards creating the demand for clean energy while making electricity affordable for all. With focus given to transforming the energy sector from fossil-based to zero carbon globally, the Government of India is also playing its role in creating a favourable environment by introducing the relevant policy interventions that are needed. In fact being among the world's fastest growing emerging economies and world's second most populous country, make the country a key player in the global energy transitions. There are many ways to contribute in this transition, FSPV being one of them. The report investigates the possible ways of utilizing the vast potential trapped in the country's inland waterbodies (medium and large reservoirs) through installation of FSPV. FSPV looks promising to become a third pillar of the solar PV sector and its market share is likely to accelerate as the technology gets mature. It provides some inherent advantages like improvement in energy yield due to evaporative cooling effect because of vicinity to the water surface, alternate to land use (land neutrality), potential to use the existing power infrastructures, potential to save water evaporation loss, etc. However, FSPV is in nascent stage of its development in India and there are lots of questions particularly regarding its long-term impact on the local environment and bio-diversity which require answers before rushing into large scale deployment. Formulation of FSPV-specific standards and project development guidelines is the need of the hour and is of vital importance to reap the actual benefit of this technology without causing any negative impact on the local environment. In this initial stage, focus must be on the viability of FSPV as a technology and not on the tariff and hence monitoring of its performance and bringing it to public domain must be encouraged. This can be achieved via following the priorities presented in this report and sharing the learnings among the stakeholders.

2.6 Techno-economic analysis of floating PV solar power plants using active cooling technique – Antoine DIZIER – KTH School of Industrial Engineering and Management Energy Technology (2018)

The thesis work is focusing on a techno-economic performance analysis of combined floating power plant and active cooling system by spraying water over the photovoltaic modules. The main objective of the present work was to investigate the impact of implementing active cooling strategies on floating power plant overall performance in Taiwan. In other terms, the major question was to determine whether or not a combined FPV plant and cooling system is economically viable and technically efficient, according to different cooling conditions. In order to reach the mentioned objective, several steps were achieved. Firstly, an extensive literature review was conducted on FPV plant design and operation. PV panel cooling physic and systems were also studied, as well as Ciel & Terre own water cooling system. Secondly, a detailed MATLAB model was developed for designing FPV plant operation. On the other hand, water cooling for PV modules was also modelled on MATLAB. Thereafter, performance indicators were calculated in terms of economic and technical operation. The complete technical model was then verified against a real case in Japan. Cases were finally simulated and compared and the performance indicators and FPV plant operation were analysed.

Two cases were simulated and provided interesting performance results, under different starting cooling condition. The cooling scenario cases were based on the pump activation or deactivation. Case 1 was performed under a constant yearly and optimal cooling condition. The pump was activated only if a minimum irradiation value of 150 W/m^2 was reached at every instant. It showed net improvement in power generation and a net generation gain of 6.6% was obtained compared to FPV plant alone. On the economic side, cooling the PV panels under Case 1 was able to reduce the LCOE of the plant by 0.89 USD/kWh. Case 2 was simulated by considering a time-dependent cooling condition, taking into account local meteorological data and FPV plant operation. The pump was activated only if the extra power generated due to cooling was higher than the pump power at every instant. The next generation gain was 6.4% compared to the FPV plant alone. On the other hand, the LCOE was reduced by 0.99 USD/kWh. While comparing to FPV alone or current cooling operation in Isawa, the two cases modelled offer positive impact on the production side and economic viability. Combining all performance indicators, Case 1 can be chosen as the optimal strategy, providing both good technical performance and high profitability. The FPV payback is reduced by more than 9.1% while implementing such cooling system condition. Irradiation is the main driver for cooling process optimization.

The concept of coupled cooling system and FPV plant is of great interest, especially in tropical and hot region such as Taiwan. The economic market is undoubtedly favourable for such projects, and the meteorological conditions are very interesting. This can be noted also with the government incentives, hardly pushing for a dynamic development of solar projects on water bodies. As an isolated system, the island of Taiwan is willing to reduce drastically the use of nuclear sources and fossil fuel in the next decades. On the other hand, the large availability of water bodies and the cheap prices of hydraulic equipment lead to the global great interest of Taiwan for developing FPV power plant with cooling system to generates electricity at the lower cost.

2.7 Floating Solar : An Emerging Opportunity at the Energy – Water Nexus – Carlos Gamarra, Jennifer J. Ronk – Texas Water Journal (2019)

Texas is experiencing tremendous growth, which brings challenges at the energy-water nexus. Texas has been a leader in renewable energy and the PV sector is predicted to grow rapidly in the next five years. In a climate where much of the state is arid or semi-arid and the entire state is subject to drought, floating solar may be part of the solution. Texas reservoirs, water and wastewater treatment facilities, power plant cooling ponds, and irrigation ponds all have the opportunity to realize benefits from floating solar that could not be achieved with standard land-mounted PV installations. Additional data on economics, evaporative effects, and environmental effects would help support planners and designers in evaluating the potential for this technology in the Texas market. The types of contributions that would be most valuable at the current life stage of this technology include: demonstration projects, laboratory studies, case studies, economic studies, and modelling of the energy, water quantity, and water quality benefits of floating solar.

2.8 Where Sun Meets Water Floating Solar Market Report

There is no significant difference in the LCOE of ground-mounted, fixed-tilt systems and FPV installations. The higher initial capital costs of FPV systems are mostly balanced out by their higher energy output. Meanwhile, other considerations might favor FPV, such as the opportunity costs of using agricultural land. FPV costs are approaching those of ground-mounted systems and may converge in time, eventually leading to an equal or lower LCOE. FPV deployment opportunities will be mainly driven by (i) jurisdictions where permitting favors them and where (ii) access to land and the scarcity/price thereof are major issues. Compared to rooftop and ground-mounted PV installations, MW-scale FPV is brand new. This technology is at the earlier stages of its learning curve, and greater cost reductions are to be expected. This is not only true for the cost of the floating system itself, but also for engineering and project development costs. As will be shown in the following chapter, only a few EPCs have realized a sizeable number of FPV plants. Finally, it is important to differentiate between risks and unknowns. Increased transparency and knowledge sharing with regards to the capital costs, environmental impact, and performance of FPV systems will help build trust among international investors and lenders, which will in turn help reduce financing capital costs

2.9 Performance analysis of a floating photovoltaic covering system in an Indian reservoir – Balamurugan Panneerselvam, Nagananthini Ravichandran and Nagavinothini Ravichandran – Clean Energy

Floating photovoltaic installation has grown tremendously in the last 3 years with a global installed capacity of 1314 MW. India, being in the development stage, has increased its FPV implementation from kW to MW scales in the last 5 years. With proper technological development in the FPV sector, India has the potential to implement ≤ 280 GW of capacity with its available water resources. This study presents a detailed numerical analysis of a model FPV system in Mettur reservoir. It is observed that the FPV cover will save 184 589 m^3 of water annually from evaporation. The demonstrative plant in this study is also analysed for various angles of inclination, mounting systems and tracking mechanisms. The main outcomes are listed below:

1. The lower tilt angle will result in a reduced number of PV panels, high PR and high PV potential, and also helps in maintaining the optimum panel temperature. A tilt angle of 10° was found to be more suitable for the Mettur location.
2. Considering the power output, energy output and PR of FPV systems with different mounting systems, a flat-mount system has been identified as being more suitable for Mettur reservoir.
3. Landscape orientation of the panels is more economical due to the reduced number of panels required in comparison with portrait orientation.
4. An FPV system with single-axis tracking yields 15.80% more energy in comparison with a fixed-tilt system without tracking. But the inclusion of a tracking mechanism is not advantageous from an economic perspective.

Following the assessment of electrical performance, the carbon footprint and cost analysis of the FPV system were also carried out. The results show that an FPV system with single-axis tracking in the Mettur reservoir will help in reducing 135 918.87 tons of CO_2 emission annually. Based on the cost-analysis study, it is estimated that 35% of the total cost of the project is associated with the construction of the floating platforms. However, this can be effectively compensated for by the cost reduction due to the existing grid connection of the HEPP. This small-scale methodology exemplified for the Mettur reservoir outlining key design factors will support the 100 MW FPV target plan of Tamil Nadu government in Mettur reservoir. As India is a tropical country with high solar irradiance throughout the nation, the installation of FPV systems in similar reservoirs with existing HEPPs will enhance the solar power production and also help in reducing water evaporation. Similarly, the parametric investigations presented in the study will also help in deciding the suitable configuration of FPV systems in several other locations all over the world. As the advantages of FPV systems have been established based on the results obtained through the present study, future investigations by the research group will be focused on the comparison of FPV systems with single- and dual-axis tracking systems, static and dynamic panel-interconnection topologies, DC–DC converter configurations and detailed operation simulations of hybrid FPV systems with HEPPs.

2.10 Review of floating solar photovoltaic technologies – Hasnain Yousuf, Muhammad Quddamah Khokhar, Muhammad Aleem Zahid and Jaeun Kim – Current Photovoltaic Research (2020)

The first floating structure dates back to 2007 (Trapani and Redón Santafé, 2015). In the initial days, pontoons were used to mount the FSPV system. Although robust in its structure, it was expensive and not specifically designed for the FSPV (Rosa-Clot and Tina, 2018). Only recently, an alternative approach to utilise high-density polyethylene (HDPE) as a floating structure with galvanised steel supporting it became very popular due to its low manufacturing cost (Sahu et al., 2016). Few plants were set up with this technology, which proved to be successful (Cazzaniga et al., 2018) Other companies followed suit and proposed an innovative solution to use plastic as the base material (Trapani and Redón Santafé, 2015). One such company, Ciel & Terre, utilised 100% HDPE and build a modular, robust floating structure (Rosa-Clot and Tina, 2018). This became widely popular and currently has the most installed capacity (Oliveira-Pinto and Stokkermans, 2020). It meets the criteria of modularity, flexibility, robustness and safety, and thus, this floating structure has been adopted for the study. Both the enhanced performance of FSPV and the availability of scalable supporting structures meant that the focus moved towards accurately estimating the solar energy at a given site.

2.11 Energy-estimation methods of floating solar photovoltaic generation

With governments and institutions across the world incentivising the implementation of clean energy, these efforts have led to the availability of open-source energy estimation software. Widely used open-source software includes RET Screen (Natural Resources Canada), PV Watts (National Renewable Energy Laboratory, USA) and PVGIS (European Commission). PV Watts was incorporated in the study, due to the availability of NREL's international data set, its features to create intuitive shapes on lake bodies in addition to having produced energy corrected to PV cell temperature, allowing for realistic forecasts (Psomopoulos et al., 2015).

2.12 Impact of floating solar panels on evaporation – P.U. Poornima, R. Brindha, K. Subha Sharmini, Mallidi Goutham Reddy, P.Pavani, Makkena Sri Hari – IJRTE (2018)

Due to increasing concern over climate change, the conservation of water becomes extremely vital. An FSPV structure has its application in reducing water evaporation from water bodies. The rate of evaporation mainly depends on two factors: vapour pressure of air temperature and wind speed at a height of 10 m.(Rosa-Clot et al., 2017). FSPV systems can help save up to 33% of the water from evaporating on a natural lake (Sahu et al., 2016). A feasibility study considering 1 MW FSPV was carried out over the Kishore Sagar dam in Kota, Rajasthan, India. The authors estimated the plant to generate 18, 38, 519 kWh of energy per year while saving 37 million litres of water from evaporation (Mittal et al., 2017). A similar study aimed at analysing large reservoir potential across the whole of India. It was found that for each square kilometre of area, 1250 million litres of water per year could be saved from evaporating (Sharma and Kothari, 2016). On analysing electrical generation and reduction in evaporation at a reservoir in Spain, it is seen that when the entire structure was covered with FSPV, it generated 4,25,000 kWh per year, saving 5000 m^3 of water by covering a 4490 m^2 surface reservoir with floating PVs, which is 25% of the total reservoir capacity (Redón Santafé et al., 2014).

2.13 Environmental impacts of floating solar photovoltaic systems

The benefits of setting FSPV plant outweigh the drawbacks, especially in an urban landscape where lakes offer a stable environment for FSPV systems to perform and maintain due to proximity with technical logistics. Although there has been concern regarding FSPV having an impact on the quality of water and flora-fauna due to increased turbidity on installing mooring and shallowers (Serrano et al., 2016) the scale of the impact is site specific. Moreover, since waterbodies under consideration are lakes within the city bounds, the footprint of the project would be small, thus causing minimum to no harm to flora–fauna while increasing water quality by reducing algal bloom and decreasing the evaporation rate (Oliveira-Pinto and Stokkermans, 2020; Pimentel Da Silva and Branio, 2018). Even under these site conditions, precautions have to be taken to ensure that the material to be used is recyclable and the water to be used for cleaning is nondetergent. Furthermore, regular check and maintenance would allow the proper and efficient functioning of the FSPV system. The various aspects of FSPV integration covering performance, energy-estimation and environmental benefits have been extensively studied for large water bodies, like reservoirs and dams. There have been no similar studies conducted on smaller water bodies in urban areas. This study explores the suitability of using a large number of small waterbodies for solar energy generation in the urban set-up of Bengaluru City. The study solely covers energy estimation, quantifies the evaporation loses and provides a cost estimate. However, it does not include field studies and the environmental impact of solar panels on the lakes' ecosystem.

3. SCOPE OF THE PROJECT

3.1 Scope of the Project

Following are the scope of the project :

1. To increase production of renewable energy.
2. To reduce land aquation.
3. To reduce evaporation of water.
4. To increase net worth.

5. To reduce emission of carbon.
6. To provide water in different states.
7. To reduce water scarcity.

4. METHODOLOGY

4.1 Indian reservoirs selected for the study of FPV

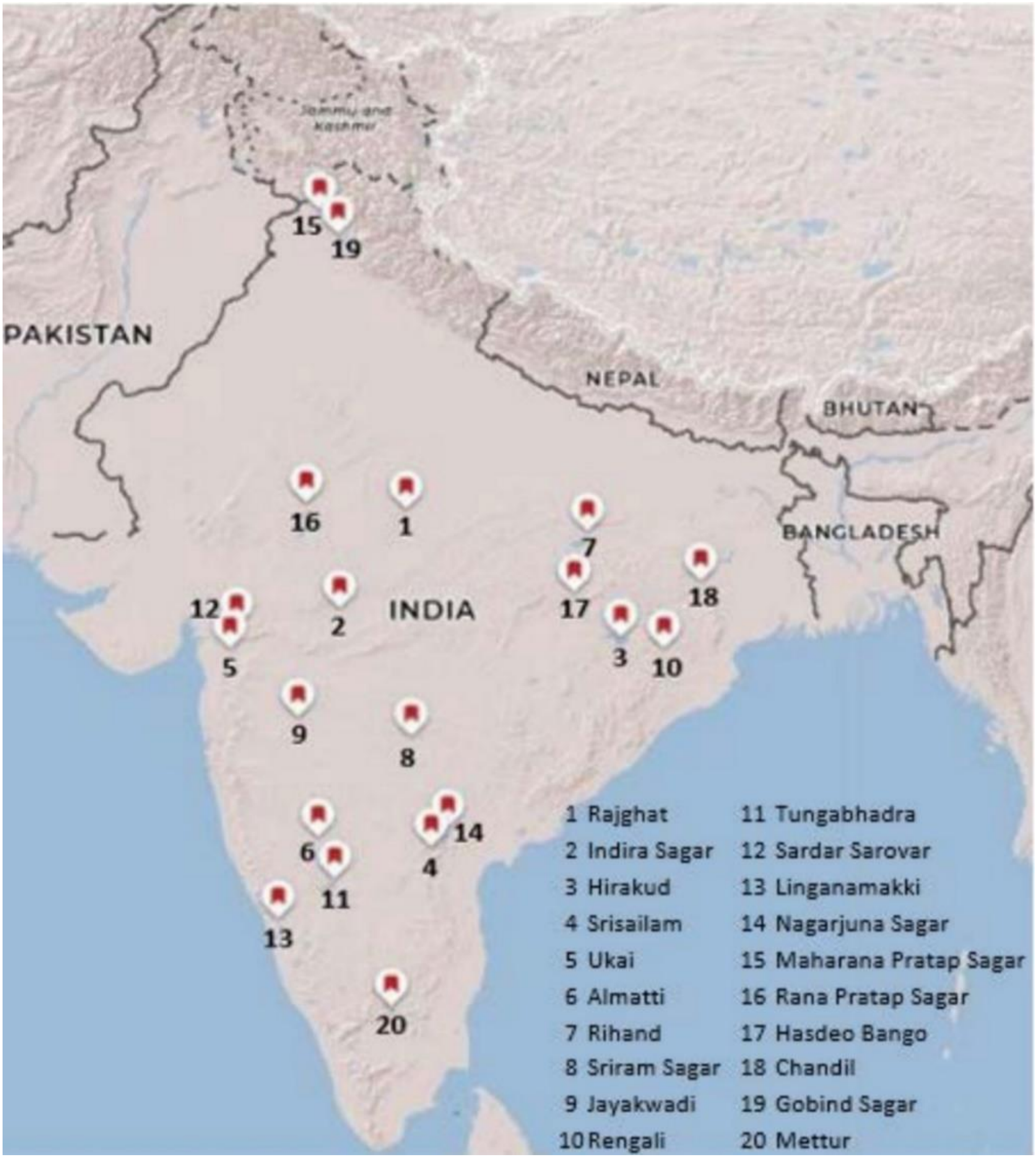


Figure 1 : Location of reservoirs in India

A detailed numerical investigation of the model FPV systems in 20 reservoirs with HEPP throughout India was carried out in the present study to predict the advantages of covering the water surface of the reservoirs with PV panels. Reservoirs located in 13 different states of India with a water surface area greater than 100 km^2 were selected for the study. The details of the selected reservoirs are listed in Table 1. The reservoirs are not selected based on the incoming irradiation levels of the location since the irradiation level across India is fair enough for power generation from the solar PV system throughout the year. The location of each selected reservoir is shown in Fig. 1. The water surface area of the selected reservoirs ranges from 153.46 to 2453 km^2, and the hydropower generation capacity of the reservoir varies from MW to GW levels.

Sr. no.	Reservoir	State	River	Total surface area (km^2)	Installed capacity of HEPP (MW)
1	Rajghat	Uttar Pradesh	Betwa	2453.00	45.00
2	Indira Sagar	Madhya Pradesh	Narmada	913.48	1000.00
3	Hirakud	Odisha	Mahanadi	743.00	331.50
4	Srisailam	Andhra Pradesh	Krishna	616.42	1670.00
5	Ukai	Gujarat	Tapi	600.95	300.00
6	Almatti	Karnataka	Krishna	487.87	290.00
7	Rihand	Uttar Pradesh	Rihand	468.00	300.00
8	Sriram Sagar	Telangana	Godavari	450.82	27.00
9	Jayakwadi	Maharashtra	Godavari	398.00	12.00
10	Rengali	Odisha	Brahmani	378.40	250.00

Sr. no.	Reservoir	State	River	Total surface area (km^2)	Installed capacity of HEPP (MW)
11	Tungabhadra	Karnataka	Tungabhadra	349.20	36.00
12	Sardar Sarovar	Gujarat	Narmada	348.67	1450.00
13	Linganamakki	Karnataka	Sharavati	317.28	55.00
14	Nagarjuna Sagar	Telangana	Krishna	284.90	815.00
15	Maharana Pratap Sagar	Himachal Pradesh	Beas	260.00	396.00
16	Rana Pratap Sagar	Rajasthan	Chambal	198.29	172.00
17	Hasdeo Bango	Chhattisgarh	Hasdeo	188.47	120.00
18	Chandil	Jharkhand	Subarnarekha	174.09	130.00
19	Gobind Sagar	Himachal Pradesh	Sutlej	168.35	1325.00
20	Mettur	Tamil Nadu	Cauvery	153.46	250.00

Table 1 : Largest reservoir in India selected for the study

Rajghat reservoir is the largest reservoir in India located in Uttar Pradesh on Betwa River, and the Rihand reservoir has the HEPP plant with a large hydropower capacity in the country. Indira Sagar dam has the second-largest reservoir with 1000 MW HEPP located in Madhya Pradesh. Srisailam dam on the river Krishna in Andhra Pradesh, Sardar Sarovar dam on river Narmada in Gujarat, and Bhakra dam (Gobind Sagar reservoir) on river Sutlej in Himachal Pradesh also have HEPP plants with a high capacity of more than 1000 MW. Ukai reservoir is the second -largest reservoir in Gujarat next to Sardar Sarovar, constructed on the river Tapi. Hirakud reservoir is the third-largest reservoir in Odisha with historic values like Asia's largest artificial lake and India's first multipurpose dam after its independence. Rengali reservoir is located in from Odisha, with the water surface area half that of Hirakud. Karnataka holds the three largest reservoirs, namely Almatti, Tungabhadra, and Linganamakki in river Krishna, Tungabhadra, and Sharavati.

Sriram Sagar reservoir on the river Godavari is the lifeline of the larger part of Telangana state. Apart from irrigation and power production, the reservoir also aids in flood control. Jayakwadi reservoir is also constructed on the same river in Maharashtra with the lowest HEPP capacity among the HEPPs in the selected dams. Nagarjuna Sagar dam stands between Andhra Pradesh and Telangana, and it is the world's largest and highest masonry dam. It is the primary source of irrigation and drinking to urban cities of the state. Maharana Pratap Sagar, situated in the foothills of Himalaya on the Beas River, is the crucial fishing reservoir of Himachal Pradesh. It is also declared as Ramsar Wetland site due to its rich waterfowl diversity. Gobind Sagar reservoir is also located on Himachal Pradesh and Punjab border. It is the second tallest dam in Asia and the highest straight gravity dam in India serving water for irrigation to Punjab, Haryana, Himachal Pradesh, and Rajasthan (Jain et al. 2007).

Figure 2 : Major components of floating solar PV

Hasdeo Bango reservoir on Hasdeo River is the first multipurpose water project in Chhattisgarh with three units of 40 MW capacity of HEPPs. Chandil reservoir is a multipurpose project in Jharkhand located on the river Subarnarekha. Finally, the Mettur reservoir on river Cauvery of Tamil Nadu is the identified spot of the state government to implement its first floating PV of 100 MW capacity. All these selected reservoirs are the major source of freshwater for agriculture, industrial, and domestic purposes. Thus, implementing FPV system will enhance their serving purpose in a better way by reducing evaporation. Further, the integration of FPV with the inbuilt HEPPs will result in increased renewable power production.

4.2 PV Modules

The basic integral part of the FSPV plant is solar PV modules and like conventional solar projects generally, poly or monocrystalline or thin film solar panels are used for the installation of the project. Selection of PV modules technology also defers because of space, cost, relative humidity, type of water-bodies, etc. The criteria for selection of PV modules are as follows:

1. Solar panel performance – power tolerance, efficiency, temperature coefficient especially in high moisture, and high humidity conditions.
2. Solar panel quality – certifications such as ISO 9001.
3. Solar panel durability – conformance to reliability standards such as IEC 61215 (wind loading).
4. Quality assurances by solar panel manufacturer – warranty.
5. IEC 62804 certification for potential-induced degradation (PID) from a solar panel manufacturer.
6. Solar panel manufacturer’s corporate profile and previous experiences.

4.3 Inverters

Like a conventional solar plant, DC power generated from solar PV modules is taken to the inverter through a series of combiner boxes and finally converted into AC power. A developer may select multiple string inverters or central inverters.

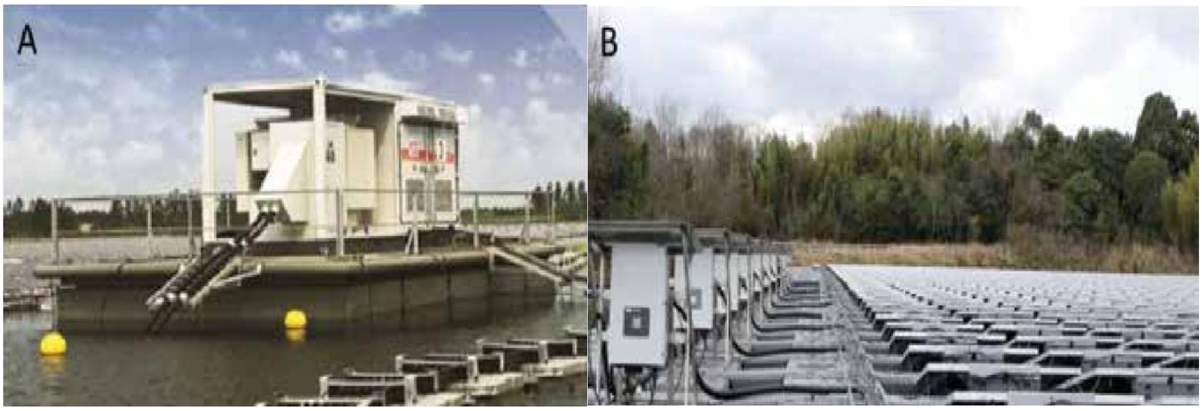


Figure 3 (A) : Central inverter placed on floating platform at China **(B)** String inverter

Depending upon scale and distance from shore, inverters can be placed either on a separate floating platform or on land. Generally, for smaller capacity FSPV inverter may be located on land near to PV arrays, otherwise for large capacity plants it is advisable to place inverter on a floating platform to avoid excessive resistive losses. Both the types have some inherited advantages and disadvantage and choosing one over another must be done wisely.

4.4 Floating Platform

This is the most crucial component of FSPV; it supports all necessary components like solar PV during the project time. Hence selection of appropriate materials for the floating platform becomes imperative. HDPE is the most popular material being used in a majority of the FSPV power plants across the globe. Other materials like FRP, medium density polyethylene (MDPE), and ferro-cement are also been utilized as materials for the floating platform. Various designs of a floating platform are described below.

Figure 4 : Floating Platform

4.4.1 Pure-floats design

It uses a specially designed float that can hold PV panels directly. The entire system is made in a modular fashion and has a provision to join with pins or bolts to make a large platform. Every single unit of such a system typically consists of the main and secondary floats. The main purpose of the secondary float is to provide a walkway for maintenance and additional buoyancy.

4.4.2 Sumitomo Mitsui Construction Co. Ltd.

The design is conceptually similar to Ciel & Terre, with some additional features like more regularly shaped float for denser packing and easy transportation. Additionally, a float is filled with polystyrene foam reducing the risk of sinking even when damaged and there is a usage of binding bands in the connecting part, which reduces the risk of structural failure for floats.

4.4.3 Hydrelio from Ciel & Terre

The Ciel & Terre is a French technology provider, providing innovative floating solar solutions since 2011. In fact, it has the majority of market share in terms of total numbers of installations across 25 countries, accounting for more than 300 MWp of installed capacity. Hydrelio floats are made of HDPE and connection pins are made of polypropylene combined with fiberglass. The floats are manufactured by blow molding and pins are made from injection molding.

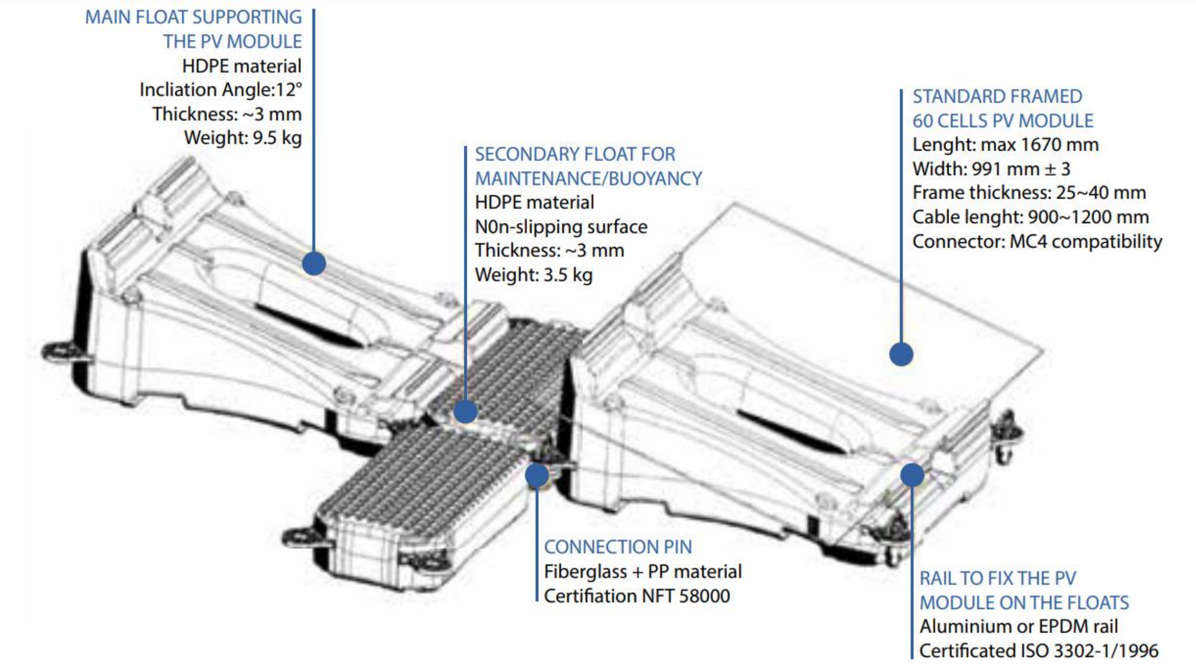


Figure 5 : Hydrelio design

4.4.4 Yellow Tropus Pvt Ltd.

The Yellow Tropus is an India-based design and engineering company focused and specialized in the development of FSPV power plants. The company is offering three types of technology for land-neutral FSPV plants which are as follows:

- **Stingray Technology** – It aims to minimize losses due to evaporation by covering more fraction of water surfaces. As per the company's claims the technology is best suitable for large waterbodies that include thermal power plants, steel plants, chemical industries, water tanks that is manmade waterbodies with no aquatic life. One unit of this supports three solar PV panels and has two float sections namely South C-Hex float and North C-Hex float.

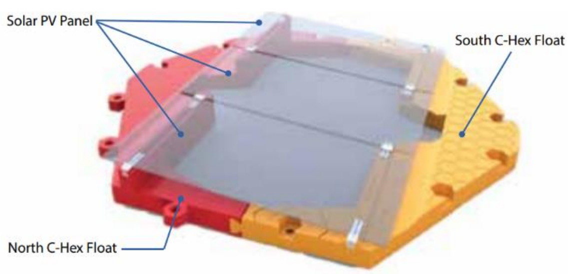


Figure 6 : Stingray technology

- **Seahorse technology** – One single unit of this consists of one walkway float and two solar PV panel float for supporting two solar PV panel.

- **Pontoon + metal structures design**

Figure 8 : Floaters design

The other common design which is used by some project developers uses a metal structure similar to land-based system and pontoons to provide buoyancy, hence eliminating the need for specially designed floats. The main advantage of this type of design is, easier to make floats and hence can be manufactured locally. However, access for operation and maintenance is difficult in such designs.

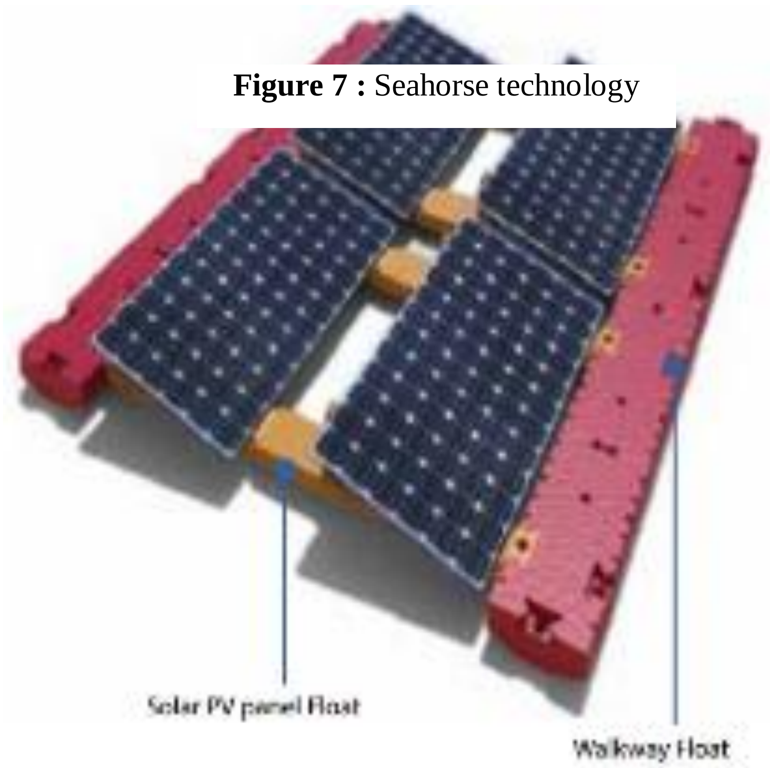


Figure 7 : Seahorse technology

4.5 Anchoring and Mooring System

Since FSPV plants are installed on water bodies, any variations in water levels induced by monsoon, wind velocity or increase/decrease in water quantity could be problematic for the plants. To avoid this situation, FSPV plants are anchored through mooring systems. The placement of a mooring system must take into account the location, bathymetry, soil conditions, and water-level variations. Mooring systems include quays, wharfs, jetties, piers, anchor buoys, and mooring buoys. Mooring system for a floating platform is generally attached with nylon polyester or nylon nautical ropes that are further tied to bollards on the bank and lashed at each corner. Mooring can be done in the following three ways – bank anchoring, bottom anchoring, and piles.

- **Bank anchoring –** This type of anchoring is particularly suitable for sites, which are shallow, small and where the bottom of the water basin does not allow any kind of anchoring. Bank anchoring is the most cost effective option and its suitability depends on the conditions of the shore. The main disadvantage of this type of mooring is its visibility from outside, impacting the landscape view.

- **Bottom anchoring –** Due to its suitability and flexibility, this type of anchoring is more popular than other types. This can be done in two ways – inserting anchors directly into the bottom of the waterbody and anchoring through concrete block placed at the bottom of the waterbody. The anchors are then connected to a floating platform with the help of mooring cable and chain. The cost of bottom anchoring is generally higher than other types as it requires careful planning while designing and involves divers.

- **Piles –** In this, piles are drilled into the bottom of the waterbody and the floating platform then be moored to the piles. The main advantage of this type of configuration is in their capability to handle water level variations however, the need for heavy equipment and civil work makes it expensive.

4.6 Cabling

In case of FSPV plants, cable routing and its management requires cautious planning. Unlike ground-based solar PV installations, movement of floating platform on a water surface causes cable length to vary in FSPV plants. The movement of floating platform is due to wind load and variations in water level. This requires extra length in form of slack to be provided for accommodating the movement of the floating platform. Neglecting this, insufficient cable length may result in cables to snap and rupture due to the tension. Apart from the cable length the other parameters upon which cable size depends are voltage and current of the cable and losses from the cable.

The cables can be routed in two ways – either via float on water surfaces or via submarine cables, later one being costlier. Cable trays, cable conduits, and cable clip holders are used to keep cables on the water surface. Cables used must be UV-resistant, and uses of wiring trunks are recommended to protect them from direct sunlight. To avoid DC cables/ conduits coming into contact with water, it is recommended to use proper cable ties or clamps. Similarly AC cables can be routed either via separate dedicated floats or via use of submarine cables for the connection to main electrical infrastructure onshore. In a nutshell the following element play vital role while sizing the cable and its routing in case of FSPV plants :

- Plot size
- Distance to shore
- Placement on inverters, transformers
- Quality of water
- Variations in water level

4.7 Unconventional Concepts in FSPV

4.7.1 Tracking

Like the ground-mounted solar PV panels, floating platforms can also be designed in a way to track the sun in single as well as dual axis, later being slightly difficult to achieve in the of FSPV. Tracking in a single axis (vertical-axis azimuth tracking) is relatively simple as low resistance is offered by water layer as compared to on land. In some of the initial designs of this type, platform (usually of circular shape) is moored around a central pile and motors are used to rotate it around a vertical axis of the central pile, thereby enabling single-axis rotation to track the sun in single axis. In some other designs, central pile is replaced by a fixed outer ring, which surrounds the floating platform.

In a recent development, India-based Yellow Tropus Pvt Ltd claims the world's first dual-axis-tracking (DAT) FSPV plant technology capable of generating 40% higher energy generation as compared to land-based solar power plants. A typical plant based on this technology consists of a toroidal wave attenuator, a Y-shaped flotation device resembling a hexagonal honeycomb shape grid after assembling, and a tracking system to track the sun in the two axes. The main function of toroidal wave attenuator is to balance out the effect of turbulence caused by high winds and waves, hence acting as the first line of defense and providing guidance for azimuthal tracking.

Figure 9 : A–200 kW grid-connected single axis based floating solar PV plant in Suvereto, Italy

4.7.2 Concentrated FSPV

As the name depicted, this uses a reflecting mirror or Fresnel lens to concentrate the sun rays on the solar PV cell/panel. In principle, the technology is similar to ground mounted concentrated solar PV (CSPV), the only difference is an assembly of solar PV cell/panel and reflecting mirror /concentrating lens is mounted on the floating platform instead of attached to the ground. Readily availability of water as a coolant and lower ambient temperature could make this technology more relevant as compared to the ground-mounted one. However, the constant movement of a floating platform on a water surface makes it difficult to track the sun along the two axes, resulting in lower concentration ratio.

In another design of its kind in India, a pilot project uses a concentrator made out of plastic also known as liquid solar array (LSA). The lightweight plastic lens rotates to track the sun to achieve the required rotation needed. The PV cells are placed beneath the concentrator in a PV container that sits in the water. This helps in dissipating heat generated due to high concentration and keeping the PV cells cool. The key feature of this technology is its simplicity and minimal use of materials.

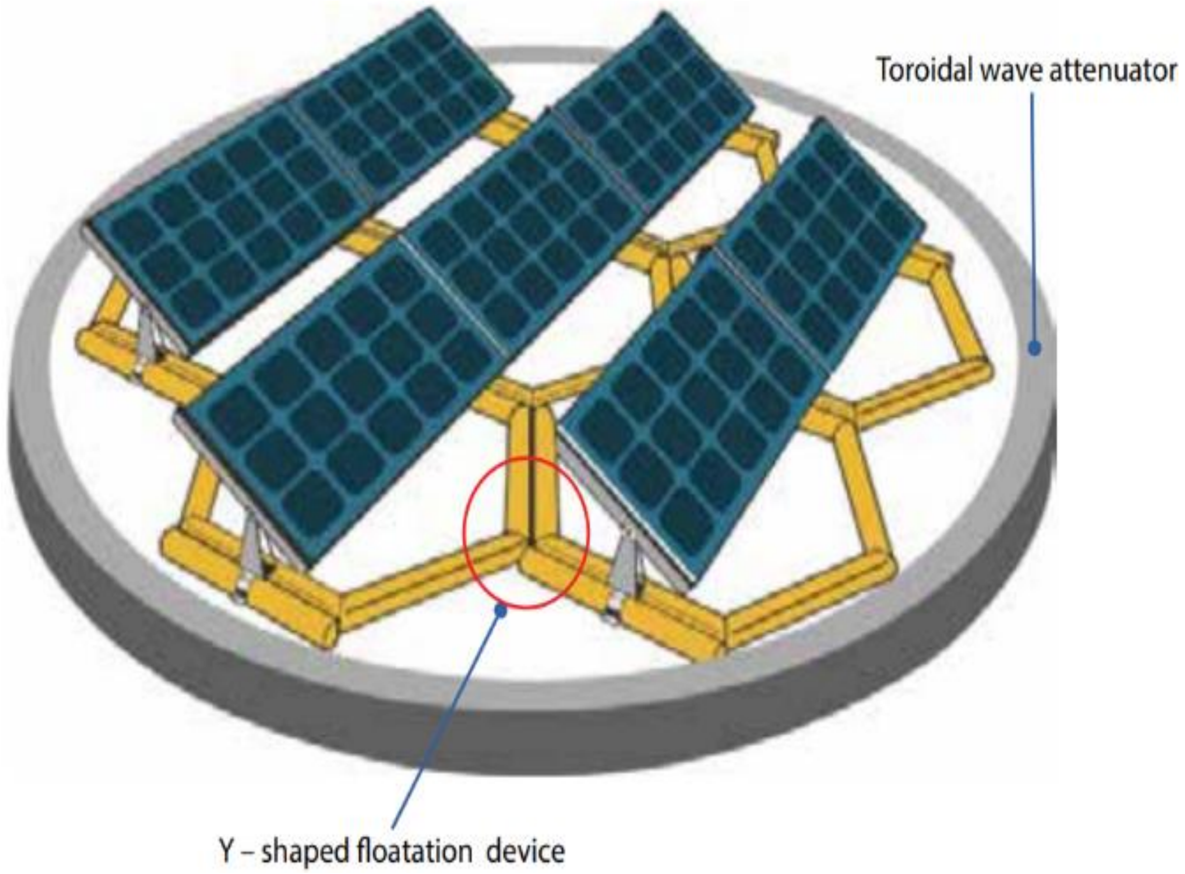


Figure 10 : Dual-axis tracking technology

Figure 11 : Phase I of 4MW floating solar PV plant at wastewater treatment facility, Jamestown Australia

Figure 12 : A pilot installation in Colignola (Pisa) on an artificial basin by Koine Multimedia

4.7.3 Membranes and mats type

In this type of platform, rubber mats are generally used to entirely cover the water surface. These rubber mats now act as a base for solar panel installation. This type is particularly suitable for small manmade waterbodies (size less than 0.2 km^2), which are primarily used for water storage and have no aquatic life. Some advantages of this type of platform are simplicity in design, easy installation, and maintenance, the ability to accommodate changes in the level of water, etc. The type is especially suitable for areas prone to water scarcity like a desert and arid areas. In another design by the company name Ocean Sun from Norway, a floating platform is made of rafts, which is 70 m in diameter. Each raft is like a giant inflatable pool made of a plastic ring and a thin membrane.

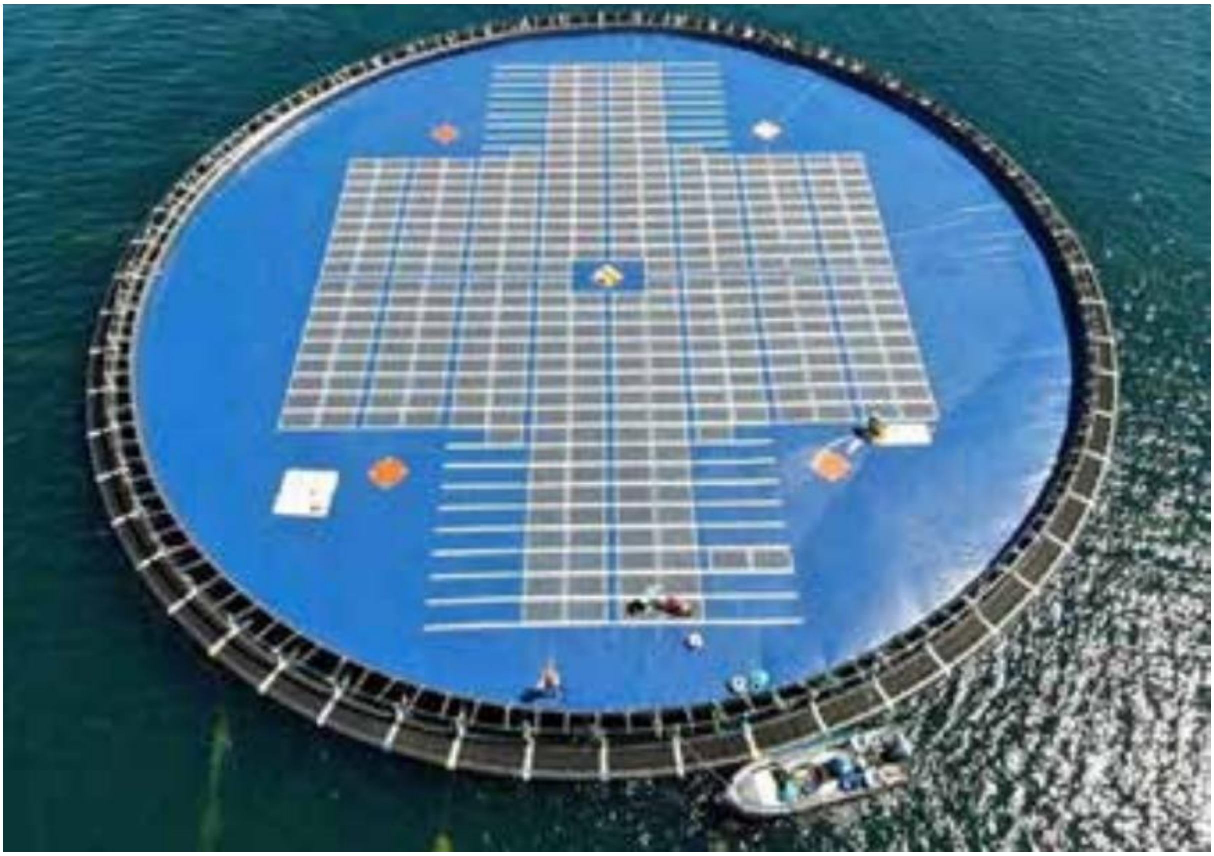


Figure 13 : Floating platform

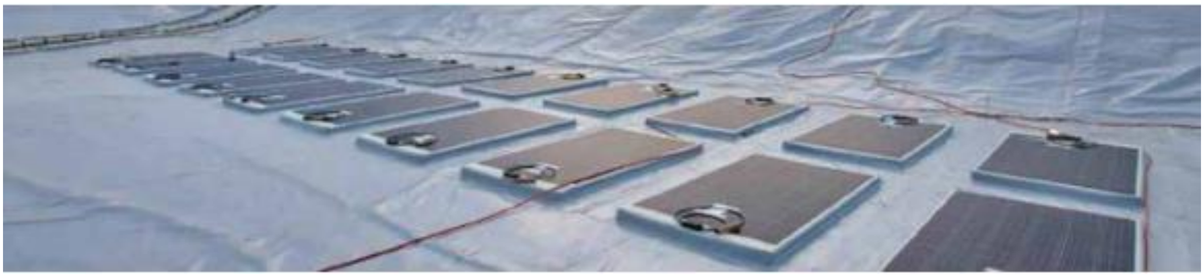


Figure 14 : Floating platform

Figure 15 : A pilot installation based on liquid solar array technology by Sun energy in hydro dam in India

4.7.4 Submerged FSPV

As the name indicates, in this type PV modules are directly placed just beneath the water surface. Apart from achieving the lower module temperatures, one major advantage of this type is its simple mooring requirement due to reducing mechanical loading and lesser internal stress because of the use of flexible modules as compared to conventional PV modules with rigid mounting structure. An increase in the flexibility of the entire system reduces the number of material requirements and also makes transportation easy. However, the technology is in its nascent stage at the moment and has some concerns like long-term reliability of PV modules and electrical safety under submersible conditions. MIRARCO mining innovation had deployed the world's first test system having 0.57 kWp capacity in 2010.

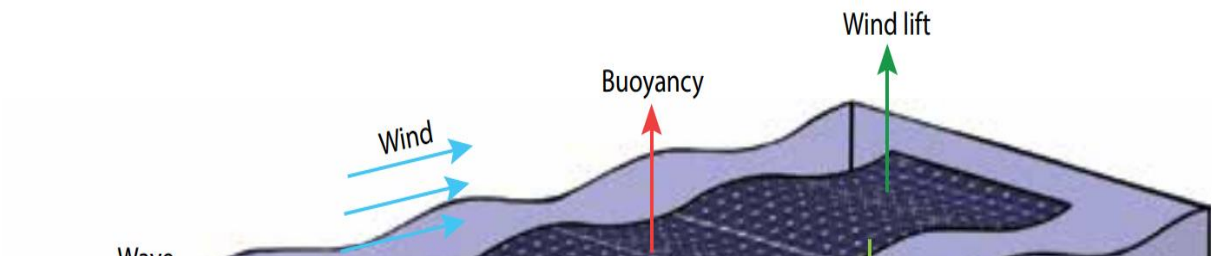


Figure 17 : 0.57 kWp submerged floating solar PV based plant

5. DETAILS OF DESIGNS, WORKING AND PROCESS

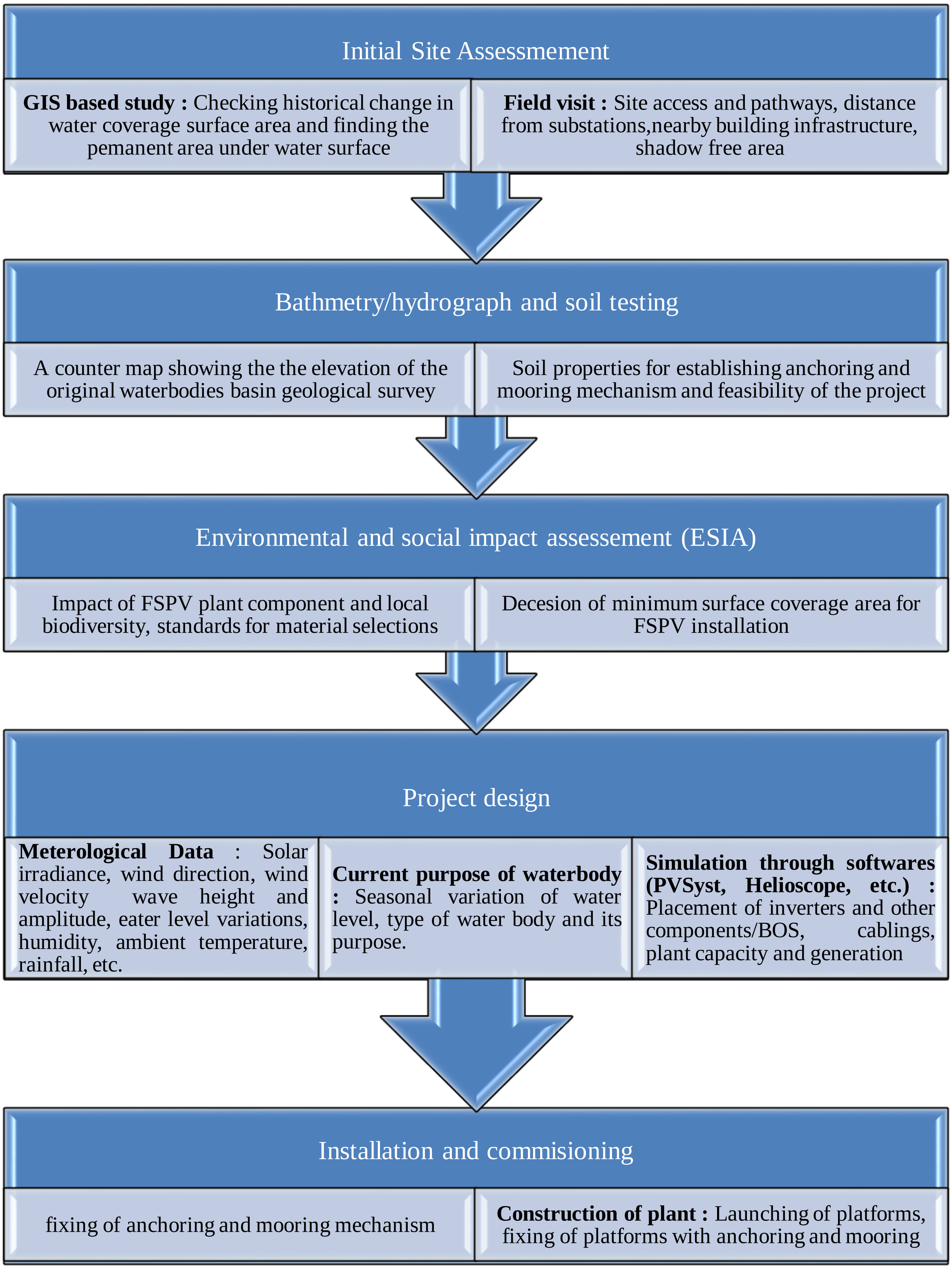


Table 2 : A flow chart of floating solar PV project design

FSPV as a technology is still in the developing phase and there are several vital elements including methods/ steps for establishing FSPV plants that are not available publically. Hence, developing the best practice guidelines for FSPV sector would help project developers, investors, and policymakers in understanding the procedures of FSPV project development. In a nutshell, major steps of developing an FSPV project can be understood through Table 2.

5.1 Initial Site Assessments

The initial site assessments of the proposed waterbody should be carried out to understand the feasibility of the site for the FSPV project development. The site assessments can be executed in the two following steps:

- **GIS-based assessment –** Assessments through the GIS tool really help in finding out the site feasibility for an FSPV plant establishment. The GIS tool provides information on water surface variations due to seasonal changes in the past years. The outcome of the analysis gives an approximate surface area of the waterbody which remains permanent irrespective of seasonal water-level deviations.
- **Field assessment –** An initial site visit is essential to understand the ground reality of the site conditions. The visit mainly covers the assessment of type of waterbody and its purpose, accessibility to the site, location of nearest substations, and information on restricted area. In case the waterbody is used for some industrial purposes or in power plants or water treatment plants, etc., details like fire hazard buffer zone, nearby building infrastructure for calculating the shadow-free area, availability of space while installation, space available near shore while placing the floating platform into waterbody, etc., are some of the important points that need to be looked into.

Eventually, the initial site assessments assist in estimating a suitable area for FSPV installation and water quality of reservoir/pond/lagoon.

5.2 Bathymetry/Hydrography and Soil Testing

A bathymetric survey is a method to estimate the depth of a waterbody, and it also helps in understanding the underwater geography of a particular waterbody. There are several methods available for carrying out bathymetric surveys such as multibeam, single beam, sub-bottom profilers, Eco Mapper Autonomous Under Vehicle (EAUV), and acoustic doppler current profiler (ADCP). A hydrography survey deals with providing physical features such as understanding of underwater navigations, accurate positions, depictions of hills, etc., of waterbodies.

Both bathymetric and/or hydrographic surveys are useful in understanding the topography of water-bed such as locating any bed-rock outcrops, obstacles at bed level if any, and optimum locations for placing anchors and mooring for the floating platform. The bathymetric and hydrographic surveys that roughly take between 7 and 15 days to conduct, involve the use of precise instruments and methods. The survey gives information on the waterbed in the form of a contour map comprising details related to the depth of the waterbed with reference to datum level. The contour map, as shown in Figure 17, is a decisive factor in identifying the best places of anchoring and mooring, desilting requirements, etc.

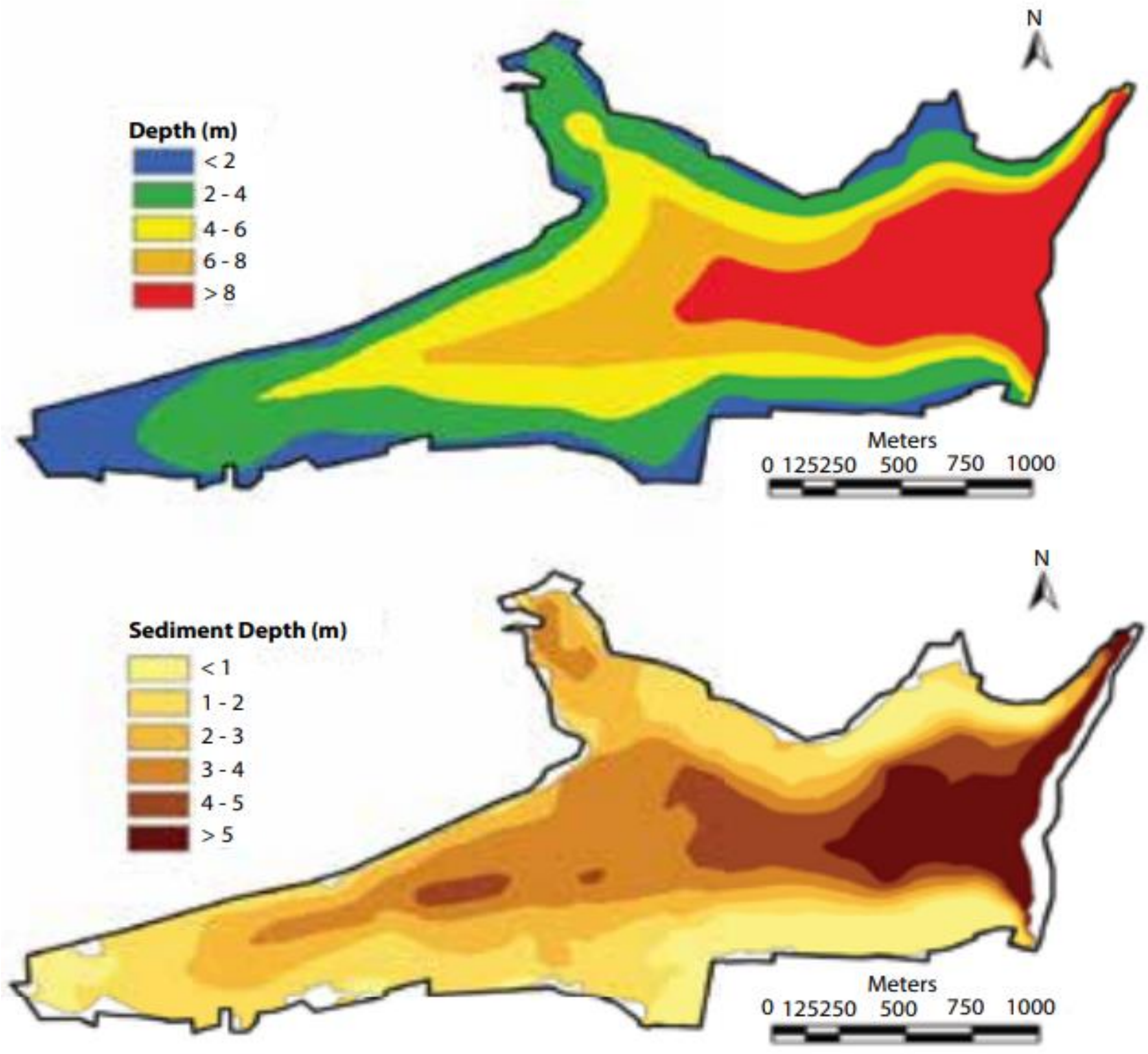


Figure 18 : (A) A historical bathymetric map of Bellandur Lake. (B) Sediment accumulation in Bellandur Lake

This step is vital to judge the overall techno-commercial viability of the projects, and failure in conducting this properly could cause extensive damage to the FSPV plant as shown in Figure 18.

Typically instruments used for bathymetric/hydrographic surveys are shown in Figure 19. Soil testing is also an important step for deciding the type and design of anchoring that would be required. It provides information on soil composition of the banks and waterbody beds, etc. The soil test must be conducted as per IS: 2131-1963 and a testing report must contain information like – natural moisture content, bulk density, dry density, specific gravity, grain size distribution, and atterberg limits along with bore logs with SPT 'N' values.

Figure 19 : Impact of improper bathymetry and/or hydrography surveys

Figure 20 : Instruments for conducting bathymetric/hydrographic surveys

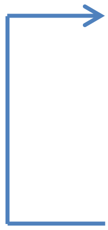
5.3 Environmental and Social Impact Assessment detail ESIA

As highlighted in this report, the long-term impacts of deploying large-scale FSPV-based plants on the local environment are poorly known. Also, an FSPV plant includes components like floating platform, anchoring and mooring system, cables, inverters, etc. which are continuously exposed to water. Additionally, these waterbodies are often used for several social usages like fishing, farming, navigation, drinking, etc. and their characteristics vary widely and are site specific. Hence, it is imperative to conduct a detail ESIA for each site to assess the long term impact of deploying an FSPV on a particular waterbody and its suitability.

5.4 Project Design

Upon receiving the clearance from ESIA, designing of FSPV plants can begin. For the sake of simplicity, the entire project design needs the following three components –

- **Meteorological data –** Meteorological or met data are essential to understand the local resources pertaining to FSPV. The met data comprise solar radiation, wind direction, wind velocity, wave height



and amplitude, humidity, ambient temperature, rainfall, etc.

Figure 21 : A flow chart of steps in floating solar PV project design

- **Water quality information** – Water quality information is really crucial in selecting the material of anchoring and mooring system, floating platform, cables and understating the long-term effects it may cause on the life of FSPV plant components. Hence it is essential to have a thorough investigation on water quality of the waterbody while taking the sample from multiple points. A typical water quality report should contain information such as physical and chemical properties of water (pH, turbidity, salinity, dissolved oxygen (DO), total dissolved solids (TDS) level, temperature of water, etc., and must follow IS:10500 2012.
- **Simulation** – Simulation softwares like PVsyst, HelioScope, ANSYS, OrcaFlex, CFD, etc., can be used in designing the layout, angle of tilt, plot size, designing of anchoring and mooring lines, placement of inverters, plant capacity, balance of system (BOS), estimates of energy generations for the entire project life, etc. The general steps for designing the FSPV plants are explained in Figure 20.

Angle of tilt Dependencies of PV modules angle of tilt on the location of the plant and wind speeds are well known. In fact, the wind load plays a vital role in deciding the quantum of drag force being induced on the mounting structure. In case of FSPV plants, this is even of much importance, as an incorrect angle of tilt can induce higher drag forces causing severe damage to the entire plant structure. Typically, wind loads are measured as per the Indian Standards IS 875 (Part 3). The standard provides details of the wind speed for every Indian city. Based on multiple discussions with various expert groups, angle of tilt in case of FSPV projects can be kept as per the details given in Table 3.

Mean wind speed (m/s)	Angle of tilt (°)
> 35	5
25 - 35	10
< 25	15

Table 3 : Angle of tilt with respect to wind speed

Plot size Generally, in ground-mounted solar PV plant, drag force is induced on the individual row of the panels and is irrespective of the plot size as shown in Figure 21. However, with respect to FSPV plants, since each row is connected to a single outer frame resembling a single plot, drag forces are induced on the entire plot as indicated in Figure 22. This makes the plot size, in the case of FSPV much more important in comparison to ground-mounted plants. To understand this let us take an example of a recent fire incident due to typhoon that happened in Japan's 13.7MWp FSPV plant. The entire 13.7MWp plant, covering a total area of 137,326 m² was assembled in a large single outer frame. Due to its large plot size, the high drag force developed during the typhoon tore the plant from the middle section while anchoring lines remained intact, as depicted in Figure 25. Hence, in order to minimize the drag force, it is recommended to keep a single plot size small and symmetrical (not more than 3–4 MWp).

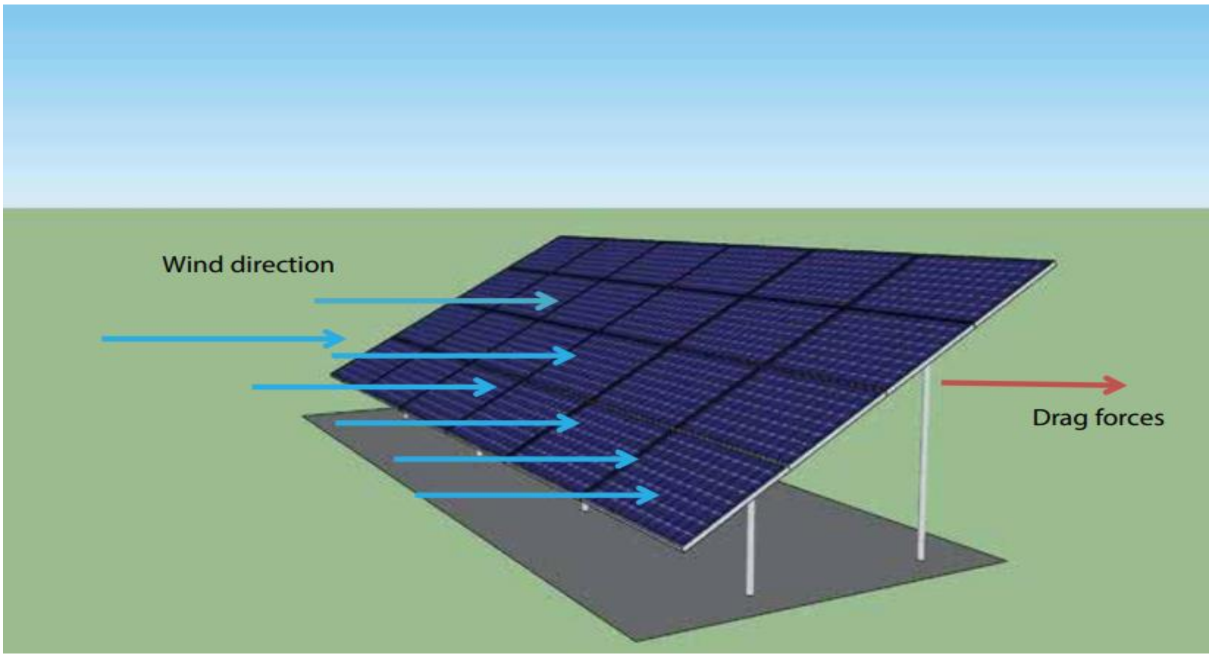


Figure 22 : Drag forces in ground-mounted solar PV (only for representational purpose)

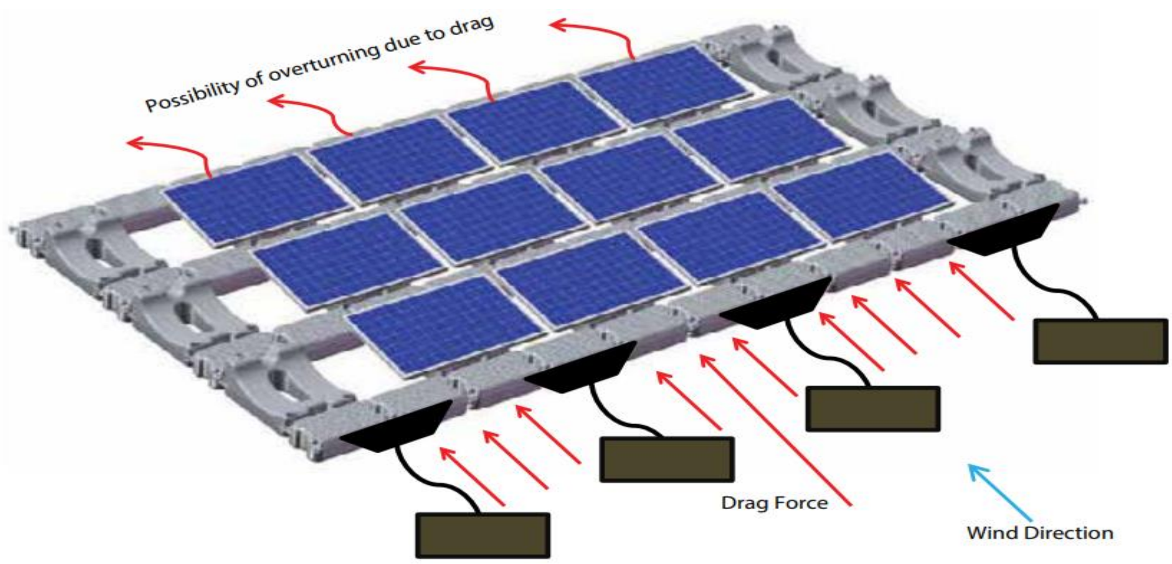


Figure 23 : Schematic of drag forces developed in floating solar PV plant

Figure 24 : Japan's 13.7MWp floating solar PV plant before (A) and after (B). The red circle indicates that the anchoring

Calculation of drag forces Once the angle of tilt and plot size are decided, the detailed analysis of drag forces over the entire plant must be investigated. CFD simulations are performed to calculate the value of drag force and its points of action over entire plot, as explained in the Figure 26.

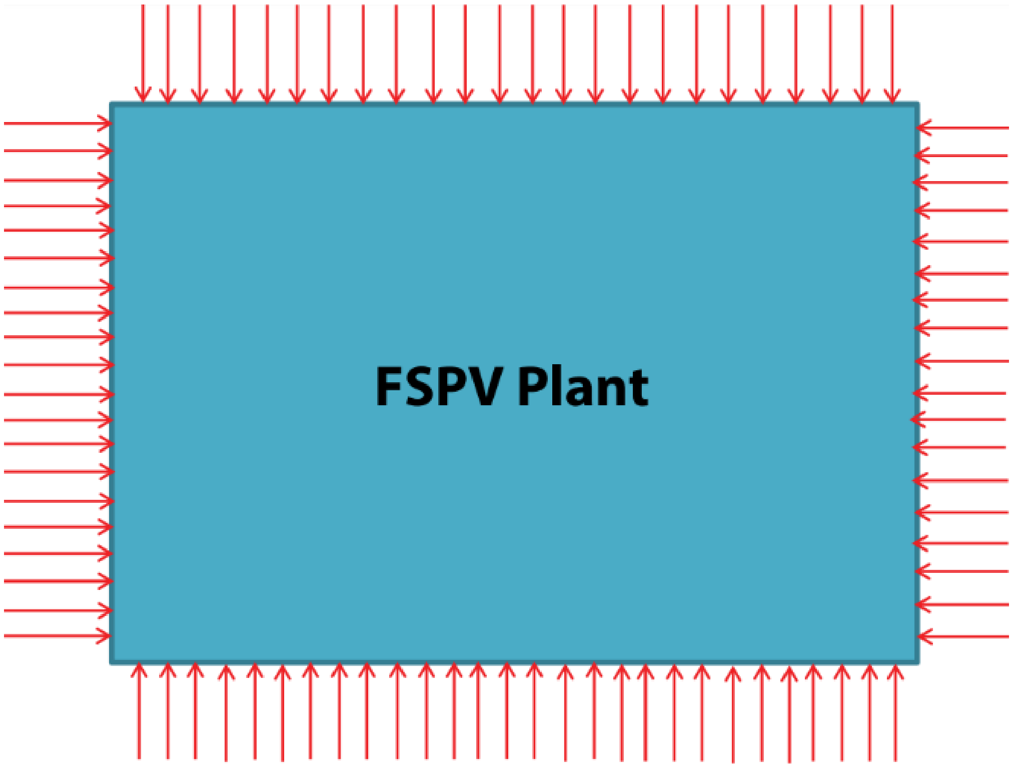


Figure 25 : Drag forces on floating solar PV plant (a representational image)

5.4.1 Calculation of anchoring and mooring lines

After drag force and its points of action get simulated, forces induced on the anchoring and mooring lines can be calculated through softwares like OrcaFlex, ANSYS, etc. The results of the software are used in calculating the forces on individual points of the anchoring and mooring lines.

5.4.2 Response amplitude operator

A response amplitude operator (RAO) is a method that is used to find the floating structure's characteristic response created by wave action. The results obtained from this study help in choosing mooring wire ropes, which can sustain sufficient tensions in extreme conditions. The calculations of tensions (in kN) on different ropes are calculated in RAO.

5.4.3 Measuring end load and its comparison with the safe load

Once the tensions in different loads are identified, the next step is to calculate end loads on each of these points and this should be performed under permissible limits. Further, this calculation should be compared with safe load. The designs considered as safe if the end load is lesser than the safe load, otherwise the process has to be repeated till the value of end load becomes lesser than safe load.

5.5 Installation and Commissioning

In comparison to ground-based solar PV plants, FSPV plants are easy to install and may not require heavy civil construction in most cases. The entire process of installation and commissioning can be divided into three steps :

1. Site preparation and construction
2. Installation
3. Commissioning

As in any solar PV-based plant development, the first step is to prepare the site. This involves civil works for grading and leveling, excavating the foundation for mooring and anchoring, fabricating a dedicated launching platform for launching the floating platform into the water surface (this depends upon access to the water surface at the site), fabricating inverter housing, building embankment for foundation protection, etc. Installation begins after the initial site preparation is completed. It includes connecting the rows of floats to form a floating platform, mounting PV panels on the floating platform, connecting cables, inverters, transmission lines, etc. Since FSPV plants are installed on waterbodies and are often subjected to harsh environmental conditions like high humidity, high winds, etc., it is recommended that the solar PV panels, supporting structure and other balance of systems such as inverters, cables, etc., are chosen wisely. Some activities involved under installation and commissioning are likely to generate air and noise emissions. Such emissions and wastes generated could have an adverse impact on local bio-diversity. Therefore, it is essential to follow the recommendations provided in the ESIA report while adhering to the specific standards; some of them are also explained in the subsequent section.

5.6 Technical Specification and Standards

As discussed in this report, FSPV plants are deployed in waterbodies and often subjected to harsh environments. Hence it is important to consider relevant standards to ensure the quality of the FSPV plant components while being cautions of not degrading the quality of water as well as local bio-diversity. It is recommended to adhere to the following technical standards of the major components used in grid-connected FSPV-based plants –

Sr. No.	Component	Standard	Description
1.		IEC 61215-1	Ed. 1.0 Terrestrial photovoltaic modules – Design qualification and type approval - Part 1: Test requirements
2.		IEC 61215-1-1 Ed. 1.0	Terrestrial photovoltaic modules – Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic modules
3.		IEC 61730-1Ed. 2.0	Photovoltaic module safety qualification Part 1: Requirements for construction
4.		IEC 61730-2 Ed.2	Photovoltaic module safety qualification Part 2: Requirements for testing
5.		IEC 61701 Ed.2	Salt mist corrosion testing of photovoltaic modules (applicable for coastal and marine environment)
6.		IEC 62716 Ed.1	Photovoltaic modules – Ammonia corrosion testing
7.		IEC TS 62804-1 Ed.1	Photovoltaic modules – Test methods for the detection of potential-induced degradation Part 1: Crystalline silicon
8.		ASTM D1693 (or equivalent ISO Standards)	Test for environmental stress cracking of HDPE
9.		ISO 16770	Stress cracking resistance of HDPE
10.		IS 15410:2003 or equivalent BS 6920:2014	Test for drinking water compatibility, material safe for drinking water
11.		RoHS directive 2002/ 95/EC	Test for restriction of hazardous substances

12.		ASTM D790 (or equivalent ISO Standards)	Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials
13.		ISO 178	Plastics – Determination of flexural properties
14.		ASTM D638, ISO 527	Standard test method for tensile properties of plastics
15.		ASTM D695, ISO 604	Standard test method for compressive strength properties of plastics
16.		ISO 16770	Full notch creep test (FNCT)
17.		ASTM D2565 (or equivalent ISO Standards)	Standard practice for xenon-arc exposure of plastic intended for outdoor applications
18.		ASTM D4329(or equivalent ISO Standards)	Standard practice for fluorescent ultraviolet (UV) lamp apparatus exposure of plastics
19.		ASTM D1693-15 (or equivalent ISO Standards)	Standard test method for environmental stress cracking of ethylene plastics
20.		ASTM D5397-07(2012)	Standard test method for environmental stress crack resistance of polyolefin geo-membrane
21.		IS 15410:2003 or equivalent BS6920	Containers for packaging of natural mineral water and packaged drinking water
22.		IEC 61683	Efficiency measurements
23.		IEC 60068-2/ IEC 62093	Environmental testing
24.		IEC 61000-6-2, IEC 61000-6-4 & other	Electromagnetic compatibility (EMC)

		relevant parts of IEC 61000	
25.		IEC 62103/ 62109-1&2	Electrical safety
26.		IEEE1547/IEC 62116/ UL1741 or equivalent BIS standards	Protection against islanding of grid
27.		LVRT compliance	As per the latest CERC guidelines/order/ regulations
28.		Grid connectivity	Relevant CERC regulations (including LVRT compliance) and grid code as amended and revised from time to time.
29.		Rated capacity	Nominal/rated output power of the inverter (if different power ratings are mentioned at different temperatures, then power rating at 50°C shall be considered) in kilowatt will be considered as inverter rated capacity
30.		BS/ EN 50618 / TUV 2pfg 1169/08.2007	Solar-grade cables for outdoor installation
31.		IEC 60227 / IS 694 IEC 60502 / IS 1554 (Pt. I & II)	General test and measuring method of PVC-insulated cables for working voltage upto and including 1100 V and UV resistant for outdoor installation
32.		IS 3043	Code of practice for earthing
33.		IEEE 80	IEEE guide for safety in AC substation surrounding

34.		IEEE 142	IEEE recommended practice for grounding of industrial and commercial power systems
35.		IEC 60947 part I,II,III	
36.		IS 60947 Part I,II,III	
37.		EN 50521	
38.		IP 65/66(for outdoor)	
39.		IP 54(for indoor)	

Table 4 : Technical standards for various components of floating solar PV plants

Apart from the aforementioned technical standards, it is also important to consider the following points before deploying the FSPV-based plants:

- The material used for the floating platform must be UV stabilized (UV20) and should be manufactured from appropriate thermoplastic having good environmental stress crack resistance (ESCR) such that the floating platform can withstand a minimum operational period of 25 years without any discolouration. Also, materials used for floating platforms should be chemically resistant to acid, lye, petrol, mineral oil, and most importantly, should not contaminate the waterbody in any condition in its lifetime. Additionally, a floating platform, when deployed in waterbodies, containing raw water, should be designed in a manner such that it does not restrict the process of gas exchange across the air–water interface. This is why voids of appropriate size must be provided and should be made an integral part of floating platform design.
- The floating platform, module-mounting structure, and anchoring and mooring system must be designed while considering the worst-case scenario and must be able to withstand variation in ambient temperature in the range of +50°C to -10°C.
- In order to perform PV module cleaning and regular operation and maintenance, appropriate measures must be incorporated in the floating platform design.

- The floating platform must re-processable and recyclable at the end of its useful life.
- The anchoring and mooring system must be designed while considering the variation in water level and prevailing wind speed. It should also restrict any lateral movement of the plant as well as not cause any negative impact on local biodiversity of the waterbody.
- All cables and connectors used in FSPV plants are of solar grade and able to withstand harsh environmental conditions for 25 years.

6. RESULTS AND APPLICATIONS

This section details the results of the performance analysis, performed by simulated different cooling conditions on MATLAB. Cooling conditions are crucial for FPV plant performance enhancement. First, the performance results of the PFV plant without cooling is detailed. The two cases mentioned in the previous section are then presented. Simulations are performed to get a full understanding of how the cooling process can impact the FPV plant performance. Both cases results are highlighted in terms of FPV plant operation and performance indicators are presented. Furthermore, the two cases are compared at the end of the section, together with the FPV plant performance without cooling, and the results obtained are discussed in great detail.

6.1 FPV Plant Performance

Before implementing cooling strategies, the FPV solar system is modelled and operation is simulated on a long-term basis during the lifetime of the plant. The results of the performance analysis of the FPV plant in Sugu are presented in Table 13. The obtained overall performance ratio is high, over 80%. However, the FPV plant is subject to high temperature losses, about 6.5% on average annually. Moreover, even with an azimuth angle of about 90°, the specific generation of the solar system is good at the chosen latitude. From an economic point of view, the total investment of the plant (CAPEX) is 1,626,701 USD, with the chosen panels and anchoring design. Total costs per year (OPEX) are 28,320 USD, taking into account maintenance and equipment replacement over the years. Finally, the lifetime revenues of the plant are 2,832,163 USD, with the current Feed-in-Tariff in Taiwan.

Performance Analysis	**Annual Indicators**	**Values**	**Unit**
	Performance Ratio PR	83.95	%
	Specific Production SP	1,362.4	kWh/kWp
	Annual Generation	1,543.3	MWh
	Lifetime Net Revenue	2,832,163	USD
	Net Present Value NPV	890,583	USD
	Levelised Cost of Electricity LCOE	117.28	USD/kWh
	Internal Rate of Return IRR	12.57	%
	FPV Pay Back	11.93	Years

Table 5 : Performance of the uncooled FPV plant

Such FPV performance can be improved by the use of cooling system, thus reducing temperature losses during the day. In the following sections, the FPV plant results are compared to cooled FPV plant results.

7. CONCLUSION AND FUTURE SCOPE

With the advancement in solar photovoltaic system, the floating solar power plant plays a vital role. The advantage of the floating system is reduction of evaporation, thus helping preserve water levels during extreme summer. When panels are installed on floating platform, the heating problem of solar panel on land is solved to a great extent. This floating technology is long-lasting, cost effective, flexible and less time for installation. The advantages and technical details of floating solar power plant are presented in this paper. With this advancement, country like India can meet its power demand in future.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 06 | June - 2022 Impact Factor: 7.185 ISSN: 2582-3930

8. APPENDIX

- GW – Giga Watt
- MW – Mega Watt
- PV – Photovoltanic
- FSPV – Floating Solar Photovoltanic
- LCOE – Levelised Cost of Electricity
- MNRE – Ministry of New & Renewable Energy
- BIS – Bureau of Indian Standards
- NISE – National Institute of Solar Energy
- SECI – Solar Energy Corporation of India
- NTPC – National Thermal Power Corporation
- EAUV - Eco Mapper Autonomous Under Vehicle
- UV – Ultra-violent
- EV – Electrical Vehicle
- DC – Direct Current
- USD – United States Dollar
- HDPE – High Density Polyethylene
- FRP – Fiber-Reinforced Plastic
- PID – Potential Induced Degradation
- DAT – Dual Axis Tracking
- MDPE – Medium Density Polyethylene
- ISO – International Organization for standardization
- IEC – International Electrotechnical Commission
- LSA – Liquid Solar Array
- CSPV – Concentrated Solar Photovoltanic
- MIRARCO - Mining Innovation Rehabilitation and Applied Research Corporation
- GIS – Geographic Information System
- ADCP – Acoustic Doppler Current Profiler
- DO – Dissolved Oxygen
- TDS – Total Dissolved Solid
- ESIA - Environmental and Social Impact Assessment
- BOS – Balance Of System
- RAO – Response Amplitude Operator
- CFD – Calculation of drag force on entire plant
- EMC – Electromagnetic Compatibility
- FNCT - Full notch creep test
- IEEE - Institute of Electrical and Electronics Engineers
- V - Voltage
- AC – Alternate Current
- PR – Performance Ratio
- SP – Specific Production
- NPV – Net Present Value
- IRR – Internal Rate of Return

9. References and Bibliography

1. https://www.icevirtuallibrary.com/doi/full/10.1680/jsmic.21.00002a#_i9
2. https://www.teriin.org/sites/default/files/2020-01/floating-solar-PV-report.pdf
3. http://data.conferenceworld.in/IETEOCTOBER2017/41.pdf
4. www.mnre.gov.in
5. https://www.ijser.in
6. Wikipedia
7. https://adwitsolar.com
8. kerala Solar Power Plant Report
9. Abdolzadeh, M. "Imroving the effectivenss of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells." Renewable Energy, 2008.
10. Bahaidarah, Haitham. "Experimental perfromance evaluation and modeling of jet impingement cooling for thermal management of photovoltaics." Solar Energy, 2016.
11. Brennan, M.P. "Effects of spectral albedo on solar photovoltaic devices." Solar Energy Materials and Solar Cells, 2014.
12. Bureau of Energy. "Developments in Taiwan's Electricity Market." 2017.
13. Castillo, Luis. Techno-economic Analysis of Combined Hybrid Concentrating Solar and Photovoltaic Power Plants: a case study for optimizing solar energy integration into the South African electricity grid. KTH, 2014.
14. Cazzaniga, R. "Floating photovoltaic plants: Performance analysis and design solutions." Renewable and Sustainable Energy Reviews, 2017.
15. Central Weather Bureau of Taiwan. 2011. http://www.cwb.gov.tw (accessed October 2017).
16. Choi, Young-Kwan. "A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact ." International Journal of Software Engineering, 2014.
17. Ciel & Terre. http://www.ciel-et-terre.net/ (accessed August 2017).
18. Ciel & Terre. "C&T Company Profile." 2017.
19. Ciel & Terre. "Floating PV solar plants using Hydrelio system." 2016.
20. Copenhagen Economics. "The future of fossil fuels: How to steer fossil fuel use in a transition to a lowcarbon energy system." 2017.