UTILITY SCALE FLOATING SOLAR PV (FSPV) PROJECTS AND THEIR PERSPECTIVE IN CONTEXT OF INDIA

Abstract

India is at the forefront of utility scale ground-mounted solar PV project (GMSPV) installation across the globe. More than 11 GW capacity of projects were commissioned in the year 2022 alone, however, about 14 GW capacity of GMPV is expected to be installed by the end of 2023. The growth for GMPV calls for substantial land space, which could be utilized for infrastructure or agriculture. The floating solar PV projects (FSPV) are installed in water bodies like lakes, man made reservoirs (dams, hydro-electric projects, drinking water reservoirs, industrial ponds), etc. The projects could be installed on the reservoirs of existing hydropower projects and could help optimize power evacuation infrastructure. Various studies have indicated substantial potential for FSPV projects in India. In a recently concluded tender in India, a 90 MW FSPV project at Omkareshwar Dam was awarded at a feed-in tariff of INR 3.79/kWh whereas a recent tender from Solar Energy Corporation of India (SECI) for GMSPV was awarded at a feed-in tariff of INR 2.60/kWh. Although, FSPV projects are costlier than GMSPV projects, they reduce land constraints, provide extra generation and save water (evaporation) loss. This chapter analyzes FSPV projects in detail and present a comparison to GMSPV projects in context of India.

KeyWords : Utility scale, national solar mission, floating solar PV, potential assessment, site assessment, financial viability

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I. INTRODUCTION

India’s aims to reach net zero emissions by year 2070. The Government of India (GoI) has set an ambitious target of having 500 GW of installed non-fossil fuels based clean energy by 2030, mainly including installation of 280 GW of utility scale solar power and 140 GW of wind power. India's installed renewable power generation capacity has grown at a CAGR of 15.92% in the last six years, and its new capacity additions are expected to double in next three years. Since, the launch of the National Solar Mission, the costs of solar power in India has reduced by more than 80%, according to a report by the Institute for Energy Economics and Financial Analysis (IEEFA). The advancements in module technology, regulatory framework, market economics, and improved project techno-economics have contributed to India's solar power sector's success. Figure-1 shows the growth of solar projects in India since National Solar Mission (NSM) launched.

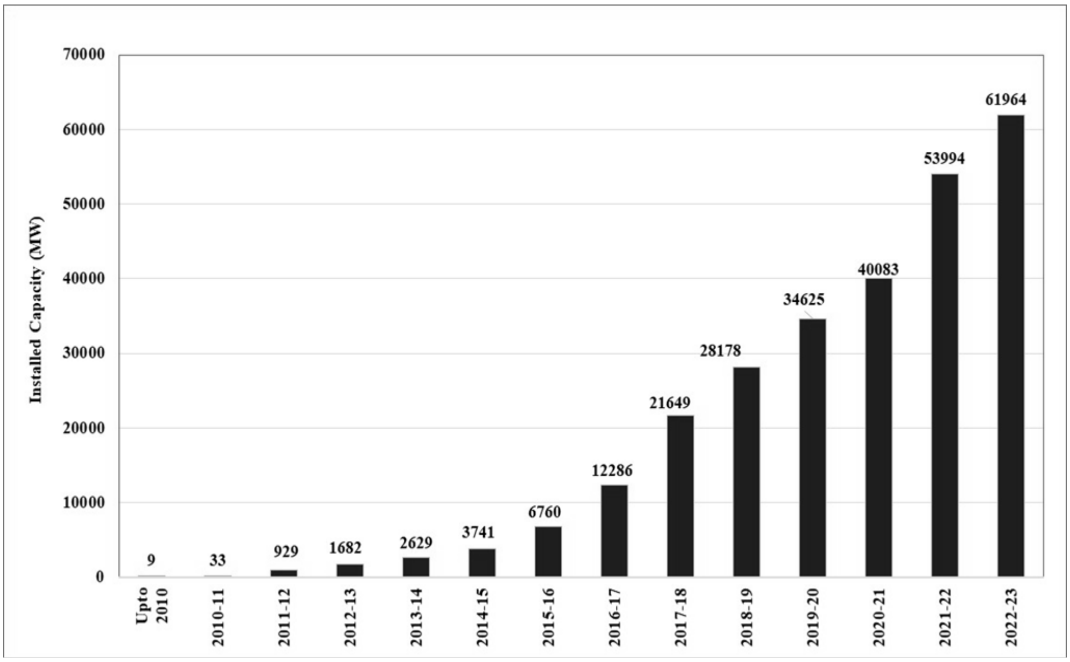

Figure 1: Growth of solar power in India

India has achieved the fourth rank in the world in solar power deployment. As on November 2022, solar projects of capacity 61.97 GW has been commissioned in the country. This capacity includes 52 GW from GMSPV projects and 9.91 GW from rooftop and off-grid solar projects [1].

Drawbacks to solar energy expansion are that traditional GMSPV projects require large land areas for installation (around 3-4 acres per MW). They also require substantial volumes of water for cleaning and are prone to heat-related losses in hot climates. Lack of availability of land for large scale solar projects and competition of land use for other economic activities like agriculture limits its application.

The FSPV market is expected to observe a compounded annual growth rate (CAGR) of maximum 15% in the next ten years. It is forecasted that about 15 countries would exceed

500 MW of cumulative FSPV installations by 2031 (see Figure-2), with Indonesia, India, and China making up almost 70% of the total FSPV demand in 2022.

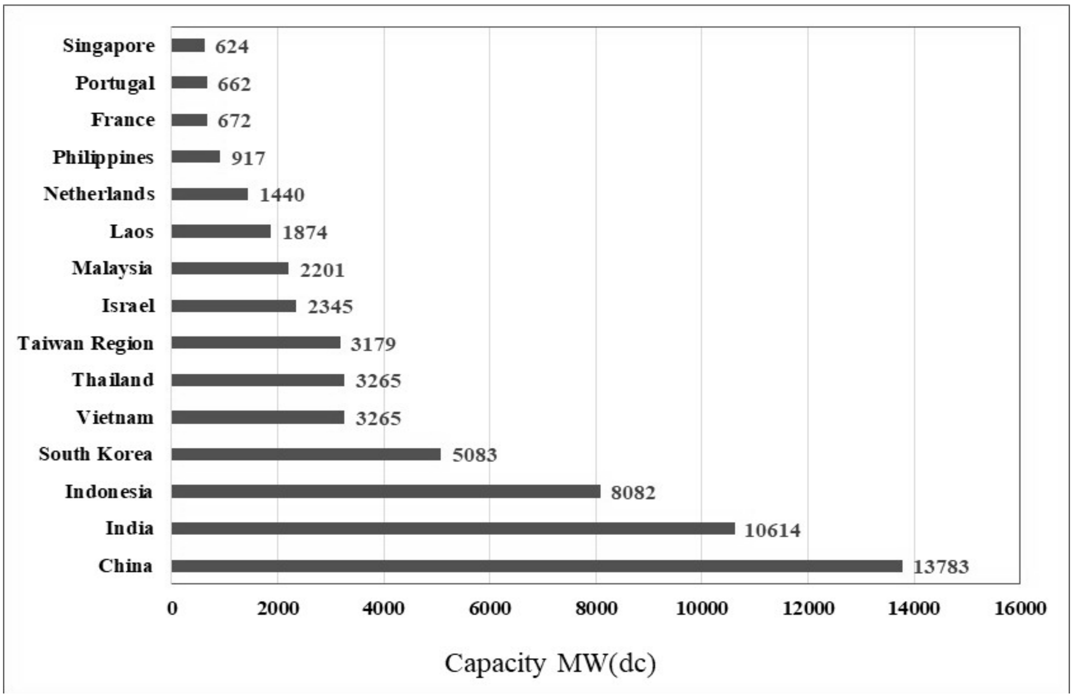

Figure 2: Country wise FSPV installation projected till FY 2031

By the next decade, China's cumulative FSPV capacity is expected to cross 13 GW growing at a CAGR of 12%. The country has used flooded coal mines decommissioned to develop FSPV projects. Global research on FSPV has identified the potential of these projects worldwide. This research is based on the condition that only 30% of the water body area is covered [3]. The analysis across 114,555 global reservoirs resulted in a generation potential of 9,434 TWh/year. The United States leads with 1,911 TWh/ year of potential, followed by China at 1,107 TWh/year and Brazil at 865 TWh/year (see Figure-3).

The analysis considers global reservoirs larger than 0.01 km^2 but not exceeding 30 km^2. It also considers only 30% of the water body area for installations. Three global databases were used to choose the suitable reservoirs - Global Reservoir and Dam (GranD), the Georeferenced Global Dam and Reservoir (GeoDAR), and OpenStreetMap (OSM). The analysis selected 114,555 reservoirs worldwide, with a total area of 554,111 km^2. About 2,561 reserviors already had hydro power generation and power evacuation infrastructure.

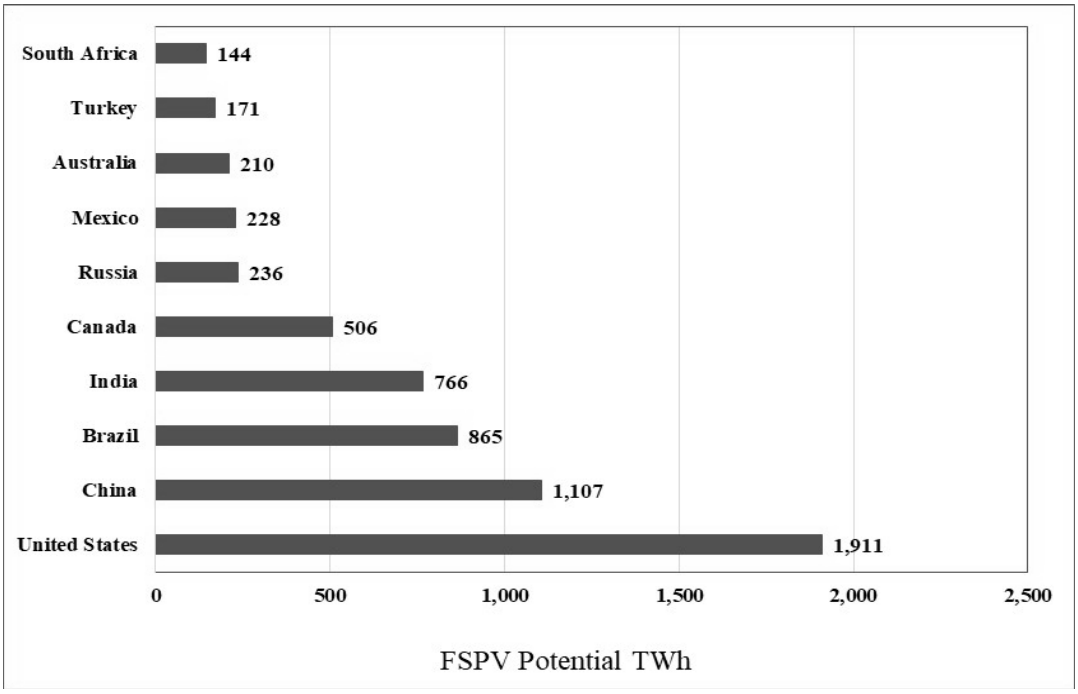

Figure 3: Potential (TWh) of utility scale FSPV (country wise)

The Energy and Resources Institute (TERI) studied Indian water bodies to estimate the potential of FSPV projects. It analyzed 30% of medium and large water bodies with a total area of 18,000 km^2. An overall potential of 280 GW was identified through this study [4].

India has already led in this direction by setting up the world's largest FSPV of 100 MW capacity at Ramagundam, Telangana. India currently has less than 300 MW of installed FSPV capacity, accounting for less than 0.5% of the country's total solar capacity. Rewa Ultra Mega Solar Limited (RUMSL) has auctioned 600 MW FSPV projects at the Omkareshwar dam reservoir in Madhya Pradesh. Once commissioned, it would be the world's largest FSPV project.

The auction by RUMSL was held in two phases of 300 MW each. RUMSL is a joint venture of Solar Energy Corporation of India (SECI) and Madhya Pradesh Urja Vikas Nigam Limited. The lowest bid quoted for a 100 MW project was INR 3.21/kWh. The government plans to provide viability gap funding (VGF) to reduce the cost to INR 2.3- 2.9 /kWh, making it competitive to GMSPV projects.

For the optimal development of an FSPV plant, it is necessary to identify a location that meets several conditions that facilitates its development. Some of the essentials for a potential site are a good availability of solar irradiation, favourable bathymetric, topographic, and environmental conditions, as well as adequate socio-economic integration. Most of the potential sites lack bathymetry data. Hence, it is important to carry out a study to characterize the physical properties of water body and assess site limitations to define the optimal location for FSPV development. Over the last few years, efforts have been made to prepare Standards and Best Practices for FSPV projects but there is still a lot of scope for improvement. These standards and practices play an essential role in developing more mature, commercially viable FSPV projects.

II. FLOATING SOLAR PV (FSPV) TECHNOLOGY

A typical configuration of a FSPV project consists of solar PV modules, inverters, the balance of system, and related evacuation infrastructure similar to GMSPV project. The vital difference is that the PV modules and sometimes inverters also float on water with the help of an anchoring and mooring system. Figure 4 depicts a FSPV project with PV modules and central inverters floating on pontoons [6].

DC power from PV module strings is collected at the combiner boxes and converted to AC power by inverters. The essential elements of the project are the floating structure, anchoring, and mooring system. The design of these elements requires critical attention as they are to be designed specific to the site requirements. The selected inverter for an FSPV project should comply to various country specific and international standards such as IEC 62920, IEC 60364, IEC 62109-1/2, IEC 61000, IEC 62116, IEEE 1547 and IEC 61727.

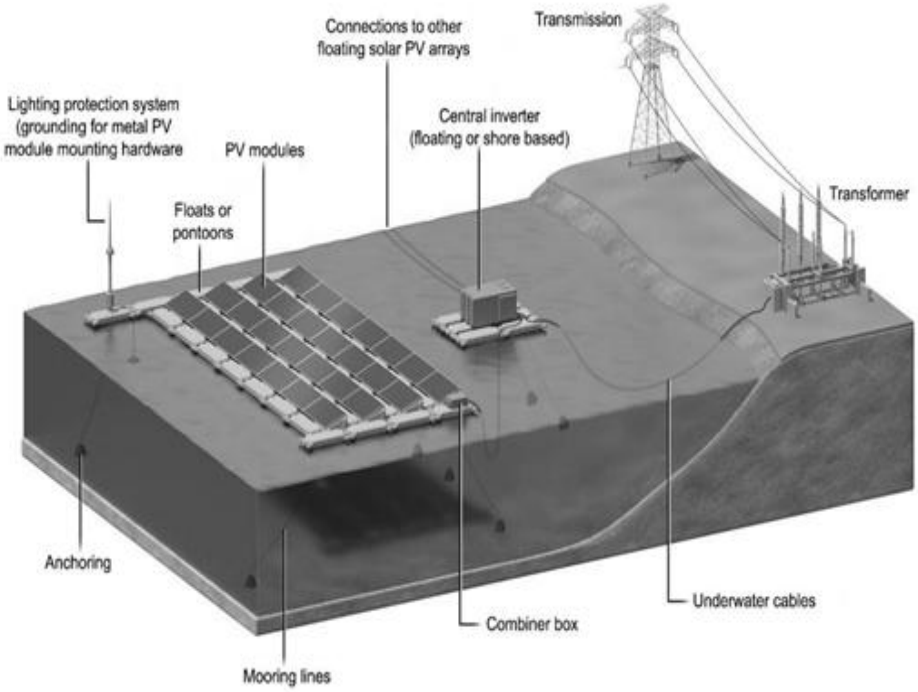

Figure 4: Schematic of a utility scale FSPV project

1. **Solar PV Modules:** All PV module technologies used for conventional solar projects like poly-crystalline, mono-crystalline or thin-film solar panels are used for FSPV projects. The biggest challenge on water for PV modules is constant high humidity and constant movement. This creates significant stress that increases risks of module degradation and failure. In general, the current ‘standard’ photovoltaic module design of a 60 or 72 mono

or poly cell glass front, aluminium framed module with IP67 rated junction box, fluoropolymer coated backsheet and EVA encapsulant has performed well under a variety of conditions and represents much of the current world-wide installed base. The existing robust PV modules suitable for tropical environments may be ideal for FSPV applications with minimal or no modification.

The selected PV modules should adhere to the following standards as per the appropriateness of the site:

- IEC 61215–- *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*.
- IEC 61730–- *Photovoltaic (PV) module safety qualification*.
- IEC 62804–- *Test methods for the detection of potential induced degradation*.
- IEC 61701–- *Salt mist corrosion testing of photovoltaic (PV) modules*.
- IEC 62716–- *Ammonia corrosion testing of photovoltaic (PV) modules*.

Solar PV modules form an essential integral of an FSPV project. The selection of PV module technology depends on space availability, cost and relative humidity. Operating temperature, high moisture, type of water body and relative humidity conditions are important criteria to be considered in comparison to solar PV modules used for land-based installations.

2. **Solar Inverters :** Inverters play an important role in solar projects by converting direct current (DC) to alternating current). Both central and string inverters can be used for FSPV projects as used in conventional solar projects. String inverters connect a string of multiple PV modules in series to one single inverter. The power conversion from DC to AC happens at a string level at the output of the inverter. In FSPV projects, string inverters are preferred because of their ease of installation at the end of each floating block. The output of each floating block is then pooled to the main power evacuation substation. A central inverter pools the output of solar PV modules to DC combiner boxes and then terminates in a central inverter.

3. **Floats:** The floats for the floating structures are designed based on the buoyancy principle and form a crucial component of the floating structure. Materials like fibre-reinforced plastic (FRP), medium density polyethylene (MDPE), ferro-cement, and high-density polyethylene (HDPE most used) are used for the design of the float. Equipment like PV modules, inverters, cables, combiner boxes, mounting structures, and transformers are kept afloat with the help of this structure. A brief overview of float designs are described below.

   - **Pure Floats:** It is one of the most matured float designs and offered by many large players in the market. Ciel & Terre (C&T), a French company, pioneered this design and is being utilized for large FSPV projects globally. Figure 5 illustrates the example of such a float time offered by C&T in the market [7]. The float system is modular with main and secondary floats. The main floats support the PV modules while the secondary floats connect to the main floats, ensure proper spacing between modules, and allow space for walkways while providing additional buoyancy. These floats are connected with the help of pins, bolts, or bands. The material used for manufacturing is HDPE with UV and corrosion resistance.

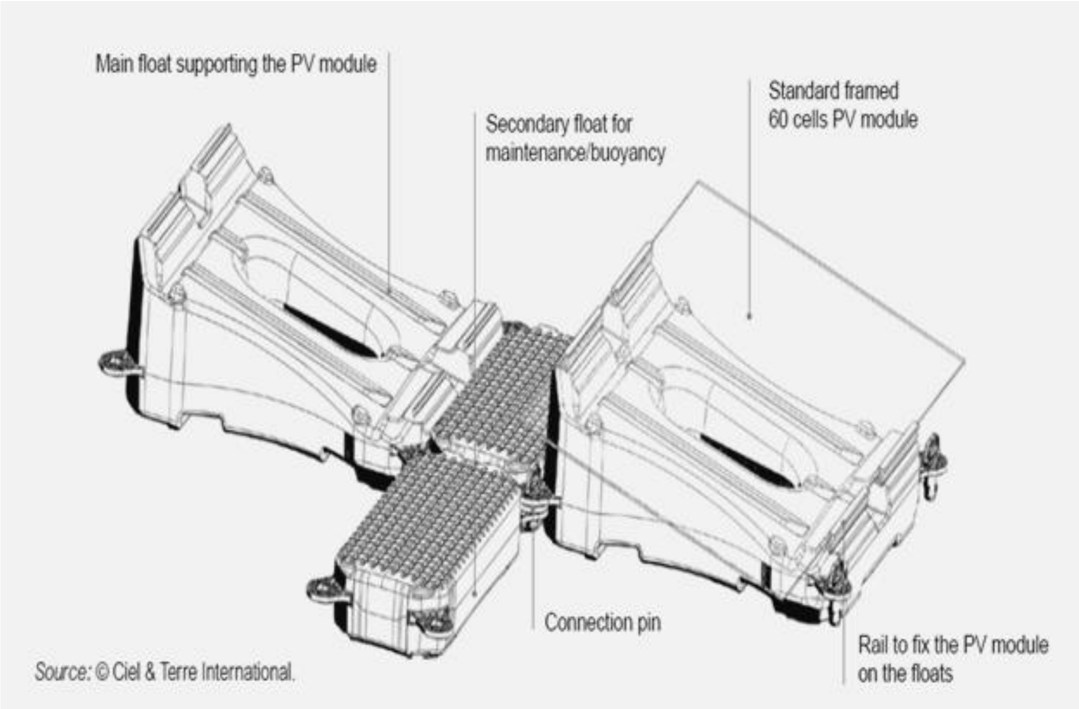

Figure 5: Schematic diagram of pure floats of FSPV system

- **Modular Raft Floats :** In this design, PV modules are placed on metal structures similar to GMSPV projects. These metal structures are fixed to floats/pontoons. These floats provide only buoyancy, eliminate the requirement for a specially designed float, and can be sourced locally [8]. The metal structures can be fixed on the floats, as designed by NRG Energia (see Figure 6)

Figure 6: Schematic diagram of modular raft floats of FSPV system

- **Membrane Floats:** The PV modules are attached to some non-permeable membrane/sheet supported by tubular plastic rings providing buoyancy. The giant pool-shaped membrane, along with the rings, make up this float system [9]. Typically, these floats are used for offshore installations, as depicted in Figure 7.

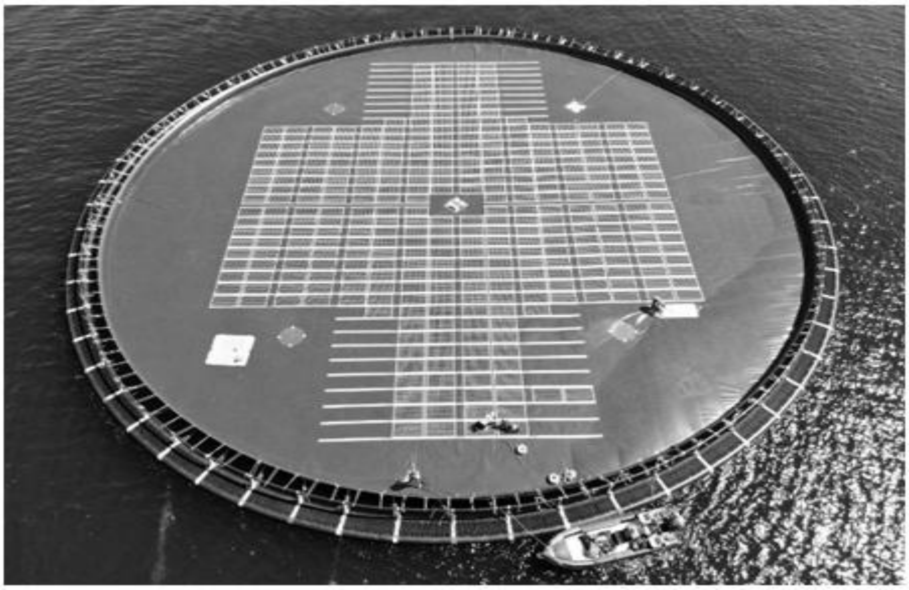

Figure 7: Schematic diagram of Membrane pure floats of FSPV system

4. **Anchoring And Mooring System:** The anchoring and mooring system are essential to the FSPV project, ensuring that the floating platforms are kept in place. The floating structures could be anchored at the bottom (bottom anchoring) or at the bank/shore (bank anchoring). These two banking options are depicted in Fig 8 and 9. One to three anchors per MWp could be required in large scale projects.

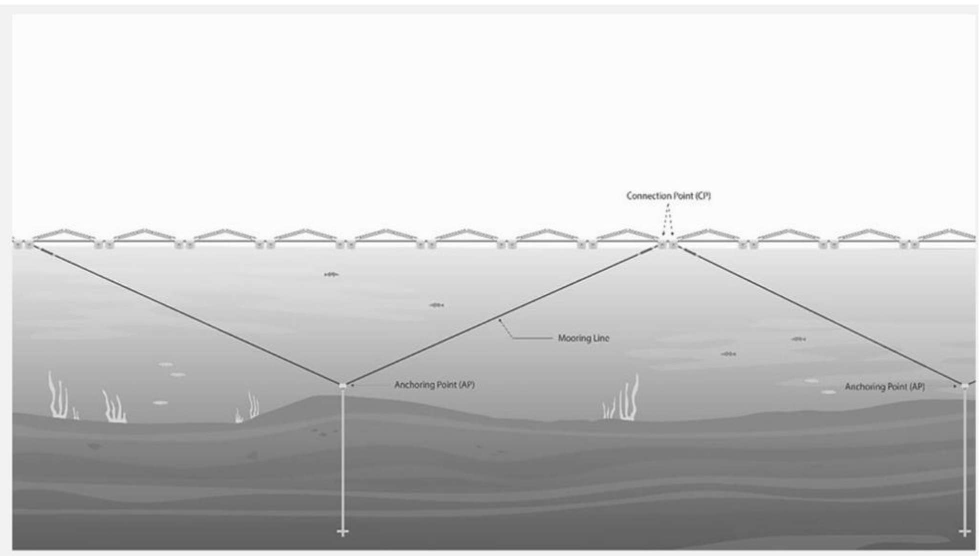

Figure 8: Schematic design diagram for bottom anchoring of FSPV system

Bank anchoring is cheaper than bottom anchoring. It is suitable for small, shallow ponds or water bodies where the FSPV project is close to the shore. Bank anchoring allows easier access to perform periodic O&M.

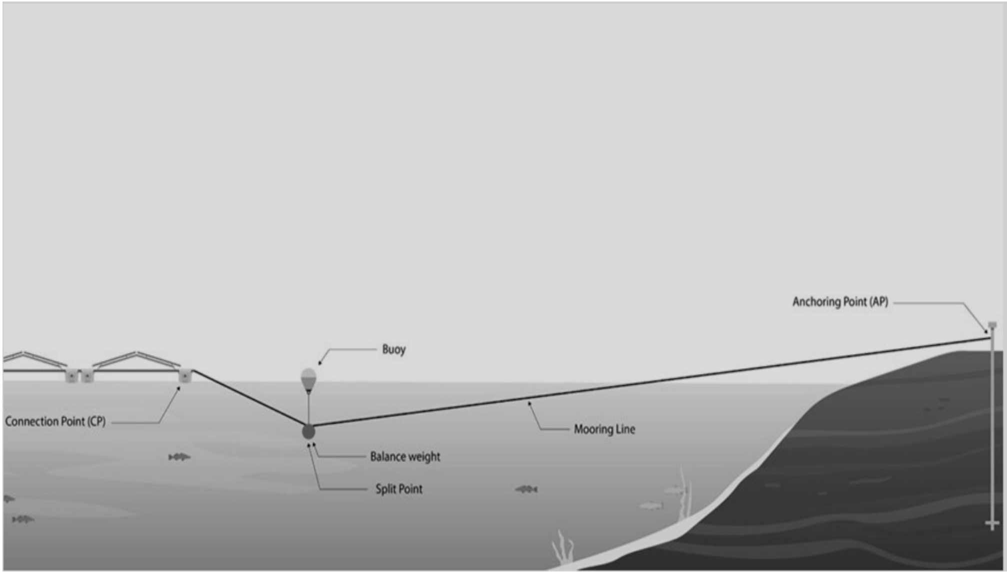

Figure 9: Schematic design diagram for shore anchoring of FSPV system

The mooring system should be customized and secured to fit local geographic and climatic conditions. This system minimizes the movement of floating structures caused due to winds, waves, and currents. It helps the structures survive under varying water levels and maintains a minimum distance between the solar arrays. Developers use various software tools like Orcaflex or NEMOH to perform simulations for appropriate mooring system.

Commonly used material for mooring lines include chain, wire ropes and a range of synthetic materials such as Nylon, Polyester, and Ultra High Molecular Weight Poly Ethylene (UHMWPE). For FSPV projects, cable size optimization, routing and management needs detailed planning. To allow the movement of the floating platform, extra cable length is provided. The cable may break due to tension if its length is is insufficient.

III. POTENTIAL SITE ASSESSMENT

A typical FSPV project starts with concept development and site identification. A phase wise development of an FSPV project is depicted in fig 10. The initial phase of designing an FSPV project starts with site selection (see Table 1). Various parameters such as the technical, commercial, environmental, and social (E&S) and interconnection should be studied for the proposed site. The preferred site should have adequate global horizontal irradiance (GHI), less prevalence of weather events such as storms, hurricanes and typhoons, shallow reservoir depth, water bodies that are not used for competing purposes such as recreation and aquaculture, accessibility for transportation power evacuation, and stable legal and regulatory framework for FSPV development.

Table 1: Key Parameters for Initial Site Selection

S.No	Parameter
1	Ownership of the water body
2	GHI/ Specific PV power output at the location
3	Existing shadow-casting objects
4	Existing use/purpose of the water body
5	Potential water surface area
6	Average depth (max, min) of the water body
7	Water level fluctuation (daily/seasonal)
8	Proximity to load center/s
9	Access to power evacuation infrastructure
10	Existing environmental & social issues

Reservoir bed characteristics should be studied, including depth and bathymetry, geology, and reservoir bed conditions (rugosity, morphology) and physicochemical properties of reservoir bed soil and water. Land requirement for power evacuation infrastructure and assembling of structures during should be analysed in terms of its ownership and proximity. The site condition and climatic factors that affect the structural behaviour must be considered while assessing the site's suitability. These parameters are bathymetry study results, bottom slope, soil, wind, wave, and current conditions.

1. **Bathymetry Survey:** The bathymetry survey provides depth of the waterbody and provides information on the underwater terrain in the form of a contour map. Depth of reservoir and reservoir bed characteristics are essential parameters for assessing and designing the anchoring and mooring of the FSPV plant.

2. **Geotechnical Survey:** The geotechnical investigation aims to examine soil and rock data's physical and chemical properties to assess and select suitable anchoring system. The geotechnical investigation includes the collection and analysis of soil and water samples. It is recommended to collect the soil samples from the reservoir bed and nearby shore and analyse them for physical and chemical parameters such as natural moisture content, bulk density, grain size and distribution, specific gravity and position limit. These soil characteristics are important to select a suitable anchoring system.

3. **Water Current Study:** Understanding the current speed at the different water column levels and the flow turbulence induced by the topography of the water reservoir would be essential for the mooring system design of FSPV. Various parameters related to water current such as speed, direction and velocity at different depths are measured by deploying ADCP (Acoustic Doppler Current Profiler). Water current and velocity profile for six months is ideal for designing the FSPV system.

4. **Geophysical Study:** Understanding the subsoil strata is essential to design the anchoring and mooring. The layers of sediment and rocks under the water body bed can view through sub-bottom profilers. The slope at the bottom directly impacts the behaviour of the FSPV project. This is because an excessive slope causes an asymmetric mooring, which can cause more significant movements in the system and, therefore, greater damage to floats and a reduction in the possible useful life of the solar plant.

A thorough investigation to be done collating all information and in consultation with stakeholders while selecting the location, avoid waterbodies with protected natural habitats or species. Natural lakes or water bodies with recreational priorities should be avoided due to higher socio-environmental impacts. The water body should have a regular shape, no obstacles, and wide to reduce currents and drags. The ideal site should be 20m away from land and less than 30 m depth; minimal variation in water level. Depths of less than 1.5 m in the water column (minimum draw down level) make the location unsuitable for floating technology installation, as the plant could rest on the bottom in dry season, causing significant damage to the components. Social aspects are crucial and need to be studied as part of the initial assessment. The project should not negatively impact the livelihood. Figure 10 depicts the various stages involved in development of a FSPV project and the variety of expertise required at each stage.

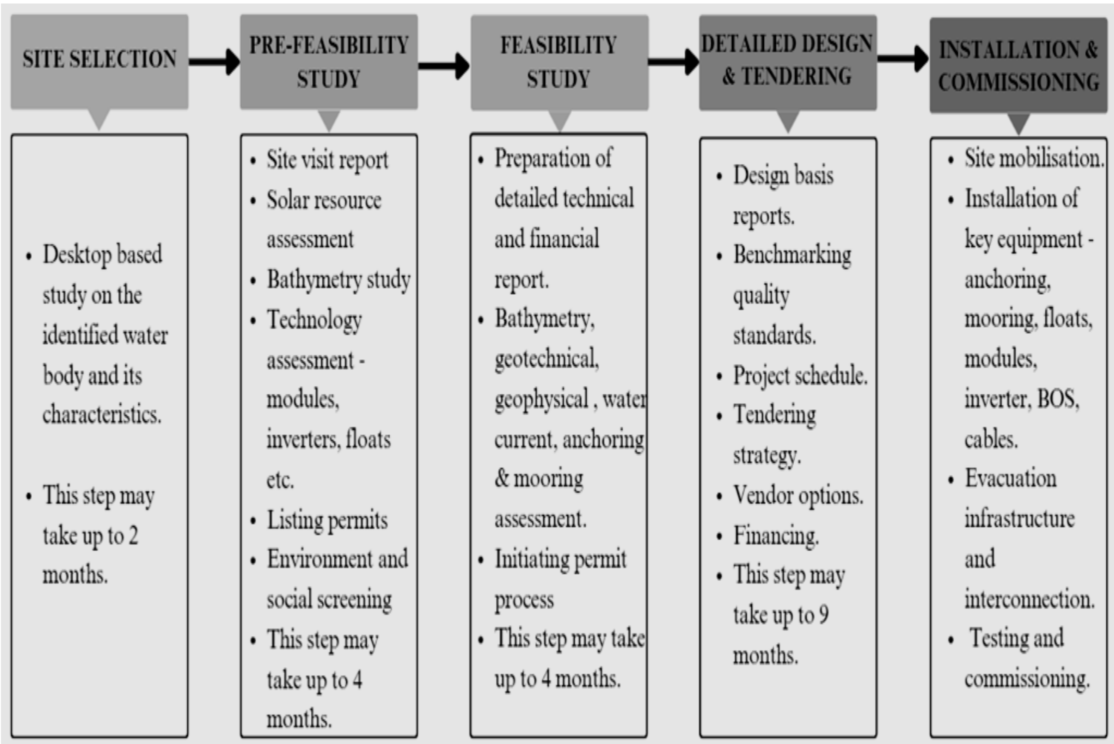

Figure 10: Stages of a typical utility scale FSPV project

IV. PROJECT COST ESTIMATES AND TECHNO-ECONOMICS

An FSPV project and a GMPV project are identical regarding their electric systems. A PV project consists of PV modules that produce DC electricity. This DC electricity fed to inverters gets converted into AC electricity and then connected to the grid network for consumption. So, a typical PV project consists of PV modules, inverters, mounting structures, and balance of system (BOS)–- cables, connectors, etc.

The most significant difference between an FSPV project and a GMPV project is how the PV modules are mounted. In a GMPV project, PV modules are mounted on a rigid structure with a firm foundation, whereas in an FSPV project, these modules are placed on a floating system on the water's surface. Another striking difference between these projects is the choice of equipment with seawater environment considerations.

The inverters, cable, fittings, and floats should be of marine grade with higher Ingress Protection (IP) ratings and corrosion-resistant materials. A typical cost break up of a 50 MW FSPV project is indicated in Figure-11. CAPEX for a MWp FSPV project can be considered in the range of USD 1.2 to 1.4 per Wp.

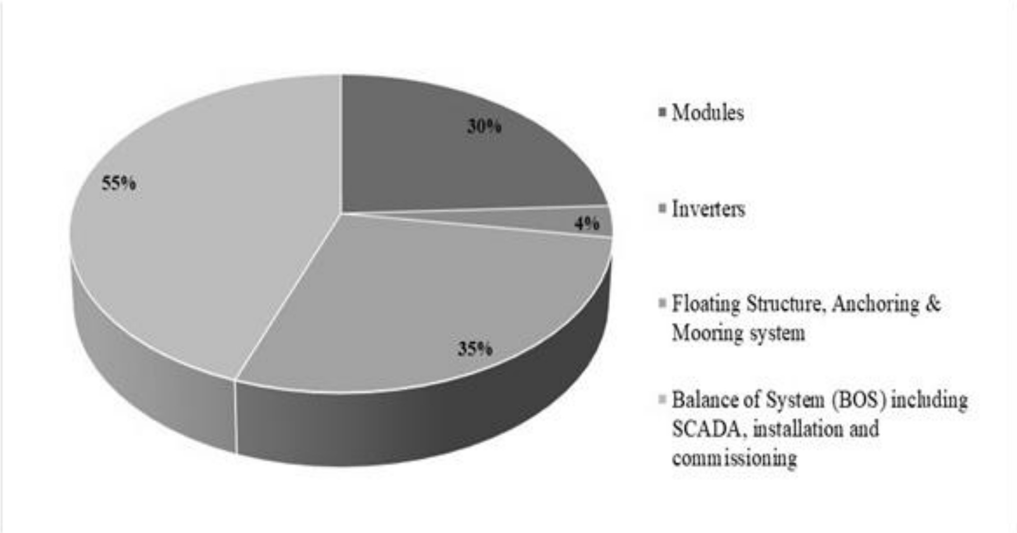

Figure 11: Project cost break-up of a utility scale FSPV solar project

There is no significant difference in the OPEX cost of an FPSV project compared to a GMPV project. OPEX of a typical GMPV project includes proper cleaning of modules along with other preventive maintenance checklists. Checking the floating structure (yearly) and verifying the integrity of the anchoring and mooring system (every three years) would be additional for an FSPV project in contrast to a GMPV project. OPEX of FPSV projects may be assumed to vary from USD 0.011 to 0.013 per Wp per annum.

Levelized Cost of Electricity (LCOE) calculations are based on the above mentioned CAPEX and OPEX estimates. A sample location of Dahod Dam reservoir (23.021°N, 77.474°E) in India is considered for energy generation estimates. The estimates are referred from Global Solar Atlas [11]. The list of assumptions for calculating LCOE are presented in Table- 2 below.

Table 2: Techno-Commercial Parameters of FSPV Project

Project Capacity	**1 MWp**
CAPEX	1300 USD/kWp
OPEX	11 USD/kWp/year
Discount rate	10%
Lifetime	30 years
Specific power output	1607.5 kWh/kWp/year

The LCOE, with the above assumptions, was obtained to be 0.093 USD/kWh. A sensitivity analysis was performed considering variation in CAPEX and specific power output. The results of the analysis are presented in Table-3.

Table 3: Sensitivity Assessment of LCOE of FSPV Project

		CAPEX (USD/kWp)		
		1203	1300	1398
Specific power output (kWh/kWp/year)	1446.8	0.096	0.103	0.110
	1607.5	0.086	0.093	0.099
	1768.3	0.078	0.084	0.090

It has been observed that LCOE of the FSPV project varies from 0.078 USD/kWh to 0.110 USD/kWh. Figure 12 indicates LCOE ranges of different renewable energy technologies for 2023 [12]. The obtained LCOE range for FSPV is observed to be competitive with other commercial scale renewable energy technologies. Factors like water conservation and land conservation will enhance the attractiveness of an FSPV project.

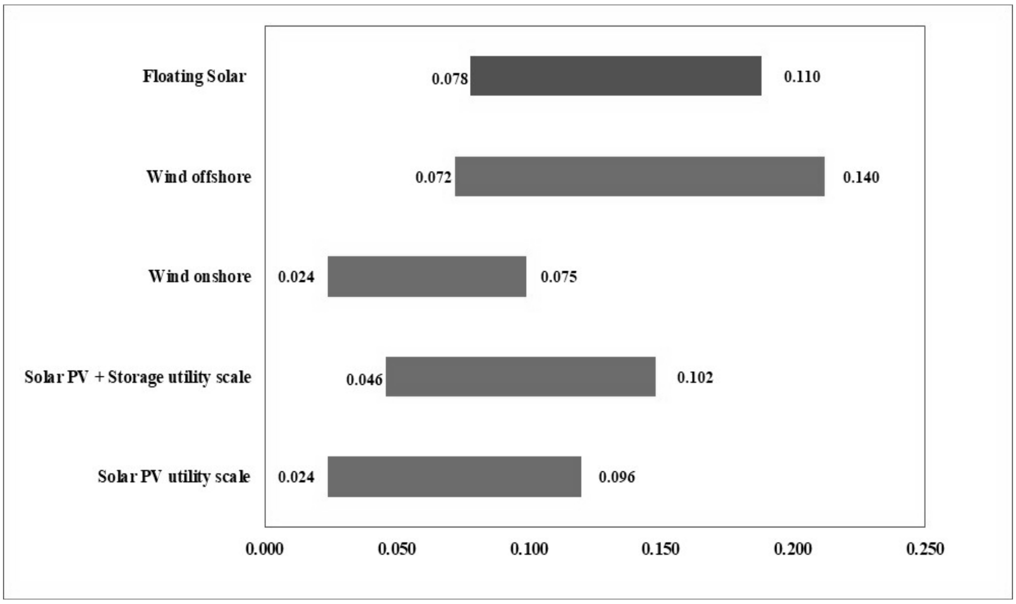

Figure 12: Comparison of LCOE of various commercialized RE technologies

V. FSPV IN INDIA (CASE STUDY)

NTPC commissioned India’s largest FSPV project of 145 MWp/100 MW in Ramagundam (fig 13), Telangana, in July 2022 [13] . The project was awarded to BHEL at a contract price of INR 423 crore and is developed on 450 acres of the Balancing reservoir of NTPC Ramagundam Station. A single block is of 2.5 MW capacity with the total project comprising of 40 such blocks. HMPE (High Modulus Polyethylene) rope is used to anchor the floating structure. The 33kV underground cables evacuate power up to the switch yard. This project is unique in the sense that all the electrical equipment including inverter, transformer, HT panel and SCADA (supervisory control and data acquisition) are also on floating ferro cement platforms. The anchoring of this system is bottom anchoring through dead weight concrete blocks.

Figure 13: Utility scale FSPV at Ramagundam, India

The presence of floating solar panels reduces the evaporation rate from water bodies, thus helping in water conservation. It also utilizes minimum land, mostly for associated evacuation infrastrcuture. The water body underneath the solar PV modules helps maintain their ambient temperature, improving their efficiency and generation. NTPC has commissioned 237 MW of FSPV capacity (table - 4) in the country so far [14].

Table 4.: List of Projects Commissioned by NTPC in India

Project name	Project capacity	Annual energy yield (MU)	Annual CO_2 savings (MT)	Location	EPC/OEM
Simhadri FSPV Project	25 MW	55.11	47.5	NTPC Simhadri (District Vishakhapatnam), Andhra Pradesh	
Ramagundam FSPV Project	100 MW	223	192	Ramagundam Village, District Karimnagar, Telangana	EPC - M/s BHEL, Floaters - M/s Prabhdayal, Anchoring system - M/s Adtech
Kayamkulam–- I FSPV	22 MW	215.5	185.5	Choolatheruvu in Alappuzha	EPC - M/s BHEL, Floaters -

Project				district of Kerala	M/s Purushottam Profiles, Anchoring system - M/s Adtech
Kayamkulam–- II FSPV Project	70 MW				EPC - M/s Tata Power, Floaters - M/s Ciel & Terre, Anchoring system - M/s Adtech
Auraiya FSPV Project	20 MW	39	33.6	Dibiyapur in Auraiya district of Uttar Pradesh	EPC - L&T, Floaters & Mooring system - M/s Purushottam Profiles

VI. BARRIERS AND DRIVERS TO FSPV PROJECTS IN INDIA

Although FSPV projects have started gaining commercial traction due to a lot of driving factors for these projects. But still, there are many challenges which needs to be addressed. This section highlights the key drivers and barriers to FSPV projects in India.

1. **Key Drivers :** The country has a huge potential (120 GWp+) for the installation of FSPV projects, even if 10% surface area of water bodies is considered [15]. The GMSPV projects are prone to land acquisition challenges and the delays in acquisition may sometimes lead to the cancellation of such projects. Recently, the project size of a tendered project has also increased up to 500 MW which helps in better techno-economic viability. In the next few years, almost a GW of FSPV project tenders per year are expected to be rolled out in India, indicating a solid market for OEMs and installers. The pooling of FSPV projects on reservoirs of existing hydropower projects provides a unique proposition by utilizing the existing power evacuation infrastructure, thereby eliminating the need for additional infrastructure. These projects also provide some higher generation compared to a GMSPV project, along with the conservation of water (reduce losses through evaporation).

2. **Site Selection And Acquisition:** For a country like India, no consolidated database provides details of water bodies with information on water surface area, water level variations, local weather profiles, historical changes in the water surface, data on local biodiversity, etc. This information is critical while designing an FSPV project and is part of risk assessment, ensuring the project's bankability. There is a lack of clarity on the ownership of water bodies and their usage for power generation vis a vis for fishing or other commercial activities. The lead time to acquire or lease these water bodies could delay the initiation/construction of proposed projects.

2. **Capital Cost (Capex):** The CAPEX of FSPV projects is higher than that of GMSPV projects. The floats, mooring and anchoring system design needs to be site specific. The electrical components should also withstand harsh marine conditions for 25 years

lifetime. CAPEX dominates the LCOE of floating solar with the operating costs being approximately 20% of the levelized costs. The CAPEX of FSPV will depend on the development of PV module costs, which has a cost-learning rate of 27% and will decline to 17% in 2050[16]. The cost of floats is also expected to drop over time. Local manufacturing and availability of floats could potentially lead to this price drop.

3. **Operation & Maintenance (O&M):** O&M activities on water are a bit tedious to perform as compared to land. The access ways, spare parts, workman, tools and tackles would add to the O&M cost for FSPV projects. The anchoring and mooring system needs regular inspection. Special interventions are required to minimize bird droppings and clean solar PV modules for energy generation. With more and more projects commissioned on a large scale, the O&M cost is expected to have a downward trend.

4. **Environmental Barriers:** The impact of an FSPV project on the environment depends on its size and existing use of the water body. The existing use of water bodies may include fishing, drinking, farming, marine research or recreational activities etc.While assessing the environmental impact of an FSPV project, the entire area of the project, including the transmission lines, towers and substations, should be considered along with the upstream/downstream water, the deployment water and their associated users. International Financial Institutions (IFIs) are very particular about the project E&S assessment; the FSPV projects are thoroughly assessed before financing. There is still a lot of uncertainity around the ecological impacts of FSPV projects which may lead to public protest and even increase the environmental assessment timeframe.

5. **Technical Challenges:** The components of an FSPV project are continuously exposed to high humidity, corrosive, highly saline, and high wind load conditions. Frequent fluctuations in temperature may cause stresses in float material and its joints.

   The long-term operational risks in a FSPV project is higher than a GMSPV project. The structures are in constant motion and are exposed to enhanced degradation and corrosion when compared to GMSPV projects. The components also face bio-fouling, which may impact its long-term reliability and safety. DNV [17] has released recommended practice document for design, development, and operation of FSPV projects. The stakeholders could evaluate these practices once large capacities of such projects are commissioned. The minimum and maximum wind resistance requirements for a floating platform is determined by a number of factors including inclination, final size of platform and whether a rigid or flexible platform is chosen. In 2019, a 13.7 MW capacity FSPV project on Yamakura Dam in Japan was destroyed due to anchor failure caused by the heavy storm[18]. It is necessary to perform bathymetry and geotechnical surveys to establish the shape of the lake's bed and soil structure across the site. There is no standard or guideline to perform these studies as of now.

6. **Regulatory Considerations:** There is no separate regulation to push the FSPV sector in most countries. Most of these projects are deployed for captive consumption only. There needs to be an integrated policy/regulation which ensures the smooth clearance of these projects across departments. The lack of clarity on environmental approvals in most countries with good potential is also making the projects less financially appealing.

VII. CONCLUSION

FSPV projects are becoming an increasingly competitive option for power generation. There are still questions technology, its benefits, its potential impacts given its small operational history. Countries like India, Netherlands and Taiwan are considering to take up FSPV projects. These countries are blessed with abundant solar and hydropower resources, can hybridize with hydropower generation, and reduce land usage for GMSPV projects [19].

The FSPV market in China, Japan and South Korea are comparatively mature. China supported FSPV projects on artificial water bodies as opposed to natural water bodies that may have a more complex environmental review process. Japan and South Korea invested in FSPV development to land energy conflicts caused by GMSPV projects.

The countries with higher technical potential need consistent and targeted government support to FSPV projects systems in the form of rebates, tax incentives, and competitive RE auctions could help de-risk FPV systems and attract private sector financing. There needs to be a clear regulatory process on the ownership and market participation models and valuation methods for FSPV hydropower hybrid systems. More research is required to study the comprehensive environmental impacts of FSPV projects. The countries with mature markets should collaborate and develop operational and engineering best practices and training of hydropower power plant operators to help ensure smooth operation of FSPV hydropower hybrid systems.

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