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A Critical Review of Development, Challenges and Techno-Economical Impacts of Floating Solar PV Systems: Bangladesh Case Study

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Original Research

Abstract:

The global shift towards land-efficient and decarbonized energy systems has driven innovation in floating solar photovoltaic (FPV) technologies. Best suited for water-surplus and land-scarce nations like Bangladesh, FPV offers a sustainable alternative to ground-mounted PV. This review critically evaluates FPV's global development, technical efficiency, and environmental impact, with particular emphasis on the energy landscape of Bangladesh. Using solar irradiance data from NASA POWER, inland water surface availability from national hydrographic surveys, and performance benchmarks from FPV deployments in India and China, this review estimates that FPV could meet $15-20\%$ of Bangladesh's national electricity demand and offset up to 10 million tons of CO_2 annually. The levelized cost of energy (LCOE) of FPV is marginally lower than that of land-based systems (0.07 vs 0.08 USD kWh^{-1}) under equivalent assumptions of 20-year life, 6% WACC, and 0.5% yr^{-1} degradation, owing to reduced O&M and higher yield. Additional lifecycle environmental assessments (LCA) are proposed to provide quantitative long-term assessments of material acquisition, deployment, and end-of-life disposal costs for FPV systems. Integration into the grid also seems to be a significant issue, particularly with respect to intermittency, grid flexibility, and near-inland water body transmission infrastructure. Hybridization possibilities with hydropower are addressed herein, and technical, regulatory, and policy frameworks are proposed for implementation. The study aims to guide researchers, investors, and policymakers on how to apply FPV as a revolutionizing tool towards sustainable energy growth in Bangladesh and other delta regions.

Keywords:

Floating photovoltaic (FPV); Renewable energy; Bangladesh; Carbon emissions; Energy transition; Sustainable Energy Systems

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1. Introduction

Growing global energy demands and climate change-related vulnerabilities make sustainable and efficient land use for renewable energy rapidly urgent. Floating solar photovoltaic (FPV) technology combines solar modules on existing water bodies (lakes, reservoirs, and some protected coastal areas) to deliver clean energy innovation while managing water resources [1, 2]. Over the last ten years, FPV has transitioned from experimental pilots to commercial scale deployment, especially in areas with competition for land use and pressures at the water-¬energy nexus.

FPV systems also have several advantages over solar systems installed on land. First, they help save land, as they do not require agricultural or mining land, thereby saving on land acquisition and preparation costs [3–6]. For Bangladesh, with its increasing energy demands and heightened vulnerability to climate change, floating PV offers a strategic renewable pathway that bypasses land acquisition constraints while maximizing water-based generation potential. FPV systems also aid in increasing power generation efficiency because they are cooler as they are in contact with water. Research indicates that FPV modules operate 2.7 – 3.5 °C below ground systems, indicating a 2.3 – 2.6% increase in daily energy yield. Water also naturally cleanses the panels by washing away dust and minimizing accumulation, thereby maximizing efficiency [7–12].

Minimizing water evaporation is another critical benefit since the FPV systems float on the water surface, preventing sunlight and significantly minimizing water loss [13–18]. Besides, FPV systems help to enhance water quality by reducing sunlight penetration, which inhibits algae growth and slows down eutrophication. This leads to enhanced water quality and decreased water treatment costs [19, 20]. These operational and environmental advantages have spurred rapid FPV adoption worldwide, as nations seek scalable renewable solutions to meet climate targets.

In the past decade, floating solar installations have quickly developed globally, particularly in nations such as the United States, India, China, and Japan, progressing forward at an unprecedented rate. However, the global energy sector is still primarily using fossil fuels-coal, natural gas, and oil. These forms of conventional energy are still a significant source of CO_2 emissions, environmental pollution, and climate change [21, 22]. Global energy demand and CO_2 emissions have risen steadily from 2017 to 2024, reflecting persistent reliance on fossil fuels despite renewable adoption (figure 1). The trend of this figure reveals the increasing use of carbon-based energy sources. The CO_2 emissions data were obtained from Our World in Data (OWID), the International Energy Agency (IEA), and Nature journal, and 2023-2024 data were taken to be interim estimates. The growth rate of emissions has varied, but overall levels are still high as we continue to consume carbon-heavy energy sources despite an increasing renewable uptake.

The 600 MW Floating Solar Farm at Omkareshwar Dam, India, with 278 MW commissioned by August 2023, is a key project in India's energy transition, set for full completion in 2024. Europe's largest 74.3 MWp floating solar plant is under construction in Haute-Marne, France, while the world's largest 145 MW project is underway at Cirata Reservoir, Indonesia. The future blueprint is usually designed for global PV development belonging to FPV, and this has been attracting many stakeholders in industry and academia. The FPV systems are playing a very important role in the world for energy sustainability and the protection of the environment [16, 23]. In China, CHN Energy has just completed a 1 GW floating solar PV facility in Shandong Province. Located offshore, the plant is forecast to generate 1.78 billion kilowatt-hours a year that would power around 2.6 million households. But China leads in this technology, and a number of more giant-sized floating solar parks are in the pipeline [24].

Developing countries like China, India, France, and the US have already adopted this technology, and research in Bangladesh, like at Chalan Beel and Kaptai Dam, suggests its scope for clean energy and a consistent power supply. In the US, for example, Florida Power & Light's net metering customers doubled between June 2021 and June 2023, contributing 38,814 MWh of clean energy back to the grid [25, 26]. These include the 4.8 MW floating solar farm in Healdsburg, California, and the 8.9 MW floating solar farm in New Jersey, currently the largest in North America [27, 28]. In this respect, the floating photovoltaic system is one innovation that tackles the challenge of expanding the solar capacity. Generally speaking, FPV has been successful in calm water installations around the world, e.g., in natural lakes [29–32] and water reservoirs [33–38]. Lately, growing interest in FPV on seas due to the abundance of space has cropped up, i.e., [39–41]. Floating Photovoltaic (FPV) technology represents a viable alternative renew-

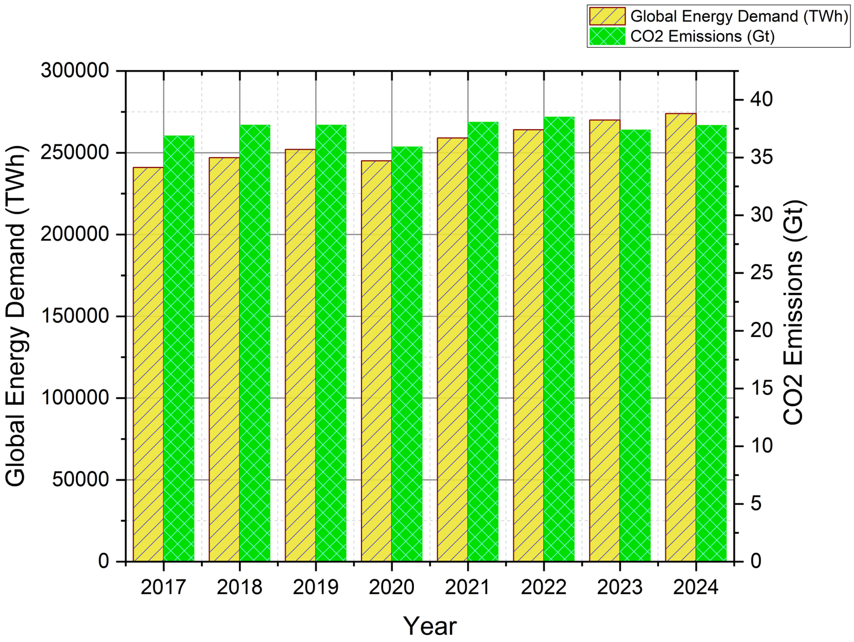


Figure 1. shows that despite recent growth in renewable energy, CO_2 emissions remain high, indicating continued global reliance on fossil fuels.

able energy solution in densely populated countries like Bangladesh. While FPVs have been proliferating worldwide, using them in South Asia's deltaic contexts is complex and multifaceted due to the range of socio-environmental conditions. Comprehensive reviews that discuss FPV's techno-environmental sustainability, sustainability synergies, and adoption barriers in this context are still extremely rare.

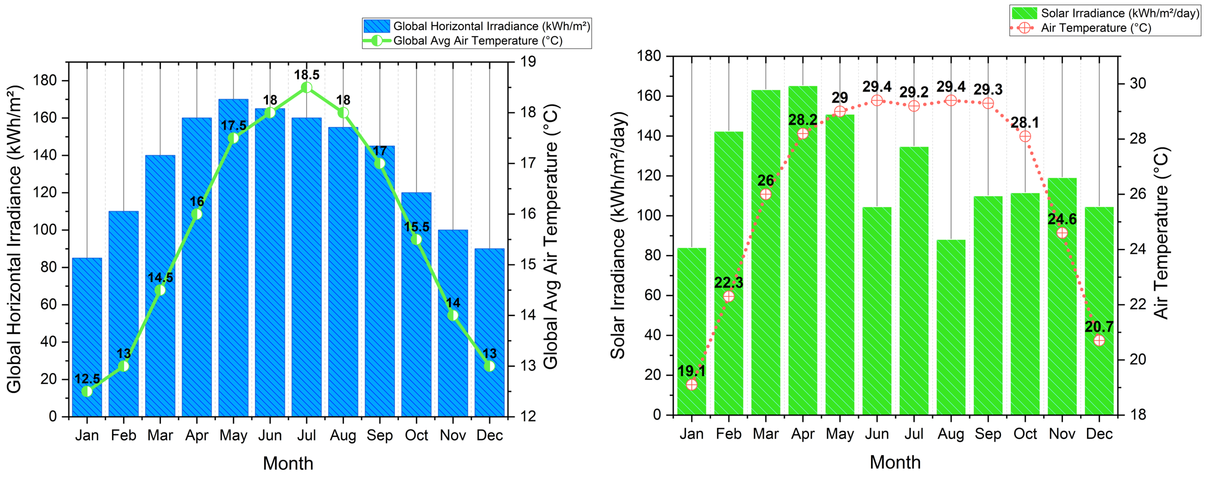
The challenging working conditions are one of the main challenges because exposure to water for long periods results in rust and corrosion that reduce the lifespan of PV modules [42, 43]. The levelized cost of electricity (LCOE) of FPV systems is around 2.5% higher compared to solar power systems on land [44, 45]. Offshore floating solar PV (FPV) systems are at high risk from strong winds and waves that threaten to compromise mooring and structures. Bangladesh's renewable energy plan under SREDA has considered FPV and identified it as one possible solution that could support SDG 7, 13, and 14. Future research should focus on hybrid energy-water integration, cyclone-resistant designs, lifecycle assessments, and synergizing solar with hydropower for the South Asian delta [46, 47]. However, in Bangladesh, the current literature on FPV is uncoordinated, with no comprehensive assessment of the technical performance, economic feasibility, environmental implications, and policy preparedness in a deltaic South Asian context, which this review provides.

As the globe is moving towards renewable energy at present, floating solar in Bangladesh can be another significant contributor to the renewable energy drive towards sustainability as it reduces greenhouse gas emissions and contributes to energy security. Bangladesh's abundant water resources can become a model of excellence in innovative solar solutions. Though numerous studies have analyzed FPV systems globally, there are limited studies that summarize the cumulative potential of FPV in the South Asian deltaic region. This review will address this gap by taking into account technical, environmental, and economic considerations pertinent to Bangladesh's aquatic geography. Seasonal and daily variations in solar irradiance and air temperature (Fig. 2a and 2b) indicate high year-round solar potential in Bangladesh, with peak values occurring from June to August. This data, provided by NASA POWER, is extremely relevant in assessing the feasibility of floating photovoltaic (FPV) systems through displaying examples of high solar energy availability.

While FPV has been widely studied globally, integrated evaluations addressing technical performance, economic viability, environmental sustainability, and policy readiness in deltaic South Asia—particularly Bangladesh-remain scarce. This review aims to fill this gap by synthesizing global lessons with a contextual analysis tailored to Bangladesh's aquatic geography. Despite great global advances of FPV application, literature today seldom incorporates complete techno-economic, environmental, and policy integration for South Asian deltaic ecosystems. Research literature covering Bangladesh is also fragmented, with minimal quantitative treatment of efficiency, cost, lifecycle effects, and policy preparedness.

2. Review of FPV systems: International developments and regional relevance

Floating photovoltaic (FPV) systems graduated from small pilot trials to an intermittent but typical deployment profile providing simultaneous land sparing, water-surface cooling, and enhanced system productivity gain. Later evaluations concur with FPV's increasing potential but point out that evidence remains intermittent for performance evaluation, hydrodynamically driven stability, environmental evaluation, and techno-economically viability, and scarce on South Asian deltaic terrains like Bangladesh [48–51]. Repeat studies and experiments inevitably substantiate that water-surface nearness causes temperature reductions, increasing photovoltaic conversion efficiency. Reported increments are highly variable: general reviews record small but regular increases of ca. 0.5 – 3% through passive modes of water-surface convection and wind-driven convection and water-surface heat exchange modes [52], while water-



(a) (b)

Figure 2. Seasonal variation of solar irradiance and air temperature in Bangladesh, based on NASA POWER data (2000–2023). Peak irradiance aligns with high demand months (June–August).

cooling-controlled direct experiments record greater short-term increments, up $10-22\%$ under lab or demonstration-scale experiments [53–55]. Passive floating installations involving higher-order modes of natural convection also record efficiency increment up 17.84% [56], and more sophisticated hybrid modes of cooling—as in atmospheric water harvesting or integrated modes of cooling—record significantly higher incremented gain in performance, once again, limited, however, to experimental installations [57]. Besides optimization of performance, structural configuration, anchoring, and reliability are still key engineering concerns of FPV. State-of-the-art surveys record how row spacing, local sea and wind states, and variations of water level exert direct impacts on energy productivity and survivability [49, 58, 59]. Quantitative correlation rules between hydrodynamical stability and thermal and electric benefits, however, are still immature. Environmental interactions of FPV farms constitute another strand through reviewed literature: positive impacts such as evaporation suppression and enhanced water quality through shading are noted in literature, but overall integrated environmental studies including dissolved gases, temperature stratification, water habitats, and avifauna are not plentiful [27, 60, 61]. Finally, since installation is proceeding increasingly on the global level, techno-economical studies lack systematics in capital expenditure allocations, or levelized cost of electricity estimation. To a great extent, reviews offer qualitative descriptions of enabling Chinese, Indian, or Japanese policies and do not proceed one level further towards delivering normalized standards or sensitivity analyses [62]. It is almost-exclusively within the international evidence base that Bangladesh appears merely as gap area. Virtually no reporting on pilot projects exists, little or no collaborative reporting on LCOE or O&M cost structures, and little on hydrological regime controlled primarily by monsoon variability, sediment burden, and cyclone risks [49, 63, 64]. Tropical FPV work is, in fact, performed under like climates, but outcomes hardly are translated into Bangladeshi-adapted projections, and least of all on local humidity, aerosol burdens, and water level seasonality, used in correction of yields. It is the majority of the studies on the cooling—in water film and spray uses, geothermal or hybrid PV/T systems, and more—that report steep efficiency gain potential [53–55, 57, 65, 66]; such outcomes, though, are obsolete from techno-economically modeled in FPV, pertinent in Bangladeshi applications. Consequently, literature does not exist to underpin an integrated framework where thermal–electrical performance, configuration of structures, environmental monitoring, and cost benchmarks are commingled within said context.

Motivated by these gaps, the present study compiles global quantitative findings and translates them into Bangladesh-relevant assumptions for yield gains, system design, and techno-economic performance. It positions FPV not only as a technology for efficiency improvement but also as a land-sparing and environmentally compatible solution. By integrating performance metrics with design guidelines, environmental baselining, and CAPEX/LCOE modeling, this review provides a comprehensive synthesis that addresses the unique challenges and opportunities for FPV deployment in Bangladesh. In doing so, it moves beyond descriptive overviews and fills the critical gap of connecting global lessons with local feasibility, offering a practical evidence base for researchers, policymakers, and investors alike.

3. Materials and methods

3.1 System overview

An FPV system is a new technology that mitigates the widespread issues concerning ground-based photovoltaics to some extent by locating the photovoltaic array on the water bodies instead of rooftops or the ground [67]. An FPV system equivalent circuit is precisely the same as a normal PV system but considers more things when deployed in water.

To provide transparency regarding the process of research, a methodology framework was designed, shown in Fig. 3. The framework reveals the procedural steps of literature review, data gathering, simulation and yield estimation, techno-economic analysis, environmental influence analysis, and policy synthesis.

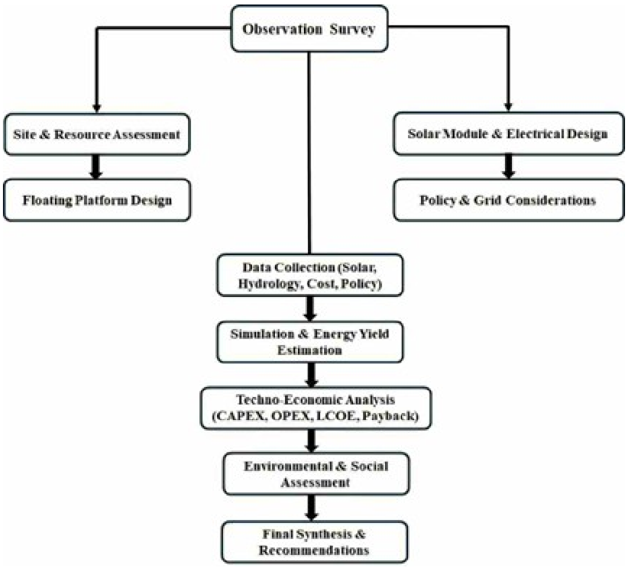


Figure 3. Methodological structure of this study, with consecutive phases of literature review and data gathering, through simulation, techno-economic studies, environmental studies, policy studies, and synthesis of results.

3.2 Structural configuration and design approach

Floating solar photovoltaic system has numerous components like solar photovoltaic panels, supporting structure, anchoring and mooring lines, inverter, transformer, and transmission cables. Therefore, adding a battery system to the system would greatly increase the efficiency by preventing fluctuation and offering a storage unit for the surplus energy produced during the day. Figure 4 shows a Floating Photovoltaic (FPV) system where photovoltaic solar panels are mounted on floating structures and anchored underwater. The produced electricity is inverted and transmitted via submarine cables to the grid.

Figure 5 represents the components of FPV system. It represents the step-by-step process, starting from the trapping of solar radiation by PV modules to energy conversion

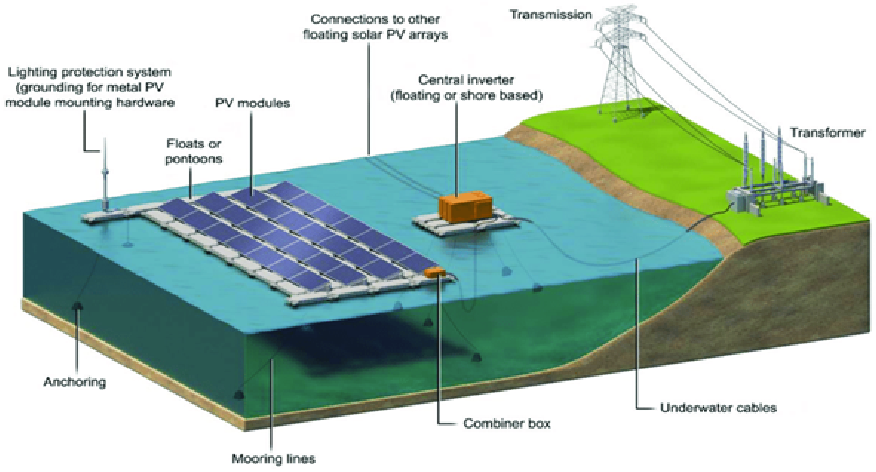


Figure 4. Structural configuration of a floating photovoltaic (FPV) system, illustrating major components and interconnections [68].

by the transmission through cables and final integration within the electrical grid. Every step is representative of the major components with which FPV technology works harmoniously.

3.2.1 FPV module

Conventional crystalline silicon solar PV panels have thus far been applied significantly to floating solar systems, though distinctive panels would be required in these newly installed initiatives on salty water surfaces depending on the exposure to greater amounts of salt mist. Most metals, including conventional aluminum frames and mounts, will corrode in a salt-laden atmosphere over some period. The need is for alternative materials such as polymer-based frames and mounts that can provide better durability and longevity, having higher resistance to corrosion and degradation. The development of these advanced materials will be very important for long-term reliability and efficiency in floating solar systems at sea. Modules are classified into three types: monocrystalline, polycrystalline, and thin film. Cells are classified into three types: they are full-cut cells, half-cut cells, and third-cut cells.
Figure 6 presents the FPV module structure suspended on water, delineating its individual layers. Each layer is separately defined to highlight its purpose. The diagram provides a clear perspective of the module's components.

3.2.2 Floating pontoon

A pontoon is a buoyant flotation device to carry heavy loads while floating either in water or even air. Pontoons, therefore, can have a very vital role in the stability and buoyancy of a floating solar platform in water or any other medium. The platform design will be different according to the specifications and space that might be available to ensure further efficiency. The modules are appropriately arranged in series-parallel combinations such that energy is maximized along with structural efficiency. The pontoon structure in figure 7 is designed to bear all environmental conditions: wind, wave, and water current. Below is the structure in detail showing floats and the pontoon structure applied within the system.

3.2.3 Mooring system

Mooring system is a permanent structure employed for the mooring of containers like quays, wharves, jetties, piers, anchor buoys, and mooring buoys. In floating solar systems, the mooring system stabilizes the panels so that they will not float or rotate. It is costly and intricate to moor a deep-water mooring system. They can be moored with the use of nylon wire rope slings with bank bollards fixed at each corner. The structure depicts the bought mooring arrangement for a floating power station. They system are categorized into four types according to their structure characteristics and behavior. These include the rigid mooring system, which takes up a fixed position with limited displacement; the

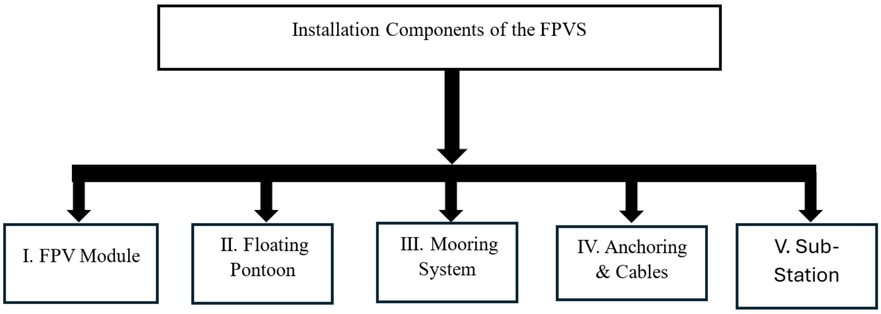


Figure 5. Functional components and energy flow pathway of a floating photovoltaic (FPV) system from generation to grid integration.

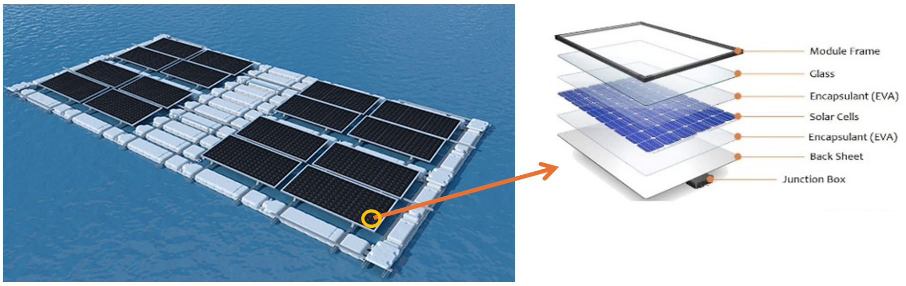


Figure 6. Layered architecture of the floating photovoltaic (FPV) module depicting material composition and protective structure.

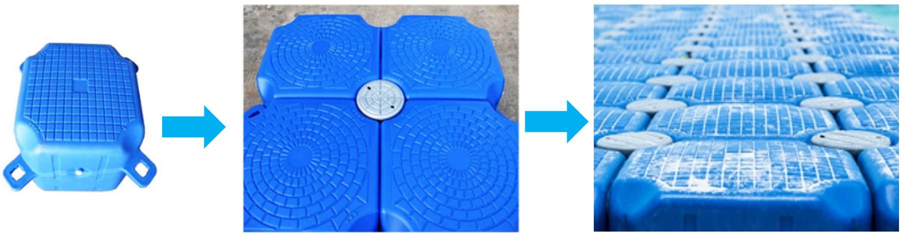
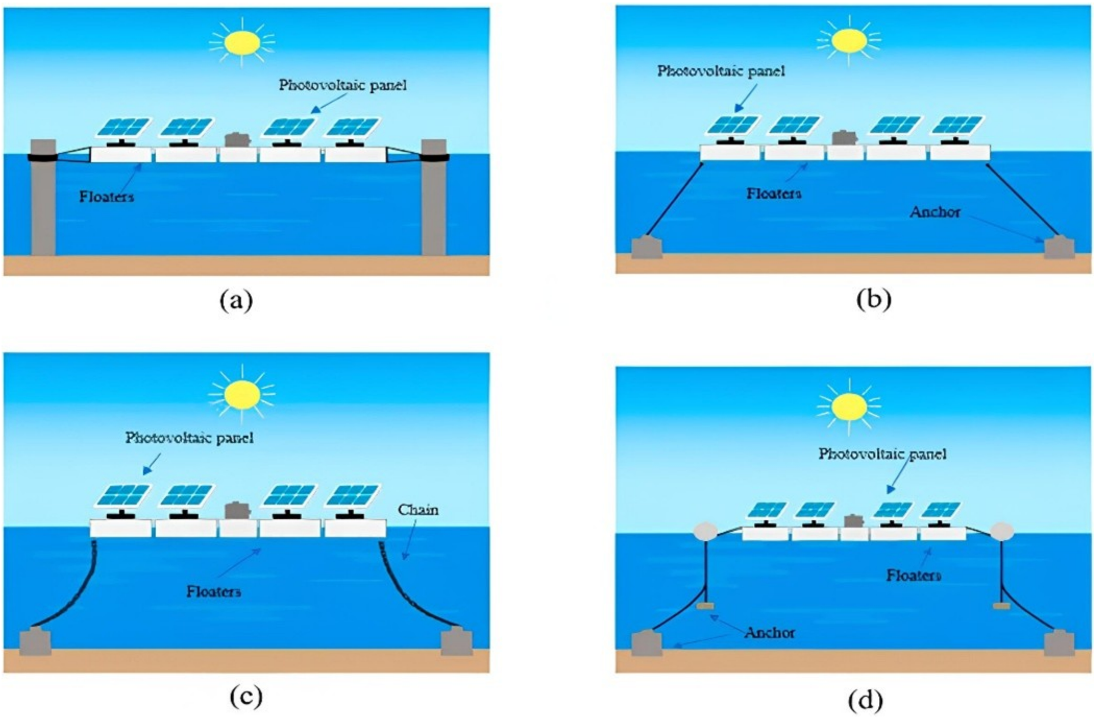


Figure 7. Design and structural layout of the floating pontoon platform supporting FPV modules [3].

taut mooring system, which uses highly tensioned lines to provide stability and reduce horizontal displacement; the catenary mooring system, which uses curved, slack mooring lines that disperse environmental forces through their mass and curvature; and the compliant mooring system, which is capable of allowing greater flexibility and movement, enabling structures to adjust to varying sea conditions and yet maintain their station [69].
Figure 8 presents the FPV mooring system suspended on water, delineating its individually. Each system is separately defined to highlight its purpose. The diagram provides a clear perspective of the module's components.

3.2.4 Anchoring & cables

- Anchoring Mechanisms [70]
  In floating solar panels, anchoring is a central aspect of their design to ensure stability, efficiency, and durability. The system of anchoring must be capable enough to support environmental loads such as wind loads, water currents, and wave actions. Most extensively employed anchoring techniques include fixed piling system, tensioned cable system, mooring line with anchors [71], and hybrid anchor system [72]. These provide support as well as stability to floating objects based on field conditions and requirement.



(a) (b)

(c) (d)

Figure 8. Mooring and anchoring configurations for stability and load distribution in floating photovoltaic systems.

- Power Transmission Cabling
  Underwater cables are typically used to transmit electricity to a substation [73]; sometimes it is advisable to have the cables over water [74]. The three main types of cables are classified based on functionality: DC cables, used for direct current transmission; AC cables, used for alternating current transmission; and grounding cables, with the function to provide a safe path for the electrical faults to the ground so that the protection and safety system is guaranteed.

3.2.5 Sub-station

The sub-station in an FPV system carries out the critical function of power transformation, protection, and control. It includes a transformer for voltage transformation for the grid. DC breakers and DC fuses offer protection to the DC circuit in case of a fault and overcurrent. A protective feature is offered for equipment with a surge arrestor, while an AC breaker offers protection for the safe disconnection of AC power. Moreover, an isolator has a physical break for maintenance, and a control system will track and correct the overall system performance of the FPV system. The sub-station consists of several fundamental elements that ensure safe and efficient functioning. Some of these are the transformer, which increases or decreases voltage levels; DC breaker and DC fuse to protect against faults on the direct current circuits; surge arrestor to protect against voltage spikes; AC breaker to interrupt alternate current flow; isolator to ensure safe removal of system sections for maintenance; and the control system, which governs and supervises the sub-station's operation as a whole.

4. Global FPV expansion and Bangladesh's floating solar potential

4.1 Suggested FPV capable proposed side of Bangladesh

Bangladesh possesses extensive inland water resources, such as major rivers like Padma, Jamuna, Meghna, and Karnaphuli, along with numerous canals and deltaic wetlands. These hydrological resources hold high potential for floating photovoltaic (FPV) applications, particularly in urban and peri-urban zones like Barisal, Khulna, and Chattogram figure 9. Estimates show that tapping only $5-10\%$ of the surface water bodies can generate $10-20$ GW of power, thereby adding to the national target of 40 GW by 2041.

Strategic expansion of FPV in Bangladesh follows global trends since floating solar is increasingly being utilized to fill the gap in land availability and stabilize the grid. High-profile global examples include the 320 MW Dezhou Dingzhuang FPV factory in China, Singapore's 60 MW Tengeh Reservoir power plant, and India's planned 600 MW Omkareshwar Dam power plant. They testify to the scale of FPV and to its integration into national grids.

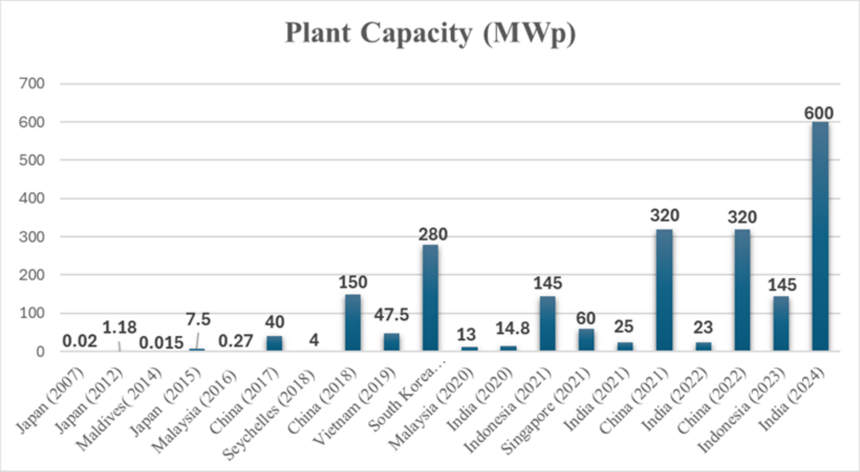
For Bangladesh, potential sites are the Meghna River Basin, Kaptai Lake, and the Rupsha River, which are extremely well-suited for supplying clean electricity to off-grid or unserved populations. Besides, deltaic regions of the Padma, Jamuna, and Meghna rivers and Sundarbans-adjacent water bodies possess untapped FPV potential with high local jobs, energy equity, and climate adaptation opportunities. With suitable policy instruments and investment

Figure 9. Spatial distribution and potential zones for floating photovoltaic (FPV) deployment across the southern region of Bangladesh.

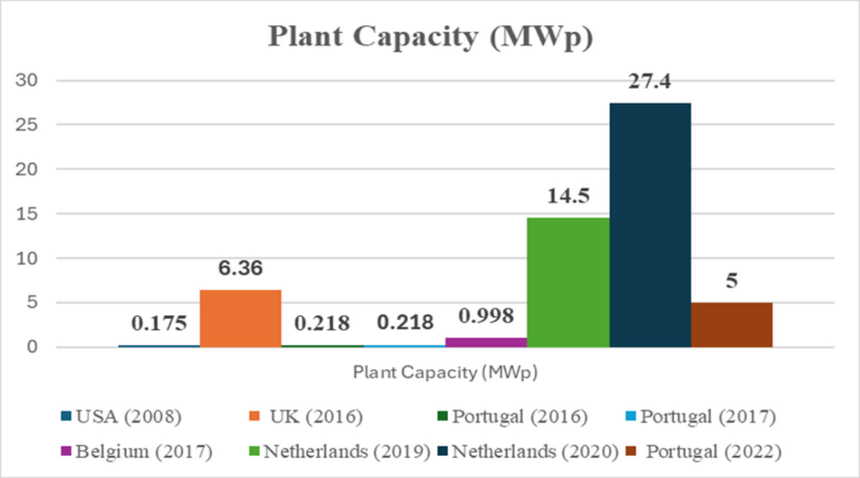
frameworks, Bangladesh can potentially utilize these solar solutions based on water to become a regional FPV champion for global decarbonization and the SDGs. Figure 9 highlights the geographic distribution of such opportunities in the context of national energy planning.

4.2 Global overview of FPV installations

The global evolution of floating solar photovoltaic (FSPV) systems can be clearly visualized through the regional deployment trends presented in Fig. 10a and 10b. While Asia has emerged as the central hub of technological innovation and large-scale capacity expansion, other regions such as Europe and North America have demonstrated steady yet smaller-scale adoption, reflecting differences in policy, geography, and market priorities. Figure 10a illustrates the temporal distribution of Asian deployment of floating solar PV (FSPV) from 2007 through 2025, demonstrating the Asian dominance of the world. It initiated with pilot-scale deployment in 2007, followed by subsequent developments, while Chinese dominance followed soon after, escalating deployments to multi-hundred-megawatt deployments in the early 2020s with huge governmental encouragement and availability of industry capacity [6, 39, 75–92]. Other notable contributions also came from India, South Korea, Singapore, and Thailand, primarily through mid-scale and large-scale deployments of 10 MWp and above than 100 MWp. As of 2025, the Asian region stood at the hub of FSPV exponential growth, where technological breakthroughs, governmental encouragement, and availability of large inland water reservoirs catalyzed exponential growth. This figure also illustrates, apart from the size of single deployments, overall trends toward accelerating throughputs, from kilowatt-scale demonstrations toward gigawatt-class deployments within just over one and half decades. On the other hand, figure 10b offers the comparatively humble but rising application of FSPV technology in non-Asian countries from 2008 through 2022. Pilot-scale application, in 2008, marked initial experimentation in the United States, illustrating technological viability of the technology in non-Asian contexts. Europe subsequently took the lead in efforts within the UK, Belgium, the Netherlands, and Portugal, where spatial limitations and renewable energy diversification programs sparked water surface applications. Most projects were below 50 MWp, but they mark critical technology spread, local climatic demonstration, and market diversification milestones. They also mark emerging, but incremental, adoption of FSPV as a complement technology to land-based solar within high-cost or environmental



(a) Installed floating solar PV (FSPV) plant capacities across Asia between 2007 and 2025.



(b) Installed floating solar PV (FSPV) plant capacities outside Asia between 2008 and 2022.

Figure 10

constraint regions [77, 93–95].

Figure 10a and Figure 10b together indicate the difference between the large-scale fast development in Asia and more limited patterns of adoption in the rest of the globe. While Asian economies and deployments have been FSPV economic and scalable, European and North America exhibit FSPV's versatility and adoption within larger renewable energy portfolios. The international view here is that FSPV has graduated from being a demonstration project to being increasingly mainstream renewable technology in very different applications.

4.3 FPV revolution of Bangladesh

Figure 11 Timeline of FPV projects in Bangladesh (2019–2027), showing operational, planned, and proposed plants across different regions.

Table 1 presents the SWOT analysis of FPV. Its main strengths include land-saving benefits at high density sites, evaporation reduction, enhanced generation efficiency due to natural cooling, and optimal utilization of otherwise non-generating water bodies. There are a few shortcomings with which it needs to cope, which are high initial capital price, technical complications during installation and servicing requirements, lack of on-site expertise, and potential environmental threats to water bodies.

4.4 Bangladesh-specific FPV suitability and policy prioritization framework

To go beyond generic guidelines, this survey develops a composite ranking specific to Bangladesh of prospective FPV sites and provides input for incentive schemes. With reference to the above SWOT analysis, the framework incorporates technoeconomic, environmental, and sociocultural indicators (Table 2).

In computing the LCOE estimates, the assumptions were for a 20-year project life, a weighted average cost of capital (WACC) of 6%, a 0.5% annual degradation, an 18% capacity factor, and an identical performance ratio of 0.8 for FPV and ground PV. FPV achieves a lower LCOE mainly due to a slightly higher yield ($2-3\%$) from the cooling of the module and reduced land use costs. The assumptions set are consistent with those from IRENA (2023) and recent FPV benchmarks from India and China. A normalized score (0–1) for each criterion can be computed:

$$\text{FPV suitability score} = \sum w_i \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

These kinds of sites may also be assessed through this composite index as a means of prioritizing pilot programs and making policy incentives (tax breaks, concessionary loans, feed-in premiums) specific to the top-performing sites. This goes beyond a descriptive SWOT toward an actionable quan-

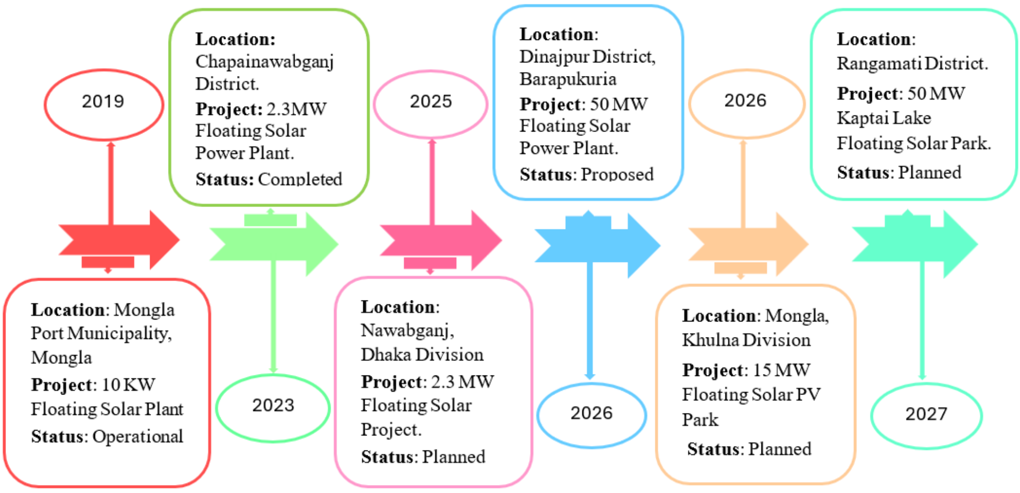


Figure 11. Current situation FPV in Bangladesh.

Table 1. SWOT analysis of Floating Solar PV (FPV) systems, summarizing internal strengths/weaknesses and external opportunities/threats.

Strengths (Internal)	Weaknesses (Internal)	Opportunities (External)	Threats (External)
Land-saving solution for dense areas.	Higher initial capital cost than ground PV.	Integration with hydropower plants for hybrid systems.	Extreme weather risks (cyclones, storms).
Reduces water evaporation from reservoirs.	Technical challenges in installation & maintenance on water.	Policy support and incentives in renewable energy sector.	Long-term corrosion and material degradation
Enhances power generation efficiency due to cooling effect.	Limited local expertise in FPV technology.	Growing global investment in FPV sector.	Potential ecological disturbances to aquatic ecosystems.
Utilizes unused water surfaces effectively.	Potential environmental impacts on aquatic ecosystems.	Employment creation and energy equity in rural areas.	Grid integration and variability challenges.

titative decision-support system.

By duly ranking websites on combined techno-economic, environmental, and social indicators, private developers of Bangladesh and the SREDA can prioritize limited incentives for projects with the highest co-benefits (energy and water savings, CO_2 mitigation, and social acceptance). Such a framework also allows updating periodically as ground data (actual irradiance and aquatic monitoring) become accessible.

5. Techno-economic comparison

The comparative analysis of floating solar photovoltaic (FPV) projects is based on both technical performance and economic feasibility. In addition to land savings and reductions in water evaporation, the comparative analysis examined price to quantify approximate value. The comparison demonstrates FPV's potential to optimize space use and provide cost-competitive energy with environmental benefits.

The equation $P = A_t \times \text{GIr} \times \eta \times R_P$; which calculates the output power of a photovoltaic system [98].

$$
\begin{aligned}
&= 2.72 \text{ GWh/year [Ground PV Area]}\\
&= 2.04 \text{ GWh/year [FPV Area Required]}
\end{aligned}
$$

where, P = Installed power (1 MW), A_t = Area of total panel (10,000 m^2/7,500 m^2), Gir = Global solar irradiance (1700 kWh/m^2/year), η = Panel efficiency (20%) and Performance Ratio $R_P = (0.8)$, It is a fundamental formula in solar energy studies [99, 100].

FPV technology then becomes significantly important in facilitating the utilization of renewable energy in land-scarce locations. for 1 MW ground-mounted solar PV requires approx. 2.5 acres land 10,117 m^2 & 1 MW FPV can be installed A_{FPV} = 7,500 m^2 water surface (better packing ratio).

$$
\text{Land Saving}(\%) = \frac{(A_{GM} - A_{FPV})}{A_{GM}} \times 100\% = 25.867\%
$$

where, A_{GM} = Area of ground-mounted solar (10,117 m^2), A_{FPV} = Area of FPV installation. FPV can save $\sim$ 25% land compared to equivalent ground-mounted systems.

In essence, Floating solar technology is utilized to tap unused water surfaces in a sustainable manner of renewable energy, addressing land limitations and fostering SDGs, with great potential in countries like Bangladesh [101]. In addition, the possibility of integrating floating solar systems with existing hydropower infrastructures significantly increases their potential in generating and storing energy [102–105]. In Bangladesh, the abundance of water bodies provides a very suitable place for the said system that will reduce CO_2 emissions, preserve aquatic ecosystems, and accelerate the adoption of renewable energy [17, 106]. Full-scale deployment of FPV systems is going to change the energy infrastructure of the country. Several large-scale floating solar farms have been completed or are under construction around the world [107].

The shallow water hourly evaporation has been calculated from the given equation. By using the Penman-Monteith equation, Evapotranspiration (ETo) is considered as [108].

$$
\begin{aligned}
\text{ETo} &= K_{ow}\frac{0.408\delta(R_h - D + \frac{\alpha\times 37}{T_{avg}+273}W_s(e_{svp}-e_{avp})}{\delta+\alpha(1+0.34W_s)}\\
&= 0.100 \text{ mm/day}
\end{aligned}
$$

where, K_{ow} = the open water coefficient (1.05), R_h = net hourly radiation on the water surface (MJ/m^2), D = hourly density of soil heat flux (MJ/m^2), $R_h - D = 0.35$ MJ/m^2, T_{avg} = average hourly air temperature (30 °C), δ = vapor pressure curve saturation slope at T_{avg} (0.188 kPa/°C), α = psychrometric constant (0.066 kPa/°C), e_{svp} = the saturation vapor pressure (kPa), e_{avp} = the mean hourly actual vapor pressure (kPa), $e_{svp} - e_{avp} = 1.8$ kPa, and W_s = mean hourly wind speed (2.5 m/s). K_{ow} has been equated to 1.05. Assuming FPV 50% of evaporation loss, the saving will be:

$$
\Delta V_{w,evap\_reduce} = \text{ETo} \times A_{cov} = 0.05 \text{ liters/day}
$$

where, ETo = Evapotranspiration (mm/day), A_{cov} = Surface coverage Area (0.5). For per square meter (1 m^2) of water surface area, 50% coverage of FPV can conserve approximately 0.058 liters/day of evaporation, assuming 50% reduction in evaporation is attained owing to the shade of the floating solar panels.

Table 2 illustrates the installation and annual cost of energy production of FPV, ground-mounted PV, and coal-based power plants. FPV systems reflect the least cost of installation (727 USD/kW) and the lowest levelized cost of energy (0.07 USD/kWh). Coal-based plants, on the other hand, reflect the highest cost in both aspects, indicating FPV's cost-effectiveness.

Yearly cost saving calculation

- FPV vs Coal-Based Plant:

$$
\begin{aligned}
\text{Cost Saveing} &= \text{Coal Based Cost} - \text{FPV Cost}\\
&= 122,400\text{USD/year}
\end{aligned}
$$

- FPV vs Ground PV:

$$
\begin{aligned}
\text{Cost Saveing} &= \text{Ground PV Cost} - \text{FPV Cost}\\
&= 20,400\text{USD/year}
\end{aligned}
$$

The LCOE assessments were derived from a project lifetime of 20 years, a WACC of 6%, with an annual degradation of 0.05% and a capacity factor of 18% for both FPV and ground-mounted systems. FPV has a hedge LCOE (0.07 USD kWh^{-1}) relative to ground PV (0.08 USD kWh^{-1}), mainly due to the natural cooling of modules and reduced costs of land preparation. In a sensitivity analysis, if the FPV CAPEX was increased by 20% or the WACC increased by 3 percentage points, the result yields an LCOE of $\approx$ 0.08 USD kWh^{-1}. Alternatively, marginal effects from an improvement of 2 percentage points in the capacity factor marginally maintain a $6-8\%$ cost advantage. This means the competitiveness of FPV is most sensitive to the finance cost and installation capital, while technical performance does not vary much [ref IRENA 2023; Garrod et al., 2024]. This saving, coupled with zero emissions of carbon and uniform energy output, makes FPV an economically viable and environmentally friendly energy option.

Table 2. Composite FPV Suitability Index for Bangladesh.

Criterion	Metric	Example Value (Bangladesh Pilot)	Weight
Levelized Cost of Energy (LCOE)	USD/kWh (lower is better)	0.07 USD/kWh (FPV vs 0.13 USD/kWh coal)	0.25
Evaporation Savings	Litres saved per m^2 per day (higher is better)	0.058 L/m^2/day at 50% coverage	0.15
CO_2 Reduction	Tons CO_2 avoided per MW per year	Around 5,000 t/MW/year vs coal baseline	0.20
Job Creation or Local Equity	Jobs per MW or % local workforce	15–20 direct jobs/MW during construction	0.10
Aquatic Impact Risk	Composite of DO, algae, fish disruption (lower is better)	Medium for Kaptai, low for Meghna	0.15
Grid Integration Readiness	Distance to substation or existing transmission (shorter is better)	<2 km to 132 kV line at Kaptai	0.15

Table 2. Comparative installation cost and power generation cost of Floating PV, ground-mounted PV, and coal power stations, showing capital cost [96].

System	Approx. Cost (USD/kW)	Approx. Total Cost (1 MW)
FPV	727	727,000 USD
Ground-mounted PV	864	864,000 USD
Coal-based Plant	1300	1,300,000 USD

Table 2. Comparative installation cost and power generation cost of Floating PV, ground-mounted PV, and coal power stations, showing Levelized Cost of Electricity (LCOE) [97].

System	LCOE (USD/kWh)	Annual Energy	Approx. Annual Cost (USD)
FPV	0.07	2.04 GWh/year	142,800 USD
Ground-mounted PV	0.08	2.04 GWh/year	163,200 USD
Coal-based Plant	0.13	2.04 GWh/year	265,200 USD

5.1 Finalized composite FPV suitability index and case study

Developing a Composite FPV Suitability Index (CFSI) to prioritize potential floating solar sites in Bangladesh based on technical, environmental, grid, logistical, and regulatory criteria. Each criterion was weighted by the reasoned expert judgment (AHP-style) and normalized from 0 to 1.

$$X_i' = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}$$

$$\text{CFSI} = \sum_{i=1}^{n} w_i X_i'$$

where, X_i' is an actual value of criterion i, $X_{\min}$ and $X_{\max}$ is the minimum and maximum values across all sites, w_i is the weight of criterion i.

Table 3 presents the essential attributes, assigned weights, data sources, and normalization methods for the Composite FPV Suitability Index (CFSI). Technical, environmental, grid, logistical, and regulatory criteria were incorporated using normalized scores on a scale from 0 to 1. The weights reflect expert judgment paired with literature benchmarks related to Bangladesh. This structure allows for a quantitative ranking of each floating solar site for decision making in policy and investment.

Table 4 gives the normalized CFSI scores for three representative reservoirs. Kaptai Lake ranks highest in suitability due to having excellent solar potential and proximity to the grid. Rupsha Basin and Meghna Estuary score in the moderate range, representing logistical and environmental limitations.

Interpretation:

Kaptai Lake ranks first as a site of high suitable potential due to its strong solar potential, being a shallow body of water, and good distance to the grid ($<$ 2 km). The Rupsha Basin is ranked second due to reasonable logistical factors; however, it is ecologically sensitive, which will require care-

Table 3. Composite FPV suitability framework.

Category	Key Criterion	Weight
Technical	Solar Irradiance	0.15
Environmental	Aquatic Impact Risk	0.10
Grid	Distance to Substation	0.20
Logistics	Distance to Road/Port	0.10
Regulatory	Ownership Clarity	0.10
Socioeconomic	Job Creation	0.15
Technical	Water Depth	0.10
Environmental	Evaporation Saving	0.10

Table 4. Case study results (normalized scores).

Reservoir	CFSI Score
Kaptai Lake	0.83
Rupsha Basin	0.76
Meghna Estuary	0.69

ful examination. The ranking that is lowest is the Meghna Estuary due to the higher distance of the grid as well as the marine exposure. These findings confirm that distance to the grid and the suitability of the ecosystem, are the two most important considerations that affect the site suitability of FPV applications in Bangladesh.

6. Implementation challenges and future outlook

6.1 Critical challenges and constraints

6.1.1 Extreme weather conditions

Bangladesh is plagued by cyclones, storms, and heavy rain, which could damage floating solar panels. They need to be anchored with robust anchoring systems and made of weather-proof materials in a bid to shield them. The solar panels are submerged in water so the performance of the system can be impacted by high humidity. The strength of floating structure can be undermined by corrosion and adverse weather conditions [109].

6.1.2 High initial costs

Setting up floating solar farms is expensive. Costs include installation, maintenance, and advanced technology. Although FPV requires a higher upfront capital expenditure than established fossil-fuel plants, the gap has narrowed substantially. Current estimates indicate FPV CAPEX of 700 to 800 USD kW^{-1} versus 1300 USD kW^{-1} for new coal units, reflecting near-parity in lifetime generation cost [110].

6.1.3 Ecological impact

Floating solar can have an effect on water quality and aquatic life. Planning and environmental analysis must be done to limit any negative effects. The installation of the FPV system can disrupt aquatic ecosystems by altering patterns of water flow, affecting the distribution of nutrients, and disrupting habitats of aquatic organisms [111].

6.1.4 Regulatory and policy barriers

Clear government policies, incentives, and easy regulations are needed to attract investors and ensure smooth project development. Public and affected organization involvement at an early stage in planning, so that there would be public acceptance [112].

6.1.5 Maintenance and operation challenges

Floating solar farms require regular cleaning and maintenance, which is more intricate compared to land-based solar farms. Schedule regular inspections of FPV installations for signs of environmental degradation and implement maintenance practices for prevention of material degradation and minimization of potential impacts.

6.1.6 Environmental and aquatic ecosystem impacts of FPV deployment in Bangladesh

Although floating solar PV panels conserve vast amounts of land and water, installation over extended water bodies could change aquatic ecosystems. The European and Asian case studies exhibit a mixed record of impacts on biodiversity, water quality, and functions of the ecosystem depending upon configuration and scale.

The parameters for water quality and environmental status compiled in Table 5 in deltaic waters of Bangladesh are some key elements of interest; factors which impact the aquatic environment and human use through salinity, suspended sediment load, and pollution.

These studies indicate the environmental effects of FPV are not always negative or positive but context dependent. In the deltaic ecosystem of Bangladesh—high aquatic diversity, shallowness, and intense aquaculture—high cover densities may boost water-column stratification or habitat alteration, but moderate covers may depress algae and halt water evaporation. Consequently, FPV planning requires:

- Preliminary pilot studies require only $\leq 30-40\%$ of the surface cover until local data affirm acceptable

Table 5. Representative results of concern for the deltaic waters of Bangladesh.

Parameter	Magnitude or Trend	Applicability to Bangladesh's Deltaic Context
Dissolved oxygen	Small decrease near surface under dense coverage; recovery downstream.	Shallow, slow-flowing Bangladeshi wetlands may experience stronger stratification; monitoring needed at pilot scale [33].
Algal growth & water temperature	1–3 °C cooling and suppressed algae; potential water-treatment cost savings.	Likely beneficial in eutrophic ponds and Kaptai reservoir where algal blooms are common [32].
Habitat or fish movement	Mixed: some shading may provide refuge; others hinder migration.	Fishermen livelihoods in Meghna & Padma could be affected; early stakeholder engagement needed [40].
Sediment & nutrient distribution	Localized turbidity increases during construction phase.	Use of floating pontoons with minimal anchoring footprint recommended for Bangladeshi FPV [59].
Dual-use potential ("Aquavoltaics")	Demonstrated synergies: fish shading, reduced evaporation, extra revenue.	Bangladesh's extensive inland fisheries present opportunities for combined FPV-aquaculture projects [19].

ecosystem responses.

- Conduct baseline and follow-up monitoring of DO, water temperature, chlorophyll-a, bentical macrofauna, and fish catch composition for each FPV site.

- Investigate “aqua voltaic” systems where FPV panels are gapped for light and water exchange but offer shading for the aquaculture.

This broader perspective supports the techno-economic study by also formally acknowledging environmental trade-offs and opportunities, integrating FPV deployment with the policies for biodiversity and fisheries of Bangladesh.

6.1.7 Socio-cultural considerations and public perception of FPV in Bangladesh

Although the economic and technical viability of Floating Photovoltaic (FPV) systems in Bangladesh has a good prospect, their success purely lies in achieving acceptance from society at large and stakeholders and local residents. For a country like Bangladesh, where the overwhelming majority of the inhabitants are rural and dependent on waterscapes, their socio-cultural effects are paramount. FPV systems generally coincide with valuable community assets like fishery resources, waterways, and community livelihood.

- Fisheries and Livelihoods: Bangladesh has one of the world’s largest inland fisheries sectors, and thousands of people rely on fishing from rivers, lakes, and ponds as their means of survival. Issues with FPV effects on fish breeding grounds and migrations and water quality can become an obstacle to community acceptance. For example, siting of floating solar panels could modify water flows and impact aquatic life and consequently lead to lesser fishing catches and community economic disturbances. Therefore, local fishing community perceptions should be integrated at an early stage of FPV project planning. Ensuring that fishing operations are not hindered with FPV systems will also remain vital in ensuring community acceptance. Certain FPV designs with higher module spacings could prevent such issues with easier flows of water currents under the panels.

- Community Involvement & Contribution of Stakeholders: Community acceptance of renewable energy initiatives often arises from the degree of community involvement at the decision-making stage. Lack of participation or failure of early consulting may elicit resistance, no matter the advantage of the technology as an access and environment-friendly measure. Large-scale use of FPV in Bangladesh will demand widespread community engagement—most importantly, of transport operators at rivers, farmers, and fishermen. Using the success of the Solar Home System (SHS) program of Bangladesh that transformed initial mistrust into success with active community engagement during project planning and implementation, FPV use can also benefit from a community approach. Demonstrations, stakeholder workshops, and workshops can enable community individuals to understand the value of FPV and how their current practices are complementary with it.

- Navigational Issues: Aside from fisheries, river and inland water navigation is a vital aspect of rural life in Bangladesh. Floating photovoltaic systems could impede the routes of water transportation and may become an issue of concern among indigenous boat operators. To prevent such from happening, proper planning of FPV siting should steer clear of major navigational routes, and coordination with the Bangladesh Inland Water Transport Authority (BIWTA) will also be crucial with a view of preventing a disruption of transportation networks. Overall, addressing socio-cultural concerns through the use of early stakeholder consultation and locally relevant solutions (e.g., versatile FPV technologies, community benefits) will enhance acceptance of FPV systems among the community. From the lessons of the successful Bangladesh SHS program with local participation, FPV also has the potential to succeed in rural, water-based settings as long as it fits with community needs and priorities.

6.1.8 Policy gap & incentive analysis

Although the increasing awareness of the prospective of Floating Photovoltaic (FPV) technology of Bangladesh has become intense lately, a number of policy gaps and issues still exist that prevent a wide-scale uptake of FPV. Most importantly, a clear policy roadmap, economic incentives, and regulatory assistance are required to get past initial challenges of FPV uptake. A comparison of the policies of major FPV markets like India, China, and Singapore indicates significant variations in their strategies of supporting renewable energy technologies. Table 6 highlights a comparison of applicable policies of their nations regarding feed-in tariffs, tax benefits, net metering, and financing schemes. Whereas other nations offer a diversified portfolio of policies supporting renewable energy, Bangladesh finds itself at a disadvantage with earmarked incentives reserved only for FPV systems. To make up for the deficiency, we suggest the following policies:

- Renewable Energy Roadmap 2041 Alignments: Make the incorporation of FPV technologies an explicit part of the Bangladesh Renewable Energy Roadmap 2041. With a vision of achieving 40 GW of renewable energy by 2041, FPV needs to be one of the significant participants towards this target milestone, particularly where land-based solar becomes unsuitable due to high water scarcity.

- Hybrid FPV-Hydro Pilot Program at Kaptai: Initiate a pilot hybrid FPV-hydropower project at the Kaptai Lake and conduct a trial of the feasibility of hybridizing both sources of energy. It may act as a prototype of FPV integration with established hydropower facilities and of clean energy production as well as water harvesting.

Table 6. Comparative policy framework for floating solar PV (FPV) development in Bangladesh, India, China, and Singapore.

Policy Area	Bangladesh	India	China	Singapore
Feed-in Tariff (FiT)	Limited FiT for solar; no dedicated FiT for FPV	FiT for solar; FPV under general solar tariff	Robust FiT for renewable energy, including FPV	Supportive FiT for FPV; solar incentives under national schemes
Tax Incentives	Tax exemption on import duties for renewable equipment	5–10 years tax holidays for renewable projects	Tax credits and incentives for renewable projects	Investment tax allowances for FPV installation
Net Metering	Net metering for rooftop solar; FPV excluded	Net metering for solar projects	Net metering available for solar and FPV systems	Net metering for solar, but not yet for FPV systems
Financing mechanisms	Limited government-backed financing	Green bonds and loans for renewable energy	Low-interest loans, subsidies for FPV installation	Financing options through public-private partnerships (PPP)

- Incentive Packages: Offer special financing incentives like tax relief, subsidy, and concessionary lending to FPV programs. A special feed-in tariff (FiT) for FPV technologies should also attract investment in this emerging technology.

- Regulatory System: Provide clear guidelines regarding installation, maintenance of FPVs and grid connection. These guidelines should embrace safety standards, environmental protection and steps to prevent disruption of aquatic ecosystems due to FPVs.

These forward-looking policies will aid in transforming Bangladesh as a leader of FPV innovations at the sub-regional level and harnessing its vast resources of water with a vision of fulfilling energy needs and supporting SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 14 (Life Below Water).

6.1.9 Lifecycle and environmental impact considerations

While FPV systems have inherent lands sparing, efficiency gain, and water-saving advantages, long-term sustainability requires assessment through the lifecycle assessment (LCA) approach. LCA covers the entire spectrum of environmental influences from raw material extraction and module manufacturing through installation, operation, and end-of-life waste management of the installed modules. Recent studies identify that while FPV saves operation emissions through fossil power plant operation reduction, embodied energy of raw materials such as polymers, pontoons, and corrosion-resistant coatings may be carbon and resource footprint generators. Submerged cables and anchoring structures also have the potential of disrupting sediment strata and marine ecosystem components, particularly at shallower deltaic ecologies. High-humidity exposure with long exposure, along with corrosion interface and biofouling influence, may enhance replacement frequencies and, consequently, material-intensive effects at the system life span. Comparative LCAs of FPV, ground PV, and coal-based power supply system demonstrated that while the first-material intensity of FPV is more, efficiency gain and extended site occupancy result in lower carbon footprint by lifecycle at the expense of kWh. To achieve energy, environmental, and economic objectives balancing at Bangladesh, LCA should be integrated into FPV planning, which enables energy, environment, and economic objectives balancing. Regulators should issue lifecycle-based environmental assessments of all large-scale FPV schemes, with requirements that FPV installations should integrate sustainable material choice such that FPV materials should be recyclable types of polymers, low-harm coatings, and end-of-life circular economic handling. Such ramifications close FPV's potential climate mitigating effects and align deployment accordingly with international sustainability norms.

6.1.10 Grid integration and energy system implications

One of the most important yet less studied fronts of FPV deployment in Bangladesh is its integration with the national grid. Since it is intermittent in nature, large FPV farms will require grid flexibility solutions such as energy storage systems (ESS), demand response systems, and hybridization with dispatchable resources such as hydropower or gas peaking units.The topographical arrangement of water bodies in the land presents challenges and opportunities for grid interconnection. Regions of high FPV potential such as Kaptai or Meghna basin may call for special transmission line upgradation and substation strengthening. Smart inverters, real-time monitoring, and predictive load balancing algorithms can smooth out the integration. Policymakers need to attend to FPV system-specific technical standards and grid codes to avoid frequency deviations and voltage instability, especially in the highest solar hours or monsoonal variation. Grid behavior simulation under high FPV penetration cases should be simulated in future research to support sound planning and investment.

6.2 Prospective research directions

Floating Solar Photovoltaic (FPV) technology holds much promise for Bangladesh, but there are several important areas to be investigated. Firstly, extensive environmental impact studies must be conducted to study FPV effects on marine life, such as water temperature fluctuation, dissolved oxygen level, and aquatic fauna diversity. Secondly, applications of FPV systems in coastal saltwater and high-wave conditions need novel engineering innovations—particularly corrosion-resistant materials and wave-resistant anchoring systems. Thirdly, harmonization of FPV deployment with aquaculture, fisheries, and agricultural water consumption is necessary to minimize sectoral conflict. Future study can also focus on full-scale Life-cycle Assessment (LCA) models' application to evaluate energy payback time, carbon footprint, and material circularity of FPV systems based on Bangladesh. Further, advanced simulation-based studies would need to model the integration of FPV systems into the grid, addressing load balancing, intermittency, and storage maximization. Pilot programs that integrate hybrid FPV-hydropower systems and smart grid technology would provide experiential lessons on scaling. Lastly, policy studies on regulatory clarity, fiscal incentives, and stakeholder engagement would be instrumental in popularizing the use of FPV. With concerted research, policy, and innovation action, Bangladesh can become a regional pioneer in floating solar power and accelerate its journey toward a low-carbon, resilient energy future.

7. Conclusion

This review elaborated on the evolution, technical potential and environmental impact of Floating Solar Photovoltaic (FPV) systems and their use in Bangladesh. As the world's energy sector is turning towards renewable energy to address the challenges of climate change and reduce dependence on fossil fuels, FPV technology is emerging as a true and new reality for clean energy generation. FPV systems have become popular globally due to their ability to utilize stagnant water bodies, prevent land-use conflicts, passively cool PV for higher efficiency, and avert water evaporation. China, Japan, and the Netherlands have demonstrated the potential for FPV scaling up in diverse climates, setting valuable examples for developing nations to emulate. In the case of Bangladesh, an energy-poor, land-scarce, and climate-risk-vulnerable country, FPV offers a strategic opportunity to expand renewable energy capacity without competing with agricultural or urban land. The technology is strongly compatible with the nation's energy goal and international commitments, i.e., the SDGs and the Paris Agreement. Although promising, widespread application in Bangladesh is beset by certain problems like high capital outlay, lack of tailored policy guidance, and paucity of technical expertise. The elimination of these limitations will require joint efforts on the part of the government departments, private entrepreneurs, and university scientists. In conclusion, FPV technology is a universally applicable, ecologically sound, and economically attractive option for future energy systems. For Bangladesh, the adoption of this innovation by way of pilot programs, policy incentives, and targeted research can open the door to a low-carbon, resilient, and sustainable energy future.

List of Abbreviations.

Abbreviation	Full Form
FPV	Floating photovoltaic
CPGCBL	Coal Power Generation Company Bangladesh Limited
EEEIC	International Conference on Environment and Electrical Engineering
ESS	Energy Storage System
FPV	Floating Photovoltaics
FSPV	Floating Solar Photovoltaics
IEA	International Energy Agency
IREC	International Renewable Energy Conference
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
OWID	Our World in Data
PDF	Probability Density Function
PVSC	Photovoltaic Specialists Conference
SREDA	Sustainable and Renewable Energy Development Authority
STI	Solar Technology Integration

Authors contributions
Abu Talha Haque Miah: Conceptualization, Methodology, Writing-Original draft preparation. Roby Mohajon: Methodology, Data curation, Software. Sabuj Ahmed: Visualization, Investigation. A.B.M. Noushad Bhuiyan: Supervision, Software, Validation. Nur Mohammad: Writing- Reviewing and Editing.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] A. E. Cagle et al. "The Land Sparing, Water Surface Use Efficiency, and Water Surface Transformation of Floating Photovoltaic Solar Energy Installations.". *Sustainability*, **12**(19):8154, 2020. DOI: https://doi.org/10.3390/su12198154.

[2] W. Bai et al. "Preparation of nano-TiO2@polyfluorene composite particles for the photocatalytic degradation of organic pollutants under sunlight.". *Sol. Energy*, **196**:616–624, 2020. DOI: https://doi.org/10.1016/j.solener.2019.12.066.

[3] A. Sahu, N. Yadav, and K. Sudhakar. "Floating photovoltaic power plant: A review.". *Renew. Sustain. Energy Rev.*, **66**:815–824, 2016. DOI: https://doi.org/10.1016/j.rser.2016.08.051.

[4] S. Sreenath, K. Sudhakar, and Y. Af. "7E analysis of a conceptual utility-scale land-based solar photovoltaic power plant.". *Energy*, **219**:119610, 2021. DOI: https://doi.org/10.1016/j.energy.2020.119610.

[5] N. Ravichandran, N. Ravichandran, and B. Panneerselvam. "Comparative assessment of offshore floating photovoltaic systems using thin film modules for Maldives islands.". *Sustain. Energy Technol. Assess.*, **53**:102490, 2022. DOI: https://doi.org/10.1016/j.seta.2022.102490.

[6] E. Cuce, P. M. Cuce, S. Saboor, et al. "Floating PVs in Terms of Power Generation, Environmental Aspects, Market Potential, and

Challenges.”. *Sustainability*, **14**(5):2626, 2022.
DOI: https://doi.org/10.3390/su14052626.

[7] L. Liu, Q. Wang, H. Lin, et al. “Power Generation Efficiency and Prospects of Floating Photovoltaic Systems.”. *Energy Procedia*, **105**:1136–1142, 2017.
DOI: https://doi.org/10.1016/j.egypro.2017.03.483.

[8] G. M. Tina, F. Bontempo Scavo, L. Merlo, et al. “Analysis of water environment on the performances of floating photovoltaic plants.”. *Renew. Energy*, **175**:281–295, 2021.
DOI: https://doi.org/10.1016/j.renene.2021.04.082.

[9] M. Abid, Z. Abid, J. Sagin, et al. “Prospects of floating photovoltaic technology and its implementation in Central and South Asian Countries.”. *Int. J. Environ. Sci. Technol.*, **16**(3):1755–1762, 2019.
DOI: https://doi.org/10.1007/s13762-018-2080-5.

[10] M. R. A. Refaai, L. Dhanesh, B. P. Ganthia, et al. “Design and Implementation of a Floating PV Model to Analyse the Power Generation.”. *Int. J. Photoenergy*, **2022**:1–13, 2022.
DOI: https://doi.org/10.1155/2022/3891881.

[11] A. Majumder et al. “Cooling Methods for Standard and Floating PV Panels.”. *Energies*, **16**(24):7939, 2023.
DOI: https://doi.org/10.3390/en16247939.

[12] A. El Hammoumi, A. Chalh, A. Allouhi, et al. “Design and construction of a test bench to investigate the potential of floating PV systems.”. *J. Clean. Prod.*, **278**:123917, 2021.
DOI: https://doi.org/10.1016/j.jclepro.2020.123917.

[13] R. Cazzaniga, M. Rosa-Clot, P. Rosa-Clot, et al. “Integration of PV floating with hydroelectric power plants.”. *Heliyon*, **5**(6):e01918, 2019.
DOI: https://doi.org/10.1016/j.heliyon.2019.e01918.

[14] N. Ravichandran, H. H. Fayek, and E. Rusu. “Emerging Floating Photovoltaic System—Case Studies High Dam and Aswan Reservoir in Egypt.”. *Processes*, **9**(6):1005, 2021.
DOI: https://doi.org/10.3390/pr9061005.

[15] N. Ravichandran, N. Ravichandran, and B. Panneerselvam. “Floating photovoltaic system for Indian artificial reservoirs—an effective approach to reduce evaporation and carbon emission.”. *Int. J. Environ. Sci. Technol.*, **19**(8):7951–7968, 2022.
DOI: https://doi.org/10.1007/s13762-021-03686-4.

[16] M. Abdelgaied, A. E. Kabeel, M. Zeleňáková, et al. “Floating Photovoltaic Plants as an Effective Option to Reduce Water Evaporation in Water-Stressed Regions and Produce Electricity: A Case Study of Lake Nasser, Egypt.”. *Water*, **15**(4):635, 2023.
DOI: https://doi.org/10.3390/w15040635.

[17] Y. Jin et al. “Energy production and water savings from floating solar photovoltaics on global reservoirs.”. *Nat. Sustain.*, **6**(7):865–874, 2023.
DOI: https://doi.org/10.1038/s41893-023-01089-6.

[18] M. O. Alhassan, R. Opoku, F. Uba, et al. “Techno-economic and environmental estimation assessment of floating solar PV power generation on Akosombo dam reservoir in Ghana.”. *Energy Rep.*, **10**:2740–2755, 2023.
DOI: https://doi.org/10.1016/j.egyr.2023.09.073.

[19] A. M. Pringle, R. M. Handler, and J. M. Pearce. “Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture.”. *Renew. Sustain. Energy Rev.*, **80**:572–584, 2017.
DOI: https://doi.org/10.1016/j.rser.2017.05.191.

[20] M. Al-Widyan, M. Khasawneh, and M. Abu-Dalo. “Potential of Floating Photovoltaic Technology and Their Effects on Energy Output, Water Quality and Supply in Jordan.”. *Energies*, **14**(24): 8417, 2021.
DOI: https://doi.org/10.3390/en14248417.

[21] K. Trapani and M. Redón Santafé. “A review of floating photovoltaic installations: 2007–2013.”. *Prog. Photovolt. Res. Appl.*, **23** (4):524–532, 2015.
DOI: https://doi.org/10.1002/pip.2466.

[22] J. L. Holechek, H. M. E. Geli, M. N. Sawalhah, et al. “A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050?.”. *Sustainability*, **14**(8):4792, 2022.
DOI: https://doi.org/10.3390/su14084792.

[23] K. F. Al-tabatabaie et al. “Taking strides towards decarbonization: The viewpoint of Bangladesh.”. *Energy Strategy Rev.*, **44**:100948, 2022.
DOI: https://doi.org/10.1016/j.esr.2022.100948.

[24] A. Ahmed, M. Elsakka, N. Elminshawy, et al. “Recent Advances in Floating Photovoltaic Systems.”. *Chem. Rec.*, **23**(12):e202300229, 2023.
DOI: https://doi.org/10.1002/tcr.202300229.

[25] N. Jones and P. Warren. “Innovation and distribution of Solar Home Systems in Bangladesh.”. *Clim. Dev.*, **13**(5):386–398, 2021.
DOI: https://doi.org/10.1080/17565529.2020.1785829.

[26] S. M. N. Hoque, B. K. Das, and Mohd. R. A. Beg. “Evaluation of Energy Payback and CO2 Emission of Solar Home Systems in Bangladesh.”. *Procedia Eng.*, **90**:675–679, 2014.
DOI: https://doi.org/10.1016/j.proeng.2014.11.792.

[27] H. M. Pouran, M. Padilha Campos Lopes, T. Nogueira, et al. “Environmental and technical impacts of floating photovoltaic plants as an emerging clean energy technology.”. *iScience*, **25**(11):105253, 2022.
DOI: https://doi.org/10.1016/j.isci.2022.105253.

[28] R. S. Spencer, J. Macknick, A. Aznar, et al. “Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States.”. *Environ. Sci. Technol.*, **53**(3):1680–1689, 2019.
DOI: https://doi.org/10.1021/acs.est.8b04735.

[29] S. Andini, N. Suwartha, E. Setiawan, et al. “Analysis of Biological, Chemical, and Physical Parameters to Evaluate the Effect of Floating Solar PV in Mahoni Lake, Depok, Indonesia: Mesocosm Experiment Study.”. *J. Ecol. Eng.*, **23**(4):201–207, 2022.
DOI: https://doi.org/10.12911/22998993/146385.

[30] V. Bax, W. I. Van De Lageweg, R. Hoosemans, et al. “Floating photovoltaic pilot project at the Oostvoornse lake: Assessment of the water quality effects of three different system designs.”. *Energy Rep.*, **9**:1415–1425, 2023.
DOI: https://doi.org/10.1016/j.egyr.2022.12.080.

[31] V. Durković and Ž. Đurišić. “Analysis of the Potential for Use of Floating PV Power Plant on the Skadar Lake for Electricity Supply of Aluminium Plant in Montenegro.”. *Energies*, **10**(10): 1505, 2017.
DOI: https://doi.org/10.3390/en10101505.

[32] J.-Y. Song, K.-M. Kim, and C.-H. Lee. “High-performance strategy of a simulated moving bed chromatography by simultaneous control of product and feed streams under maximum allowable pressure drop.”. *J. Chromatogr. A*, **1471**:102–117, 2016.
DOI: https://doi.org/10.1016/j.chroma.2016.10.015.

[33] M. Redón Santafé, J. B. Torregrosa Soler, F. J. Sánchez Romero, et al. “Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs.”. *Energy*, **67**:246–255, 2014.
DOI: https://doi.org/10.1016/j.energy.2014.01.083.

[34] E. M. D. Sacramento, P. C. M. Carvalho, J. C. De Araújo, et al. “Scenarios for use of floating photovoltaic plants in Brazilian reservoirs.”. *IET Renew. Power Gener.*, **9**(8):1019–1024, 2015.
DOI: https://doi.org/10.1049/iet-rpg.2015.0120.

[35] R. Naganathini and R. Nagavinothini. “Investigation on floating photovoltaic covering system in rural Indian reservoir to minimize evaporation loss.”. *Int. J. Sustain. Energy*, **40**(8):781–805, 2021.
DOI: https://doi.org/10.1080/14786451.2020.1870975.

[36] M. R. Santafé, P. S. Ferrer Gisbert, F. J. Sánchez Romero, et al. "Implementation of a photovoltaic floating cover for irrigation reservoirs.". *J. Clean. Prod.*, **66**:568–570, 2014. DOI: https://doi.org/10.1016/j.jclepro.2013.11.006.

[37] P. Yang, L. H. C. Chua, K. N. Irvine, et al. "Impacts of a floating photovoltaic system on temperature and water quality in a shallow tropical reservoir.". *Limnology*, **23**(3):441–454, 2022. DOI: https://doi.org/10.1007/s10201-022-00698-y.

[38] M. Perez, R. Perez, C. R. Ferguson, et al. "Deploying effectively dispatchable PV on reservoirs: Comparing floating PV to other renewable technologies.". *Sol. Energy*, **174**:837–847, 2018. DOI: https://doi.org/10.1016/j.solener.2018.08.088.

[39] T. T. E. Vo, H. Ko, J. Huh, et al. "Overview of Possibilities of Solar Floating Photovoltaic Systems in the OffShore Industry.". *Energies*, **14**(21):6988, 2021. DOI: https://doi.org/10.3390/en14216988.

[40] J. Wang and P. D. Lund. "Review of Recent Offshore Photovoltaics Development.". *Energies*, **15**(20):7462, 2022. DOI: https://doi.org/10.3390/en15207462.

[41] Y. Wei et al. "Simulation of a floating solar farm in waves with a novel sun-tracking system.". *IOP Conf. Ser. Mater. Sci. Eng.*, **1288** (1):012041, 2023. DOI: https://doi.org/10.1088/1757-899x/1288/1/012041.

[42] M. Liu, X. Zhang, J. Ji, et al. "Review of research progress on corrosion and anti-corrosion of phase change materials in thermal energy storage systems.". *J. Energy Storage*, **63**:107005, 2023. DOI: https://doi.org/10.1016/j.est.2023.107005.

[43] R. Pimpalkar, A. Sahu, R. B. Patil, et al. "A comprehensive review on failure modes and effect analysis of solar photovoltaic system.". *Mater. Today Proc.*, **77**:687–691, 2023. DOI: https://doi.org/10.1016/j.matpr.2022.11.353.

[44] K. M. Rikhi Ramkissoon. "Cost Benefit Analysis of Implementing a Solar Photovoltaic System.". *Int. J. Innov. Res. Sci. Eng. Technol.*, **4**(12):11696–11703, 2015. DOI: https://doi.org/10.15680/ijirset.2015.0412006.

[45] A. Goswami and P. K. Sadhu. "Degradation analysis and the impacts on feasibility study of floating solar photovoltaic systems.". *Sustain. Energy Grids Netw.*, **26**:100425, 2021. DOI: https://doi.org/10.1016/j.segan.2020.100425.

[46] Md. I. Islam et al. "Harnessing Waterbodies in Dhaka: Exploring the Feasibility of Floating Solar PV to Alleviate the Energy Crisis in Bangladesh.". *2023 5th International Conference on Sustainable Technologies for Industry 5.0 (STI)*, pages 1–6, 2023. DOI: https://doi.org/10.1109/STI59863.2023.10464785.

[47] L. Xiong, C. Le, P. Zhang, et al. "Harnessing the power of floating photovoltaic: A global review.". *J. Renew. Sustain. Energy*, **15**(5): 052701, 2023. DOI: https://doi.org/10.1063/5.0159394.

[48] Q. Abdelal. "Floating PV; an assessment of water quality and evaporation reduction in semi-arid regions.". *Int. J. Low-Carbon Technol.*, **16**(3):732–739, 2021. DOI: https://doi.org/10.1093/ijlct/ctab001.

[49] P. Ranjbaran, H. Yousefi, G. B. Gharehpetian, et al. "A review on floating photovoltaic (FPV) power generation units.". *Renew. Sustain. Energy Rev.*, **110**:332–347, 2019. DOI: https://doi.org/10.1016/j.rser.2019.05.015.

[50] C. S. Lai, Y. Jia, L. L. Lai, et al. "A comprehensive review on large-scale photovoltaic system with applications of electrical energy storage.". *Renew. Sustain. Energy Rev.*, **78**:439–451, 2017. DOI: https://doi.org/10.1016/j.rser.2017.04.078.

[51] R. S. Spencer, J. Macknick, A. Aznar, et al. "Floating Photovoltaic Systems: Assessing the Technical Potential of Photovoltaic Systems on Man-Made Water Bodies in the Continental United States.". *Environ. Sci. Technol.*, **53**(3):1680–1689, 2019. DOI: https://doi.org/10.1021/acs.est.8b04735.

[52] G. Chowdhury, M. Haggag, and J. Poortmans. "How cool is floating PV? A state-of-the-art review of floating PV's potential gain and computational fluid dynamics modeling to find its root cause.". *EPJ Photovolt.*, **14**:24, 2023. DOI: https://doi.org/10.1051/epjpv/2023015.

[53] C. A. Matias, L. M. Santos, A. J. Alves, et al. "Increasing photovoltaic panel power through water cooling technique.". *Trans. Environ. Electr. Eng.*, **2**(1), 2017. DOI: https://doi.org/10.22149/teee.v2i1.90.

[54] W. Owhaib, Y. Qanadah, H. Al-Ajalin, et al. "Photovoltaic Panel Efficiency Improvement by using Direct Water Passive Cooling with Clay Pot.". *2021 12th International Renewable Engineering Conference (IREC)*, pages 1–4, 2021. DOI: https://doi.org/10.1109/IREC51415.2021.9427805.

[55] C. A. Matias, L. M. Santos, A. J. Alves, et al. "Electrical performance evaluation of PV panel through water cooling technique.". *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*, pages 1–5, 2016. DOI: https://doi.org/10.1109/EEEIC.2016.7555643.

[56] R. Cazzaniga, M. Cicu, M. Rosa-Clot, et al. "Floating photovoltaic plants: Performance analysis and design solutions.". *Renew. Sustain. Energy Rev.*, **81**:1730–1741, 2018. DOI: https://doi.org/10.1016/j.rser.2017.05.269.

[57] R. Li, Y. Shi, M. Wu, et al. "Photovoltaic panel cooling by atmospheric water sorption–evaporation cycle.". *Nat. Sustain.*, **3**(8): 636–643, 2020. DOI: https://doi.org/10.1038/s41893-020-0535-4.

[58] N. A. S. Elminshawy, A. Elminshawy, and A. Osama. "An innovative cooling technique for floating photovoltaic module: Adoption of partially submerged angle fins.". *Energy Convers. Manag. X*, **20**: 100408, 2023. DOI: https://doi.org/10.1016/j.ecmx.2023.100408.

[59] Y. A. Sheikh, A. D. Butt, K. N. Paracha, et al. "An improved cooling system design to enhance energy efficiency of floating photovoltaic systems.". *J. Renew. Sustain. Energy*, **12**(5):053502, 2020. DOI: https://doi.org/10.1063/5.0014181.

[60] H. M. Pouran, M. Padilha Campos Lopes, T. Nogueira, et al. "Environmental and technical impacts of floating photovoltaic plants as an emerging clean energy technology.". *iScience*, **25**(11):105253, 2022. DOI: https://doi.org/10.1016/j.isci.2022.105253.

[61] C. Ma, R. Wu, and H. Su. "Design of floating photovoltaic power plant and its environmental effects in different stages: A review.". *J. Renew. Sustain. Energy*, **13**(6):062701, 2021. DOI: https://doi.org/10.1063/5.0065845.

[62] S. Z. Golroodbari, A. W. A. Ayyad, and W. Van Sark. "Offshore floating photovoltaics system assessment in worldwide perspective.". *Prog. Photovolt. Res. Appl.*, **31**(11):1061–1077, 2023. DOI: https://doi.org/10.1002/pip.3723.

[63] G. Huang, Y. Tang, X. Chen, et al. "A Comprehensive Review of Floating Solar Plants and Potentials for Offshore Applications.". *J. Mar. Sci. Eng.*, **11**(11):2064, 2023. DOI: https://doi.org/10.3390/jmse11112064.

[64] G. D. Pimentel Da Silva and D. A. C. Branco. "Is floating photovoltaic better than conventional photovoltaic? Assessing environmental impacts.". *Impact Assess. Proj. Apprais.*, **36**(5):390–400, 2018. DOI: https://doi.org/10.1080/14615517.2018.1477498.

[65] H. S. Arunkumar, N. M. Hitesh, N. Madhwesh, et al. "Exergy and economic analysis of a photovoltaic panel cooling with air bubble induced water jacket.". *Sol. Energy*, **266**:112161, 2023. DOI: https://doi.org/10.1016/j.solener.2023.112161.

[66] S. Odeh and M. Behnia. “Improving Photovoltaic Module Efficiency Using Water Cooling.”. *Heat Transf. Eng.*, **30**(6):499–505, 2009.
DOI: https://doi.org/10.1080/01457630802529214.

[67] J. Song, J. Kim, J. Lee, et al. “Dynamic Response of Multiconnected Floating Solar Panel Systems with Vertical Cylinders.”. *J. Mar. Sci. Eng.*, **10**(2):189, 2022.
DOI: https://doi.org/10.3390/jmse10020189.

[68] N. Lee et al. “Hybrid floating solar photovoltaics-hydropower systems: Benefits and global assessment of technical potential.”. *Renew. Energy*, **162**:1415–1427, 2020.
DOI: https://doi.org/10.1016/j.renene.2020.08.080.

[69] Y. Lian et al. “Effects of Mooring Line with Different Materials on the Dynamic Response of Offshore Floating Wind Turbine.”. *J. Mar. Sci. Eng.*, **11**(12):2302, 2023.
DOI: https://doi.org/10.3390/jmse11122302.

[70] J. Altuzarra et al. “Mooring System Transport and Installation Logistics for a Floating Offshore Wind Farm in Lannion, France.”. *J. Mar. Sci. Eng.*, **10**(10):1354, 2022.
DOI: https://doi.org/10.3390/jmse10101354.

[71] M. Kumar, H. Mohammed Niyaz, and R. Gupta. “Challenges and opportunities towards the development of floating photovoltaic systems.”. *Sol. Energy Mater. Sol. Cells*, **233**:111408, 2021.
DOI: https://doi.org/10.1016/j.solmat.2021.111408.

[72] W. Kang, Z. Lian, and Y. Han. “Design and Hydrodynamic Performance Analysis of a Two-module Wave-resistant Floating Photovoltaic Device.”. *J. Phys. Conf. Ser.*, **2565**(1):012014, 2023.
DOI: https://doi.org/10.1088/1742-6596/2565/1/012014.

[73] J. Gordonnat and J. Hunt. “Subsea cable key challenges of an intercontinental power link: case study of Australia–Singapore interconnector.”. *Energy Transit.*, **4**(2):169–188, 2020.
DOI: https://doi.org/10.1007/s41825-020-00032-z.

[74] S. Oliveira-Pinto and J. Stokkermans. “Assessment of the potential of different floating solar technologies – Overview and analysis of different case studies.”. *Energy Convers. Manag.*, **211**:112747, 2020.
DOI: https://doi.org/10.1016/j.enconman.2020.112747.

[75] L. Essak and A. Ghosh. “Floating Photovoltaics: A Review.”. *Clean Technol.*, **4**(3):752–769, 2022.
DOI: https://doi.org/10.3390/cleantechnol4030046.

[76] Y. K. Choi, W. S. Choi, and J. H. Lee. “Empirical Research on the Efficiency of Floating PV Systems.”. *Sci. Adv. Mater.*, **8**(3): 681–685, 2016.
DOI: https://doi.org/10.1166/sam.2016.2529.

[77] A. Garrod, S. N. Hussain, A. Ghosh, et al. “An assessment of floating photovoltaic systems and energy storage methods: A comprehensive review.”. *Results Eng.*, **21**:101940, 2024.
DOI: https://doi.org/10.1016/j.rineng.2024.101940.

[78] J. Dai et al. “Design and construction of floating modular photovoltaic system for water reservoirs.”. *Energy*, **191**:116549, 2020.
DOI: https://doi.org/10.1016/j.energy.2019.116549.

[79] Md. I. Islam et al. “Techno-Economic and Carbon Emission Assessment of a Large-Scale Floating Solar PV System for Sustainable Energy Generation in Support of Malaysia’s Renewable Energy Roadmap.”. *Energies*, **16**(10):4034, 2023.
DOI: https://doi.org/10.3390/en16104034.

[80] H. M. Tróndheim. “Expansion Planning Theory.”. *Ensuring Supply Reliability and Grid Stability in a 100Renewable Electricity Sector in the Faroe Islands*, pages 21–41, 2023.
DOI: https://doi.org/10.1007/978-3-031-28368-0_2.

[81] A. Skumanich, P. Mints, and M. Ghiassi. “Considerations for the use of PV and PT for sea water desalination: the viability of floating solar for this application.”. *2020 47th IEEE Photovoltaic Specialists Conference (PVSC)*, pages 0633–0635, 2020.
DOI: https://doi.org/10.1109/PVSC45281.2020.9300446.

[82] P. A. Bui. “Assessing the technical, economic, and environmental feasibility of floating solar power generation on water reservoirs in Vietnam.”. *Cal Poly Humboldt Theses Proj.*, 2019.

[83] Y. Qin et al. “Flexibility and intensity of global water use.”. *Nat. Sustain.*, **2**(6):515–523, 2019.
DOI: https://doi.org/10.1038/s41893-019-0294-2.

[84] H. Liu, A. Kumar, and T. Reindl. “The Dawn of Floating Solar—Technology, Benefits, and Challenges.”. *WCFS2019*, **41**:373–383, 2020.
DOI: https://doi.org/10.1007/978-981-13-8743-2_21.

[85] D. Misra. “Floating Photovoltaic Plant in India: Current Status and Future Prospect.”. *Advances in Thermal Engineering, Manufacturing, and Production Management*, pages 219–232, 2021.
DOI: https://doi.org/10.1007/978-981-16-2347-9_19.

[86] T. Rizvi, S. P. Dubey, N. Tripathi, et al. “FSPV-Grid System for an Industrial Subsection with PV Price Sensitivity Analysis.”. *Sustainability*, **15**(3):2495, 2023.
DOI: https://doi.org/10.3390/su15032495.

[87] Y. Liu, S. Li, Q. Yi, et al. “Developments in semi-submersible floating foundations supporting wind turbines: A comprehensive review.”. *Renew. Sustain. Energy Rev.*, **60**:433–449, 2016.
DOI: https://doi.org/10.1016/j.rser.2016.01.109.

[88] H. Wang, Y. Yang, and S. Zhang. “Study on the structure of offshore wind and solar hybrid power generation device under the background of green energy.”. *J. Phys. Conf. Ser.*, **2649**(1):012034, 2023.
DOI: https://doi.org/10.1088/1742-6596/2649/1/012034.

[89] D. F. Silalahi, A. Blakers, M. Stocks, et al. “Indonesia’s Vast Solar Energy Potential.”. *Energies*, **14**(17):5424, 2021.
DOI: https://doi.org/10.3390/en14175424.

[90] H. G. Febrian, A. Supriyanto, and H. Purwanto. “Calculating the energy capacity and capacity factor of floating photovoltaic (FPV) power plant in the cirata reservoir using different types of solar panels.”. *J. Phys. Conf. Ser.*, **2498**(1):012007, 2023.
DOI: https://doi.org/10.1088/1742-6596/2498/1/012007.

[91] D. F. Silalahi and A. Blakers. “Global Atlas of Marine Floating Solar PV Potential.”. *Solar*, **3**(3):416–433, 2023.
DOI: https://doi.org/10.3390/solar3030023.

[92] J. Charles Rajesh Kumar and M. Majid. “Floating solar photovoltaic plants in India – A rapid transition to a green energy market and sustainable future.”. *Energy Environ.*, **34**(2):304–358, 2023.
DOI: https://doi.org/10.1177/0958305X211057185.

[93] M. A. Rahaman, T. L. Chambers, A. Fekih, et al. “Floating photovoltaic module temperature estimation: Modeling and comparison.”. *Renew. Energy*, **208**:162–180, 2023.
DOI: https://doi.org/10.1016/j.renene.2023.03.076.

[94] C. Cristofari, C. Storai, and J. L. Canaletti. “Development policy to increase the competitiveness of renewable energy-sector companies in a territory like Corsica (France).”. *Renew. Sustain. Energy Rev.*, **32**:61–66, 2014.
DOI: https://doi.org/10.1016/j.rser.2014.01.006.

[95] V. Vidović, G. Krajačić, N. Matak, et al. “Review of the potentials for implementation of floating solar panels on lakes and water reservoirs.”. *Renew. Sustain. Energy Rev.*, **178**:113237, 2023.
DOI: https://doi.org/10.1016/j.rser.2023.113237.

[96] Md. N. Hossain, S. K. Paul, and Md. M. Hasan. “Environmental impacts of coal mine and thermal power plant to the surroundings of Barapukuria, Dinajpur, Bangladesh.”. *Environ. Monit. Assess.*, **187**(4):202, 2015.
DOI: https://doi.org/10.1007/s10661-015-4435-4.

[97] Md. M. I. Chowdhury, S. M. Rahman, I. R. Abubakar, et al. "A review of policies and initiatives for climate change mitigation and environmental sustainability in Bangladesh.". *Environ. Dev. Sustain.*, **23**(2):1133–1161, 2021.
DOI: https://doi.org/10.1007/s10668-020-00627-y.

[98] M. F. I. Faruqui, A. Jawad, and N.-A. Masood. "Techno-economic assessment of power generation potential from floating solar photovoltaic systems in Bangladesh.". *Heliyon*, **9**(6):e16785, 2023.
DOI: https://doi.org/10.1016/j.heliyon.2023.e16785.

[99] A. Kowsar et al. "Optimization and techno-economic assessment of 50 MW floating solar power plant on Hakaluki marsh land in Bangladesh.". *Renew. Energy*, **216**:119077, 2023.
DOI: https://doi.org/10.1016/j.renene.2023.119077.

[100] N. M. Kumar, S. Islam, A. K. Podder, et al. "Lifecycle-based feasibility indicators for floating solar photovoltaic plants along with implementable energy enhancement strategies and framework-driven assessment approaches leading to advancements in the simulation tool.". *Front. Energy Res.*, **11**:1075384, 2023.
DOI: https://doi.org/10.3389/fenrg.2023.1075384.

[101] H. A. Kazem, M. T. Chaichan, A. H. A. Al-Waeli, et al. "A systematic review of solar photovoltaic energy systems design modelling, algorithms, and software.". *Energy Sources Part Recovery Util. Environ. Eff.*, **44**(3):6709–6736, 2022.
DOI: https://doi.org/10.1080/15567036.2022.2100517.

[102] G. Mamatha and P. S. Kulkarni. "Assessment of floating solar photovoltaic potential in India's existing hydropower reservoirs.". *Energy Sustain. Dev.*, **69**:64–76, 2022.
DOI: https://doi.org/10.1016/j.esd.2022.05.011.

[103] O. K. Bishoge, G. G. Kombe, and B. N. Mvile. "Community participation in the renewable energy sector in Tanzania.". *Int. J. Sustain. Energy Plan. Manag.*, pages 121–134, 2020.
DOI: https://doi.org/10.5278/IJSEPM.4477.

[104] J. Farfan and C. Breyer. "Combining Floating Solar Photovoltaic Power Plants and Hydropower Reservoirs: A Virtual Battery of Great Global Potential.". *Energy Procedia*, **155**:403–411, 2018.
DOI: https://doi.org/10.1016/j.egypro.2018.11.038.

[105] M. A. R. Miah, S. R. Rahman, and R. Kabir. "Techno-Economic Analysis of Floating Solar PV Integrating with Hydropower Plant in Bangladesh.". *2021 IEEE Green Technologies Conference (GreenTech)*, pages 30–36, 2021.
DOI: https://doi.org/10.1109/greentech48523.2021.00016.

[106] H. Pouran, M. Padilha Campos Lopes, H. Ziar, et al. "Evaluating floating photovoltaics (FPVs) potential in providing clean energy and supporting agricultural growth in Vietnam.". *Renew. Sustain. Energy Rev.*, **169**:112925, 2022.
DOI: https://doi.org/10.1016/j.rser.2022.112925.

[107] H. Mahmud and J. Roy. "Barriers to Overcome in Accelerating Renewable Energy Penetration in Bangladesh.". *Sustainability*, **13** (14):7694, 2021.
DOI: https://doi.org/10.3390/su13147694.

[108] P. E. Campana, L. Wästhage, W. Nookuea, et al. "Optimization and assessment of floating and floating-tracking PV systems integrated in on- and off-grid hybrid energy systems.". *Sol. Energy*, **177**:782–795, 2019.
DOI: https://doi.org/10.1016/j.solener.2018.11.045.

[109] C. Ferrer-Gisbert, J. J. Ferrán-Gozálvez, M. Redón-Santafé, et al. "A new photovoltaic floating cover system for water reservoirs.". *Renew. Energy*, **60**:63–70, 2013.
DOI: https://doi.org/10.1016/j.renene.2013.04.007.

[110] "Design parameters of 10 kW floating solar power plant.". *ResearchGate*.
DOI: https://doi.org/10.17148/IARJSETP10.

[111] K. Ilgen, D. Schindler, S. Wieland, et al. "The impact of floating photovoltaic power plants on lake water temperature and stratification.". *Sci. Rep.*, **13**(1):7932, 2023.
DOI: https://doi.org/10.1038/s41598-023-34751-2.

[112] T. Tsoutsos, N. Frantzeskaki, and V. Gekas. "Environmental impacts from the solar energy technologies.". *Energy Policy*, **33**(3): 289–296, 2005.
DOI: https://doi.org/10.1016/S0301-4215(03)00241-6.

Appendix A. National demand and FPV potential calculation.

Parameter	Symbol or Value	Source
Bangladesh electricity demand (2024)	95 TWh yr^{-1}	BPDB Annual Report 2024
Utilizable inland water area	1700 km^2 (10% of total inland surface)	Hydrographic Survey 2023
FPV packing density	10 MW km^{-2} (7500 m^2 MW^{-1})	Derived from Table 2
Capacity factor	18% ± 2 pp	NASA POWER (2000–2023)
Loss factors (soiling, temp., wiring)	0.9	0.9
Usable capacity	17 GW	Computed
Annual generation	26.8 TWh 28% of 2024 demand	
Rounded to	15–20% when practical losses & grid constraints included	

Appendix B. LCOE methodology and sensitivity analysis.

Parameter	Base Value	Variation Range (for Sensitivity)	Effect on LCOE (USD kWh^{-1})
System lifetime	25 n (years)	± 5 years	Negligible ($< \pm 0.005$)
Weighted average cost of capital	6%	3 – 9% (± 3 pp)	0.07 → 0.08
CAPEX	727 USD kW^{-1}	± 20% (582 – 872)	0.06 – 0.09
OPEX	1.5%	1 – 2%	± 0.002
Performance degradation (% yr^{-1})	0.5%	0.3 – 0.7%	± 0.001
Capacity factor	18%	± 2 pp (16 – 20%)	0.06 – 0.08
Base-case LCOE	0.07 USD kWh^{-1}		

CO_2 Abatement Calculation
Grid emission factor = 0.72 t CO_2 MWh^{-1} (SREDA 2024).
Annual FPV 26.8 TWh → 19.3 Mt CO_2 avoided; assuming 50% realistic adoption = 10 Mt CO_2 yr^{-1} avoided.