IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, October 2026
Impact Factor: 8.2

A Review of Floating Solar Power Plants: Design, Modelling and Environmental Effects

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Abstract: *Floating solar power plants, also called floating photovoltaic (FPV) systems, place photovoltaic modules on water bodies instead of conventional ground-mounted structures. This approach can expand solar generation while reducing competition for land and may provide additional benefits through panel cooling and reduced water evaporation. However, the floating environment introduces engineering issues that are not normally present in land-based plants. This review synthesizes the major technical themes associated with FPV systems, with emphasis on floating structural arrangements, anchoring and mooring, hybrid renewable-energy configurations, cooling and cleaning methods, environmental loads, computational modelling, power prediction and ecological effects. Modular, integrated and superficial floating concepts are compared from the perspective of scalability and interaction with wind and waves. The review also examines how wind, waves and currents influence structural response and why fluid-structure interaction is important for large installations. Environmental aspects such as evaporation, water temperature, light penetration, water quality and aquatic ecosystems are considered alongside performance benefits. The literature indicates that FPV is technically promising, but design practices are still evolving and long-duration field evidence is required, particularly for extreme weather, corrosion, fatigue and large multi-body arrays. Future work should therefore combine structural engineering, hydrodynamics, electrical performance and environmental assessment in integrated design and monitoring frameworks.*

Keywords: Floating photovoltaic, floating solar, renewable energy, structural design, hydrodynamic modelling, power prediction, environmental effects.

I. INTRODUCTION

Solar photovoltaic generation is expanding as electricity systems move toward lower-carbon energy sources [2], [3]. Conventional photovoltaic plants require significant land area, which can create competition with agriculture, infrastructure and other land uses. Floating photovoltaic (FPV) technology offers an alternative by placing solar modules on reservoirs, lakes and other water surfaces, thereby shifting the deployment environment while retaining the basic photovoltaic conversion principle [4].

FPV installations can provide several potential advantages over land-based systems. Water-assisted heat transfer may reduce module temperature, while partial water-surface coverage can reduce evaporation and alter light penetration [4], [6]. Reservoir-scale assessments also indicate potential energy and water-management benefits, although the magnitude depends on coverage, climate, reservoir characteristics and system configuration [13], [14], [15].

At the same time, a floating plant is exposed to environmental actions that are less important for a conventional ground-mounted plant. Wind can produce drag and lift on large panel surfaces, while waves and currents create additional hydrodynamic loading. Anchors, mooring lines, connectors and floaters must maintain system stability under changing conditions. These requirements make FPV a multidisciplinary engineering problem involving renewable-energy systems, structural engineering and environmental science [1], [4], [6].

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This paper presents an original synthesis of the major issues reported in the supplied review literature. The discussion is organized around three connected areas: (i) FPV design, (ii) modelling and performance prediction, and (iii) interactions between FPV systems and the surrounding environment. The aim is to provide a concise engineering perspective and identify areas where further research can improve reliability, scalability and sustainability.

II. OBJECTIVES OF THE REVIEW

The main objectives of this review are:

- To explain the operating concept and engineering structure of floating photovoltaic plants.
- To compare major floating-support configurations and identify their suitability for different water environments.
- To examine wind, wave and current loading and the modelling methods used to predict structural response.
- To summarize cooling, cleaning, hybrid-energy and material-related developments that can improve FPV performance.
- To discuss environmental interactions, including evaporation, water temperature, light penetration and aquatic effects.
- To identify research gaps and future directions for reliable, scalable and environmentally responsible FPV deployment.

III. METHODOLOGY

The study follows a literature-review approach rather than experimental testing. The supplied base article conducted a Web of Science search using terms including “floating solar”, “floating photovoltaic”, “floating PV” and “FPV”. More than 900 publications were identified, after which approximately 400 papers were selected for detailed discussion, with emphasis on technical areas that were comparatively underdeveloped [1].

For the present paper, the information in the base review was reorganized into an engineering-oriented framework. The selected themes were structural design, floating support, hybrid systems, auxiliary technologies, materials, environmental loading, computational modelling, power prediction and environmental effects. Findings were compared conceptually rather than treated as results from a new experiment [1], [4], [6].

This methodology is appropriate for identifying trends and research gaps, but it also has limitations. A review cannot replace site-specific field measurements, and reported performance values can vary with climate, water conditions, plant size, module technology and system design. Therefore, numerical values from individual studies should be interpreted within their original experimental or modelling context [1].

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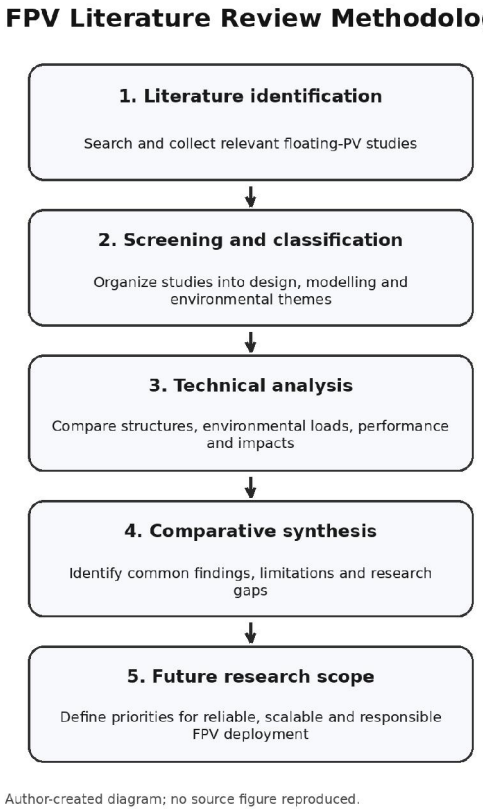


Fig. 1: Author-created methodology framework for the floating solar literature review.

IV. FLOATING SOLAR SYSTEM DESIGN

4.1 Floating Support

The floating support is the physical foundation of an FPV plant. It provides buoyancy for the photovoltaic modules and transfers environmental forces toward the anchoring or mooring system. The literature broadly distinguishes modular, integrated and superficial configurations [1]. A modular plant consists of interconnected floating units and can be expanded by adding modules. An integrated arrangement uses a larger raft-like structure, while a superficial concept places the photovoltaic surface close to the water surface and allows greater flexibility.

Modularity is particularly attractive for large projects because individual units can move with the water surface and can be assembled in stages. Flexible connections may reduce local stress concentrations compared with a completely rigid array. However, connections also become important structural components because repeated movement can produce fatigue and maintenance requirements.

Anchoring and mooring maintain the position of the array. Their design must account for water depth, current, wind direction, wave conditions and possible changes in water level. Offshore deployment is more demanding because the system may experience combined wind, wave and current loading. The review therefore emphasizes the need for site-specific design rather than a single universal FPV structural standard [1].

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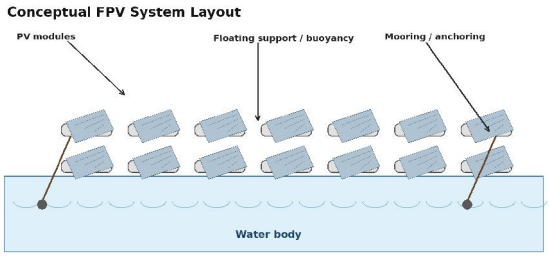


Fig. 2: Conceptual layout of a floating photovoltaic system with support and mooring elements.

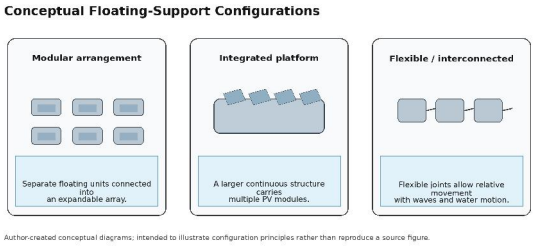


Fig. 3: Author-created conceptual comparison of common floating-support arrangements.

4.2 Materials and Durability

Floating components operate continuously in a wet environment. Material selection therefore has to balance buoyancy, mechanical strength, ultraviolet exposure, corrosion, fatigue and maintenance. Review studies also emphasize that material and platform choices should be matched to the deployment environment and system scale [1], [6], while foam-based concepts have been investigated as a lower-cost floating approach [10].

4.3 Hybrid Renewable-Energy Systems

FPV can share infrastructure with other renewable technologies and energy systems. The literature discusses hybrid and integrated deployment concepts, but also emphasizes that combined systems introduce additional electrical, structural and operational constraints [1], [6], [12].

4.4 Cooling and Cleaning

Water surrounding an FPV installation can support passive or active heat transfer, and lower module temperature can improve photovoltaic conversion performance. Earlier reviews identify cooling as one of the potential performance benefits of FPV, while broader reviews caution that the magnitude of the benefit depends on site and system conditions [4], [6]. Cleaning remains important because soiling and biological deposits can reduce optical performance and increase maintenance requirements [1], [6].

V. MODELLING AND PERFORMANCE PREDICTION

5.1 Wind Loading

Wind is a major design input because photovoltaic modules present a large exposed surface. The drag force can be expressed in general form as $F_D = 0.5\, C_D\, \rho\, V^2\, A$, where C_D is the drag coefficient, ρ is air density, V is wind speed and A is the projected area. Lift also influences stability because it changes the balance between gravitational and buoyant forces [1], [4], [12].

Wind direction, module tilt, array spacing and shielding can alter the load distribution. The first row of a large array can experience different loading from rows behind it because upstream modules modify the airflow. This means that isolated-panel experiments cannot always represent the behaviour of a full-scale array.

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Table 1: Selected aerodynamic boundary conditions reported in reviewed FPV studies [1], [4], [12].

Study	Location	Wind speed (m/s)	Tilt / direction / wave
Yang et al. [1]	Inland	6.0–25.0	10° / All / Yes
Choi et al. [1]	Inland	12	15° / 0–180° / No
Choi et al. [1]	Inland	13.4	10° / 0–180° / No
Su et al. [1]	Offshore	20	20°/40° / 0–180° / No
Lee et al. [1]	Nearshore	45	15° / 0–180° / No
Elminshawy et al. [1]	Inland	0–4.2	30° / 0–180° / No
Choi et al. [1]	Nearshore	35–75	14° / 0–180° / No
Honaryar et al. [1]	Nearshore	30–40	10° / 0° / No

5.2 Wave and Current Loading

Unlike ground-mounted PV, FPV systems move with the water surface and are therefore affected by wave and current forces. Wave conditions, water depth, deployment location and mooring configuration influence structural response. These site-dependent issues are particularly important for lake and marine applications [1], [8], [12].

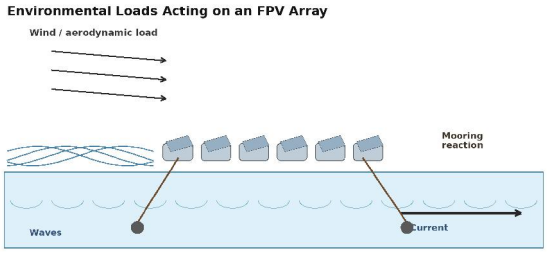


Fig. 4: Author-created conceptual representation of wind, wave, current and mooring loads on FPV.

5.3 Fluid-Structure Interaction

Fluid-structure interaction (FSI) is important when structural movement changes the surrounding flow and the resulting flow changes the structural load. High-fidelity simulations can represent these interactions, but modelling thousands of connected floating units can become computationally expensive. Reduced-order models and staged array simulations are therefore promising approaches for large-scale design optimization.

5.4 Thermal Behaviour and Power Prediction

Photovoltaic output depends on irradiance, module temperature, system efficiency, soiling and degradation. FPV can benefit from the thermal environment of water, but the cooling response is not identical for every water body [4], [6]. Site-specific simulations have also been used to estimate annual generation and economic performance [7], [13], while reservoir-scale studies demonstrate the importance of coupling energy-yield assessment with water-resource considerations [14], [15].

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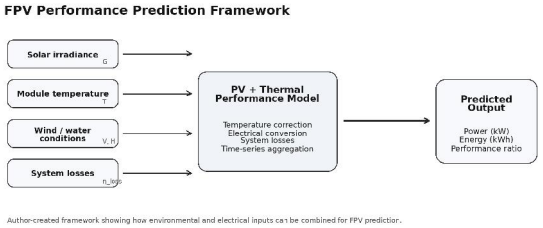


Fig. 5: Conceptual framework for FPV thermal and electrical performance prediction.

VI. ENVIRONMENTAL EFFECTS

6.1 Effects on the Water Environment

One of the most discussed benefits of FPV is the potential reduction in water evaporation. Solar modules shade part of the water surface and can reduce the area directly exposed to the atmosphere. Reservoir assessments have quantified potential water savings, but the magnitude depends strongly on coverage, climate and water-body characteristics [13], [14], [15]. FPV shading can also reduce light penetration and influence water temperature and aquatic conditions [5], [9], [11].

These effects are not automatically beneficial in every location. Aquatic organisms depend on light, temperature and circulation, so large coverage ratios require ecological assessment. Marine and freshwater studies both emphasize that environmental responses are site-specific and that evidence from one water body cannot automatically be transferred to another [5], [9], [11].

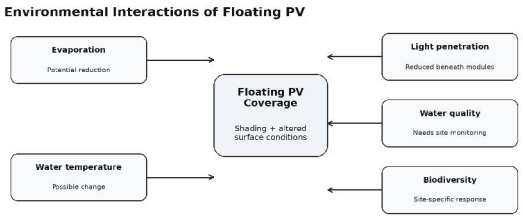


Fig. 6: Author-created conceptual map of FPV interactions with the water environment.

6.2 Effects of the Environment on FPV

The environment also affects the plant. Wind, waves and currents influence structural motion and mooring loads, while humidity and water exposure can accelerate degradation or biological growth. Marine studies particularly identify biofouling and extreme environmental exposure as important research concerns [5], while freshwater pilot work demonstrates the need for site-specific monitoring [9], [11].

Consequently, environmental assessment should be treated as a two-way problem: designers must evaluate how FPV changes the water environment and, at the same time, determine how that environment changes the reliability and performance of the plant.

VII. COMPARATIVE DISCUSSION

Table 2 summarizes the principal design and analysis aspects identified from the reviewed literature.

Table 2: Comparison of major characteristics of land-based and floating photovoltaic systems [4], [6], [12].

Aspect	Land-based PV	Floating PV	Key consideration
Land requirement	Requires dedicated ground area	Uses water surface	Site suitability and coverage ratio

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Thermal environment	Ground/air cooling	Water-assisted cooling possible	Depends on water temperature and airflow
Structural loading	Wind and ground loads	Wind, wave and current loads	Mooring and connector design
Water interaction	Minimal direct interaction	Can reduce evaporation and light penetration	Long-term ecological assessment
Scalability	Mature utility-scale practice	Modular concepts support expansion	Connection reliability becomes important

VIII. RESEARCH GAPS AND FUTURE SCOPE

8.1 Structural Design and Durability

Structural design standards for FPV systems are still developing, and long-duration evidence on fatigue, corrosion, connector reliability and extreme-weather performance remains limited. Future floating structures should therefore be designed for both routine operation and severe environmental events, with material and platform choices matched to the deployment environment [1], [5], [9], [10].

8.2 Modelling and Performance Prediction

Large FPV arrays require efficient computational tools. Full multi-body fluid–structure simulations can be expensive, so reduced-order models and hybrid-fidelity approaches could support faster design iteration. Site-specific energy modelling has already been demonstrated for mine-pit-lake and reservoir applications [7], [13], while broader reviews identify advanced modelling and data-driven prediction as future opportunities [1], [6], [12].

8.3 Environmental Assessment

Environmental research should move toward long-duration, site-specific monitoring. Important topics include biodiversity, algae growth, water quality, water temperature, evaporation and the effect of different coverage ratios [5], [9], [11]. Reservoir studies also show the importance of linking environmental effects with energy and water-resource outcomes [14], [15].

8.4 Hybrid and Integrated Systems

Hybrid systems offer an important future direction. Combining FPV with complementary renewable resources, storage or other energy pathways could increase the value of shared infrastructure, but economic, electrical, structural and environmental performance should be evaluated together [1], [6], [12].

IX. CONCLUSION

Floating photovoltaic systems provide a promising pathway for increasing solar generation where land availability is constrained. The technology retains the basic advantages of photovoltaic generation while introducing a water-based operating environment that can provide cooling and reduce evaporation. At the same time, floating structures must withstand wind, waves, currents and long-term exposure to water.

The reviewed literature shows that no single structural configuration is suitable for every location. Modular, integrated and flexible concepts offer different trade-offs in scalability, structural response and maintenance. Accurate modelling of environmental loads and fluid-structure interaction is therefore essential, especially for large or offshore arrays. Power prediction must also consider temperature, irradiance, soiling, degradation and local environmental conditions.

Overall, FPV should be treated as an interdisciplinary engineering system rather than simply a photovoltaic plant placed on water. Future development should focus on durable and scalable structures, improved modelling, intelligent monitoring, efficient cooling and cleaning, and long-term environmental assessment. Such an integrated approach can improve the reliability and sustainability of floating solar power plants.

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ACKNOWLEDGEMENT

The authors acknowledge the guidance and academic support received during the preparation of this review paper.